SCIENTIZATION AND ECONOMIC DEVELOPMENT:

A CROSS-NATIONAL COMPARATIVE ANALYSIS

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Annelie Gunborg Anne-Marie Strath

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UMI Number: 9810214

UMI
300 North Zeeb Road
Ann Arbor, MI 48103

I certify that I have read this dissertation and that in my opinion it is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

6/25/97

Francisco O. Ramirez (Principal Adviser)

I certify that I have read this dissertation and that in my opinion it is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

John W. Meyer

I certify that I have read this dissertation and that in my opinion it is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Jerald R. Herting

Approved for the University Committee on Graduate Studies:

Thomas Wasow

ABSTRACT

During the last few decades, economic development policies have been shaped around the assumption that technological progress is the key to economic growth. To this end, educational policies have emphasized the need for expanded enrollment in science and technical education. Such an expansion has been thought to enhance the technical and scientific capacity of the labor force, a necessary ingredient in the creation of a foundation for technological change and economic development.

This dissertation is a cross-national longitudinal study examining the relationship between scientization of higher education and scientization of the labor force, on one hand, and the relationship between scientization of the labor force and economic development, on the other.

My research demonstrates that scientization of higher education leads to scientization of the labor force. Furthermore, the findings indicate that there is a tighter connection between scientization of higher education and the labor force in economically more advanced countries and, to some degree, in countries with higher levels of secondary education enrollment.

This dissertation also shows that scientization of the labor force is positively linked to economic development and that this relationship appears to be stronger in countries with an expanded export market and in countries with higher levels of capital per worker.

These findings imply a looser coupling between scientization of higher education

and scientization of the labor force in countries that do not have an economical and educational infrastructure that can support the employment of scientist and engineers. The findings also suggest that the sheer number of scientists and engineers in the labor force may not guarantee an effective contribution to economic growth. The impact of scientists and engineers on economic growth seems to be influenced by certain complementary factors some of which have been identified in this study.

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CHAPTER 1

INTRODUCTION

This dissertation examines the relationship between the scientization of higher education and the scientization of the labor force, on the one hand, and the relationship between the scientization of the labor force and economic development, on the other. Much of the literature on human capital and modernization suggests a positive relationship between science and technology and development. Other theoretical perspectives subscribe to the idea that the effect of science and technology will be stronger in countries with a more developed economic and social infrastructure.[1] This study evaluates both of these assertions.

For the last few decades, economic development policies have been shaped around the assumption that technological progress is the key to economic growth. For example, the Swedish Academy of Engineering (1992) asserts that more knowledge-intensive production processes must be utilized in order for Swedish industry to successfully compete with other industrialized nations. To this end, educational policies have emphasized the need for expanded enrollment in the fields of science and technical education. This, in turn. is thought to enhance the technical and scientific capacity in the labor force, a necessary ingredient in the creation of the foundation for technological change and economic development (e.g.,

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[1]The relationship between technological development and economic growth is complex. It involves many facets which are still in need of exploration. Although the issue of technological development is central to the link between science and technical education and economic development, I do not attempt to explain the process of technological change and its determinants.

Gilford 1993).

An increase in the number of scientists and engineers is considered to be important for all types of societies regardless of the level of socioeconomic development. The more technically advanced nations need more scientists and engineers in order to maintain their leading positions in high tech industrial production while less developed countries need scientists and engineers in order to catch up with technology developed elsewhere. In addition, the small fraction of scientists and engineers engaged in research and development (R&D) in developing countries has been used to explain why these countries are lagging behind in their movement into the age of information technology (Haddad, et. al. 1990).

This dissertation follows a tradition of macro-sociological cross-national research on issues of development. Macro-sociological theories seek to explain some societal level variations as a function of others. With regard to the effect of education on economic growth, early research within this tradition focused on how variations in levels of primary, secondary, or tertiary education enrollments influenced national economic growth across societies (Meyer and Hannan 1979). The focus, then, shifted from a comparison of different levels of education to a comparison of the benefits of different forms of schooling, such as science verses non science education (Benavot 1992; Ramirez and Lee 1995). I continue this tradition by investigating the conditions under which scientization of higher education contributes to economic growth. With this dissertation I examine whether certain aspects of the socioeconomic infrastructure - such as the level of economic development, the level of secondary education enrollment, the size of the market, and the amount of capital available per worker - make the links between scientization of higher education and the labor force and economic development stronger or weaker. I do not study country specific strategies or mechanisms by which the training of scientists and engineers and their participation in the labor force contribute to economic growth. My emphasis is on the macro-level societal conditions which affect the strength of these relationships. For example, I investigate whether the relationship between scientization of higher education and scientization of the labor force is stronger in countries which are economically more developed or in countries with an expanded secondary education enrollment.

Most research exploring the relationship between education and economic growth has primarily focused on one particular society across time. This line of research imposes some limitations. Specifically, it ignores the influence of country-specific factors on the relationship between education and economic growth. In response to these limitations the present study uses a cross-national comparative perspective in which each unit of analysis is a nation state. This type of research approach takes into consideration the political, social, and economic conditions of countries in the study (Ramirez and Meyer 1993). Since the effect of education upon the size of the scientific and technical labor force, and its subsequent effect on economic development, is not immediate, the study is longitudinal, covering the period 1970-1990.

Because of the existence of collinearity among the independent variables in the sample this study employs ridge regression as the estimation procedure. Enrollment data on tertiary science and technical education and data on scientists and engineers in the labor force are obtained from UNESCO. Data on the remaining variables are mainly from the Summers and Heston data series. (For more details, see Chapter 3, Key Concepts and Indicators).

Chapter 3 describes the methodology, data, and sources used in this study.

In Chapter 4, I show that variations in the relative number of scientists and engineers in the labor force is positively associated with the level of tertiary science and technical education. I also provide some evidence of a tighter coupling between expanded tertiary science and engineering enrollment, and the proportion of scientists and engineers in the labor force, in countries with more economically developed economies and, to some extent, in countries where the level of secondary education enrollment is high.

Chapter 5 focuses on how variations in the proportion of scientists and engineers in the labor force influence the level of economic development. I demonstrate that the degree of concentration of scientists and engineers in the labor force is positively linked to economic development. The empirical analysis also suggests that this relationship is stronger in countries with expanded export markets and with greater amount of capital per worker. In addition, the evidence indicates that scientists and engineers in R&D are more important in generating economic growth in the OECD countries while the scientists and engineers in non-R&D activities are more crucial in less developed countries. In Chapter 2 which follows, I present the theoretical foundation for this project and the propositions to be tested.

CHAPTER 2

REVIEW OF LITERATURE

This study focuses on cross-national variations in the amount of science and tertiary education, the size of the scientific and technical labor force and economic development. In this pursuit it is important to have an understanding of the role education plays in the process of economic development as well as the specific contribution of scientists and engineers to this process. Hence, this literature reviews both theories and previous research on the relationship between education and economic development on the one hand, and on the relationship between science and technology and economic development, on the other.

Theories on the Relationship between Education and Economic Development

Most of the literature on the relationship between education and social and economic change has concentrated on individual level effects, and the effect on national level economic growth has been inferred from the assumption that individual effects aggregate to national level effects. Despite this limitation this literature provides a useful background and framework for the conceptualization of the role of education in economic development.

The literature on the effect of education on economic development originates from the theory of human capital, which posits a strong positive relationship between schooling and economic development. This theory is associated with the school of neoclassical economics, mainly Schults (1971) and Becker (1964).

During the first half of the 20th century economists observed that the national economic product grew much faster than the corresponding increase in the basic factors of production (capital and labor) (Abramovitz 1956). It was also noted during this period that the investment in human capital such as formal schooling had been much higher than investment in other conventional or tangible capital. The relationship between education and economic development was thereby inferred.

According to human capital theory, education provides individuals with skills that enhance their productivity, which in turn contributes to economic growth. Since it is assumed that workers are paid according to their marginal contribution to productivity, the increased earnings that education brings is taken as an evidence for higher productivity. The aggregate return to individual workers is then taken as the aggregate effect on national income (Rubinson and Browne 1993; Walters and O'Connell 1990).

A similar perspective linking education and economic growth is the technical functionalist perspective, which regards the expansion of education as a necessary means to sustain the modern society (Inkeles and Smith 1974). According to this view education expands in response to the demand for skilled manpower resulting from technological change and the need for the modern society to have individuals with modern attitudes.

Both the human capital theory and the technical functionalist perspective have been criticized on several points. The first is the assumption that differences in earnings due to educational attainment is associated with differences in productivity of individual workers. The fact that people with similar educational backgrounds have different income profiles suggests that income differences are not only based on educational attainment but often reflect gender and race differences. Moreover, productivity might have a greater association with the specific type of job than with the productivity of an individual worker. Educational attainment may function as a signal to the employer for a more trainable worker (Thurow 1974; Collins 1979). In addition, the method of aggregating individual workers' rates of return to education as a way of assessing the effect on a national level has been criticized for its aggregation fallacy (e.g., Meyer and Hannan 1979)

The second flaw with the theories mentioned above is the assumption that increased schooling leads to the creation of more productive jobs. This is not necessarily the case; if the distribution of jobs does not change, increased education will only lead to inflation of educational credentials and will have weak effect on economic growth (Collins 1979).

A third criticism of the human capital theory and the technical functionalist perspectives questions whether education provides skills that are relevant for the economy. This point has mainly been articulated by social stratification theorists, who claim that what is going on in school is decoupled from the economy. Instead, education is seen as serving the interest of particular segments of society to ensure their positions in the social hierarchy (Bowles and Gintis 1976; Collins 1979; Rubinson and Browne 1993). For example, the status conflict theory claims that educational requirement for jobs does not reflect the level of skills needed to function in a particular job but instead reflects the interests of status groups in the organization that have the power to reinforce these requirements. Accordingly, educational expansion is driven by the need for different status groups to compete for positions within the occupational status hierarchy. As one group moves ahead, other groups follow, which in turn causes the leading group to pursue further education; this results in a spiral of educational expansion.

While status conflict models view educational expansion as a result of the struggle between different status groups, class reproduction models assign the primary role of education as reproducing the existing class structure. According to this view, education expands as a way to ensure that the capitalist system is maintained: to enforce capitalist authority, to discipline the working class, to create proper work attitudes, and to block anti-capitalist movements (Bowles and Gintis 1976).

A modified version of class conflict models (Carnoy and Levin 1985) contends that education serves two purposes in terms of reproducing class structure. First, it allocates individuals into different tracks enabling their subsequent differentiation in the labor market, and second, it provides the skills necessary for sustaining the capitalist system. Moreover, since education is perceived as the dominant means to upward social mobility, different groups in society exert demands on the state to expand education. At the same time the business world exerts pressure to obtain the kind of skills necessary for continued capital accumulation. For instance, high technology firms push for science and math education. This modified perspective is not quite as pessimistic when it comes to the contribution of education to economic development. The effect may not be uniformly distributed but may affect selected sectors that demand certain types of skills.

All of the theories mentioned above, view the emergence of social structures as a consequence of processes of conflict or consensus between social class, status groups, and other actors. The institutionalist perspective, moves away from this functionalist outlook and points out that societal and organizational structures are not only influenced, but internally constituted, by the wider environment. The wider setting contains prescriptions that are socially enacted throughout much of the world (Meyer *et al.* 1987). The institutionalist theory asserts its relevance through the fact that countries of widely different political, economic, and social conditions, exhibit very similar institutional structures. Meyer *et al.* argue that if such institutions were simply the products of competing interests and political negotiations, there would be much less uniformity in these dimensions across societies.

The contribution of the institutionalist perspective to the discourse on education and social change is the notion of isomorphism. Educational systems throughout the world are becoming increasingly similar despite national variations in political, economic, and social characteristics. This is argued to be a reflection of the adherence of nation-states to a uniform model describing the role of education in the relationship between states and individuals. In the process of nation-state building, education is seen as the mechanism through which individuals become citizens. In addition, education is seen as a legitimate and a rational means for social and economic progress. This explains why educational systems look alike in many respects, despite varying national characteristics (Ramirez and Boli 1987: Ramirez and Ventresca 1992).

To summarize, the interest in the relationship between schooling and economic development has given rise, on one hand, to theories that predict a strong positive relationship between education and economic growth, and on the other, to theories that give education very little credit for economic development. Instead of setting the human capital and modernization theories against the other perspectives, one should consider the following question: under what conditions is there a positive association between education and economic growth? This question is addressed in the next section.

The Contribution of Education to Economic Growth

Lately, it has been argued that the effect of education on economic development is contingent upon the degree to which formal education provides skills that are relevant for the economy (Rubinson and Fuller 1991). For example, Rubinson and Ralph (1984) found that during certain periods between 1890 and 1970, technical change measured in terms of increase in total factor productivity[2] had a positive and statistically significant effect on subsequent expansion of primary and secondary education[3]. During the same periods the expansion of primary and secondary education also positively influenced economic development. On the basis of these findings, Rubinson and Ralph concluded that education has an effect on economic development when it expands in response to technical change but has no effect when it is linked to status competition. Likewise, Hage (1988) and Garnier (1990) showed that in France and Germany the tracks feeding directly into industry and commerce positively influenced economic growth during the period 1850-1950, whereas those streams based on classical curriculum decoupled from the economy did not have any effect.

In line with the notion that education contributes to economic growth only when coupled to the economy, the emphasis has recently shifted from general education to specific forms of schooling as especially important in generating economic growth. In accordance

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[2]Enrollment in primary and secondary education, respectively, was regressed on total factor productivity lagged between 8-12 years.

[3]For the periods when the effect was not statistically significant, they associated the expansion of education with the need for different groups to acquire more education in order to participate in the status competition process.

with the trend in the world economy towards a technologically complex world along with the assumption that development of science and technology is the key for economic growth, strong preparation in mathematics and science education has been conceptualized as indispensable for improved productivity and economic development. Science and mathematics education is thought to provide tools for solving different types of problems that are increasingly common in the contemporary world (e.g., Gilford 1993).

A further implication of this perspective, is the high regard for the role of scientifically and technically trained manpower in the process of technological change and economic development. The popular belief is that economic growth is contingent upon the expansion and improvement of the scientific and technical capacity in the labor force. This, in turn, is believed to be dependent on the amount and quality of higher levels of training in science and technical education. Countries with more scientists and engineers are in a better position to adapt and develop new technology (e.g., Haddad *et al.* 1990; Swedish Academy of Engineering 1992). Consequently, educational policies have emphasized expanded training of scientists and engineers. This is believed to be important for all countries regardless of their level of industrial development. The technologically advanced countries are contingent upon university graduates in science and technology to maintain their leading positions in technological development. For example, the Swedish Academy of Engineering has recently stated that in order for Swedish industry to compete successfully with other industrialized nations, more scientists and engineers must be trained in the utilization of knowledge-intensive production processes. In less advanced nations, economic development is presumed to depend on the existence of technically and scientifically trained manpower who will understand the latest technological advances made by the industrialized countries, and be able to apply them for local production of goods and services. Consequently, these countries must also be concerned about educating university graduates in science and technology (e.g., Haddad *et al.* 1990). The "science and technology for progress" model as it is conceived can be formalized into the following hypotheses:

Hypothesis 1:

The greater the level of tertiary science and technical education the greater the concentration of scientific and technical labor force.

Hypothesis 2:

The greater the concentration of scientific and technical labor force the greater the level of economic development.

As a consequence of the perceived importance of science and technology for economic progress, the institutionalization of science and technology has become a worldwide phenomenon. Since World War II science instruction has become part of the curriculum in primary and secondary education in an increasing number of countries and the number of hours devoted to science has increased as well (Benavot 1992:Kamens and Benavot 1991). Regarding higher levels of schooling, science and engineering enrollment has expanded in most nation-states regardless of the level of socioeconomic development (Ramirez and Lee 1995). The institutionalization of science and technology is also evidenced by the increased number of scientists and engineers in the labor force (Ramirez and Drori 1992).

Interestingly enough, there is very little empirical evidence in support of the argument that science and technical education is crucial for productivity growth beyond the higher salaries earned by those with scientific and technical training. It is very much a taken for granted assumption which is based more on an intuitive appeal than on empirical evidence.

For example, a time series analysis of the effect of degrees awarded in different disciplines at the tertiary level on labor productivity in the United States showed that degrees awarded in math, engineering or physical sciences had weak and statistically insignificant effects on labor productivity[4] in the post-World War II period (Walters and O'Connell 1990).[5] While this study was based on the United States alone, a cross-national study by Ramirez and Lee (1991) found that tertiary science enrollment had a positive impact on economic growth for the time periods 1960-1969 and 1970-1980. In the same analysis, however, the level of economic development was unaffected by the number of scientists and engineers or by the amount of expenditure on research and development.

Research investigating the links between tertiary science and technical education

[4]Labor productivity was measured as output in the nonfarm private economy per person hour of labor employed.

[5]First, a baseline model was estimated by OLS with factors explaining the variation in the annual change in labor productivity for the period 1950-1985. Number of degrees awarded in a particular discipline, standardized for the population at risk (e.g., 23 for bachelor's degree), was added to the baseline model as a lagged variable. Walters and O'Connell estimated models with lags between 3-20 years for each individual discipline, business administration, natural sciences, social sciences, humanities and mathematics. With the exception of a significant positive three year lagged effect of degrees in engineering, none of the lagged effects in technical fields had a statistically significant effect on changes in labor productivity. For the nontechnical fields a positive and significant effect was obtained for the 14-16 year lags.

and the participation of scientist and engineers in the labor force and economic growth is inconclusive. Thus, it is important both from a theoretical and a policy perspective to investigate the conditions under which the expansion of tertiary science and technical education and the participation of scientists and engineers in the labor force may contribute to economic growth. In framing this problem, I follow the "science and technology for progress" model which breaks down the relationship between science and technical education and economic development into two parts; (1) the link between tertiary science and technical education and the size of the scientific and technical labor force, and (2) the link between the number of scientists and engineers and economic development.

With this dissertation I explore the following questions:

1) *Is there a relationship between the level of tertiary science and technical education and the number of scientists and engineers in the labor force? Does the effect vary depending on particular political and socioeconomic conditions?*

2) *Does the number of scientists and engineers in the labor force affect the level of economic development? Does the effect vary depending on particular political and socioeconomic conditions?*

3) *Does the number of scientists and engineers engaged in research and development affect the level of economic development? Does the effect vary depending on particular political and socioeconomic conditions?*

The following sections describe the conceptual framework under which institutionalization of science and technical education may contribute to economic growth. The first part of the conceptual framework lays the foundation for the factors conditioning the relationship between tertiary science and technical education and the size of the scientific and technical labor force structure.

Science and Technical Education, and Economic Development

To investigate the effect of tertiary science and technical education on economic development, I start by relying on the conditions for the contribution of education to economic development stated by Rubinson and Fuller (1991). The central tenet of their argument is that in order for education to have an effect on the economy there has to be a close coupling between the skills needed in the economy and the skills produced within the formal educational system. More specifically, in order for a human capital process to generate economic growth the following conditions should be satisfied:

> a) education must create the kind of skills required by the economy,
> b) the economy must be able to absorb the skills created by schooling and
> c) there must be a close coupling between the educational and the economic systems so that the people with the appropriate skills are allocated to jobs that can utilize them. (Rubinson and Fuller 1991)

I argue that the same conditions apply to the output of engineers and scientists from tertiary education. There must be a close coupling between the level of enrollment and the demand for scientists and engineers, for the former to affect economic development. This link is a function of the degree to which there is an infrastructure that can absorb the output of scientists and engineers from tertiary education. As documented earlier the worldwide diffusion of the "science and technology for progress" model has resulted in the expansion of science and technical education in most nation-states irrespective of the level of national development. In fact, the rate of expansion of science and technical education has been higher in less developed countries than in developed ones (Ramirez and Lee 1995).

The adherence to the "science and technology for progress" model, among countries committed to the project of development and modernization, sustains the process of globalization of science and technology. This process, in turn, leads to an increasing isomorphism which is likely to "result in loose coupling between science policy and science practice" (Ramirez and Drori 1992). This is because societies that do not have the means to sustain an infrastructure still hang on to the myth that science and technology are the keys to national progress.

Scientists and engineers are a professionally mobile group which creates the potential for migration of talents or "brain drain." A well known fact is the existence of "brain drain" of scientifically and technically trained manpower from third world countries when they are not able to find jobs matching their qualifications. This may happen if there is not a sufficient base of people possessing lower level schooling such as secondary education. In that case university trained scientists and engineers may have to take jobs that are below their qualifications. Likewise, if the economy is not sufficiently developed to absorb graduates in science and technology, unemployment of scientists and engineers is likely to follow. The inability to take advantage of a scientifically and technically educated labor force has been a problem in some less developed countries such as India and China, for example, where scientists and engineers have migrated abroad, remained unemployed for a long time, or have had to take jobs that they are not trained for (Fortney 1970; Prasad 1979; Unesco Principal Regional Office for Asia and the Pacific 1987). Consequently, the link between the level of tertiary science and technical education and the number of scientists and engineers is likely to be weakened under such conditions.

Hypothesis 3:

In societies with an expanded coverage of secondary education, the greater *the level of tertiary science and technical education the greater the concentration of scientists and engineers in the labor force.*[6]

Hypothesis 4:

In societies with a developed economy, the greater the level of tertiary science and technical education the greater the concentration of scientists and engineers in the labor force.

The next section provides the framework for the link between scientists and engineers in the labor force and economic development.

[6]This hypothesis and the following hypotheses do not rule out the possibility of a positive link in societies in which the stated conditions do not hold, i.e. when access to higher education is not nationally controlled. They only stipulate that the link is weaker in such societies.

Science, Technology, and Economic Development

In order to examine the effects of expanded scientific and technical manpower on economic development it is useful to evaluate the role of scientists and engineers in this process. It is generally perceived that the role of scientists and engineers is to develop, modify, and adopt new technology (e.g. ,the Swedish Academy of Science 1992). Technological progress, in turn, is believed to lie at the heart of economic progress.

The importance of science and technology in economic growth has mainly been advocated by neoclassical economists. Specifically, they conceptualize economic growth in terms of the production function, in which the total output or the national product is explained by the basic factors of production (labor and capital). As mentioned earlier, between 1870 and 1950 in the United States the growth in national income had exceeded by far the growth in labor and capital. In fact, it was found that the residual or the amount of the unexplained variance in the growth in national product between 1870 and 1950 constituted about 80%. In other words, only 20% of the growth in national product was explained by the growth in conventional resources (Abramovitz 1956; Solow 1957; Denison 1962 1979). The huge residual was interpreted as technical change, which is sometimes labeled as total factor productivity. Solow's main argument was as follows: as the capital/labor ratio increases due to capital accumulation, the marginal product of capital decreases, which in turn lowers the national savings rate and investment rate, and eventually only capital sufficient to replace obsolete capital will be added. Consequently, the economy will reach a steady state when the level of the living standard will remain constant. However, with technological progress, entailing an exogenous outward shift of the production function and constant returns to scale,[7] the economy will be able to continue expanding.

A common assumption in this line of research and for neoclassical economists in general is that technical progress[8] is an exogenous phenomena, determined outside the economic system like a free gift from heaven. Specifically, neoclassical growth models assume that technology is given in the form of a set of production possibilities from which firms choose in order to maximize their profit. Technological change, in this sense, is not determined in the growth model and is thus exogenous to economic growth. A different way of expressing this, is that neoclassical growth models assume that science drives technological progress entailing new and more efficient production possibilities that, in turn, lead to economic growth. Kline *et al.* (1986) describes the process of technological change within neo-classical economic growth models in the following way: "In particular, this model postulates that one does research, research then leads to development, development to production and production to marketing."

Edquist (1992, p.8) defines technical change from its conception to its actual commercialization as invention, innovation, and diffusion.

> Through technical R & D new ideas or inventions emerge, e.g., in the forms of technically feasible prototypes which are potentially useful for the economic sphere. These are adopted and modified into innovations, which are economically feasible technologies. Through innovation, the inventions have been transformed into products and processes actually used in the economic system for the first time.

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[7]Constant returns to scale implies that if all the inputs are scaled up by some constant factor t the output will also be scaled by the same factor t. This can be expressed mathematically by the following equation in the case of two inputs:
$tf(x1, x2)=f(tx1,tx2)$.

[8]Technological change has often been equated to the residual derived from estimating the production function.

> Together invention and innovation constitute what we call technological development: the process through which new technologies emerge and enter the economic sphere for the first time.

After the innovation has been introduced, other producers may absorb the technology, resulting in diffusion. For production technologies diffusion means that additional producers (firms) introduce the innovation in their manufacturing process. When the innovation is a new product, diffusion means that additional producers begin to produce the product. [9]

Against this background it seems logical that one possible way in which the presence of scientists and engineers in the labor force affects productivity growth and economic development is through engagement in research and development. However, the increasing mobility of scientific and technical knowledge makes technological change possible without national investment in research and development. The crucial point here is the availability of trained manpower that knows how to apply technology developed abroad. As Rosenberg (1994, p.18) states: "The ability to exploit new scientific knowledge in a commercial context depends directly upon the technological capabilities that are available within an economy. "

To conclude: I envisage that scientists and engineers may contribute to technological change and economic development through two main processes. First, scientists and engineers will contribute to economic development by engaging in research and

[9] However, it should be noted that this unidirectional growth model ,which assumes that technological change is determined outside the economic system, has been criticized (see Kline *et al.* 1986;Romer 1990; Grossman and Helpman 1994). The progress of scientific and technological knowledge does not proceed independently from economic incentives. Instead, the decision of what kind of scientific and technical research to undertake is often made on the basis of foreseen economic opportunities or demand.

development of new products and processes. Secondly they will contribute through the adaption and modification of technology that has either been developed domestically or imported from abroad.

Until now the discourse on this subject seems to regard the impact of scientists and engineers on economic development as uniform and independent of country or societal factors. But we know from the case of the Soviet Union, with its large scientifically and technically trained labor force but inefficient and technologically backward manufacturing and service sector, the sheer number of scientists and engineers is not enough to generate economic growth (Rosenberg 1994).[10]

I will argue that the effect of educating scientists and engineers, and their presence in the labor force is probably more complex than the simple "science and technology for progress" model would suggest. Rather, the effect is conditional upon a number of societal factors. The following sections delineate some possible factors operating at the nation-state level.

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[10] To clarify, I mean that the linear growth model assumes a strong positive correlation between the number of scientists and engineers in the labor force and economic development irrespective of country-specific factors. The more scientists and engineers in the labor force, the greater the economic growth. I am not claiming that the discourse on this subject regards the process by which scientists and engineers contributes to economic growth to be similar across societies.

The Effect of Research and Development on Economic Growth

The US lead in economic growth has, among other things, been attributed to a higher investment in research and development and comparatively higher ratio of scientists and engineers involved in R&D (e.g., Nelson 1992). Despite this reference to national level effects, most research in support of this argument has focused on particular sectors of the economy, such as manufacturing, and to a very small extent on the national or macro level. Research in this area has in general compared the growth rate in different industries with the intensity of research and development. In studies carried out in the United States and in Sweden , for example, the difference in research and development intensity significantly explained variations in total factor productivity between different sectors (Edquist 1990; Mansfield 1968 1972; Terleckyj 1974).

Studies that have related national emphasis on research and development to national level economic growth using indicators such as expenditure level and number of scientist and engineers involved in R&D suggest that the effect of R&D on economic development may be contingent upon levels of industrialization. For example, Ramirez and Lee (1995) found in a cross-national comparative analysis that the number of scientist and engineers engaged in R&D did not affect economic growth. However, their study was based on a full sample of countries and did not differentiate between different levels of economic development. In fact, the few studies carried out based on the OECD countries alone suggest that investment in R&D significantly contributes to economic growth in these countries. For example, working with OECD countries Eaton and Kortum (1993) and Lichtenberg (1992) found respectively that the number of scientists and engineers and the level of spending on R&D

significantly contributes to a country's income level. Focusing on less developed countries, however, Shenhav and Kamens (1991) did not find this positive effect. The conclusion here is that more advanced economies probably benefit more from scientists and engineers engaged in R&D.

Hypothesis 5:

In societies with more technologically developed economies, the greater the number of scientists and engineers engaged in research and development the greater the level of economic development.

In addition, the development of new technology is a risky and costly operation, especially in high tech industries, due to the uncertain outcome (Okimoto 1987). Therefore I argue that the effect of research and development on economic growth will be affected by the size of the market. Larger markets can absorb the cost to a greater extent.

Hypothesis 6:

In societies in which the market is large, the greater the number of scientists and engineers engaged in research and development the greater the level of economic development.

The next section discusses conditions that apply not only for scientists and engineers engaged in research and development but for the entire stock of scientists and engineers.

Scientists and Engineers as a Whole and Economic Growth

As stipulated above, expanded export markets make scientists and engineers in research and development more profitable from an economic point of view because of the opportunity of spreading the cost of research and development. As the market becomes larger it becomes possible to take advantage of division of labor and the realization of economies of scale (Abroamovitz 1991). This makes technological change in general more possible to realize; therefore the contributions of scientists and engineers as whole are more favorable under those conditions.

Hypothesis 7 :

In societies in which the market is large, the greater the concentration of scientists and engineers in the labor force the greater the level of economic development.

Moreover, the process of technological change is complex and its progress does not depend on the availability of scientists and engineers alone. In many cases technological progress has been achieved without new technology but with more efficient organization of existing production processes. As Rosenberg (1994, p.18) points out:

> "The ability to achieve the commercial exploitation of new scientific knowledge is heavily dependent upon social capabilities that are remote from the realm of science. These capabilities involve skills in organization, management and marketing in addition to those of a technological sort."

Hence, that the efficient utilization of scientists and engineers in the labor force may require the availability of people with business and administrative skills. In fact, Walters and O'Connell (1990) found that degrees awarded in business administration had a higher impact on US economic growth since World War II than those awarded in science and technical fields.

Hypothesis 8:

> *In societies with a large number of people in the labor force with business and administrative skills, the greater the concentration of scientists and engineers in the labor force the greater the level of economic development.*

As stated above, neoclassical economists often conceptualize technological progress as the additional growth in national income not accounted for by change in the size of conventional inputs. Accordingly, there are two sources for economic growth: investment in tangible capital such as machines and equipment, labor, and human capital and intangible capital such as technological progress.

The growth accounting exercise applied by neo-classical economists is based on the assumption of additive effects where each factor acts independently of one another (factors included in the model add up in explaining economic growth). However, most new technology to be adapted and diffused requires investment in new machinery, which means that technological progress is embedded in new gross investment.

Lau (1994) argues that: "technical progress as a form of intangible capital may have low marginal productivity in developing countries where the tangible capital to labor ratio is low or human capital to labor ratio is low, or both, that is when the complementary factor inputs are lacking." Lau further states that the new investments embedded in technological progress make the creation of technological progress inefficient as long as a certain level of physical capital has not been reached. One conclusion to make on the basis of this argument is that the level of capital formation interacts with the effect that scientist and engineers have on economic growth.

Hypothesis 9:

In societies in which the level of capital is large, the greater the concentration of scientists and engineers in the labor force the greater the level of economic development.

These nine propositions constitute the foundation for the conceptual framework. In Chapter 4 the hypotheses regarding the relationship between tertiary science and technical education and the size of the scientific and technical labor force structure are tested. Chapter 5 evaluates the hypotheses pertinent to the effect of the number of scientists and engineers and economic development. The next chapter, Chapter 3, documents the methodology used throughout this study.

CHAPTER 3

RESEARCH DESIGN

The methodology of this study is aimed at evaluating the validity of the "science and technology for progress" model, which asserts a universal positive connection between the amount of science and technical education and economic development through the expansion of the scientific and technical labor force. Specifically, the methodology is intended to gain insight into the following questions: (1) how do variations in the amount of tertiary science and technical education affect the growth in the scientific and technical labor force, (2) to what extent can different levels of economic growth be attributed to the variation in the relative number of scientists and engineers, and finally (3) are these casual links conditioned by any of the societal characteristics outlined in the conceptual framework?

This chapter describes the methodology, the indicators, and the data used in this project. It begins with a general overview of the research design followed by a documentation of the models and indicators employed to test the hypotheses outlined in the previous chapter. The overview is followed by a description of the data and the discussion of the inappropriateness of using OLS regression to estimate the models. Based on this, I offer a justification for the use of ridge regression as the estimation procedure. In the last section I describe the principles of ridge regression.

Research Strategy

This project employs a cross-national comparative research strategy in which the unit of analysis is the nation-state. Educational systems are institutions whose structural arrangements are shaped by the nation-state and in most systems the nation-state, regulates the admission standards, the curricular content, the examination and graduation standards and the licensing of teachers. It is the nation-state which most often has the legitimate authority to make changes in the organization of the educational system (Meyer 1977). Since the focus of this project is on how variations in the national emphasis on tertiary science and technical education affect differences in the scientific and technical labor force structure and subsequent variations in the level of economic development, the appropriate unit of analysis is the nation-state.[11] (For a lengthy justification for the use of the nation-state as the unit of analysis, see Benavot 1985 and Meyer and Hannan 1979).

The relationship between the size of tertiary science and engineering enrollment, the participation of scientists and engineers in the labor force, and economic development is assessed using panel analysis. Panel analysis is the most widely used procedure in cross-national sociological studies. It takes into consideration both variations between nations and variations over time for each nation (Meyer and Hannan 1979). It involves regressing the dependent variable on a number of earlier measured explanatory variables, including the lagged dependent variable. It is also necessary to conduct the analysis based on data collected at two points in time in order to isolate the direction of causality.

This project covers the period 1970 to 1990 and its intent is to investigate the validity of the "science and technology for progress" model during a time period in which there has

[11]This is in contrast to a human capital perspective in which schooling brings economic benefits for the individual. The effect of expanded schooling on national level economic growth is inferred from the aggregate differences in income between individuals with different levels of schooling. In this case the unit of analysis would be both the individual and the nation-state.

been much confidence in science and technology for national economic progress. It is beyond the scope of this study to account for specific historical conditions that may influence this particular relationship. Thus, the result of this study is not assumed to hold for all time periods.

The causal direction considered within the framework of this project links economic growth to an increase in the number of people trained in the field of science and engineering resulting in a stronger scientific and technical infrastructure. However, it does not rule out the possibility that education expands in response to labor force needs and that the scientific and technical labor force structure expands as a consequence of economic growth; this is more of a theoretical issue. A greater number of technically and scientifically trained manpower may not imply higher levels of economic development; however, there is no reason to assume a priori that is the case. Previous research has highlighted disjunction between tertiary education and economic development. After the Second World War, all levels of education, including tertiary science and engineering education, have expanded in most countries regardless of socioeconomic conditions (Ramirez and Lee 1995). Cross-national studies focusing on this period show weak linkages between the level of economic development and industrialization and the expansion of education (e.g., Ramirez and Lee 1995). Thus it seems reasonable not to refute a priori the argument that variations in the amount of tertiary science and technical education explain subsequent variations in the labor force structure and the level of economic development.

Since initially it may take some time for the labor market to absorb those who are leaving tertiary education, and the level of scientific and technical concentration in the labor force does not affect the level of economic development immediately, it is necessary to use time lags. As mentioned previously, time lags are also needed to address the issue of causality. There is no clearly established theory to guide the choice of the time lag between tertiary enrollment, the labor force structure, and economic growth. Previous studies (e.g Benavot 1992; Ramirez and Lee 1995; Walters and O'Connell 1990) show that the effect of education on economic growth is rather long term (15-20 years). Therefore, the models estimated within the framework of this project use five and ten years' lag to estimate the link between tertiary science education and labor force structure and ten and twenty years' lag to estimate the impact of scientific and technical labor force capacity on economic development.

Model Specification

This project involves estimating two groups of regression models. The results from the estimation of these models are reported in Chapters 4 and 5. The first set of models considers the link between tertiary science and technical education and the degree of technical and scientific concentration in the labor force. The second group of models estimates the relationship between the relative size of scientists and engineers in the labor force and subsequent economic growth. In addition to the baseline models, more complex models with interaction terms are included to evaluate whether the strength of these two links is conditioned by specific societal features which were outlined in the theoretical framework. The general model for examining the effect of tertiary science and engineering enrollment on the number of scientists and engineers in the labor force is estimated by the following equation:

$$Y_t = a_0 + b_1 Y_{t-1} + b_2 X1_{t-1} + b_3 X2_{t-1} + b_4 X3_{t-1} + b_5(X1_{t-1} * X2_{t-1}) + b_6(X1_{t-1} * X3_{t-1}) + e_t$$

Where:

Y_t = measure of the number of scientists and engineers in the labor force at time (t)

Y_{t-1} = measure of the number of scientists and engineers in the labor force at time (t-1)

$X1_{t-1}$ = measure of tertiary science and engineering enrollment at time (t-1)

$X2_{t-1}$ = measure of the coverage of secondary education at time (t-1)

$X3_{t-1}$ = measure of economic development at time (t-1)

The second part of the empirical analysis investigates the relationship between the relative number of scientists and engineers in the labor force and the level of economic development. The models are estimated by the following equation:

$$Y_t = a_0 + b_1 Y_{t-1} + b_2 X1_{t-1} + b_3 X2_{t-1} + b_4 X3_{t-1} + b_5 X4_{t-1} + b_6 X5_{t-1} + b_7(X1_{t-1} * X4_{t-1}) + e_t$$

Where:

Y_t = measure of economic development at time (t)

Y_{t-1} = measure of economic development at time (t-1)

$X1_{t-1}$ = measure of the number of scientists and engineers in the labor force at time (t-1)

$X2_{t-1}$ = measure of tertiary science and engineering enrollment at time (t-1)

$X3_{t-1}$ = measure of the coverage of secondary education at time (t-1)

$X4_{t-1}$ = measure of the size of market at time (t-1) or measure of the total stock of capital at time (t-1)

$X5_{t-1}$ = measure of investment in conventional capital at time (t-1)

Data and Indicators

Indicators of Tertiary Science and Technical Education

To assess the impact of the national emphasis on tertiary science and technical education two indicators are used throughout this study: (1) the number of students enrolled in tertiary science and engineering, and (2) the number of students graduating from these fields in a given year. Both these measures are standardized for the population "at risk", which is considered to be the population in the university age group, 20-24. Data on enrollment and on population are obtained from the UNESCO Year Book and UN Demographic Yearbook, respectively (various years).

The tertiary science and engineering enrollment ratio (the number of students enrolled in tertiary science and engineering programs standardized for the population at risk) has been used in prior cross-national research (Ramirez and Lee 1995). The number of graduates in science and engineering (standardized for the population at risk) has been used in a time series analysis focusing on the United States (Walters 1990) but rarely in cross-national research. This measure more directly captures the potential addition of scientists and engineers to the labor force because it focuses on degree holders.

Indicators of Scientific and Technical Labor Force Structure

The technical and scientific capacity in the labor force is measured by using two indicators: the relative concentration of scientists and engineers in research and development and the total stock of scientists and engineers in the labor force. These two measures are computed per 10,000 of the economically active population.

Data on scientists and engineers in research and development and as a whole are taken from the UNESCO Statistical Yearbook (various years). Although UNESCO has the most comprehensive cross-national data on science and technology, it is important to keep in mind some caveats as to the quality and comparability of the data. As reported by UNESCO, statistics on science and technology have not reached the same level of comprehensiveness in all the countries. Whereas some countries have established systems for data collection by means of regular surveys, other countries are just beginning to create a systematic organization for data collection. At the time the data were collected many countries did not have an established infrastructure for data collection on science and technology and thus had to rearrange their national data to conform with the classification imposed by UNESCO. This had an impact on the topics covered and on the methods of measurement. For instance, while some countries include social sciences and humanities in their definition of research and development, others omit these categories. Furthermore, while most countries include only those activities that can clearly be classified as research or experimental development in the measure on research and development, in some countries the total volume of activities performed by departments or institutes in research and development was included. These countries did not make adjustment for those activities that are not classified as R&D. UNESCO has made efforts to rectify the problem by continously updating its database adjusting for inconsistencies between countries. Therefore, earlier data for a particular year have been replaced with later published data. The labor force data are obtained directly from ILO Office of Statistics and they represent the latest update (1996).

Economic Development

As in prior research (e.g., Ramirez and Lee 1995; Benavot 1992; Lau 1994) this study uses the real gross domestic product per capita (Summers and Heston 1995) as the indicator for economic development. The domestic product is the sum of all goods and services produced within a country's territory (both by residents and non-residents) and it is calculated by taking the value of GNP[12] and subtracting the difference between the value of goods imported and exported by a country (World Bank 1982:161). The real gross domestic product is adjusted to take into account the relative purchasing power, and it has been converted into constant prices and units that are internationally comparable. The Summers and Heston data series are constructed to maximize the comparability of RGDP by adjusting for differences in economic and occupational structure that distinguish LDCs from the more industrialized nations (for an elaborate discussion, see Benavot 1985).

The Coverage of Secondary Education

This study uses the gross enrollment ratio for secondary education, which is the most commonly used indicator for the level of attainment of secondary education. The secondary enrollment ratio is obtained from enrollment ratio tables, as reported by UNESCO, for a

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[12]GNP refers to the quantity of all goods and services that are available for consumption and investment in a country including, "factor income (such as investment receipts and workers' remittances) accruing to residents from abroad, less the income earned in the domestic economy accruing to persons abroad."

variety of years. It is calculated as the number of students enrolled in secondary education standardized for the population of ages 14-18. This measure obviously has some limitations. First, the denominator sometimes does not accurately represent the age-spread of the students. This may be due to educational systems that allow students to repeat years of school, which causes some students to extend their stay. Enforcement of admission age is not as stringent in some countries which implies that students may enter at a later age than is stated. A better measure would be obtained by using the net enrollment ratio which excludes from the numerator the students who are not in the relevant age group. However, very few countries report data enabling the calculation of net enrollment ratio at the time point of interest.[13] A second limitation is that the enrollment ratio does not take into account those who do not complete secondary education. Thus, the enrollment ratio does not truly capture the level of attainment of secondary education. However, the secondary enrollment ratio still has some value. It does capture the level of ideological commitment to provide education for the population, and it also shows the potential supply of people with a secondary education degree able to enter tertiary education and the labor force.

Size of Market

The market constituting the base for total demand comprises both the domestic market as well as the expanded market in terms of export. For countries with a larger

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[13]As compared to primary education, the discrepancy between the net and gross enrollment ratio is less of a problem in secondary education. The reason for this is that the difference between the gross and net enrollment ratio is more pronounced in less developed countries for primary education because of the massive expansion of this level since the 1960's.

population , the domestic market may be large enough to support a large scientific and technical infrastructure, but smaller countries need to rely on exports. Since most of the countries in my sample are small to medium size, I use the proportion of export to GNP (World Tables, World Bank 1983) as a measure for the relative size of the market. This measure has been employed in prior research (e.g., Benavot 1985).

Domestic Capital Formation

The rate of domestic capital formation has been shown in earlier research to be important in generating economic growth and thus it is necessary to control for it statistically. This project employs the real investment share of GDP (Summers and Heston 1995).

The Total Stock of Capital

While the investment share of GDP is an indicator of the overall investment, it does not tell much about the level of the total stock of tangible capital (machinery and equipment) that is available. The impact of scientists and engineers on economic growth may be limited when there is insufficient level of investment, since technological progress in the form of new knowledge is often embedded in investment in new equipment and machinery. In addition to investment share of GDP, this study employs a second measure of the level of capital accumulation: the amount of capital per worker. It is measured by the non residential capital per worker, which is the sum of machinery and equipment in all sectors excluding residential construction and foreign investment (Summers and Heston 1995). Table 3.1 below provides a summary of the indicators and data sources employed in the empirical analyses.

Table 3.1 SUMMARY OF INDICATORS AND DATA SOURCES

Concept	Indicator	Data Source
Economic Development	Log Real GDP/Capita	Summers & Heston
Scientization of Higher Education	1) Log Science & Engineering enrollment per 100 Pop Age 20-24 2) Log Graduates in Science and Engineering per 10,100 Pop Age 20-24 3) Index of 1) and 2) above	UNESCO Statistical Year Book, various years
Scientization of the Labor Force	1) Total Stock of Scientists and Engineers per 10,000 Economically Active Pop 2) The number of R&D Scientists and Engineer/ 10,000 Econ Active Pop 3) Index of 1) and 2) Above	UNESCO Statistical Year Book, various years
Coverage of Secondary Education	Enrollment in Secondary Education per 100 Pop Age 14-18	UNESCO Statistical Year Book, various years
Size of the Market	Export as proportion of GNP	WORLD BANK 1970 1975
Gross Capital Formation	Real Investment Share of GDP	Summers & Heston
Capital Stock	Non Residential Capital Stock per Worker (Sum of machinery and Equipment, excluding residential construction)	Summers & Heston

A detailed description of the measures employed in the empirical investigation and the data source from which they have been obtained can be found at the end of this chapter.

Description of the Data

This section provides a general description of the data in terms of means, standard deviations and zero-order correlations for each of the variables employed in the empirical analyses. Because of missing values for a variety of variables the subsequent analyses use three sets of partially overlapping cases determined by the specific dependent and independent variable of interest. The first part of the analyses, presented in Chapter 4, examines the relationship between tertiary science and technical education and the level of scientific and technical infrastructure. There are 51 cases in which the dependent variable is the total stock of scientists and engineers in the labor force, while there are 40 cases in the models based on the level of concentration of scientists and engineers in research and development. Chapter 5 looks at the effect of variations in the level of scientific and technical capacity in the labor force and economic growth. Throughout this chapter 48 cases are employed. The descriptive statistics presented below are based on the largest set of cases used in the models (51), and the remaining variables are selected on the basis of pairwise deletion. Descriptive statistics as well as the bivariate correlations for each subset of cases do not depart significantly from what is presented here. Table 3.2 below presents the descriptive statistics for all the variables employed in this study.

Table 3.2 Descriptive Statistics

Variable	Mean	Standard Deviation
Real Gross Domestic Product per Capita 1970	1684	1229
Real Gross Domestic Product per Capita 1990	8785	6464
Scientists and Engineers per 10,000 Econ. Active Pop. 1970/75	29	25
Scientists and Engineers per 10,000 Econ. Active Pop. 1980/85	47	37
R&D Scientists and Engineers per 10,000 Econ. Active Pop. 1970/75	1.6	1.5
R&D Scientists and Engineers per 10,000 Econ. Active Pop. 1980/85	2.4	2.1
Non R&D Scientists and Engineers per 10,000 Econ. Active Pop. 1980/85	28	23
Tertiary Science and Engineering Enrollment per 100 Pop. Age 20-24 1970	2.5	1.8
Graduates in Science and Engineering per 10,000 Pop. Age 20-24 1970	33	28
Secondary Education Enrollment per 100 Pop. Age 14-18 1970	48	27
Export as % of Gross National Product 1970	26	18
Real Investment Share of Gross Domestic Product 1970	22	9
Non Residential Capital per Worker 1970	74	37

First, it should be noted that, on a global scale, the average number of scientists and engineers in the labor force per 10,000 economically active population rose by more than fifty percent in the 10-15 year period, from 28 in 1970/75 to 46 in 1980/85. Similarly, the global average of the number of scientists and engineers in research and development increased nearly 1.5 times during the same period. The mean Gross Domestic Product per capita increased by a factor of five between 1970 and 1990.

Except for the correlation between the export share of GNP and the non residential capital per worker the bivariate correlations often exceed 0.7. The measures of tertiary science and technical education and the two measures of the technical and scientific labor force structure are correlated at 0.7 and 0.8, respectively. As expected, correlations between the dependent variable and the lagged dependent variable are high, since the infrastructure of each country is presumably quite stable from one time point to the next. The autocorrelation between the total stock of scientists and engineers in 1970/75 and in 1980/85 is 0.94, and between scientists and engineers engaged in research and development the corresponding correlation is 0.92. The autocorrelation between GDP per capita in 1970 and in 1990 is 0.94.

OLS Regression and Diagnostics

The measures of scientists and engineers in the labor force are positively skewed. This means that for most countries in the sample scientists and engineers constitute a small proportion of the total labor force, while only a few countries have a high proportion of scientists and engineers in the labor force. Since OLS regression analysis presumes that the dependent variable is normally distributed, the skewness must be corrected. Among the independent variables, the measure of tertiary enrollment and graduates in science and engineering as well as the measure of the size of export and the amount of capital per worker are also positively skewed. Regression requires no assumption about the distribution of the

X variables, but in practice skewed X distributions are often associated with statistical problems such as influence and nonconstant variance of the error term (heteroscedasticity). Heteroscedasticity leads to inefficiency and biased standard error estimates (Neter, *et. al.* 1990). Therefore, to reduce the degree of skewness, all the models use a logarithmic transformation of the measures on scientists and engineers, the measures on tertiary science and engineering education, and the measures on the size of export and the amount of capital per worker.[14] Although the measure on economic development is less skewed than it is normally in cross-national studies, it is also logged in order to make it comparable to other studies.[15]

In addition to homeoscedastic error terms, OLS requires that there are no exact linear relationships among the explanatory variables (Dillon and Goldstein 1990).[16] In the presence of collinearity or linear dependence among the independent variables the estimated coefficients tend to have large sampling variability.[17] Consequently, only imprecise

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[14]The logarithmic transformation is done according to the following formula:

$$T(x) = \ln(x) \text{ or } T(x) = \ln(x+1)$$

[15]It should be noted that residual plots against the dependent and the independent variables in all the models do not reveal any signs of nonconstant variance of the error term. In all the residual plots, the residuals are uniformly scattered around zero without any pattern suggesting problems of heteroscedastic error terms or other misspecifications of the model.

[16]This refers to the rank assumption, $r(x)=p$ where $p<n$. This means that the rank of the data matrix X is p, the number of columns in X, and is less than n, the number of observations.

[17]In matrix notation the basic linear regression model is expressed as:

$$\mathbf{Y} = \mathbf{XB} + \mathbf{U}$$

where: **Y** is a column vector of observations on the dependent variable, **X** is a matrix of observations on the independent variables, **B** is a column vector of the true coefficients, and **U** is a column vector of the true error terms. Replacing **B** and **U** with **b** and **e**, where b is a vector of the estimated coefficients and e is a vector with the observed error terms, the above relationship becomes:

$$\mathbf{Y} = \mathbf{Xb} + \mathbf{e}$$

and the normal equations for solving b in matrix form is:

information may be available for individual coefficients and the extent to which inferences can be made is limited outside the region of observations.[18]

Not presented here, the correlation matrix shows that there is some collinearity present. The partial correlation coefficient between individual variables are high, often greater then 0.70. However, a serious problem of collinearity is not revealed in a correlation matrix with bivariate correlation coefficients.[19] A method commonly used to identify the presence of collinearity is to inspect the variance inflation factor (Neter, *et. al.* 1990).[20,21]

$$\mathbf{b}=(\mathbf{X'X})^{-1}\mathbf{X'Y}$$

In the face of collinearity between two or more variables, the $(\mathbf{X'X})^{-1}$ matrix will tend to have large diagonal elements. Since the estimated standard errors are directly proportional to the square root of the diagonal elements in the matrix $(\mathbf{X'X})^{-1}$, collinearity, gives rise to inflated standard errors (Miller and Smith 1980)

[18]It should be noted, however, that collinearity is mainly a sample problem. The sample does not contain sufficient information about variations in Y associated with changes in each explanatory variable for constant values of the other independent variables to correctly estimate the separate effects of the variables that covary (Hanushek and Jackson 1977)

[19]A greater problem exists if more than two independent variables are a linear combination of each other.

[20]The variance-covariance matrix of the estimated coefficients is given by: $\{\mathbf{b}\}=(\mathbf{X'X})^{-1}$ and in the case of standardized coefficients by the means of correlation transformation the $\mathbf{X'X}$ becomes the matrix of the pairwise correlation coefficients $\mathbf{r}_{xx}$ and $\{\mathbf{b}\}=(\sigma')^2\,\mathbf{r}_{xx-1}$ where $(\sigma')^2$ is the error term variance for the transformed model. The variance of b'_k (k=1 ....,p-1) is equal to the product of the error term variance $(\sigma')^2$ and the kth diagonal element of the matrix $\mathbf{r}_{xx-1}$. The kth diagonal element is called the variance inflation factor for b'_k, $(VIF)_k$ and can be expressed as $(VIF)_k = (1-R_k^2)^{-1}$ where R_k^2 is the coefficient of the multiple determination when x_k is regressed on p-2 other variables in the equation (Neter, *et. al.* 1990).

[21]It follows from the definition of the variance inflation factor (footnote 20) that in the special case of two variables the coefficient of the multiple determination $R_k^2 = r_{12}^2$, the coefficient of simple correlation between x_1 and x_2. Thus, in the case of a 2 x 2 correlation matrix based on standardized coefficients,

This factor measures how much the variances of the estimated regression coefficients are inflated due to the presence of collinearity. When there is no linear relationship among the independent variables in the regression model the VIF is equal to 1 (Neter, *et. al.* 1990). The variance inflation factor for the first two models estimated are given in the table below.

Table 3.3 Variance inflation factor for Models 1 and 2

Variable	VIF Model1	VIF Model2
Log Real GDP per Capita	5	44
Lagged Dependent Variable	4	7
Log Tertiary Science and Engineering Enrollment Ratio	4	265
Secondary Enrollment Ratio	5	67
Interateraction by Log Real GDP per Capita		554

As noted, the variance inflation factor when only the main effects are included is between 3 and 5, indicating that the variance is increased by three to five times due to the existence of collinearity. When interaction effect is included the inflation factor reaches

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$$[X'X]=\begin{bmatrix} 1 & r_{12} \\ r_{12} & 1 \end{bmatrix} \quad \textit{and} \quad [X'X]^{-1}=\begin{bmatrix} \frac{1}{1-r_{12}^2} & -\frac{r_{12}}{1-r_{12}^2} \\ -\frac{r_{12}}{1-r_{12}^2} & \frac{1}{1-r_{12}^2} \end{bmatrix}$$

If collinearity is evidenced by a correlation between x_1 and x_2 equal to r_{12} = .80 then the Variance Inflation Factor for the two variables will be equal to 1/1-.64 = 2.78.

extreme levels. The VIF is equally high for the other models. Under these circumstances OLS regression is not the most efficient estimator. A strategy often employed in the presence of collinearity is to drop one or more independent variables to lessen the degree of collinearity and estimate several models using different explanatory variables. This approach has some serious drawbacks. First, the coefficients are affected by the correlated independent variables that are not included in the model. Second, in panel analysis dealing with indicators of social and economic development, the lagged dependent variable is often correlated with the other independent variables. Hence, estimating separate models would not be a practical solution. A better remedial measure of dampening the effect of collinearity is to use a different estimation procedure such as ridge regression. Although ridge regression has been avoided by economists, "perhaps because of their aversion to biased estimators and partly because of the difficulty it presents for statistical inference" (Greene 1993, p. 271), it has been recommended by others arguing that ridge regression can produce a smaller mean square error than the OLS estimator in the presence of collinearity (Neter, *et. al.* 1990; Miller and Smith 1980). As evidenced by the bivariate correlation matrix and the variance inflation factor, the variables included in the empirical analysis are collinear to different degrees. Therefore, all the models in this study are estimated by the means of ridge regression.

Ridge Regression

The ridge regression technique results in a more stable estimation of the coefficients by making them less affected by small changes in the data such as deletion or addition of a few cases. Since the problem caused by collinearity is rooted in the relatively enlarged diagonal values in the inverse of the matrix **X'X**, ridge regression reduces this tendency by adding a small positive constant, k, to the diagonal of this matrix such that **b'=[X'X + K]$^{-1}$ X'Y**. The addition of this constant sharply reduces the diagonal values (the variance inflation factors) of the inverse matrix and, therefore, the standard errors of the estimates.[22] This in

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[22]To understand how adding a small constant, k, will reduce, the variance inflation factor, consider the 2 x 2 [X'X] matrix from footnote 21 in which r_{12} = .80.

$$[X'X] = \begin{bmatrix} 1 & .80 \\ .80 & 1 \end{bmatrix}$$

The content of the inverse matrix is based on the determinant of the matrix above which is equal to: (1 x 1) - (.80 x .80)=.36 so that

$$[X'X]^{-1} = \begin{bmatrix} \frac{1}{.36} & -\frac{.80}{.36} \\ -\frac{.80}{.36} & \frac{1}{.36} \end{bmatrix}$$

In this case the variance inflation factor as given by the diagonal entries is equal to 2.78. If a constant, k = .2 is added to [X'X] so that

$$[X'X + k] = \begin{bmatrix} 1.2 & .80 \\ .80 & 1.2 \end{bmatrix}$$

then the determinant becomes equal to: (1.2 x 1.2) - (.80 x.80)=.8 and

$$[X'X]^{-1} = \begin{bmatrix} \frac{1}{.8} & -\frac{.80}{.8} \\ -\frac{.80}{.36} & \frac{1}{.8} \end{bmatrix}$$

turn makes the estimated coefficients closer to the true population parameters than OLS would produce. The explanation for this is best understood by considering the relationship between the mean square error, the variance and the bias of an estimator.[23] The mean square error can be partitioned into two parts, the variance of the estimator and another nonnegative term, the squared bias.[24] This relationship then can be expressed as: mean square error = Variance + $(\text{Bias})^2$. Both the variance and the squared bias are a function of k and the nature of the relationship is such that the addition of a constant k to the diagonal elements of the inverse matrix causes the variance to decrease, but at the same time the bias increases; thus creating a necessary tradeoff. It can be shown that the variance is a monotonic decreasing function of k while the squared bias monotonically increases with k. However, the rate by which the squared bias increases as a function of k is slower than the corresponding decrease in the variance. Initially, as k moves away from zero (implying that small values are added to the diagonal), the variance decreases rapidly while the squared bias remains almost zero and will then increase faster as k becomes bigger. Consequently, it is possible

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Consequently, the inflation factor has now been decreased from 2.78 to 1.25.

[23]The most commonly used measure for the evaluation of the efficiency of an estimator is the mean square error (MSE) (Lindgren 1976). In the case of linear regression the means square error for the whole model is equal to:

$$\sum \frac{e_i^2}{n-1}$$

[24]The term bias refers to the amount by which the expected value of the estimator differ from the true population value, for example (E(x)-μ) . An unbiased estimator such as OLS implies that the value of the bias is equal to zero.

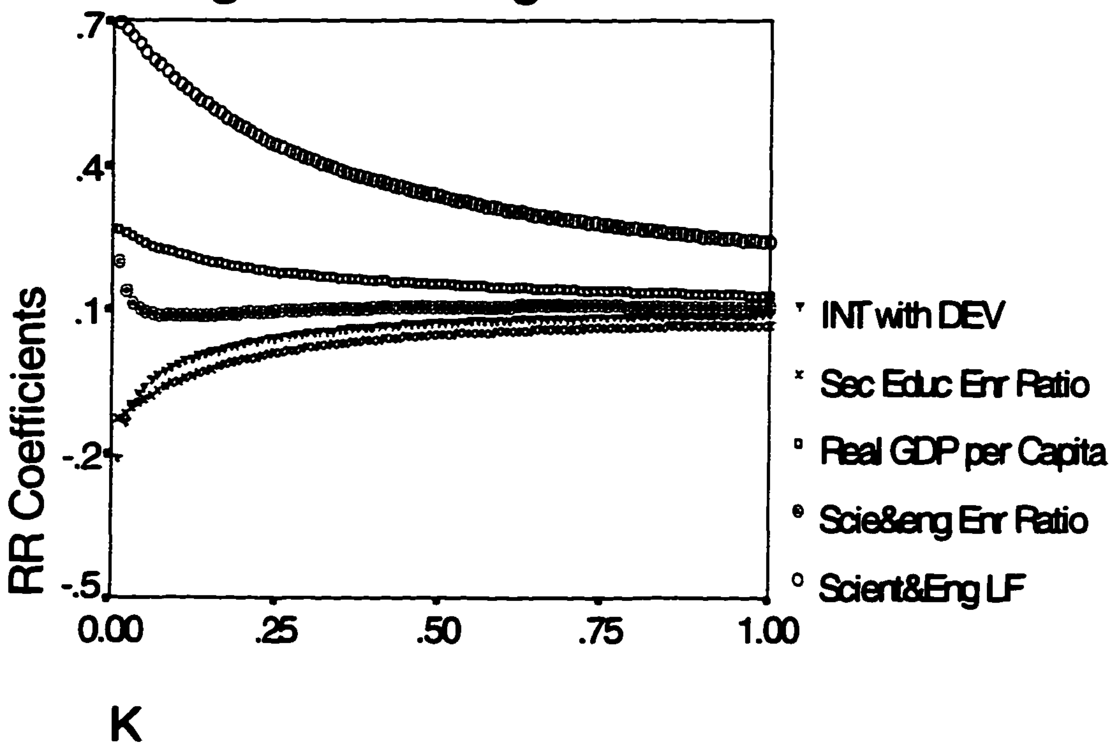
to accomplish a reduction in the mean square error while at the same time obtaining a substantially smaller variance. Thus, in the face of collinearity, ridge regression can produce estimates that are closer on average to the true values than OLS can achieve. (Neter, *et. al.* 1990; Miller and Smith 1980).

The question then becomes how to determine the right value of k. One commonly utilized strategy is the use of a graphical technique called the ridge trace (Hoerl and Kennard 1970). This technique involves the estimation of the ridge coefficients as in $\mathbf{b}^r = [\mathbf{X'X} + \mathbf{K}]^{-1}\mathbf{X'Y}$ for different values of k, ranging from 0 to 1. The estimated beta coefficients are then plotted against different values of k. In the presence of collinearity the estimated coefficients change rapidly when small values of k are added to the [X'X] matrix and then tend to stabilize as k becomes larger. In addition to the rate of change in the magnitude of the coefficients as k increases there may also be a reversal in the sign of some coefficients (see Figure 3.1). Thus, the value of k is normally selected on the basis of the following guidelines: (1) stability of the trace in terms of the magnitude and sign reversal of the estimated coefficients and (2) the increase in the residual sum of squares (Miller and Smith 1980). The appropriate value of k, in the models reported in this study, has been chosen by examining the ridge trace. Specifically, it has been chosen at the point when the coefficients start to stabilize.

It should be noted, however, that the residual sum of squares for the model as a whole increases with increases in k; thus the R-Square increases as well. Normally, this is not of any great concern since the more important goal is to achieve stability of the coefficient estimates and less important is how well the model fits the data. Stability of the estimates in turn will provide a better framework for future inferences (for further discussion, see for instance Marquardt *el al.* 1975).

This chapter has defined the methodology employed in this project. The empirical investigations are carried out using a cross-national comparative research design entailing multivariate ridge regression analysis. The next two chapters present the results of the analyses.

Figure 3.1: Ridge Trace



Key Concepts and Indicators

Economic Development

Real gross domestic product per capita (curr. intl. prices), 1970 1980 and 1990

Data Source: An update of Appendix B of "The Penn World Table (Mark 5): An Expanded Set of International Comparisons 1950-88, "The Quarterly Journal of Economics, May 1991 to correspond to PWT 5.6.

Tertiary Science and Technical Education

1. Tertiary Science and Engineering Enrollment Ratio = enrollment in engineering + enrollment in the natural sciences/population age 20-24 1970

Data Sources: *Unesco Statistical Yearbook*, different years

Data for 1970 refer to 1969 1970 or 1971.

Data on tertiary science and engineering enrollment include all university levels.

Population data comes from *Demographic Yearbook*, different years

2. Tertiary Science and Engineering Graduation Rate = the number of students graduating in science and engineering in the given year/population age 20-24, 1970

Data Sources: *Unesco Statistical Yearbook*, different years

Data for 1970 refer to 1969 1970 or 1971.

Data on tertiary science and engineering graduates include all university levels.

Population data comes from *Demographic Yearbook*, different years

Whenever possible missing data have been replaced by interpolation according to the formula: $P_n = P_0(1+r)^n$ where

P_n = the measure in the final year

P_0 = the measure for the initial year

r = average annual growth rate

For example:

n = the number of years in the period

r = (exp((ln(graduates in 1965)-ln(graduates in 1980))/15))-1

(graduates in 1970) = (graduates in 1965) $(1+r)^5$

Scientists and Engineers in Labor Force

1. Scientists and Engineers as a whole = total stock of scientists and engineers / total labor force (economically active population in 10,000s)

Data Sources: *Unesco Statistical Yearbook*, different years

Data for 1970 refer to 1969 1970 or 1971.

Population data come from *ILO Statistical Yearbook*, different years

2. Scientists and Engineers in research and development = the number of scientists and engineers in research and development/total labor force (economically active

population in 10000s)

Data Sources: *Unesco Statistical Yearbook*, different years

Data for 1970 refer to 1969 1970 or 1971,

for 1975 refer to 1974 1975 or 1976 and for 1980 refer to

1979 1980 or 1981.

Population data come from *ILO Statistical Yearbook*, different years

When ever it has been possible missing data have been replaced by intrapolation

according to the formula: $P_n = P_0(1+r)^n$ where

P_n = the measure in the final year

P_0 = the measure for the initial year

r = average annual growth rate

For example:

n = the number of years in the period

r = (exp((ln(scientists and engineers in 1965)-ln(scientists and engineers in 1980))/15))-1

(scientists and engineers in 1970) = (scientists and engineers in 1965) $(1+r)^5$

Coverage of Secondary Education

Secondary Enrollment Ratio = enrollment in secondary education / population age 14-18

For 1970, data is obtained from enrollment ratio tables

Data Sources: *Unesco Statistical Yearbook*, different years

Population data comes from *Demographic Yearbook*, different years

The Size of the Market

Export as proportion of gross national product = export/GNP

Data Sources: 1970 1975 World Bank

The organizational capacity

The number in the labor force in managerial and administrative positions relative to economically active population.

Data Sources: *ILO Statistical Yearbook*, different years

Data for 1970 refer to 1969 1970 or 1971.

The Gross Capital Formation

Real investment share Gross Domestic Product (curr intl. prices) 1970

Data Source: An update of Appendix B of "The Penn World Table (Mark 5): An Expanded Set of International Comparisons 1950-88, "The Quarterly Journal of Economics, May 1991 to correspond to PWT 5.6.

The Capital/Labor Ratio

Non Residential Capital Stock per Worker (KAPW) (1985 intl. prices) 1970

Data Source: An update of Appendix B of "The Penn World Table (Mark 5): An Expanded Set of International Comparisons 1950-88, "The Quarterly Journal of Economics, May 1991 to correspond to PWT 5.6.

KAPW has been estimated assuming a geometric depreciation rate for different classes of assets. It is based on the sum of machinery and equipment, non-residential and other construction. Change in stocks and foreign investment are not included.

Following is a listing of definitions in the UNESCO classification.

Engineering	applied sciences, construction, geodesy, metallurgy, mining, surveying, technology, textiles and similar subjects.
Natural Sciences	astronomy, bacteriology, biochemistry, biology, botany, chemistry, entomology, geology, geophysics, mathematics, meteorology, mineralogy, physics, zoology, and similar subjects.
Scientists and Engineers	includes any person who has received scientific or technical training in the exact and natural sciences, engineering, agricultural, medical and social sciences as follows: completed education at the third level leading to an academic degree: or completed third-level non-university education (or training)

which does not lead to an academic degree but is nationally recognized as qualifying for a professional career; or training and professional experience which is nationally recognized (e.g. membership in professional societies, professional certificate or license) as being equivalent to the formal education indicated.

R&D — any creative systematic activity undertaken to increase the stock of scientific and technical knowledge and to devise new applications. It includes fundamental research, applied research in such fields as agriculture, medicine,industrial chemistry, etc., and experimental development work leading to new devices, products or processes.

CHAPTER 4

SCIENTIZATION OF HIGHER EDUCATION AND THE LABOR FORCE

This chapter reports the findings from the empirical analyses which test the first set of hypotheses outlined in Chapter 2. The analyses presented here explore the link between the emphasis on tertiary science and technical education, on the one hand, and the scientific and technical capacity in the labor force, on the other. It is hypothesized that the greater the level of tertiary science and technical education, the greater the number of scientists and engineers in the labor force. In addition, this relationship is stipulated to be stronger in societies in which the economy and educational system are more developed because in such societies there is a greater capacity to absorb scientists and engineers.

The chapter is organized into five sections; each section presents the results from a ridge regression analysis to explain the variance in the number of scientists and engineers in the labor force. Each of the five sections represents different combinations of measures of the amount of tertiary science and engineering education and measures of the relative number of scientists and engineers in the labor force.

The emphasis on tertiary science and technical education is measured by two indicators, correlated at 0.88. The first measure is the number of students enrolled in natural sciences and engineering programs in tertiary education. The second one is the number of graduates in the same fields. Both of these measures are standardized for the university-age population, 20-24 years. The tertiary science and engineering enrollment ratio is expressed per 100 university-age population while the number of graduates in science and engineering is computed per 10,000 university age population.

Likewise, for the number of scientists and engineers in the labor force, two measures are employed. While the first measure is the total number of scientists and engineers in the labor force, the second one is a subset of the former: the number of scientists and engineers engaged in research and development. Both measures of scientists and engineers are expressed per 10,000 economically active population.[25]

The last two sections evaluate the combined effect of enrollment and graduates in science and engineering. To this end, the models estimated in those sections use an index for science and technical education which is constructed by the addition of the two individual indicators after they are standardized and centered.

In each section the labor force measure for 1980 is regressed on the 1970 value of the independent variables. Hence, the effect of tertiary science and engineering education on the number of scientists and engineers in the labor force is assessed with a ten-year lag. For countries for which the labor force measure is missing for 1970 or 1980, the value for 1975 or 1985 is used instead. This was done in order to maximize the number of cases. Models which include only cases which have values of the dependent variable for 1970 and 1980 are reported in footnotes. The overall effect and direction of these restricted models follow the same pattern as the models reported. In addition, models containing a five-year lag have also been estimated and are reported in footnotes as well.

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[25]These measures are correlated at 0.68, 0.74 and 0.53 for 1970 1975 and 1980, respectively.

The basic models estimated in this chapter take the following functional form:

$$Y_t = a_0 + b_1 Y_{t-1} + b_2 X1_{t-1} + b_3 X2_{t-1} + b_4 X3_{t-1} + b_5 X4_{t-1} + e_t$$

where:

Y_t = measure of the number of scientists and engineers in the labor force at time (t)

Y_{t-1} = measure of the number of scientists and engineers in the labor force at time (t-1)

$X1_{t-1}$ = measure of the amount of tertiary science and engineering education at time (t-1)

$X2_{t-1}$ = measure of the level of economic development at time (t-1)

$X3_{t-1}$ = measure of the coverage of secondary education at time (t-1)

Each one of the partial regression coefficients ($b_1, b_2, \ldots, b_5$) estimated in the model above measures the change in Y_t produced by a unit change in X holding the other X variables constant. For example, the coefficient b_2 refers to the effect of tertiary enrollment in science while controlling for the effect of the level of economic development and the coverage of primary and secondary education. A two-tailed test of significance is employed to test whether each coefficient is significantly different from zero. The significance level is reported at 0.1, 0.05, or 0.01 level. All the partial effects are expressed both in standardized and unstandardized units.

The model described above assumes that the effect of the amount of tertiary education in science and engineering on the number of scientists and engineers in the labor force is uniform in all countries. However, the impact of the number of students enrolled in tertiary science and engineering programs may be different in certain subgroups of countries, for example, by the level of economic development or by the level of educational attainment of the population in general. Treating all these subgroups of countries the same in the analysis may lead to misspecification of the model. One approach would be to stratify countries into different subgroups and then to estimate a model for each of these subgroups. This strategy is not recommended because it will result in fewer cases and new estimation problems. A more reasonable solution is to multiply the measure of tertiary science and engineering education by the measures of economic development and coverage of secondary education and to include these two interaction terms in the model. Thus, each section includes a more complex model with added interaction effects in addition to the baseline model above.

Data availability limits which cases are included in the analyses. The models regressing total number of scientists and engineers in the labor force on the size of tertiary science and engineering enrollment or the number of graduates in science and engineering use one set of cases. When the dependent variable is the proportion of scientists and engineers in R&D in the labor force, a slightly different set of cases is used. Otherwise a loss in the number of cases would result.[26]

[26]Although most of the effort made to detect the presence of outlier and non-constant error term variance was done initially using OLS, some residual analyses have been carried out in the context of ridge regression analyses. The transformation of the independent variables by taking the logarithm which made the error terms more homeoscedastic and the omission of influential cases in the initial analysis based on OLS seemed to have carried over in the ridge regression.

Tertiary Science and Engineering Enrollment and the Concentration of Scientific and Technical Labor force

This section examines the effect of tertiary science and engineering enrollment on the number of scientists and engineers in the labor force. The results from the empirical analysis are shown in Table 4.1. All the models here clearly support the argument that variation in tertiary science and engineering enrollment affect subsequent variation in the proportion of scientists and engineers in the labor force. Moreover, the models provide support for the argument that the effect of this relationship is stronger in societies with a higher level of economic development.

The first model assesses the impact of tertiary science and engineering enrollment on the proportion of scientists and engineers in the labor force for the panel 1970-1980/85. The size of tertiary science and engineering enrollment as a proportion of the university age population has a strongly significant and positive effect. One percentage change in the tertiary science and engineering enrollment ratio results on the average in a 0.4 percentage increase in the proportion of scientists and engineers in the labor force, controlling for other effects. The effect of both control variables, real GDP per capita and secondary education, is positive but the effect of secondary education, fails to reach any conventional level of significance. As displayed by the beta coefficient, excluding the autocorrelation or lagged dependent variable, the indicator for economic development has the strongest impact on the proportion of scientists and engineers in the labor force.[27, 28]

In Models 2 and 3 the interaction terms are added. The main effect of tertiary science and engineering enrollment remains positive and highly significant. The effects of the two control variables, economic development and secondary education, are similar to the baseline model including only the main effects. Note that the interaction with economic development (.026) is also positive and significant (Model 2), suggesting that the positive link between the number of students being trained in science and engineering and the size of the technical and scientific manpower is strengthened by the level of economic development.[29] Interestingly, the interaction with secondary education is negative but statistically insignificant.[30, 31]

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[27]The same analysis in which the dependent variable is measured in 1980 and 1970 (N=40) yields very similar results. The effect of the two control variables is slightly weaker, while the effect of log tertiary enrollment in science and engineering is somewhat stronger.

[28]In the same analysis for the 1970-75 panel the direction of the results are very similar. The effects are somewhat weaker with the exception of secondary education, the effect of which is also significant at the level of $p<0.05$.

[29]The positive interaction between RGDP and the size of the tertiary science and engineering enrollment ratio also implies that the effect of RGDP on the proportion of scientists and engineers in the labor force (.285) also depends on the interaction with the tertiary science and engineering enrollment ratio (.026). Thus, the total effect of log RGDP on the labor force variable is 0.285 + 0.026 x log (tert. Science and engineering enrollment ratio). Likewise, the total effect of the tert. enrollment in science and engineering is 0.282 + 0.026 x log RGDP.

[30]In the same analysis for the 1970-75 panel the direction of the results are very similar. However, none of the interaction terms are significant.

[31]The same analysis in which the dependent variable is measured in 1980 and 1970 (N=40) yields very similar results.

When both the interaction terms are entered in the same model (see Table A.1 in Appendix A), the result essentially remains the same. The only difference is the negative and significant effect of the interaction with secondary education (-.002). This finding seems counterintuitive. It could possibly reflect a process in which people trained as scientists and engineers in countries with more secondary education, controlling for the level of economic development, are more likely to take a job in managerial positions and will therefore not be classified as a scientist or engineer. Nevertheless, this explanation is only speculative and should not be taken as a firm statement.

The conclusion follows that the relationship between the amount of tertiary science and technical education and the number of scientists and engineers in the labor force appears stronger in economically more advanced societies, while the level of secondary education does not seem to matter.

Graduates in Science and Engineering and the Concentration of Scientific and Technical Labor force

This section repeats the analysis carried out in the previous section; but instead of the number of students enrolled in science and technical fields, the number of graduates in science and engineering is used as a measure for the emphasis on science and technical education. Like the models with the tertiary enrollment ratio in science and engineering, the models here support the argument that greater emphasis on tertiary science education leads to a larger proportion of scientists and engineers in the labor force. As in the previous models, it is also clear that the relationship is stronger for more economically advanced societies.

Table 4.2 reports the results from the analyses with the number of graduates in science and engineering per 10,000 university age population of 20-24.

In Model 4, which includes the main effects only, the number of graduates in science and engineering varies positively and significantly with the number of scientists and engineers in the labor force. One percentage increase in the number of graduates per 10,000 university age population leads to a 0.113 percent increase in the number of scientists and engineers per 10,000 economically active population, controlling for other effects. Similar to the models with tertiary enrollment in science and engineering, the level of economic development positively and significantly influences the relative number of scientists and engineers, while the level of secondary education enrollment has no effect on the degree of concentration of scientists and engineers in the labor force.[32, 33]

In Models 5 and 6 the interaction effects are included. Compared to the baseline model, there is little change in the magnitude of the main effects. As evident from the positive and significant interaction effect with log real GDP per capita (.007), the greater the level of economic development the stronger the relationship between the number of graduates in science and engineering and the proportion of scientists and engineers in the labor force. By contrast, this relationship is not affected by the interaction with the level of

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[32]The same analysis, in which the dependent variable is measured in 1980 and 1970 (N=40), yields very similar results.

[33]In the same analysis for the 1970-75 panel the direction of the effects are the same. The main effects of log S&E graduates and log RGDP per capita are weaker and less significant; the effect of secondary education is stronger and significant at the level of $p<0.01$.

secondary education enrollment.[34, 35] In all the models here, the initial level of scientists and engineers in the labor force accounts for most of the variation in the subsequent share of scientists and engineers.

When the two interaction terms are included in the same model (Model A.2 in Appendix A) there is very little change in the result. The interaction between economic development and the number of graduates in science and engineering is positive and significant (.009), while the interaction with secondary education remains negative and insignificant. The difference is negligible whether the interactions are entered separately or combined in the same model.

The findings obtained in this section point to the same conclusions reached earlier when enrollment in science and engineering was used as the indicator for tertiary science and technical education. The relative number of scientists and engineers in the labor force is linked to the number of graduates in science and engineering. This relationship, however, is not uniform across countries; there is a looser coupling between the number of degree holders in science and engineering and the number of people in the labor force classified as scientists and engineers in less economically developed countries. As shown previously, this relationship does not appear to depend on the level of secondary education enrollment.

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[34]The same analysis in which the dependent variable is measured in 1980 and 1970 (N=40) yields similar results, with the exception of the interaction between graduates in science and engineering and economic development, which becomes slightly weaker and ceases to be significant.

[35]In the same analysis for the 1970-75 panel the direction of the effects are the same. While the main effects of log S&E graduates and log RGDP per capita are weaker and less significant, the effect of secondary education is stronger and significant at the level of $p<0.05$. None of the interaction effects are significant at the level of $p<0.1$ or less.

Tertiary Science and Engineering Enrollment and the Number of R&D Scientists and Engineers

This section evaluates how variations in the tertiary science and engineering enrollment ratio affect the proportion of scientists and engineers engaged in research and development. As outlined in the theoretical framework, there are two paths by which scientists and engineers are thought to contribute to economic growth, either by developing new technology or by modifying or adopting existing technology. The measure employed here explores the former avenue. Table 4.5 below reports the findings derived from regressing the log of the number of scientists and engineers engaged in R&D as proportion of the total size of the labor force. As in the case of the total number of scientists and engineers, the models here show that the tertiary science and engineering enrollment varies positively with the proportion of scientists and engineers in R&D to the labor force. In contrast to the earlier models, this relationship varies both with the level of economic development and with the degree of coverage of secondary education.

Model 7 assesses the main effect of tertiary science and engineering enrollment on the relative size of scientists and engineers in R&D, controlling for other effects for the 1970-1980/85 panel (N=36). The proportion of scientists and engineers in R&D to the labor force is positively affected by the level of tertiary science and engineering enrollment. One percent increase in the tertiary science and engineering enrollment ratio raises the number of R&D scientists and engineers per 10,000 economically active population by 0.15 percent, holding real GDP per capita and the secondary enrollment ratio constant. The effect is significant at the level of $p<0.1$. The effect of both control variables is positive, although only the effect of secondary education is statistically significant. This is in sharp contrast to the models with the total number of scientists and engineers as the dependent variable. In those models the variation in the number of scientists and engineers was positively influenced by the level of economic development whereas the size of the secondary education enrollment ratio did not have any effect. As in the other models presented thus far, the lagged dependent variable explains most of the variation in the dependent variable.[36, 37]

The interaction with economic development and secondary education enrollment are included in Models 8 and 9, respectively. The main effect of tertiary science and engineering education is still positive but no longer significant after the inclusion of the interaction effects. The positive and significant interaction between the emphasis on tertiary science and technical education and economic development persists (.015). Unlike the models in which the dependent variable is the number of scientists and engineers as a whole, the interaction with secondary education is positive and significant (.002) and is the most important among the independent variables (Model 3).[38, 39] The positive and significant interaction with

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[36]The same analysis in which the dependent variable is measured in 1980 and 1970 (N=29) yields a similar result. The effect of log tertiary enrollment in science and engineering is stronger while the effect of secondary education is somewhat weaker.

[37]The same analysis for the 1970-75 panel with slightly different mix of cases (N=37) yields very similar results. The effect of log tertiary enrollment in science and engineering is stronger while the effect of secondary education is somewhat weaker.

[38]The same analysis in which the dependent variable is measured in 1980 and 1970 (N=29) yields a similar results with the exception of a stronger and more significant main effect ($p<.05$) of log tertiary science and engineering enrollment and a slightly weaker interaction effect with secondary education.

[39]The same analysis for the 1970-75 panel yields a similar results with slightly different mix of cases (N=37) (more NIC and developing countries).

secondary education indicates that the greater the coverage of secondary education, the greater the impact of tertiary science and engineering enrollment on the number of scientists and engineers engaged in R&D in proportion to the total labor force.

In the case when the two interaction terms are combined in the same model (Table A.4 in Appendix A), the interaction with secondary education remains the same (.002) while the interaction with real GDP per capita becomes weaker (.010) and is no longer statistically significant.

Graduates in Science and Engineering and the Number of R&D Scientists and Engineers

This section considers the impact of the number of graduates in tertiary science and engineering on the proportion of scientists and engineers in research and development. The findings from the analysis carried out in this section are given in Table 4.4 below. The results obtained here suggest a positive association between the relative number of graduates in science and engineering and the relative number of scientists and engineers in research and development. Similar to the models based on the enrollment ratio in tertiary science and engineering, the proportion of graduates in science and engineering has a stronger impact on the proportion of scientists and engineers in R&D in economically more developed countries, and particularly in countries where a greater percentage of the school-age population is enrolled in secondary education.

Model 10, which constitutes the baseline model without the interaction effects, reveals a positive but not quite significant effect of the number of graduates in science and engineering on the proportion of scientists and engineers in R&D for the 1970-1980/85 panel (N=37). One percentage increase in the number of graduates in science and engineering per 10,000 university-age population results on the average in a 0.066 percentage increase in the number of scientists and engineers in research and development. Both of the control variables vary positively with the relative number of scientists and engineers in research and development, although only the effect of secondary education is statistically significant. Apart from the lagged dependent variable, secondary education is the most influential among the independent variables in determining the relative number of scientists and engineers in research and development.

The addition of the interaction effects (Models 11 and 12) gives further support to the earlier findings that the relationship between the number of students or graduates in science and engineering and the subsequent concentration of scientists and engineers in the labor force differs depending on the level of economic development and the coverage of secondary education. Both interaction terms are positive and significant (0.006 and 0.001, respectively). As displayed by the standardized coefficient (Model 12), the interaction with secondary education is most influential in explaining the level of of scientists and engineers in research and development.[40]

When the two interactions are included in the same model (Table A.4 in Appendix A), it becomes increasingly apparent that the interaction with secondary education is more important than the corresponding interaction with the level of economic development. In

[40]The same analysis in which the dependent variable is measured in 1980 and 1970 and with the 1970-75 panel yields very similar results.

addition, the interaction with secondary (.001) is not affected by the inclusion of the interaction with economic development whereas the latter becomes weaker (.004) and insignificant.[41]

It is clear from the results here, that there seems to be a tighter link between the number of graduates in science and engineering and the subsequent number of scientists and engineers in research and development in countries with a greater proportion of the school age population enrolled in secondary education, and to a certain degree, in countries with a higher level of economic development.

Until now, all the models estimated have employed either the number of students enrolled in science and technical fields or the number of graduates in these fields as the measure for tertiary science and technical education. The remainder of this chapter evaluates whether the relative number of scientists and engineers in the labor force is affected by the overall emphasis on science and technical education, both in terms of the size of enrollment, and the number of graduates. In this pursuit, the following analyses incorporate an index of tertiary science and technical education as defined earlier.

Tertiary Science and Technical Education Index and the Concentration of Scientific and Technical Labor force

The focus of this section is the combined effect of the two indicators for science and

[41]The same analysis in which the dependent variable is measured in 1980 and 1970 and with 1970-75 panel, the direction of the effects is the same. However, the effect of number of graduates in science and engineering is stronger and significant at the level of $p<0.10$. Both the interaction terms are significant.

technical education, the size of enrollment and the number of graduates in science and engineering given by the earlier defined index for science and technical education. The findings in this section clearly show a strong association between the amount of tertiary science and technical education and the proportion of scientists and engineers in the labor force. Similar to the models with single indicators, the amount of science and technical education has a stronger impact on the proportion of scientists and engineers in economically more developed countries. This effect is not mediated by the degree to which the school-age population is enrolled in secondary education.

Model 13, which constitutes the baseline model without interaction effects, reveals a large and significant effect of the size of the tertiary science and engineering index. One percentage increase in this index results, on the average, in a 0.111 percentage change in the number of scientists and engineers per 10,000 economically active population. Excluding the lagged dependent variable, the level of economic development indicated by the log real GDP per capita is most influential in determining the size of the science and technical labor force capacity. Similar to the single indicator models with graduates or enrollment in science and engineering, the degree to which the school-age population is enrolled in secondary education does not have any effect on the subsequent variation in the relative number of scientists and engineers in the labor force.[42, 43]

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[42]The same analysis, in which the dependent variable is measured in 1980 and 1970, yields very similar results.

[43]In the same analysis for the 1970-75 panel the main effects of the education index and log real GDP per capita are weaker but still significant. The main effect of secondary education is stronger and significant.

When the interaction effects are added (Models 14 and 15), the main effect of the tertiary science and engineering index is still positive and significant at the level of $p<0.01$. Likewise, the main effect of the indicator for economic development continues to have a significant impact on the proportion of scientists and engineers in the labor force. While the interaction with secondary education is insignificant, the interaction with economic development is positive and highly significant (.006). As in all the models discussed to this point the lagged dependent variable in both models above is the most influential among the independent variables.[44, 45] This lends further support to the earlier finding that the higher the level of economic development, the stronger the effect of tertiary science and engineering education on the number of scientist and engineers in the labor force while the effect is similar across different levels of secondary education enrollment.

Like the single indicator models with tertiary enrollment in science and engineering, the inclusion of both interaction terms (Table A.5 in Appendix A) makes the negative interaction with secondary education significant.[46]

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[44]The same analysis, in which the dependent variable is measured in 1970 and 1980, yields very similar results.

[45]In the same analysis for the 1970-85 panel, the direction and magnitude of the effects are similar. However, the interaction with economic development is weaker and none of the interaction effects are significant.

[46]Further analyses have been undertaken including a control variable for the economic growth rate for the periods 1960-70 and 1970-80. The results from these analyses do not depart significantly from the original analyses presented in this section. In neither of these two analyses does the level of economic growth rate have any effect on the level of scientists and engineers in the labor force. When the economic growth rate is based on the period 1960-1970, the interaction with economic development is slightly weakened and becomes less significant ($p=0.12$).

Tertiary Science and Technical Education Index and the Number of R&D Scientists and Engineers

This final section attends to the question, how the relative concentration of scientists and engineers in research and development is affected by the overall emphasis on science and technical education? The main conclusion to draw from these analyses is that the index of the combined measure of the level of science and technical education affects the relative concentration of the R&D scientists and engineers in the labor force 10 to 15 years later. It is also apparent that this relationship is tighter in societies with higher levels of economic development and greater coverage of secondary education.

Model 16 estimates the effect of the size of tertiary science and engineering enrollment and graduates index on the relative number of scientists and engineers in research and development with a 10-15-year lag. The baseline model implies that the combined size of tertiary enrollment in science and engineering and the number of graduates varies positively with the proportion of scientists and engineers in research and development. The effect is significant at the level of $p<0.01$. One point increase in the tertiary science and engineering index raises the log number of R&D scientists and engineers per 10,000 labor force by 0.066. As in the models with single item indicators (Tables 4.3 and 4.4), the size of the secondary education enrollment ratio positively and significantly influences the proportion of R&D scientists and engineers while the level of economic development has no effect.

When the interaction terms are added to the baseline model (Models 17 and 18), the tertiary science and engineering index loses some of its strength but is still significant. Like the models with single indicators, both the interaction effects are positive and highly significant (0.006 and 0.001, respectively).[47]

The interaction with secondary education enrollment becomes weaker and is no longer significant when the two interaction terms are included in the same model (Table A.6 in Appendix A). This is the reverse of the situation in which the tertiary science and engineering enrollment ratio or the number of graduates in science and engineering was used as a measure for science and technical education. In those models, the interaction with the level of secondary education enrollment was most influential in determining the relative number of scientists and engineers in research and development.[48, 49]

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[47]The same analysis in which the dependent variable is measured in 1970 and in 1980, and for the 1970-75 panel, the tertiary science and engineering index is stronger and highly significant. The interaction with log RGDP is also stronger while the interaction with secondary education enrollment ratio is somewhat weaker. Both the interaction terms are significant at $p<0.01$.

[48]The same analysis in which the dependent variable is measured in 1970 and in 1980 and for the 1970-75 panel the tertiary science and engineering index is stronger and highly significant. The interaction with log RGDP is also stronger while the interaction with secondary education is somewhat weaker. Both the interaction terms are significant at $p<0.05$.

[49]Additional analyses have been carried out including a control variable for the economic growth rate for the periods 1960-70 and 1970-80. As in the previous section (4.5) the inclusion of a control variable for the economic growth rate does not alter the result to any great extent. The inclusion of a growth rate for 1970-80 produces a result that is almost identical to the original analyses. When the growth rate covers the period 1960-70 the main effect of the measure for scientization of higher education becomes weaker and less significant. The same applies to the interaction with secondary education enrollment whose significance level drops to ($p=0.12$). Similar to the models with scientists and engineers as a whole as the dependent variable, the rate of economic growth does not have any bearing on the level of scientization of the labor force as measured by R&D scientists and engineers.

Summary

This chapter showed that the relative number of scientists and engineers in the labor force is positively linked to the level of tertiary science and technical education; the greater the level of science and engineering enrollment in higher education, the greater the concentration of scientifically and technically trained manpower in the labor force. This conclusion holds regardless of the measure of tertiary science and technical education used: tertiary science and technical enrollment ratio, number of graduates in science and engineering, or a combined index of tertiary science and technical education. However, the findings also suggest that the above relationship is not uniform across all the countries included in this study. In fact, the result points to a looser coupling between the number of scientists and engineers being trained in higher education and the concentration of scientists and engineers in the labor force in less developed countries. This relationship is mediated slightly differently depending on which measure of scientists and engineers is used. When the number of scientists and engineers as a whole is employed as the measure of the amount of technical and scientific labor force, the relationship is conditioned by the level of economic development. On the other hand, when the measure is based on the number of scientists and engineers in research and development alone, this relationship is affected both by the level of economic development and, in particular, the level of secondary education enrollment.[50] Despite these differences in what affects the strength of the link between the

[50]A re-estimation of the models in Sections 4.6 and 4.7, in which the cases are restricted to be the same for both scientists and engineers as a whole and for scientists and engineers in research and development (N=29), gives rise to the conclusion that the relationship between tertiary science and technical education and the amount of scientists and engineers as a whole is influenced by the level of economic development, while the relationship between the concentration of scientists and engineers

level of tertiary science and technical education and the concentration of scientists and engineers in the labor force, the notion of loose coupling still holds.[51]

in R&D is mediated primarily by the coverage of secondary education.

[51]As documented in Chapter 3, the value of k has been selected based on the ridge trace where the estimated coefficients start to stabilize (around k=0.2). For the same analyses based on OLS in which k=0, only the indicator for economic development positively and significantly contributes to the level of scientization of the labor force. However, with a small increase in k such as k=0.05, the level of scientization of higher education becomes significant, and its effect remains stable thereafter regardless of the value of k. By contrast, the interaction with economic development does not stabilize until k=.20. Secondary education enrollment does not stabilize until k approaches unity.

When the dependent variable is the number of scientists and engineers in R&D, the level of secondary education enrollment is unaffected by the value of k. It is significant when k=0 and does not change with k. Likewise, the interaction with economic development stabilizes at k=0.05. The effect of economic development is also unaffected by the value of k; it never becomes significant. By contrast, the scientization of higher education and the interaction with secondary education are sensitive to k. These two variables do not stabilize until k=0.15.

Table 4.1 Effects of Tertiary Science and Engineering Enrollment Ratio on the Proportion of Scientists and Engineers in the Labor Force 1970-80

N=51

Standardized Ridge Regression Coeffecients

(unstandardized regression coefficients in parenthesis)

Equation number:	(1)		(2)		(3)	
	Log Scientists & Engineers Per 10000 Econ. Active Population 1980/85		Log Scientists & Engineers Per 10000 Econ. Active Population 1980/85		Log Scientists & Engineers Per 10000 Econ Active Population 1980/85	
INDEPENDENT VARIABLES	Beta (b)	s.e	Beta (b)	s.e	Beta (b)	s.e
Log Tertiary S&E Enrol. 1970	.183*** (.400)	.100 (.282)	.129***	.071	.198*** (.432)	.090
Log RGDP per capita 1970	.220*** (.313)	.063	.200*** (.285)	.065	.223*** (.319)	.064
Secondary Enrollment 1970	.032 (.002)	.002	.023 (.001)	.002	.050 (.002)	.002
Lagged Dep. Variable 1970/75	.515*** (.495)	.043 (.498)	.505***	.046	.515*** (.508)	.044
INTERACTION EFFECTS: Log Tertiary S&E Enrol.						
By Log RGDP Per Capita	- -	-	.095*** (.026)	.008	- -	-
By Secondary	-	-	-	-	-.039	.001
Education	-		-		(-.001)	
Adjusted R^2	.90		.90		.90	
Constant	.000** (-.832)	.385	.000** (-.664)	.395	.000* (-.886)	.397
k	.20		.20			

*** p<.01 ** p<.05 * p<.10

Table 4.2 Effects of Graduates in Tertiary Science and Engineering on the Proportion of Scientists and Engineers in the Labor Force 1970-80

(N=51)

Standardized Ridge Regression Coeffecients

(unstandardized regression coefficients in parenthesis)

Equation number:	(4) Log Scientists & Engineers Per 10000 Econ. Active Population 1980/85		(5) Log Scientists & Engineers Per 10000 Econ. Active Population 1980/85		(6) Log Scientists & Engineers Per 10000 Econ. Active Population 1980/85	
INDEPENDENT VARIABLES	Beta (b)	s.e	Beta (b)	s.e	Beta (b)	s.e
Log S&E Graduates 1970	.109** (.113)	.047	.075** (.077)	.035	.117** (.120)	.046
Log RGDP per capita 1970	.246*** (.351)	.065	.233*** (.333)	.066	.249*** (.356)	.067
Secondary Enrollment 1970	.040 (.002)	.002	.033 (.002)	.002	.052 (.003)	.002
Lagged Dep. Variable 1970/75	.547*** (.539)	.045	.542*** (.534)	.047	.548*** (.540)	.045
INTERACTION EFFECTS: Log S&E Graduates						
By Log RGDP Per Capita	- -	-	.060** (.007)	.003	- -	-
By Secondary	-	-	-	-	-.025	. 0 0 0
Education	-		-		(-.000)	
Adjusted R^2	.89		.89		.89	
Constant	.000*** (-1.109)	.412	.000*** (-1.006)	.397	.000** (-1.083)	.408
k	.20		.20		.20	

*** p<.01 ** p<.05 * p<.10

Table 4.3 Effects of Tertiary Science and Engineering Enrollment Ratio on the Proportion of R&D Scientists and Engineers in the Labor Force 1970-80

(N=36)

Standardized Ridge Regression Coeffecients
(unstandardized regression coefficients in parenthesis)

Equation number:	(7) Log R&D Scientists & Engineers Per 10000 Econ. Active Population 1980/85		(8) Log R&D Scientists & Engineers Per 10000 Econ. Active Population 1980/85		(9) Log R&D Scientists & Engineers Per 10000 Econ Active Population 1980/85	
INDEPENDENT VARIABLES	Beta (b)	s.e	Beta (b)	s.e	Beta (b)	s.e
Log Tertiary S&E Enrol. 1970	.129* (.150)	.083	.067 (.079)	.062	.072 (.084)	.081
Log RGDP per capita 1970	.002 (.002)	.055	-.018 (-.014)	.056	-.014 (-.011)	.056
Secondary Enrollment 1970	.178** (.004)	.002	.171** (.004)	.002	.100 (.002)	.002
Lagged Dep. Variable 1970/75	.589*** (.643)	.080	.575*** (.637)	.084	.569*** (.631)	.082
INTERACTION EFFECTS: Log Tertiary S&E Enrol.						
By Log RGDP Per Capita	- -	-	.104** (.015)	.006	- -	-
By Secondary Education	- -	-	- -	-	.169*** (.002)	.001
Adjusted R^2	.81		.80		.81	
Constant	.000 (.070)	.357	.000 (.158)	.359	.000 (.214)	.368
k	.20		.20			

*** p<.01 ** p<.05 * p<.10

Table 4.4 Effects of Graduates in Tertiary Science and Engineering on the Proportion of R&D Scientists and Engineers in the Labor Force 1970-80

N=36

Standardized Ridge Regression Coeffecients
(unstandardized regression coefficients in parenthesis)

Equation number:	(10) Log R&D Scientists & Engineers Per 10000 Econ. Active Population 1980/85		(11) Log R&D Scientists & Engineers Per 10000 Econ. Active Population 1980/85		(12) Log R&D Scientists & Engineers Per 10000 Econ Active Population 1980/85	
INDEPENDENT VARIABLES	Beta (b)	s.e	Beta (b)	s.e	Beta (b)	s.e
Log S&E Graduates 1970	.106 (.068)	.045 (.038)	.060	.035	.056 (.036)	.044
Log RGDP per capita 1970	.015 (.011)	.055	-.004 (-.003)	.055	-.004 (-.003)	.056
Secondary Enrollment 1970	.177** (.004)	.002	.170** (.004)	.002	.092 (.002)	.001
Lagged Dep. Variable1970	.600*** (.614)	.080	.590*** (.653)	.084	.586*** (.649)	.082
INTERACTION EFFECTS: Log S&E Graduates						
By Log RGDP Per Capita	- -	-	.081 (.006)	.003	- -	-
By Secondary Education	- -	-	- -	-	.165*** (.001)	.000
Adjusted R^2	.81		.80		.81	
Constant	.000 (-.046)	.362	.000 (.035)	.354	.000 (.121)	.372
k	.20		.20		.20	

*** p<.01 ** p<.05 * p<.10

Table 4.5 Effects of Tertiary Science and Engineering Enrollment and Graduates Index on the Proportion of Scientists and Engineers in the Labor Force 1970-80

(N=51)

Standardized Ridge Regression Coeffecients

(unstandardized regression coefficients in parenthesis)

Equation number:	(13)		(14)		(15)	
	Log Scientists & Engineers Per 10000 Econ. Active Population 1980/85		Log Scientists & Engineers Per 10000 Econ. Active Population 1980/85		Log Scientists & Engineers Per 10000 Econ Active Population 1980/85	
INDEPENDENT VARIABLES	Beta (b)	s.e	Beta (b)	s.e	Beta (b)	s.e
Log S&E Enrol. and Grad Index 1970	.164*** (.111)	.030	.126*** (.086)	.020	.195*** (.132)	.028
Log RGDP per capita 1970	.228*** (.325)	.064	.222*** (.316)	.066	.229*** (.326)	.063
Secondary Enrollment 1970	.030 (.001)	.002	.025 (.001)	.002	.041 (.002)	.002
Lagged Dep.	.523***	.044	.516***	.046	.522***	.044
Variable 1970	(.515)		(.509)		(.514)	
INTERACTION EFFECTS: Log S&E Graduates						
By Log RGDP Per Capita	- -	-	.060* (.006)	.003	- -	-
By Secondary Education	- -	-	- -	-	-.053 (-.001)	.001
Adjusted R^2	.90		.89		.90	
Constant	.000 (-.501)	.422	.000 (-.418)	.449	.000 (-.503)	.416
k	.20		.20		.20	

*** p<.01 ** p<.05 * p<.10

Table 4.6 Effects of Tertiary Science and Engineering Enrollment and Graduates Index on the Proportion of R&D Scientists and Engineers in the Labor Force 1970-80

N=36

Standardized Ridge Regression Coeffecients

(unstandardized regression coefficients in parenthesis)

Equation number:	(16) Log R&D Scientists & Engineers Per 10000 Econ. Active Population 1980/85 N=36		(17) Log R&D Scientists & Engineers Per 10000 Econ. Active Population 1980/85 N=36		(18) Log R&D Scientists & Engineers Per 10000 Econ. Active Population 1980/85 N=36	
INDEPENDENT VARIABLES	Beta (b)	s.e	Beta (b)	s.e	Beta (b)	s.e
Log S&E Enrol. and Grad Index 1970	.214*** (.066)	.021	.117** (.036)	.014	125* (.038)	.019
Log RGDP per capita 1970	.012 (.009)	.053	.011 (.008)	.054	.017 (.013)	.053
Secondary Enrollment 1970	.168** (.004)	.002	.163** (.004)	.002	.163** (.001)	.000
Lagged Dep. Variable 1970	.526*** (.583)	.078	.500*** (.554)	.082	.507*** (.562)	.081
INTERACTION EFFECTS: Log S&E Graduates						
By Log RGDP Per Capita	- -	-	.142*** (.006)	.002	- -	-
By Secondary Education	- -	-	- -	-	.132** (.001)	.000
Adjusted R^2	.82		.81		.81	
Constant	.000 (.266)	.360	.000 (.301)	.370	.000 (.245)	.363
k	.20		.20			

*** p<.01 ** p<.05 * p<.10

CHAPTER 5

SCIENTIZATION OF THE LABOR FORCE AND ECONOMIC DEVELOPMENT

In this chapter I will evaluate the argument that the level of economic growth is positively associated with the relative number of scientists and engineers in the labor force. I will further investigate whether this relationship is influenced by the size of the market and the level of capital available per worker. Finally, I will attend to the question of whether the relationship between the size of the scientific and technical labor force structure and economic development differs between industrialized countries and less developed ones.

This chapter is organized into two sections. The first section looks at the relationship between scientization of the labor force and economic development. In this section I also examine the aforementioned relationship as it is conditioned by the size of the export market and the amount of capital per worker. In the last section I evaluate how the effect of scientists and engineers varies depending on the stage of industrialization.

Throughout this chapter three measures of scientization of the labor force are employed. While the first two, the total stock of scientists and engineers in the labor force and scientists and engineers in research and development, are single item indicators, the last measure combines the two earlier indicators into a scientists and engineers index. This index is constructed by adding the standardized and centered individual indicators, the log of the number of scientists and engineers as a whole, and the log of the number of scientists and engineers in research and development. Both these quantities refer to the number of scientists and engineers per 10,000 economically active population.

In the previous chapter (Chapter 4) it was found that combining the size of enrollment and the number of graduates in science and engineering had an effect on scientization of the labor force similar to the effect of the indicators considered separately. Hence, the models presented in this chapter include the education index instead of the individual indicators for science and technical education.[52]

Each model presented is based on a 20-year lag 1970-90. Models with a shorter lag, 10 years (1970-80), have also been estimated. The results from those models are reported in footnotes. To increase the number of cases, scientists and engineers are measured in 1975 for those cases for which data is not available for 1970.

The models estimated within this chapter take the following functional form:

$$Y_t = a_0 + b_1 Y_{t-1} + b_2 X1_{t-1} + b_3 X2_{t-1} + b_4 X3_{t-1} + b_5 X4_{t-1} + e_t$$

Where:

Y_t = measure of economic development at time (t)

Y_{t-1} = measure of economic development at time (t-1)

$X1_{t-1}$ = measure of the level of tertiary science and technical education at time (t-1)

$X2_{t-1}$ = measure of the number of scientists and engineers in the labor force at time (t-1)

$X3_{t-1}$ = measure of the coverage of secondary education at time (t-1)

$X4_{t-1}$ = measure of the size of market at time(t-1) or measure of the capital stock per worker

[52]Models which include the individual indicators have also been estimated. The results of these analyses do not depart from the outcomes here.

at time (t-1)

$X5_{t-1}$ = measure of investment in conventional capital at time (t-1)

As in the previous chapter, the conditional effects of the size of the market and the capital stock per worker are assessed by the inclusion of interaction terms. These are constructed by the multiplication of each variable with the measure of scientists and engineers. However, in the last section which focuses on the economic benefits of scientists and engineers in different stages of industrial development, the evaluation is carried out by splitting the sample between the countries in OECD and less developed countries. Models, including an interaction with a dummy variable for OECD countries, have also been estimated. The results from these analyses did not provide sufficient evidence to conclude that the relative number of scientists and engineers in the labor force have different effects on economic development depending on the level of industrialization. However, the use of a dummy variable, as compared to a continous variable, in the interaction term, is a constraint which results in the same relationship for each case within the defined category: OECD versus LDC. Hence, I determine whether the level of industrialization makes a difference in how the relative number of scientists and engineers affects economic development by estimating separate models for OECD and non-OECD countries. The analyses reported in this chapter use a constant number of cases (N=46).

The Concentration of Scientific and Technical Labor Force and Economic Growth

The proponents of "science and technology for progress" believe that a foundation of solid scientific and technical infrastructure is the key to continued economic growth. To that effect it is crucial to maintain a steady flow of technically and scientifically trained manpower. Their argument is formalized in Hypothesis 2:

Hypothesis 2:

The greater the concentration of scientific and technical labor force the greater the level of economic development.

This section evaluates the argument that variations in the relative number of scientists and engineers in the labor force explain different levels of economic development. The argument is evaluated with respect to the entire stock of scientists and engineers, the number engaged in research and development as well as the combined effect of the total stock and the number engaged in research and development.

The result from the empirical analysis for the panel 1970-90 is presented in Table 5.1. The models here indicate that, in general, the number of scientists and engineers in the labor force accounts for some of the variations in the level of economic growth in the long term. Model 1 examines the effect of scientists and engineers as a whole on the level of economic development. The number of scientists and engineers per 10,000 economically active population varies positively with the level of economic development, controlling for other effects. One percentage increase in this measure raises the real GDP per capita by .101 percent. The effect is significant at the level of $p<.05$. There is a direct effect of the amount of tertiary science and technical education and of the size of the secondary enrollment ratio on economic growth net of the relative number of scientists and engineers in the labor force. The domestic capital formation does not have any effect on the real GDP per capita after controlling for the other independent variables.[53] As indicated by the beta coefficients, the two education variables contribute the most to economic growth, with tertiary science and engineering education being the most significant contributor.[54]

Model 2 includes scientists and engineers in research and development per 10000 economically active population as the measure for scientific and technical labor force capacity. The result indicates a positive but not quite significant effect of the quantity of scientists and engineers in research and development. One percentage increase in the number of scientists and engineers in research and development increases real GDP per capita by .168 percent controlling for other effects. Like the model using scientists and engineers as a whole, tertiary science and engineering education and the coverage of secondary education contribute the most to economic growth, while the effect of domestic capital formation is negligible.

The third model in this section takes into consideration the combined effect of the total number of scientists and engineers in the labor force and the quantity of scientists and engineers in research and development. This effect is summarized in the scientific and

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[53]It should be noted, however, that the effect of the domestic capital formation becomes stronger but not quite significant when secondary education enrollment is omitted. These two measures are highly correlated (0.70).

[54]Analysis by the means of residual plots against the predicted variable and each explanatory variable was carried out to detect influential cases and non constant error term variance. As a result of this procedure the two socialis countries were excluded from this analysis and the following analyses on the grounds of being outlier.

technical labor force index. As in the models with (1) the total number of scientists and engineers and (2) the number of scientists and engineers in research and development, the combined effect clearly demonstrates a positive link between the amount of technical and scientific manpower and economic growth.

As can be observed, the scientist and engineer index has a positive and significant effect on the log real GDP per capita. One point increase in the index raises the real GDP per capita 1.09 times.[55] Likewise, the effect of tertiary science and engineering index and the effect of secondary education are positive and significant at the level of $p<.01$. As in the previous models the domestic capital formation does not contribute significantly to the variations in the level of economic development. In terms of relative importance, the index of tertiary science and engineering education is most influential in determining the level of economic development.

The result thus far provides support for the "science and technology for progress" model in general terms; the greater the relative number of scientists and engineers in the labor force the greater the level of economic growth. However, the analysis carried out above does not provide evidence of a uniform effect of scientists and engineers unaffected by specific national characteristics. As outlined in my theoretical discussions, I believe that the link between the number of scientists and engineers and economic growth is not the same across societies but is conditioned by, for example, the size of the market. The ultimate contribution of scientists and engineers to economic growth is through the production of new

[55] In order to express the effect of the science and engineering index on real GDP per capita, the base for natural logarithm (e) is raised by the power of the unstandardized coefficient (.084).

products, and as explained earlier (Chapter 2), a larger market will make the effort of scientists and engineers more cost-effective. The market constituting the base for total demand comprises both the domestic market as well as the expanded market in terms of export. For larger countries, population-wise, the domestic market may be large enough to support a large scientific and technical infrastructure, while smaller countries need to rely on exports. Since most of the countries in my sample are small to medium-sized I use the export share of GNP as a measure of the size of the market. Hence, the following argument is evaluated here:

Hypothesis 6:

In societies in which the market is large, the greater the number of scientists and engineers in research and development the greater the level of economic development.

and Hypothesis 7:

In societies in which the market is large, the greater the concentration of scientists and engineers in the labor force the greater the level of economic development.

Table 5.2 contains the estimations of the interaction effect of scientists and engineers and the size of export to GNP for the three different measures of scientific and technical manpower.

Model 4 regresses the log real GDP per capita on the total stock of scientists and engineers in the labor force. As expected, the main effect of the log scientists and engineers in the labor force is weaker (.069) than in the baseline model (Model 1, Table 5.1).

Otherwise, there is not much change in the magnitude of the other coefficients. The interaction between the number of scientists and engineers in the labor force and the export share of GNP (.020) is positive and significant at the level of $p<.05$. This suggests that the greater the export market the greater the effect of relative number of scientists and engineers in the labor force on economic growth.[56]

The next model repeats the analysis using only scientists and engineers in research and development instead of the entire stock of scientists and engineers. The main effect of log scientists and engineers in research and development (0.087) is weaker than in the baseline model (2). The effect of the other variables are the same as in the baseline model. As noted the interaction with the log export as proportion of GNP (0.039) is positive and significant at $p<.1$.[57]

Model 3 considers the impact of the scientific and technical labor force index (the entire stock and the number of scientists and engineers in R&D). When the interaction effect between the log scientists and engineers index and the share of export to GNP is added to the baseline model, the main effect of scientists and engineers index (.055) is still positive and significant at $p<.01$. The effect of the control variables are stable and are of similar magnitude. As revealed by the positive and significant interaction effect (.018), the relative size of export constitutes a conditional factor on the link between the number of scientists

[56] The same analysis for 1970-80 panel yields very similar results. The effects of tertiary science and technical education and secondary education are weaker but still explains most of the variation in economic growth.

[57] In the same analysis for the 1970-80 panel, the direction of, and level of, significance of the effects are very similar to the 1970-90 panel, with the exception of the indicators for secondary education and tertiary science and technical education. These indicators are less important in explaining the level of economic development.

and engineers in the labor force and the level of economic development from a long-term perspective (20 year lag). This effect is significant at $p<.01$.[58,59,60]

As mentioned in Chapter 2, the growth accounting exercise utilized by neoclassical economists assumes that the different factors (machines and equipment, labor, human capital and technological progress) contributing to economic growth are additive in their effects. It was also pointed out, however, that the creation and adoption of new technology may be difficult to accomplish unless there is sufficient amount of investment in new machinery because most technological progress is embedded in new gross investment. Hence, I have argued that the effect of scientists and engineers on economic growth is conditioned by the amount of conventional capital at their disposal. To this end the following hypothesis is tested:

Hypothesis 9:

In societies in which the level of capital is large, the greater the

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[58] In the intermediate term, represented by a 10 year lag 1970-80, the effects and level of significance are very similar to the 1970-90 panel. The magnitude of the effects of secondary and the index of tertiary science and engineering education is somewhat lower but still significant.

[59] Further analyses have been undertaken using log import/GNP in place of log export/GNP. The results from these analyses indicate that the import and export work the same way. The only difference is found in respect to scientists and engineers in R&D. In this case the interaction between imports and R&D scientists and engineers is weaker and less significant than the corresponding interaction with export/GNP.

[60] An F-test based on OLS estimation does not yield significant result, suggesting that the increase in explained variance is not sufficient to statistically justify the inclusion of the main effect and interaction of export as proportion of GNP. This is not surprising since neither the main effect nor the interaction term is statistically significant when the estimation is based on OLS. The F-test takes the following form:

$$F= \frac{(R^2_2-R^2_1)/df_2-df_1}{(1-R^2_2)/(N-df_2)}$$

concentration of scientists and engineers in the labor force the greater the level of economic development.

The three models estimated here consider the interaction between the amount of capital per worker (excluding residential production) and the three different measures on the technical and scientific labor force capacity. The first model (Model 7) portrays how the relationship between the size of the total stock of scientists and engineers and economic development is affected by the size of non-residential capital per worker. As indicated by the result, the effect of scientists and engineers as a whole is influenced by the availability of resources in terms of equipment and machinery. The interaction effect (.017) is highly significant. The main effect of capital per worker does not have any bearing on the level of economic development. The direction and the magnitude of the effects of the remaining variables are similar to those in the previous models; the amount of tertiary science and technical education and the coverage of secondary education have the largest influence on economic growth.

Model 8 estimates the effect of the interaction between scientists and engineers in research and development and the amount of capital per worker. The result clearly shows that the amount of capital per worker makes a difference on how investment in technical and scientific manpower affects the level of economic development. The interaction effect (.032) is significant at the level of $p<.05$. In comparison to the previous models, the effects of the other variables are stable.

Finally, the last model (9) in this section evaluates how variations in the combined measure of scientists and engineers in the labor force interact with the amount of capital per worker. As expected, the interaction effect (.015) is positive and highly significant. The main effect of the science and engineering index (.052) still has an independent effect on the level of economic development. Note, that the indicator for the amount of tertiary science and technical education and the secondary education enrollment ratio continues to be highly significant and exerts the largest influence on the level of economic development. [61],[62]

R&D Scientists and Engineers and Economic Development According to Stage of Industrialization

I have argued that the process by which scientists and engineers may contribute to economic progress is through the development of new products and processes or through the adoption and modification of technology that has either been developed domestically or imported from abroad. Depending on the stage of industrialization the relative importance of scientists and engineers engaged in research and development may differ. As documented

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[61]An F-test based on OLS estimation yields a significant result at the level of $p<.05$ indicating that the combined effect of the main effect of capital per worker and the interaction with scientization in the labor force is significant. It should be noted that the interaction with capital per worker is also significant ($p=.06$) when OLS is used as the estimation procedure.

[62]It should be noted that in corresponding analyses with OLS ($k=0$), only the effect of secondary education and the indicator for scientization of higher education have a positive and significant effect on economic development. This is consistent with previous research (e.g. Ramirez and Lee, 1995). The effect of these two variables is relatively unaffected by the level of k. The same applies to the indicator for the size of the market (log export/GNP), the capital per worker and to some extent the indicator for domestic capital formation, which never becomes significant. The interaction with capital per worker is also less sensitive to the value of k. It stabilizes at $k=.05$, when it also becomes significant. Both the indicator for scientization of the labor force and the interaction with export/GNP are sensitive to the value of k. They start to stabilize around $k=.15$.

earlier in Chapter 2, previous studies suggest that research and development is more important for economic growth in industrialized countries. In order to reap the benefit of an expanded research and development sector a country needs to have a certain level of industrial and economic infrastructure. This section tests the following argument:

Hypothesis 5:

In societies with more technologically developed economies, the greater the number of scientists and engineers engaged in research and development the greater the level of economic development.

To this end, separate models have been estimated for the OECD countries and for non-OECD countries (LDC). Table 5.4 displays the results derived from regressing the level of economic development in 1990 on the relative number of scientists and engineers in research development for 1970. The findings obtained here indicate that the concentration of scientists and engineers in research and development is more closely related to economic growth in the OECD countries than in less developed countries. Despite the low number of cases the effect (.120) is almost significant at the level of $p<.1$ in the OECDs. By contrast, the number of scientists and engineers in research and development does not appear to have any effect in the less industrialized nations.

The impact of secondary education is significant in both less developed and in the OECD countries, although the effect is stronger in the former (.014 verses .003). Note that the level of tertiary science and engineering enrollment does not have any effect in the OECDs, while it is highly significant in the less developed countries. As expected, the earlier measured level of economic development predicts the level of economic development better in the OECDs.[63]

The findings here indicate that the effect of scientists and engineers in research and development is different in less developed countries than in the OECDs. A further question to consider is whether scientists and engineers engaged in non-R&D activities would also have different effects depending on the level of industrialization. As outlined in the theoretical framework, the existence of technological transfer makes the creation of technological change possible without domestic research and development. The crucial point is the availability of scientists and engineers who are able to understand and adopt technology developed abroad. In the NICs a great degree of technological change has occurred from technological transfer (e.g., Amsden 1989). Table 5.5 compares the relative benefit of scientists and engineers in non R&D for economic growth in the OECDs and the LDCs. Although the effect of the labor force variable is not statistically significant in any of the subset of cases (it is estimated with fewer errors in the less developed countries), the findings here suggest the reverse of the situation with scientists and engineers in research and development; the level of concentration of scientists and engineers in non-R&D seems more important in less developed countries in generating economic growth (.093 as compared to .005 for the OECDs). The effect of the control variables is similar to the models above.[64, 65]

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[63]The same analysis for the 1970-80 panel yields very similar results. For the full sample and for the LDC the effect of secondary education and tertiary science and technical education is weaker and less significant.

[64]If the category of scientists and engineers as a whole is used instead of the number of scientists in non-R&D, the result remains the same.

[65]The same analysis for the 1970-80 panel yields very similar results. For the full sample and for the LDC the effect of secondary education and tertiary science and technical education is weaker and less significant.

The findings from the above analyses suggest that the type of work scientists and engineers are engaged in (research and development versus manufacturing and service-oriented activities) makes a difference in their contribution to economic growth. In the OECDs the contribution of R&D scientists and engineers seems more important, while in the LDCs the engagement in non-R&D-related activities seems to be more crucial.

To give further support for this finding, models including both the number of scientists and engineers in non-R&D and the number engaged in R&D are estimated. Table 5.6 contains the analyses from these models. None of the effects of the different types of scientists and engineers are statistically significant after breaking down the full sample to the two subsamples which probably reflects the small number of cases. Despite the lack of statistical significance, for the less developed countries the result indicates that the importance of non-R&D scientists and engineers by far exceeds those engaged in research and development (the beta for non-R&D scientists is .121 as compared to .021). By contrast, in the OECD countries the result suggests that the main contribution to economic growth comes from the research and development scientists and engineers . These findings are consistent with Shenav and Kamens (1991) study focusing on the effect of R&D in less developed countries, and Eaton (1993) and Lichtenberg (1992) focusing on the OECD countries.[66]

There are a couple of possible explanations for these findings. One reason could be that the distribution of the respective category of scientists and engineers within the two

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[66]The same analysis for the 1970-80 panel yields very similar results. For the full sample and for the LDC the effect of secondary education and tertiary science and technical education is weaker and less significant.

subgroups of countries is very narrow; most LDCs have similar numbers of scientists and engineers in research and development, and among the OECDs the level of scientists and engineers in non-R&D is similar. Under these circumstances there would not be enough variation for a particular labor force category of scientists and engineers to have a significant impact on economic growth. In order to find out whether this is the case, I have inspected the distributions of the two types of scientists and engineers (Graphs 5.1 through 5.4). The distribution of R&D scientists and engineers in the LDCs is not as dispersed as the distribution of non-R&D scientists and engineers. In the OECDs the situation is reversed. Apart from a few outliers, the distribution of non-R&D scientists and engineers is more narrow than the corresponding distribution of R&D scientists and engineers. Although the findings obtained above indicate that the number of scientists and engineers in R&D is more important in generating economic growth in the OECDs while, in the LDCs the number of scientists and engineers in non-R&D is more important, the result could be affected by the lack of variation in the data.

The difference in the effects of R&D scientists and engineers may also be a measurement issue. As described in Chapter 3, aata collection for R&D has not reached the same level in all countries. In some countries there was not an established infrastructure for collection of data on R&D at the time the data was reported. Therefore data on R&D may be less reliable in the LDCs. In addition, it may be more difficult to classify R&D scientists and engineers as compared to the total stock of scientist and engineers.

Another possibility is that the insignificant effect of non-R&D scientists and engineers in the OECDs may reflect some kind of threshold effect; once a certain level of scientists and engineers in the labor force has been reached, the additional contribution of scientists and engineers comes from research and development. Expressed differently, the competitiveness in more technologically advanced societies comes from the development of new technology rather than just reliance on the manufacturing of goods. The infrastructure of less-developed countries is more suited for manufacturing of products, the technology for which has been developed elsewhere. This is coincide with the general types of argument concerning the relative importance of different types of scientists and engineers depending on the stage of industrialization.

In order to ascertain whether scientization effects diminishe at higher levels of scientization further analysis has been undertaken by means of piecewise linear regression[67] and by adding a square term to the model representing the squared indicator for scientization of higher education or scientization of the labor force. The results of these analyses suggest that the effect of scientization on economic development decreases with higher levels of scientization. The estimation of models with an added squared term yields negative and significant effect of the square term, indicating that the functional form is concave and thus diminishing marginal returns. The result of piecewise regression with an added "threshold term", indicating different slopes depending on the level of scientization, provided some indication of diminishing returns to higher levels of scientization (negative "threshold term").

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[67]The baseline model is modified to include a dummy variable (D1), which is equal to 1 if the indicator for scientization exceeds a given threshold value (x^*), and 0 otherwise. The model takes the following functional form:

$$y_t = a_0 + b1y_{t-1} + b2x1_{t-1} + b3(x1_{t-1} - x_{t-1}^*)d1 + CTRL_{t-1} + e_{t-1}$$

This was particularly the case for scientization of the labor force (t-value for the threshold effect=1.4).[68]

Further Considerations

In the theoretical framework, it was stipulated that the effect of scientists and engineers in the labor force is favorably conditioned by the amount of labor force in managerial or administrative positions. When that variable was included in the sample, the cases dropped to 25, which reduces the amount of variation in the sample needed to accurately assess the impact of this variable. In an effort to reestimate the effect of the proportion of the labor force in administrative and managerial positions, the number of cases was increased by using data on the total number of scientists and engineers, regradless of whether data on R&D scientists and engineers were available. When the total stock of scientists and engineer was used (N=33) the interaction effect, reflecting the impact of scientists and engineers on economic growth conditioned by the level of managerial and administrative labor force capacity, was positive and with a t-value of 1.5 indicating a statistical significance at the level of $p<.15$. This finding provides some validity for the thesis that countries, not only with an expanded scientific and technical labor force sector, but with more people in management, are in better position to take advantage of their scientific and technical labor force capacity. However, to be able to determine whether this is the case, the analysis should be repeated with more cases.

[68]It should be noted that similar results are obtained when using OLS regression; the squared terms are negative and significant and the coefficient for the threshold effect of labor force scientization is negative with a t-value=1.6.

Summary and Discussion

The findings in this chapter have shown that the variation in the level of scientific and technical labor force structure positively influences the level of economic development. This effect was strongest for the number of scientists and engineers as a whole and for the combined measure of scientists and engineers in research and development and the total stock of scientists and engineers. As previously mentioned, the difficulty in correctly classifying an engineer or scientist as an R&D scientist or engineer may influence this result to some extent.

I was also able to demonstrate that the relationship between the number of scientists and engineers in the labor force and the subsequent level of economic development was influenced by the size of the export market and by the amount of nonresidential capital per worker. In countries with a large export share of GNP or high amount of nonresidential capital per worker, the greater the number of scientists and engineers the greater the level of economic development.

The last section provided some indication of different effects of scientists and engineers on economic growth depending on the type of scientist and engineer (R&D versus nonR&D) and on whether the country was part of OECD or a less-developed countries. In this context, there was some evidence that scientists and engineers in research and development are more important for economic development in the OECD countries while scientists and engineers working with non-R&D related tasks seemed most important in the less-developed countries.

One final point to emphasize, is the strong and significant effects of the secondary education enrollment and in particular the amount of tertiary science and engineering education. As has been demonstrated throughout this chapter, the effect of the tertiary science and engineering index was, in general, stronger and more significant than the labor force measure of science and technology. In the last section this was shown to be especially important in the less developed countries. Interestingly, the level of tertiary science and engineering education did not have any impact on economic growth in the OECDs. This raises the question: what accounts for the direct effect of scientization of higher education, and lack of it, in the OECDs. In Chapter 4 the result points to a tighter coupling between scientization of higher education and scientization of the labor force in economically more developed countries. This may account for the lack of direct effect of scientization of higher education on economic growth in the OECD countries. In these countries the effect of scientization in higher education is mainly channeled through labor force participation as scientists or engineers. However, in societies where the economy is not sufficiently developed to support an expanded tertiary science and technical sector, scientists and engineers may end up in positions other than as scientists and engineers, but may still contribute to economic growth. Yet another possibility that this dissertation has not dealt with, is to what extent the scientization of higher education is connected to scientization of the labor force? This dissertation did not distinguish between different levels of scientization of higher education and different categories of scientifically and trained labor force. For instance, in some countries tertiary education in science and engineering may primarily comprise two year degree programs producing technicians instead of scientists and engineers, and in those societies the structure of the labor market may also be oriented towards jobs as technicians, rather than jobs as scientists and engineers. In that case the effect of scientization of higher education on economic development would not come through the labor force participation of scientists and engineers.

Part of the direct effect of scientization of higher education may be spurious in the sense that the emphasis on science and technical education reflects a rationalized culture that is more tuned to the notion of science and technology for progress. More rationalized cultures contain elements such as modern work attitudes, timeliness, and entrepreneurial spirit which may themselves determine the level of economic development. If it would be possible to control for the degree of rationalism the direct effect may in part disappear. One reason for the lack of direct effect of scientization of higher education in the OECDs may be some threshold effect of rationalism. It may not make any difference whether the trains are right on time, or five minutes delayed, or if not all workers work exactly the same hours, etc. Considering measurement problems, it is also possible that the measure of tertiary science and technical education may better represent the degree of commitment to science and technology than the corresponding labor force measure; and this may particularly be the case in the less developed countries.

A further issue to consider is whether there are any particular countries that may be driving the direct effect of scientization of higher education on economic growth. Appendix C lists the countries according to the rate of economic growth, the level of scientization of higher education and the labor force.

As can be observed, there are two countries, Singapore and South Korea, that have had a high economic growth rate during the period in question and which also have high levels of scientization of higher education and low levels of scientization of the labor force. A third country, United Kingdom, is among the countries with the highest growth rate that also have a high level of scientization of higher education and a low level of scientization of the labor force. These countries may potentially influence the direct effect of scientization of higher education on economic growth.

As a further way of identifying countries that account for the direct effect of scientization of higher education on economic growth, influential analysis by the means of dfbetas[69] and partial residual plots has been carried out on the baseline model with the scientization index as the measure of scientization of the labor force.

The dfbetas do not single out any countries that are particularly influential. The absolute value of all the dfbetas is less than 0.06 and the value for the majority of countries is below 0.006, which is for the sample size far below the cut-off point (about 1). Although Singapore and South Korea have, absolutely speaking, low dfbetas, they still display values (.03 and 0.2, respectively) that are high, relatively speaking. Still another country, Zambia, with a dfbeta value for scientization of higher education of 0.05, is among the three that differ from the rest of the countries, showing positive dfbetas that are higher than the remaining countries by a factor of 10. The partial residual plot (Figure 5.5) shows that

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[69]The dfbetas are based on OLS regression analysis and are defined as follows:

$$(\text{Dfbeta})_{k(I)} = \frac{b_k - b_{k(I)}}{MSE_{(I)}\, c_{kk}}$$

Where: $b_{k(I)}$ = is the coefficient obtained when the ith case is deleted
c_{kk} is the kth diagonal element of $(X'X)^{-1}$
$MSE_{(I)}$ is the MSE excluding the ith case.

Zambia pulls the effect up and that South Korea also pulls it up to some extent.

On the basis of this information, the baseline model was re-estimated, omitting the cases that the influential analysis suggested to be influential: Singapore, South Korea, and Zambia. In this analysis the direct effect of education was weaker while the direct effect of scientization of the labor force was somewhat stronger as compared to the baseline model. However, the effect of scientization of higher education remained strong and significant and was still relatively speaking the most important of the predictors.

Table 5.1 Effects of Scientists and Engineers in the Labor Force on Economic Develoment, 1970 to 1990

(N=46)

Standardized Ridge Regression Coeffecients

(unstandardized regression coefficients in parenthesis)

Equation number:	(1) Log RGDP Per Capita 1990		(2) Log RGDP Per Capita 1990		(3) Log RGDP Per Capita 1990	
INDEPENDENT VARIABLES	Beta (b)	s.e	Beta (b)	s.e	Beta (b)	s.e
S&E Enrol. and Grad Index 1970	.245*** (.139)	.027	.259*** (.147)	.028	.240*** (.136)	.027
Log Sci&Eng/10K Econ Act Pop 1970	.122** (.101)	.040	- -	-	- -	-
Log R&D Sci&Eng/10K Econ Act Pop 1970	- -	-	.079 (.168)	.104	- -	-
Sci&Eng Index 1970	- -	-	- -	-	.142*** (.084)	.028
Secondary Enrollment 1970	.225*** (.009)	.002	.216*** (.008)	.002	.207*** (.008)	.002
Dom Capital Formation 1970	.032 (.004)	.006	.054 (.005)	.006	.032 (.004)	.006
Lagged Dep. Variable 1970	.352*** (.397)	.052	.367*** (.414)	.054	.345*** (.389)	.053
Adjusted R^2	.90		.89		.90	
Constant	.000*** (5.094)	.346	.000*** (5.105)	.360	.000*** (5.448)	.369
k	.20		.20		.20	

*** p<.01 ** p<.05 * p<.10

Table 5.2 Effects of Scientists and Engineers in the Labor Force on Economic Development Conditioned by Market Size 1970 to 1990

(N=46)

Standardized Ridge Regression Coefficients
(unstandardized regression coefficients in parenthesis)

Equation number:	(4) Log RGDP Per Capita 1990		(5) Log RGDP Per Capita 1990		(6) Log RGDP Per Capita 1990	
INDEPENDENT VARIABLES	Beta (b)	s.e	Beta (b)	s.e	Beta (b)	s.e
S&E Enrol. and Grad Index 1970	.249*** (.141)	.027	.264*** (.150)	.028	.235*** (.133)	.028
Log Sci&Eng/10K Econ Act Pop 1970	.084** (.069)	.029	- -	-	- -	-
Log R&D Sci&Eng/10K Econ Act Pop 1970	- -	-	.041 (.087)	.080	- -	-
Sci&Eng Index 1970	- -	-	- -	-	.093** (.055)	.021
Secondary Enrollment 1970	.212*** (.008)	.002	.205*** (.008)	.002	.189*** (.007)	.002
Dom Capital Formation 1970	.014 (.002)	.006	.037 (.005)	.006	.020 (.002)	.006
Log Export/GNP 1970	.032 (.059)	.073	.025 (.047)	.078	.045 (.084)	.078
Lagged Dep. Variable 1970	.335*** (.377)	.053	.356*** (.402)	.056	.325*** (.367)	.055
INTERACTION EFFECTS: Log Scient&Engin/ 10000 Econ Act pop						
By Log Export/GNP 1970	.082** (.020)	.008	.061* (.039)	.022	.098*** (.018)	.006
Adjusted R^2	.90		.89		89	

Constant	.000***	.400	.000***	.426	.000***	.436
	(5.047)		(5.062)		(5.409)	
k	.20		.20		.20	

*** p<.01   ** p<.05   * p<.10

Table 5.3 Effects of Scientists and Engineers in the Labor Force on Economic Development Conditioned by non residential capital per worker 1970 to 1990
(N=46)
Standardized Ridge Regression Coefficients
(unstandardized regression coefficients in parenthesis)

Equation number:	(7) Log RGDP Per Capita 1990		(8) Log RGDP Per Capita 1990		(9) Log RGDP Per Capita 1990	
INDEPENDENT VARIABLES	Beta (b)	s.e	Beta (b)	s.e	Beta (b)	s.e
S&E Enrol. and Grad Index 1970	.232*** (.131)	.028	.241*** (.137)	.028	.215*** (.122)	.028
Log Sci&Eng/10K Econ Act Pop 1970	.065** (.054)	.026	- -	-	- -	-
Log R&D Sci&Eng/10K Econ Act Pop 1970	- -	-	.054* (.114)	.068	- -	-
Sci&Eng Index 1970	- -	-	- -	-	.088*** (.052)	.019
Secondary Enrollment 1970	.228*** (.009)	.002	.215*** (.008)	.002	.203*** (.008)	.002
Dom Capital Formation 1970	.023 (.003)	.006	.036 (.004)	.006	.020 (.002)	.006
Log Non-Res Capital/Worker 1970	-.043 (-.160)	.149	-.057 (-.213)	.155	-.046 (-.171)	.151
Lagged Dep. Variable 1970	.350*** (.395)	.054	.368*** (.415)	.055	.336*** (.379)	.055
INTERACTION EFFECTS: Log Scient&Engin/ 10000 Econ Act pop						
By Log Non-Res Capital/Worker 1970	.086*** (.017)	.006	.065** (.032)	.015	.112*** (.015)	.004

Adjusted R^2	.90		.89		.90	
Constant	.000***	.694	.000***	.731	.000***	.729
	(5.743)		(5.978)		(6.283)	
k	.20		.20		.20	

*** p<.01 ** p<.05 * p<.10

Table 5.4 Effects of R&D Scientists and Engineers in the Labor Force on Economic Development, 1970 to 1990

Full sample, less developed countries and OECD

Standardized Ridge Regression Coefficients

(unstandardized regression coefficients in parenthesis)

Equation number:	(10) Log RGDP Per Capita 1990 Full Sample		(11) Log RGDP Per Capita 1990 LDC		(12) Log RGDP Per Capita 1990 OECD	
INDEPENDENT VARIABLES	Beta (b)	s.e	Beta (b)	s.e	Beta (b)	s.e
S&E Enrol. and Grad Index 1970	.259*** (.147)	.028	.290*** (.145)	.045	.000 (.000)	.016
Log R&D Sci&Eng/10K Econ Act Pop 1970	.079 (.168)	.104	.036 (.111)	.279	.144 (.120)	.072
Secondary Enrollment 1970	.216*** (.008)	.002	.245*** (.014)	.005	.148* (.003)	.002
Dom Capital Formation 1970	.045 (.005)	.006	.010 (.001)	.009	.047 (.003)	.005
Lagged Dep. Variable 1970	.367*** (.414)	.054	.369*** (.427)	.106	.628*** (.570)	.079
Adjusted R^2	.89		.78		.85	
Constant	.000*** (5.105)	.360	.000*** (4.777)	.660	.000*** (4.620)	.602
k	.20		.20		.20	
N	46		26		20	

*** p<.01 ** p<.05 * p<.10

Table 5.5 Effects of Scientists and Engineers in Non Research and Development on Economic Development 1970 to 1990

Full sample, less developed countries and OECD

Standardized Ridge Regression Coefficients

(unstandardized regression coefficients in parenthesis)

Equation number:	(13) Log RGDP Per Capita 1990 Full Sample		(14) Log RGDP Per Capita 1990 LDC		(15) Log RGDP Per Capita 1990 OECD	
INDEPENDENT VARIABLES	Beta (b)	s.e	Beta (b)	s.e	Beta (b)	s.e
S&E Enrol. and Grad Index 1970	.250*** (.142)	.027	.264*** (.132)	.045	.036 (.007)	.016
Log Non R&D Sci&En /10k Econ Act Pop 1970	.102*** (.081)	.038	.123 (.093)	.067	.014 (.005)	.028
Secondary Enrollment 1970	.231*** (.009)	.002	.249** (.014)	.005	.158* (.003)	.002
Dom Capital Formation 1970	.035 (.004)	.006	.002 (.000)	.009	.064 (.004)	.006
Lagged Dep. Variable 1970	.360*** (.406)	.052	.330*** (.381)	.104	.685** (.622)	.077
Adjusted R^2	.90		.79		.84	
Constant	.000*** (5.070)	.348	.000*** (4.953)	.646	.000*** (4.275)	.602
N	46		26		20	
k	.20		.20		.20	

*** p<.01 ** p<.05 * p<.10

Table 5.6 The Effect of Scientists and Engineers in R&D verses Non R&D on Economic Development, 1970 to 1990

Full sample, less developed countries and OECD

Standardized Ridge Regression Coefficients

(unstandardized regression coefficients in parenthesis)

Equation number:	(16) Log RGDP Per Capita 1990 Full Sample		(17) Log RGDP Per Capita 1990 LDC		(18) Log RGDP Per Capita 1990 OECD	
INDEPENDENT VARIABLES	Beta (b)	s.e	Beta (b)	s.e	Beta (b)	s.e
S&E Enrol. and Grad Index 1970	.234*** (.133)	.028	.261** (.130)	.047	-.003 (-.001)	.017
Log R&D Sci&Eng/10K Econ Act Pop 1970	.075 (.161)	.105	.021 (.066)	.287	.145 (.120)	.074
Log Non R&D Sci&Eng/ Econ Act Pop 1970	.100** (.080)	.039	.121* (.091)	.070	.016 (.006)	.029
Secondary Enrollment 1970	.208*** (.008)	.002	.240** (.013)	.005	.148 (.003)	.002
Dom Capital Formation 1970 (.004)	.029	.006 (.000)	.001	.010 (.003)	.042	.006
Lagged Dep. Variable 1970	.340*** (.383)	.055	.326*** (.377)	.110	.630*** (.572)	.082
Adjusted R^2	.89		.78		.83	
Constant	.000*** (5.183)	.361	.000*** (4.973)	.672	.000*** (4.596)	.628
N	46		26		20	
k	.20		.20		.20	

*** p<.01 ** p<.05 * p<.10

Figure 5.1: Log Scientists and Engineers in R&D
Per 10,000 Econ Active Pop, 1970

Less Developed Countries

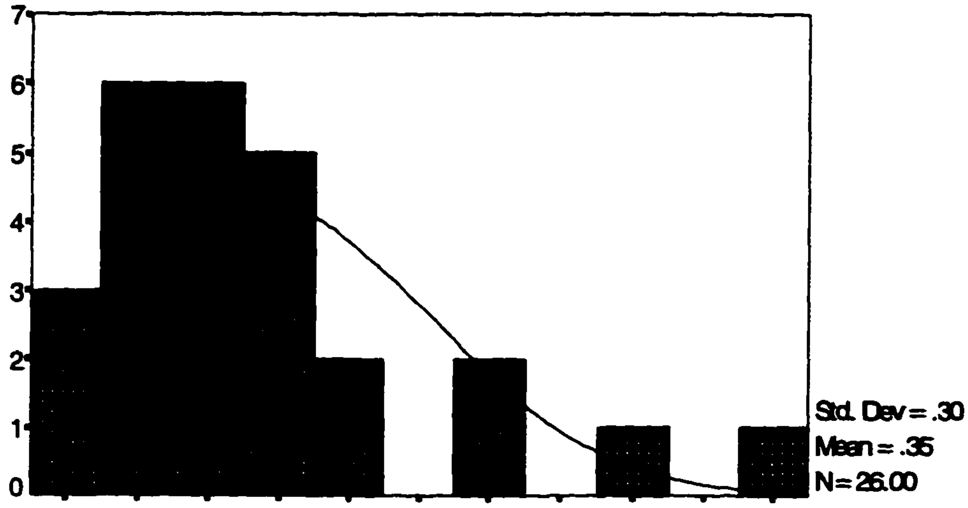

Figure 5.2: Log Scientists and Engineers in nonR&D
Per 10,000 Econ Active Pop, 1970

LDC

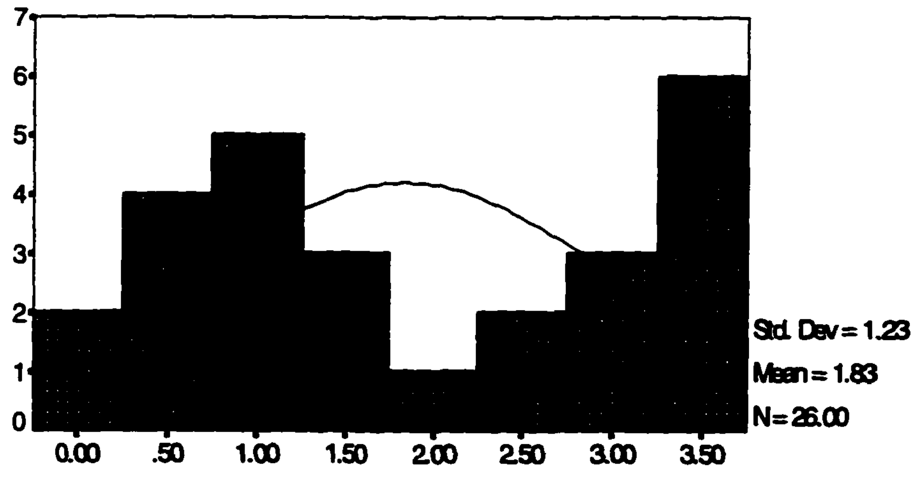

Figure 5.3: Log Scientists and Engineers in R&D

Per 10,000 Econ Active Pop, 1970

OECD

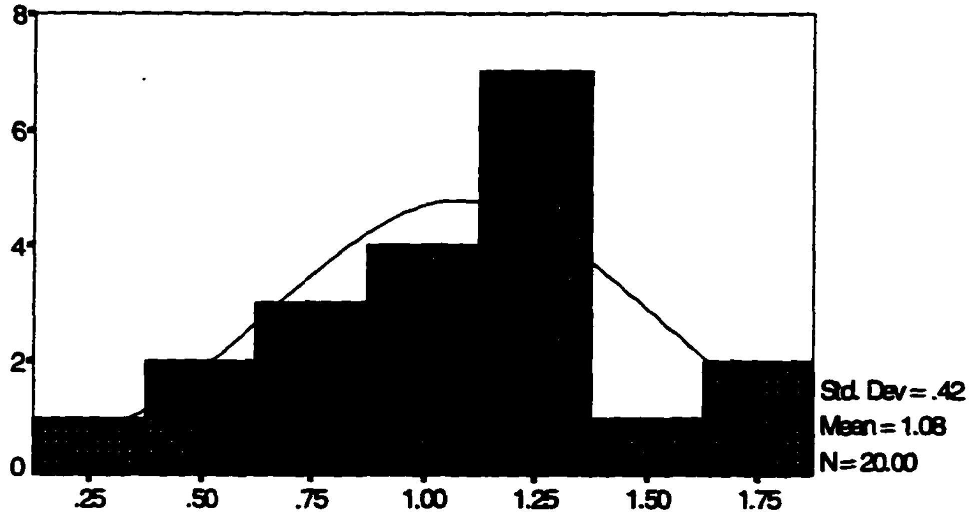

Figure 5.4: Log Scientists and Engineers in NonR&D

Per 10,000 Econ Active Pop, 1970

OECD

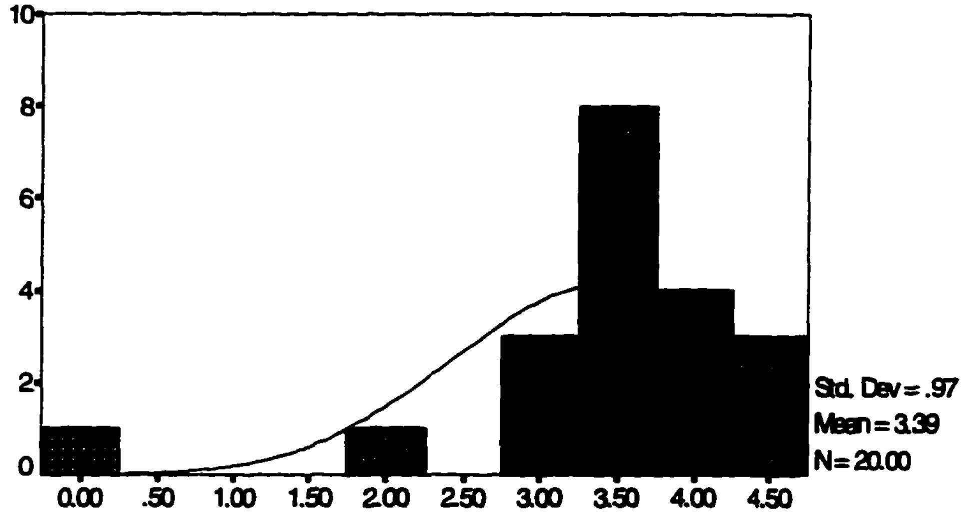

Figure 5.5 Partial Residual Plot: Res(Y) with Res(Education factor)

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          ++----+----+----+----+----+----+----+----+----+----
          |
          |
         2+
          |
 R        |
 E        |                              1          1      1
 S        |              1       1   21 21     1  11     1 S.
 Y       0+       1              22   1131 11 4   1 11
          |                    11  231      1
          |
          |        1 Zambia
          |
        -2+
          ++----+----+----+----+----+----+----+----+----+----
          -3        -2        -1         0         1

                                      RESX
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CHAPTER 6

CONCLUSION

This research project has examined the relationship between scientization of higher education and scientization of the labor force as well as the relationship between both forms of scientization and economic development. To ascertain these relationships ridge regression analysis using cross national data for the period 1970-90 was carried out. Most literature based within the traditions of human capital and modernization theories impute positive links between science and technology and economic growth. Other perspectives are more critical of the direct connection argument and suggest that this relationship may be stronger in countries with initially more developed infrastructures. This study has evaluated both of these contentions. What follows is a review of research propositions and related findings, discussions and implications of the findings and suggestions for future research.

The Relationship Between Scientization of Higher Education and Scientization of the Labor Force

As documented in Chapter 2, enrollment in tertiary science and engineering has expanded globally in the decades after the second World War. It was also shown in Chapter 3, Table 3.1, that the average number of scientists and engineers per 10,000 economically active population rose by more than fifty percent in the 10-15 year period considered in this study, from 28 in 1970/75 to 46 in 1980/85. The first question examined in this dissertation was whether variations in the level of tertiary science and engineering enrollment positively influenced the degree of concentration of scientists and engineers in the labor force. The following hypothesis was tested:

Hypothesis 1:

> *The greater the level of tertiary science and technical education the greater the concentration of scientific and technical labor force.*

The results of this inquiry were presented in Chapter 4. The level of tertiary science and technical education measured by either the size of the enrollment ratio, the number of graduates per 10,000 university age population or the index of science and technical education was found to have a positive and significant effect on the number of scientists and engineers in the labor force during the period 1970/75- 1980/85. The level of technical and scientific education was found to contribute positively both to the number of scientists and engineers as a whole and to the number of scientists and engineers in research and development. Thus, hypothesis 1 is supported. In addition, the level of economic development was found to be the most influential factor in determining the relative size of the scientific and technical labor force. By contrast, in the case of the concentration of scientists and engineers in R&D, the extent to which the school age population was enrolled in secondary education was the most important predictor.[70]

The second issue attended to in this dissertation was the question of whether the

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[70]The difference here may be partially due to the different cases although a rerun on a smaller set of cases, restricted to be the same for R&D and the total stock, still indicated the same conclusion.

link between the scientization of higher education and the scientization of the labor force is equally strong in countries with different levels of social and economic infrastructure. To this effect Chapter 4 also evaluates the following two hypotheses:

Hypothesis 3:

In societies with an expanded coverage of secondary education the greater the level of tertiary science and technical education the greater the concentration of scientists and engineers in the labor force.

Hypothesis 4:

In societies with a developed economy, the greater the level of tertiary science and technical education the greater the concentration of scientists and engineers in the labor force.

In the case of scientists and engineers as a whole, it was shown (Table 4.1) that the interaction with the level of economic development and the level of tertiary science and engineering enrollment was positive and significant. The corresponding interaction with secondary education enrollment was negative but statistically insignificant. The same result was found for the interaction with the number of graduates in science and engineering (Table 4.2) and for the index of tertiary science and technical education (Table 4.5). Hence, these findings provide support for hypothesis 4; the relationship between the number of people trained in science and engineering and subsequent proportion of scientists and engineers in the labor force is stronger in more economically developed countries. The result, however, did not provide support for hypothesis 3 that an expanded coverage of secondary education matters in influencing the relationship between scientization of higher education and subsequent scientization of the labor force.

Regarding the relationship between tertiary science and technical education and the number of scientists and engineers in R&D it was found that the interaction with both the level of economic development and with secondary education enrollment was positive and significant. The same findings held across all three measures of tertiary science and technical education: enrollment, graduates or the index of tertiary science and technical education (Tables 4.3, 4.4 and 4.6). In this regard, both hypothesis 3 and 4 are supported; the relationship between the amount of tertiary science and technical education and the relative number of scientists and engineers in R&D varies with the level of economic development and the coverage of secondary education.

All the six models which include the interaction with economic development estimated in Chapter 4 supports the thesis that there is a stronger link between scientization in higher education and scientization of the labor force in countries that are economically more advanced. In three out of six models including the interaction with secondary education enrollment (the models in which the measure of scientization of the labor force was the proportion of R&D scientists and engineers to the labor force) the level of secondary education enrollment also positively influenced this link.

The Impact of Scientization of the Labor Force on Economic Development

The next issue considered within this dissertation is whether societies with a stronger scientific and technical labor force infrastructure are better off in terms of national economic development. The descriptive statistics (Table 3.1) revealed that the mean Gross Domestic Product per capita increased by a factor of five between 1970 and 1990.Those advocating the importance of science and technology for national progress believe that a scientific and technical skilled labor force is crucial for economic development. Chapter 5 evaluated the argument that variations in the level of economic development is positively associated with variations in the level of concentration of scientists and engineers in the labor force. This relationship, formally expressed in hypothesis 2 below, was tested for the period 1970-90.

Hypothesis 2:

The greater the concentration of scientific and technical labor force the greater the level of economic development.

The empirical analysis showed that the relative number of scientists and engineers as a whole (Table 5.1) had a positive and significant impact on the level of economic growth for the panel 1970-90. The same long term effect was found for the combined measure of scientists engineers as a whole and scientists and engineers in R&D. The effect of R&D scientists and engineers alone was positive but did not quite reach a conventional level of significance. These findings lend support for hypothesis 2.

Moreover, It was stipulated that the relationship between scientization of the labor force and economic development is conditioned by the size of the market. This is because a large market offers the opportunity of realization of economies of scale and division of labor which is believed to be conducive for technological progress. Hypothesis 6 and 7 below formalizes this argument:

Hypothesis 6:

In societies in which the market is large, the greater the number of scientists and engineers engaged in research and development the greater the level of economic development.

Hypothesis 7:

In societies in which the market is large, the greater the concentration of scientists and engineers in the labor force the greater the level of economic development.

The result of the analyses indicated that the size of the export economy positively interacts with the number of scientists and engineers in R&D in their contribution to economic development. The interaction term with the share of export to GNP was positive and significant. The same applied to the number of scientists and engineers as a whole and the combined index of scientific and technical labor force (Table 5.2). These findings provide support for the hypothesis that larger export markets make the participation of scientists more effective in the process of generating economic growth.

It was also stipulated that the creation of technological change is less efficient if the amount of conventional capital per worker is lacking. This argument is expressed in hypothesis 9 below.

Hypothesis 9:

In societies in which the level of capital is large, the greater the concentration of scientists and engineers in the labor force the greater the level of economic development.

Table 5.3 showed that the interaction with the amount of capital per worker measured by the non-residential capital was uniformly positive and significant for all three labor force measures of scientists and engineers. These findings provide support for hypothesis 9.

As mentioned in Chapter 2 , previous research on research and development suggests that the effect of research and development on economic growth varies depending on the stage of industrialization. The level of R&D scientists and engineers has been found to have little if any impact on economic growth in less developed countries while the contribution of R&D has been found to significantly influence the level of economic development in the OECD countries (Ramirez & Lee 1995; Eaton & Kortum 1993; Lichtenberg 1992). Hypothesis 5 formally articulates this argument

Hypothesis 5:

In societies with more technologically developed economies, the greater the number of scientists and engineers engaged in research and development the greater the level of economic development.

Although the effect of R & D scientists and engineers was not quite statistically significant the results indicated that the relative number of R & D scientist and engineers is more important in explaining the level of economic development in the OECD countries than in the LDC countries (Table 5.4). Furthermore, it was found that the effect of scientists and engineers in non-R&D did not have any effect in the OECD countries but contributed more significantly to the level of economic growth in the less developed countries included in the study (Tables 5.5 and 5.6). Thus, to some extent hypothesis 6 is supported by these analyses.

In terms of relative importance, it is seems clear from these analysis (in particular Table 5.6) that variations in the level of scientists and engineers in R&D is more important in generating economic growth than the level of scientists and engineers in non R&D in the OECD countries. The opposite seems to be the case in the less developed countries of the sample.[71]

With the exception of the OECD countries, all the models presented in Chapter 5, showed that the most important overall predictor of economic development among the independent variables were secondary education and the measure of the level of tertiary science and technical education. In addition, further analysis revealed (Chapter 5) that the direct effect of scientization of higher education and the labor force diminishes at higher levels of scientization.

Discussion and Implications of Findings

The central tenet of human capital theory and social modernization theories is that further social and economic progress can be obtained by increased access to education and improved quality of schooling. The argument that the more people being trained in high quality institutions the greater the economic and social progress has framed the general discourse on the relationship between schooling and economic development

[71]One should keep in mind, however, that the countries in the less developed category constitute a quite diverse set of countries, including both some newly industrialized countries as well as some African, less developed countries. There may be better ways of categorizing countries according to the level of industrialization than present division of OECD and non OECD. One way would be to use a measure of the concentration of high tech industry.

during the time frame of this dissertation. A further implication of this tenet is that education should equip individuals with particular skills that are thought to be necessary for national economic and social progress. The discovery of the "great residual" by neoclassical economist, entailing the amount of the variation in national economic growth left to be explained after the basic factors of production, has created the notion that science and technology are the route to take in order for higher levels of economic growth to be attained. Consequently, in this process it is imperative that more scientists and engineers be trained.

This raises the question, through what process does the institutionalization of science and technology in higher education contribute to economic growth? Although the dissertation has not explicitly been based on a path analysis, it has implicitly assumed that scientization of higher education leads to scientization of the labor force which in turn causes economic growth. With this in mind, there are two stages at which the contribution of scientization of higher education to economic growth could be hampered. The first stage is the entrance into the labor force; will the labor market be able to absorb the technically and scientifically trained? By this I mean, does the number of and type of graduates match the demand in the labor force?

The findings obtained in this dissertation indicate that the ability of absorbing the output from technical and scientific fields is dependent on the level of economic development. It was shown that the relationship between the level of tertiary science and technical education and the concentration of scientists and engineers in the labor force, independent of the measure used for the labor force, was influence by the level of economic development. A possible explanation for this finding is that countries with a more developed economy are more likely to have an industrial base with a labor market structure that matches the skill level of those trained as scientists and engineers.

Moreover, an economy needs people to carry out a variety of tasks at different skill levels. In addition to specialized skills needed for certain professional categories of jobs, there has to be a base of people that can perform jobs that require less formal training , i.e, truck drivers, construction workers, sales and service personnel, etc. Depending on the stage of development this base may vary. In addition to the level of economic development, the findings of this study hint at the importance of having a sufficient base of people with secondary education in order to take advantage of the opportunities offered by an expanded tertiary science and technical education sector. This finding applies specifically to the concentration of R&D scientists and engineers. The data showed that the relationship between the level of tertiary science and technical education and the number of R&D scientist and engineers was stronger in countries with an expanded level of secondary education enrollment.

The second factor that may restrain the contribution of an expanded tertiary science and technical education sector to economic growth is the degree to which a society is able to take advantage of its scientific and technical labor force capacity. Although the allocation of jobs in the labor market matches the supply of scientists and engineers, it does not ensure the efficient utilization of scientists and engineers in the context of economic growth. The findings here provide some evidence that countries with more export oriented economies are in a better position of utilizing its scientific and technical labor force capacity. One reason for this could be the possibility of the realization of economies of scale and the possibility of more efficient production processes such as division of labor that can be accomplished with greater volumes of outputs. The findings here also cast some doubts on the neoclassical economists or growth accounting exercise entailing that the basic factors of production are additive in their effects. The realization of technological change often requires investment in new equipment and machinery. The findings here suggests that countries with a greater level of capital stock per worker are in a better position of effectively utilizing their technical and scientific labor force base.

The findings obtained in this dissertation provide some evidence of a positive connection between the number of people being trained in science and engineering, the number of scientists and engineers in the labor force and economic development. This may reflect a human capital process or some other process. Moreover, the results also suggests that this process is not as simple as the "science and technology for progress" model or human capital theory would predict; this model seems biased toward more educationally and economically developed countries.

As evidenced by the worldwide expansion of technical and natural sciences fields in higher education and the higher concentration of scientists and engineers in the labor force, more and more countries are adhering to the “science and technology for progress” model. As scholars operating within the institutionalist framework would argue, countries committed to the goal of national progress adhere to a rational model which has proved to be important for economic progress in countries with a certain level of economic and social infrastructure. To this end countries continues to expand tertiary science and technical education regardless of the level of socioeconomic conditions. This expansion is likely to result in loose coupling between scientization of higher education and scientization of the labor force on the one hand, and labor force scientization and economic development on the other. To be more concrete, an expanded enrollment in tertiary science and technical education does not have the same payoff in countries which does not have an industrial base that can absorb the output from tertiary science and technical institutions. The fact that more people get trained does not necessarily lead to the availability of more jobs which is one major criticism against human capital theory.[72] As the Fuller and Robinson thesis (1991) specifies, the effect of schooling on economic growth depends on the extent to which the economy is able to absorb the skills created by schooling.

In countries which do not have sufficiently developed economy, and thus the allocation of jobs match the level of skills created by schooling, technically and scientifically trained people may have to take jobs that they are over qualified for or they may migrate to a more developed country. This "brain drain" has happen in many third world countries. This in turn may result in waste of resources that could be used more productively in providing training in areas that would be more relevant for the level of industrial development. In addition, the sheer number of scientists and engineers in the labor force does not necessarily ensure the efficient contribution of scientists and engineers to

[72]The findings here could be confounded with the accuracy by which someone is classified as a scientist or engineers which may explain some of the looser coupling found in less developed countries.

economic growth. The ability to take advantage of the opportunity offered by an expanded scientific and technical labor force sector depends upon a number of factors some of which have been evaluated here.[73]

However, the findings obtained within this dissertation do not exclude the possibility that the effect on economic development may also differ depending on other factors not controlled for in this study. One possible factor that has not been dealt with in this dissertation and which may determine the relative effect of scientization on economic development is the quality and content of science education. According to the literature on science and technical education the general emphasis differs between countries in terms of applied verses more theoretical approaches. In addition, achievement tests in science and mathematics show that there are cross-national variations in the scoring on these tests. These differences may influence the degree to which scientization of higher education affects economic development.

Another issue that has not been consider here is the involvement of the state in orchestrating scientific activities by, for example, providing support to technology based industry and thereby stimulating the growth in these industries. This would enhance the contribution of scientists and engineers to economic development. A well know example of this type involvement of the state is Japan. Still another possibility that has not been the focus here is the existence of venture capitalists. The development of new technology does not guarantee that the technology is turned into a product. The conditions of Silicon

[73]By this I do mean that there is no effect of expanded enrollment in science and engineering, it only means that the effect is weaker.

Valley do not exist everywhere. For example, a new form of liquid crystals were developed by the University of Gothenburg in Sweden which could have been used for enhancing the quality of television screens. Due to lack of venture capital the invention was never developed any further. Kamien and Schwartz (1982) describe Schumpeter as emphasizing the role played by the entrepreneur in bringing an invention to its fruition. The entrepreneur is defined as the person who creates new combinations-the one who sees how to fulfill currently unsatisfied needs or perceives a more efficient means of doing what is already being done. In some societies the concept of entrepreneurship may be have little value. This has been pointed out as one of the major obstacles to the achievement of economic growth in some less developed countries.

The policy recommendations I make on the basis of the results of this study are that a country should not uncritically adopt a model simply because it may have proven to be successful under certain conditions; it may not be appropriate for the particular conditions prevalent in the country in question. On the other hand, it is also important to recognize that a country in which the necessary conditions for technological change are in place will not be able to take advantage of that position unless it has a sufficient pool of scientists and engineers ready to be to be employed.

This research project has provided some indication of the uses and limits of the science and technology model. However, more research needs to be done to give further credence to this finding. Next I outline some directions for future research.

Directions for Further Research

This dissertation has among other things given rise to the question, what forms of knowledge or skills created by schooling are relevant for a particular level of socioeconomic development in the context of generating economic growth. To some extent the findings obtained in this study imply that university level training of scientists and engineers seems more suitable for countries which are more economically and socially developed. This dissertation and other research carried out are inadequate to fully understand the process and all its details by which schooling contributes to economic growth. For instance, this dissertation did not distinguish between different levels of tertiary science and technical education, such as training leading to a B.S. degree or masters and Ph.D. level. A cross-national study comparing the relative benefits of technicians with scientists and engineers found that technicians contribute more economic growth than scientists and engineers (Honig & Ramirez 1996). Moreover, this `dissertation did not differentiate between different fields of science and engineering. It is possible that the effect on productivity growth and on economic development differ depending on what field of science and engineering that is considered. One possible direction for future research is to examine the relative importance of different levels of degrees and fields of science and engineering.

Although, the benefits of manpower planing has been debated, societies in which the expansion of science and engineering enrollment is regulated may result in a closer coupling between the educational system and the labor market. In an open system, like the one in the United States, there is hardly any restriction on the number of schools that can be established. Therefore, tertiary education in science and engineering can, for example, be a result of a status competition process rather than serving societal needs (Rubinson & Ralph 1984). Consequently, the relationship between science and engineering education and the size of scientific and technical labor force in such a society ought to be weaker than under a closed or centrally controlled educational system. It would be worth investigating whether societies in which access to higher education is nationally controlled, the link between the amount of science and technical education and the number of scientists and engineers is tighter.

This dissertation indicated that the amount of non residential capital per worker and expanded export market influence the relationship between scientization of the labor force and economic development. Further research could take this finding into account and select four countries, each one falling into a separate category, based on the following divisions: countries with either a small or large export market and countries with either a low or high level of capital per worker. In these four countries a time series analysis could be carried out to assess the effect over time as well as the impact of an expanded export market and the amount of capital per worker (For example, see Ragin 1987, for different comparative strategies). This strategy could allow a better quality of data and provide more insight into the relationship between the level of R&D scientists and engineers and economic development.

Moreover, the contribution of scientization to economic growth does not solely stem from technological development leading to new products. Productivity gains have also been achieved through more efficient organization of production, in which management skills have been an important factor (for instance, see Amsden 1992). This dissertation hinted at the possibility that scientists and engineers contribute more to economic growth when a greater proportion of the labor force are in managerial and administrative positions. However, the number of cases was not sufficient to confirm whether this is the case. Further research should follow up on this question with more data.

Furthermore, this research project gave some indication of the positive role of R&D scientists and engineers in economic development in the OECD. There is still much to be explained about how the contribution of R&D scientists and engineers operates. Are there any particular conditions that make the level of R&D scientists and engineers more related to economic growth? Further research could focus on the OECDs using a pooled cross-sectional time series analysis to assess different factors that may condition the impact of R&D scientists and engineers on economic development. For example, where the R & D is carried out may be critical. Rosenberg (1994) points out that the organization of universities into departments may render research less effective. He claims that such departmental structure may prevent disciplines from interacting and since many of today's technical problems require an interdisciplinary approach the positive effect of R & D may be hampered. By contrast, R & D carried out in industry often allow such an interdisciplinary approach. Therefore, the investment in R & D may be more effective when carried out in industry. Further research could focus on the question of whether societies where most research and development is undertaken within industry instead of solely within universities, will benefit more from research and development in respect to economic growth.

However, in some societies such as the United States there is a close cooperation between industry and universities which should offset some of the disadvantages of university based research (Rosenberg 1994). In addition to looking at the effect of location of R&D, it would be worthwhile considering whether societies in which there is a close cooperation between university research and industry, the level of R&D contributes more to economic development.

The source of funding is another element which may affect the efficiency of R & D. Rosenberg (1994) argues that in a situation when funding comes from public sources a project may be allowed to continue despite lack of success which will result in waste of resources. By contrast when research and development is privately funded there is often a stricter control for when it is time to discontinue an unpromising project. However, the active role of the state in the process of technological change in the south Asian countries may contradict this argument(see, Amsden 1989; Lau 1990). Thus, further research should look into how the source of funding affects the degree to which R&D scientists and engineers contribute to economic growth.

APPENDIX A

Table A.1 Effects of Tertiary Science and Engineering Enrollment Ratio on the Proportion of Scientists and Engineers in the Labor Force

Standardized Ridge Regression Coefficients
(unstandardized regression coefficients in parenthesis)

Equation number:	(1) Log Scientists & Engineers Per 10000 Econ. Active Population 1980/85		(2) Log Scientists & Engineers Per 10000 Econ. Active Population 1980/85	
INDEPENDENT VARIABLES	Beta (b)	s.e	Beta (b)	s.e
Log Tertiary S&E Enrol. 1970	.183*** (.400)	.100	.144*** (.314)	.071
Log RGDP per capita 1970	.220*** (.313)	.063	.202*** (.288)	.065
Secondary Enrollment 1970	.032 (.002)	.002	.051 (.002)	.002
Lagged Dep. Variable 1970/75	.515*** (.495)	.043	.505*** (.498)	.045
INTERACTION EFFECTS: Log Tertiary S&E Enrol.				
By Log RGDP Per Capita	- -	-	.114*** (.031)	.007
By Secondary Education	- -	-	-.067* (-.002)	.001
Adjusted R^2	.90		.90	
Constant	.000** (-.832)	.385	.000* (-.722)	.400
k	.20		.20	

*** p<.01 ** p<.05 * p<.10

Table A.2 Effects of Graduates in Science and Engineering on the Proportion of Scientists and Engineers in the Labor Force

(N=51)

Standardized Ridge Regression Coefficients

(unstandardized regression coefficients in parenthesis)

Equation number:	(3) Log Scientists & Engineers Per 10000 Econ. Active Population 1980/85		(4) Log Scientists & Engineers Per 10000 Econ. Active Population 1980/85	
INDEPENDENT VARIABLES	Beta (b)	s.e	Beta (b)	s.e
Log S&E Graduates 1970	.109** (.113)	.047	.082** (.084)	.036
Log RGDP per capita 1970	.246*** (.351)	.065	.236*** (.337)	.067
Secondary Enrollment 1970	.040 (.002)	.002	.052 (.003)	.002
Lagged Dep . Variable 1970/75	.547*** (.539)	.045	.543*** (.535)	.047
INTERACTION EFFECTS: Log S&E Graduates				
By Log RGDP Per Capita	- -	-	.070** (.009)	.003
By Secondary Education	- -	-	-.040 (-.000)	.000
Adjusted R^2	.89		.89	
Constant	.000*** (-1.109)	.412**	.000 (-1.056)	.483
k	.20		.20	

*** p<.01 ** p<.05 * p<.10

Table A.3 Effects of Tertiary Science and Engineering Enrollment Ratio on the Proportion of R&D Scientists and Engineers in the Labor Force

(N=36)

Standardized Ridge Regression Coefficients
(unstandardized regression coefficients in parenthesis)

Equation number:	(5) Log R&D Scient & Engineers Per 10000 Econ. Active Population 1980/85		(6) Log R&D Scient & Engineers Per 10000 Econ. Active Population 1980/85	
INDEPENDENT VARIABLES	Beta (b)	s.e	Beta (b)	s.e
Log Tertiary S&E Enrol. 1970	.129* (.150)	.083	.036 (.043)	.064
Log RGDP per capita 1970	.002 (.002)	.055	-.026 (-.020)	.057
Secondary Enrollment 1970	.178** (.004)	.002	.102 (.009)	.006
Lagged Dep. Variable 1970/75	.589*** (.643)	.080	.561*** (.622)	.085
INTERACTION EFFECTS: Log Tertiary S&E Enrol				
By Log RGDP Per Capita	- -	-	.068 (.010)	.006
By Secondary Education	- -	-	.155** (.002)	.001
Adjusted R^2	.81		.80	
Constant	.000 (.070)	.357	.000 (.260)	.370
k	.20		.20	

*** $p<.01$ ** $p<.05$ * $p<.10$

Table A.4 Effects of Graduates in Science and Engineering on the Proportion of R&D Scientists and Engineers in the Labor Force

(N=36)

Standardized Ridge Regression Coefficients
(unstandardized regression coefficients in parenthesis)

Equation number:	(7) Log R&D Scientists & Engineers Per 10000 Econ. Active Population 1980/85		(8) Log R&D Scientists & Engineers Per 10000 Econ. Active Population 1980/85	
INDEPENDENT VARIABLES	Beta (b)	s.e	Beta (b)	s.e
Log S&E Graduates 1970	.106 (.068)	.045	.031 (.020)	.035
Log RGDP per capita 1970	.015 (.011)	.055	-.014 (-.011)	.056
Secondary Enrollment 1970	.177** (.004)	.002	.092 (.002)	.001
Lagged Dep. Variable 1970	.600*** (.614)	.080	.580*** (.642)	.085
INTERACTION EFFECTS: Log S&E Graduates				
By Log RGDP Per Capita	- -	-	.050 (.004)	.003
By Secondary Education	- -	-	.156*** (.001)	.000
Adjusted R^2	.81		.80	
Constant	.000 (-.046)	.362	.000 (.723)	.622
k	.20		.20	

*** p<.01 ** p<.05 * p<.10

Table A.5 Effects of Science and Engineering Enrollment and Graduates Index on the Proportion of Scientists and Engineers in the Labor Force

(N=51)

Standardized Ridge Regression Coefficients

(unstandardized regression coefficients in parenthesis)

Equation number:	(9) Log Scientists & Engineers Per 10000 Econ. Active Population 1980/85		(10) Log Scientists & Engineers Per 10000 Econ. Active Population 1980/85	
INDEPENDENT VARIABLES	Beta (b)	s.e	Beta (b)	s.e
Log S&E Enrol. and Grad Index 1970	.164*** (.111)	.031	.149*** (.101)	.022
Log RGDP per capita 1970	.228*** (.325)	.064	.219*** (.313)	.065
Secondary Enrollment 1970	.030 (.002)	.002	.037 (.002)	.002
Lagged Dep. Variable 1970	.523*** (.515)	.044	.510*** (.503)	.045
INTERACTION EFFECTS: Log S&E Graduates				
By Log RGDP Per Capita	- -	-	.099*** (.010)	.003
By Secondary Education	- -	-	-.082* (-.001)	.001
Adjusted R^2	.90		.90	
Constant	.000** (-.500)	.422	.000** (-.366)	.435
k	.20		.20	

*** p<.01 ** p<.05 * p<.10

Table A.6 Effects of Science and Engineering Enrollment and Graduates Index on the Proportion of R&D Scientists and Engineers in the Labor Force

(N=36)

Standardized Ridge Regression Coefficients

(unstandardized regression coefficients in parenthesis)

Equation number:	(11) Log R&D Scient & Engineers Per 10000 Econ. Active Population 1980/85		(12) Log R&D Scient & Engineers Per 10000 Econ. Active Population 1980/85	
INDEPENDENT VARIABLES	Beta (b)	s.e	Beta (b)	s.e
Log S&E Enrol. and Grad Index 1970	.214*** (.066)	.021	.081 (.025)	.014
Log RGDP per capita 1970	.012 (.009)	.053	.015 (.011)	.055
Secondary Enrollment 1970	.168** (.004)	.002	.161** (.004)	.002
Lagged Dep. Variable 1970	.526*** (.583)	.078	.494*** (.547)	.084
INTERACTION EFFECTS: Log S&E Graduates				
By Log RGDP Per Capita	- -	-	.097** (.004)	.002
By Secondary Education	- -	-	.099 (.001)	.000
Adjusted R^2	.82		.80	
Constant	.000 (.266)	.360	.000 (.274)	.373
k	.20		.20	

*** p<.01 ** p<.05 * p<.10

APPENDIX B

List of countries included in the analyses
Dependent variable: total number of scientists and engineers in the labor force (N=51)

Africa	North America	South America	Asia	Europe	Oceania
Cameroon Egypt Kenya Malawi Nigeria Rwanda	Canada Guatemala Panama	Argentina Bolivia Brazil Guyana Uruguay Venezuela	Hong-Kong India Indonesia Iran Iraq Israel Japan Jordan Malaysia Pakistan Phillippines Singapore Sri-Lanka Thailand Turkey	Austria Czechoslovakia Denmark Finland France Germ-Dr(E) Germ-Fr(W) Greece Hungary Iceland Ireland Italy Netherlands Norway Poland Spain Sweden United Kingdom Yugoslavia	Australia New-Zealand

List of countries included in the analyses
Dependent variable: number of scientists and engineers R&D (N=36)

Africa	**North America**	**South America**	**Asia**	**Europe**	**Oceania**
Mauritius Senegal	Canada Mexico Trinidad&Tobago	Argentina Chile Colombia Ecuador	India Japan Jordan Korea-R(S) Pakistan Singapore Sri-Lanka Turkey	Austria Czechoslovakia Denmark Finland France Germany-Fr(W) Greece Hungary Iceland Ireland Italy Netherlands Norway Poland Portugal Spain Sweden Yugoslavia Australia	

List of countries included in the analyses
Dependent variable: Economic Development(Real GDP per capita) (N=51)

Africa	North America	South America	Asia	Europe	Oceania
Ghana Kenya Malawi Mauritius Nigeria Togo Sudan Zambia	Canada Guatemala Panama Mexico Trinidad&Tobago	Argentina Bolivia Chile Columbia Ecuador Uruguay Venezuela	India Indonesia Iran Israel Japan Korea-R(S) Pakistan Sri-Lanka Turkey	Austria Belgium Denmark Finland France Germ-Fr(W) Greece Iceland Ireland Italy Netherlands Norway Spain Sweden United Kingdom	Australia New-Zealand

APPENDIX C

List of countries according to the level of economic growth rate, the level of scientization of higher education and the labor force (N=46)

Country	Economic growth rate	Scientization of higher education index	Scientization of the labor force index
Korea-S(R)	12.15	1.31	.00
Singapore	11.06	1.83	.45
Indonesia	8.68	-2.56	-1.99
Mauritius	7.04	-1.56	-1.87
Iceland	5.48	-.33	1.21
Japan	5.22	2.06	3.65
Ireland	4.91	1.05	1.42
Canada	4.62	2.44	2.36
Finland	4.60	1.85	2.05
Austria	4.51	1.14	1.09
Norway	4.48	1.98	1.94
Sri-Lanka	4.41	-2.38	-1.35
Turkey	4.36	.39	-.34
Spain	4.32	.49	-.36
Italy	4.32	.43	.95
Greece	4.21	.84	.33
Belgium	4.15	.79	.39
Germ-Fr(W)	4.08	2.50	2.30
India	4.07	.40	-1.78
Israel	4.01	2.41	1.93
United-Kingdom	3.94	2.39	.36

Colombia	3.93	-.91	-2.89
France	3.82	1.63	2.23
Nigeria	3.69	-3.24	-2.65
Mexico	3.66	-.46	.03
Ecuador	3.63	-.59	-.24
Denmark	3.55	1.63	1.39
Netherlands	3.55	1.75	3.64
Kenya	3.32	-2.95	-2.73
Australia	3.31	2.27	1.77
Sweden	3.31	2.35	1.53
Pakistan	3.15	-.99	-2.52
New-Zealand	3.10	2.21	2.59
Trinidad& Tobago	2.95	-.48	.09
Venezuela	2.84	-.51	-.36
Chile	2.68	.82	1.07
Malawi	2.58	-3.05	-2.80
Uruguay	2.49	-2.31	-.36
Panama	2.33	-.46	-2.33
Guatemala	2.16	-2.28	-1.43
Togo	2.10	-2.33	-2.80
Ghana	1.84	-2.62	-1.66
Iran	1.83	-.01	-.52
Argentina	1.65	.45	.06
Sudan	1.61	-2.93	-2.33
Zambia	.38	-3.45	-.196

Dfbetas for Scientization of Higher Education Index and Scientization of the Labor force Index

NAME	DFBETAS (education)	DFBETAS (laborforce)
KOREA-R(S)	.03324	.00649
SINGAPOR	.02310	-.00877
INDONES	-.00374	.01808
MAURITIUS	.00254	-.02090
ICELAND	-.01756	.00342
JAPAN	.00047	-.00152
IRELAND	-.00004	.00036
CANADA	.00145	.00188
FINLAND	.00202	.00128
AUSTRIA	-.00045	-.00133
NORWAY	-.00002	.00005
SRI-LAN	-.00227	.00196
TURKEY	.00142	.00033
SPAIN	.00001	-.01081
ITALY	-.00733	-.00194
GREECE	-.00023	.00093
BELGIUM	-.00085	-.00466
GERM-FR(W)	.00361	.00726
INDIA	-.03711	.00728
ISRAEL	-.00469	-.00401
UN-KING	-.00806	.00958
COLOMBIA	.00496	-.01721
FRANCE	.00026	-.00056
NIGERIA	-.00364	.00153
MEXICO	-.00271	.00640
ECUADOR	-.00003	.00073
DENMARK	.00012	.00151
NETHERL	.00316	-.01050
KENYA	-.00130	-.00063
AUSTRAL	-.00224	.00378
SWEDEN	-.00466	.00763
PAKISTAN	-.00718	.00495
NEW-ZEAL	-.00411	-.00626
TRIN&TOB	-.00192	.00076
VENEZU	-.00373	-.00293
CHILE	-.00332	-.01038
MALAWI	.00172	-.00273
URUGUAY	-.00649	.00361
PANAMA	-.00459	.02643
GUATEMA	-.00178	.00110
TOGO	.00427	-.00035
GHANA	.00438	-.00925
IRAN	-.00561	.00167
ARGENTIN	-.00303	.00613
SUDAN	.00291	-.00719
ZAMBIA	.05191	.00123

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