OCCASION

This publication has been made available to the public on the occasion of the 50th anniversary of the United Nations Industrial Development Organisation.

TOGETHER
for a sustainable future

DISCLAIMER

This document has been produced without formal United Nations editing. The designations employed and the presentation of the material in this document do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations Industrial Development Organization (UNIDO) concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries, or its economic system or degree of development. Designations such as "developed", "industrialized" and "developing" are intended for statistical convenience and do not necessarily express a judgment about the stage reached by a particular country or area in the development process. Mention of firm names or commercial products does not constitute an endorsement by UNIDO.

FAIR USE POLICY

Any part of this publication may be quoted and referenced for educational and research purposes without additional permission from UNIDO. However, those who make use of quoting and referencing this publication are requested to follow the Fair Use Policy of giving due credit to UNIDO.

CONTACT

Please contact publications@unido.org for further information concerning UNIDO publications.

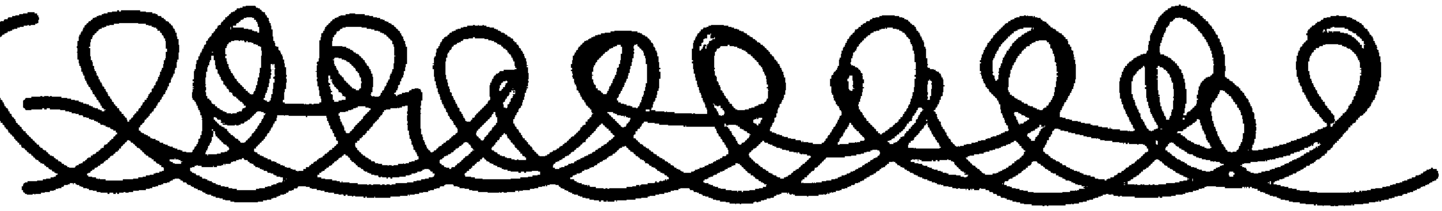
For more information about UNIDO, please visit us at www.unido.org

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

Industrial Development Report 2005
Background Paper Series

23131

The Pillars of Progress: Metrics for Science and Technology Infrastructure



UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

Industrial Development Report 2005 Background Paper Series

The Pillars of Progress:

Metrics for

Science and Technology Infrastructure

Caroline S. Wagner, Ph.D.
Marnina S. Reed

April 2005

Office of the Director-General

This series includes the background papers commissioned to cover specific aspects addressed in the Industrial Development Report 2005 "Capability building for catching-up – Historical, empirical and policy dimensions". The digital versions are available, together with the full report, on the IDR 2005's website at www.unido.org/idr.

For further information on the IDR05, please contact f.sercovich@unido.org.

Contents

Appendices

Summary

Science and technology are viewed as building blocks of economic and social progress. Countries with an advanced science and technology (S&T) system often have a robust economy. S&T is seen as so important that its inputs and outputs are carefully measured. Metrics (or measures) for infrastructure supporting science and technology (S&T) systems are often excluded from such studies: if an S&T system exists, an infrastructure is assumed. Nevertheless, as more countries seek to create a knowledge-based economy, a need arises to understand the components of an S&T system *and* the related infrastructure that supports its effective conduct. This report seeks to close a gap in the literature by defining and identifying metrics for S&T infrastructure.

S&T infrastructure is defined as those functions which support the conduct research or disseminate its results; it also includes activities to assure the quality of scientific or technical products. This report focuses on *direct* infrastructure support functions, generally provided by the public sector, including:

- Scientific and technical institutions
- Agencies dedicated to standards, testing, and metrology
- Extension services, technology transfer, and information collection
- Intellectual property protection agencies
- Vocational and technical training
- Regulatory agencies and compliance services.

For each of these related science and technology activities (RSTA), to the extent possible, institutional support and spending in the S&T-advanced countries is detailed; where appropriate, spending is averaged and a range is suggested. The suggested metrics are based on a share of the population to enable scaling of RSTA to countries of different sizes.

The table below summarizes the metrics proposed.

Rethinking the RSTA Model

In the S&T-advanced countries, RSTA have evolved within a nationally-based industrial system, and thus have been provided largely by national and local governments. This is not necessarily the most effective provider in the future, particularly for those developing countries seeking to expand capacity. Investment could be more efficiently made based upon scale, scope, and location of expertise than on national borders. Since countries have limited resources, it is not at all clear that they need to replicate in miniature all the institutions created in advanced countries to support their S&T system. Metrics can be a guideline but they should not be considered as a blueprint.

While it is clear that governments should coordinate it, it is worth further discussion on how best to structure RSTA in developing countries. Some RSTA functions require a hands-on approach and a geographical presence. The learning involved in creating the function and the spillover benefits of having it close to knowledge-retaining institutions may warrant direct investment in 1) laboratories, 2) regional extension services, and 3) vocational training. These are cases where local infrastructure is clearly needed and there is no substitute for proximity.

Infrastructural Component or Function	***Sub-component***	**Metric range in S&T-advanced countries**
S&T laboratories		2 - 9 S&T institutions per 100,000 inhabitants
	S&T laboratory equipment	R&D funds require an additional 20 percent spent on equipment
	S&T laboratory space	Between 25 and 180 sq meters is allocated per research staff member
	Public spending on research	R&D spending of ~$60 million (GERD) per 100,000 population
	Government share of academic research	Government funds 60-70 percent of university-based research
	Government share of business research	Government funds more than 6 percent of business-based research
	Industrial contribution to academic research	Industry funds ~6 percent of academic research
Standards, testing, and metrology services		Governments spend $150,000 per 100,000 inhabitants on standards, testing, and metrology
Extension services, technology transfers and information collection		Governments contribute close to $200,000 per 100,000 inhabitants on manufacturing extension services
Metrics for the following infrastructural components were not estimable with available data		
Intellectual property protection	Government provides legal framework; public sector grants and litigates IP rights; patent offices often self-funded	*Companies in many countries tend to patent in the US, Europe, and/or Japan to gain broad market protection*
Vocational education and training	Government (national, regional, local), private sector provide training opportunity; spending ranges considerably; difficult to estimate	*Governments are generally highly committed to vocational and technical training*
Regulatory and compliance services	Governments (national, regional, local) create regulations and offer compliance services; businesses also provide compliance services; spending difficult to estimate	*Different countries have quite a different mix of regulations and services; the responsible party (public or private) also differs considerably among countries*

In other cases, information which is easily shared among knowledgeable groups may be conducive to other types of investment, including virtual agencies, fee-for-service links, or regionally-shared agencies. These might include aspects of 1) standards setting, 2) metrology, 3) information collection and dissemination, 4) intellectual property protection, 5) technical training manuals, and 6) compliance testing. These RSTA could be established by international agencies or by coalitions of interested governments. Experiments in alternative approaches to RSTA for development should be considered for support.

Steps towards building RSTA for development should be aware of best practices in S&T advanced countries. These include:

- convening stakeholders to provide input to key governmental budgetary and structural decisions;
- aligning RSTA with national goals and targets;
- building public-private partnerships to ensure quality and efficiency;
- ensuring open information about processes, services, and outcomes of RSTA.

Science & Technology Capability-building: Infrastructure Issues and Metrics

Purpose, Organization and Methodology for this Study

The infrastructure supporting national science and technology (S&T) systems has received little attention from official statisticians, economists or policy analysts. Indeed, the Organization for Economic Cooperation and Development (OECD) has noted in several publications that "related scientific activities" (RSA) are difficult to measure: these activities are not included in widely available publications on S&T activities.[1] Benoit Godin reports that "in the past fifty years RSA have rarely been collected in the measurement of science and technology or been discussed as activities in their own right."[2] Yet, the physical plant, technical services, and infrastructure of an economy are clearly important to the development of scientific research and technological development. This paper attempts to fill the gap in the literature by focusing on metrics for RSTA. The paper first defines the infrastructure underlying S&T capacity, suggests metrics, and extrapolates from these metrics a first cut at the potential RSTA needs of countries at various levels of development.

Organization

Following this introduction, the paper discusses the infrastructure supporting S&T systems in advanced countries. The first part of this discussion reviews the history of the treatment of infrastructure by groups that measure S&T. A discussion of different types of RSTA follows, detailing the differences between direct and indirect support. In the succeeding section, direct, public-sector investment in RSTA is discussed. Section 3 places RSTA in a larger context by discussing the development of a science and technology system and its relationship to innovation. Section 4 discusses lessons learned from this study by offering new ways to think about RSTA. Appendix 1 discusses the measurement of national S&T capacity; Appendix 2 discusses the basic infrastructure needs of an economy seeking to increase S&T capacity.

Methodology

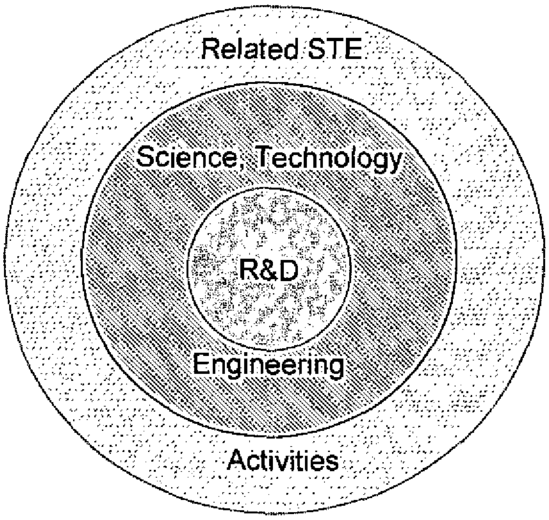
The authors conducted a literature review to collect information about S&T capability-building and RSTA in S&T-advanced countries. The publications were drawn primarily from major international organizations such as OECD, the RAND Corporation, the World Bank, the Brookings Institution, the European Commission, the United Nations, the National Science Board (NSB), the National Science Foundation (NSF) and the National Institute of Standards and Technology (NIST). In addition to contacting experts, we also examined the bibliographies of relevant reports, and in this way identified and obtained additional documents. The focus throughout the analysis was on specific measures in order to develop a set of good practices investment. We also scanned the literature for examples of decision-making about these specific capabilities and infrastructural investments.

Throughout the paper, whenever possible, relevant data are presented in relationship to a *per capita measure*. This is done for a specific purpose that requires an explanation. Using a population base to develop metrics allows a focus on the RSTA *function* rather than upon the institutional structure. This allows a consideration of investment and resource demand based, not on political borders and boundaries, but upon the scale and scope of the investment or resource required. The assumption is that an identifiable RSTA may not be needed to the same extent by every nation. Some smaller countries (or countries with smaller GDPs) may wish to share resources rather than develop all the institutions and resources. Some investments may be coordinated across two or more countries. Some may be accessed virtually using the Worldwide Web. It may also be that RSTA investments require multiple investments within a single country. Accordingly, rather than presenting resources and investments using *nations* as the basic unit, this paper uses per capital inhabitants. The World Bank figures for population in 2002 were used to calculate spending per 100,000 inhabitants.[3] For the sake of consistency, data measures from 2002 are used whenever possible. Funds are generally denominated in current U.S. dollars unless otherwise stated.

Infrastructure Supporting S&T Systems

The S&T system[4] has various functions that help produce and use knowledge. Figure 1 provides a schema within which to consider different parts of the system. Research and development at the center of the circles in Figure 1 is the most intensive and easily identifiable part of the S&T system. This is also the part of the system whose activities are likely to be reported in statistical reviews of national investment. R&D is embedded in a larger scientific, technological, and engineering system (STE) that contains knowledge developed over decades, as well as representing the applied knowledge within industry, medicine, and agriculture.

Figure 1
Components of a Science & Technology system



The outer ring of Figure 1 has a dotted line for the Related Science and Technology Activities (RSTA). RSTA infrastructure is defined for the purpose of this paper as the physical plant (e.g., laboratories) and services in information, training, and measurement that contribute to the maintenance of an S&T system. (A basic physical and industrial infrastructure is assumed.) The specific infrastructure features explored in this paper are:

- S&T laboratories
- Standards, testing, and metrology services
- Extension services, technology transfers and information collection
- *Intellectual property protection*
- Vocational education and training
- Regulatory and compliance services.

Integrating RSTA as part of an S&T System

The major reports on metrics on science, technology, and engineering rarely contain data on RSTA. [5] In their initial efforts to define metrics for S&T in the 1950s, the experts consulting on the OECD's seminal Frascati Manual stated their intention to focus on "high end" research and development.[6] The 1970 edition of the Frascati Manual notes that the report did not include "related scientific activities" (RSA); we are calling these related scientific and technological activities in this report (RSTA). Ironically, these activities are the ones of principal interest to this paper. In its early reports, the National Science Board of the National Science Foundation (US) also chose a definition for research and development that excluded infrastructure and other RSTA. In a 1958 report "Federal Funds for Science," the NSB estimated that RSA amounted to about 7.8 percent of all scientific activities.[7] By the late 1970s, the NSB had dropped reporting of RSA data on anything but information and communications activities.[8] In a more recent report,[9] the NSB estimated that public spending on scientific and technological infrastructure was 20 percent of R&D spending. (We will return to this measure when we attempt to make an assessment of RSTA spending.)

In the late 1970s, as the NSB reduced reporting of RSTA, UNESCO took up the challenge in an assessment of S&T. In a paper written for UNESCO, a justification for examining RSTA is offered, one similar to the motivation for undertaking the inquiries in this paper. Specifically, the paper notes:

> "The priority given to R&D in data collection is only a matter of expediency, and does not mean that the importance of an integrated approach to R&D seen within a full context of education and other services is underestimated. One may even argue that it is only in close conjunction with these services that R&D can be meaningfully measured – because they are indispensable for research efficiency… and should precede rather than follow the emergence of R&D in a country."[10]

The linear view of development—one that begins with infrastructure and then moves to R&D—cannot be supported by a review of the history of science. It has been replaced by a systems approach, one that sees RSTA as co-evolving with scientific capacity and the role of institutions. Still, UNESCO emphasizes the importance of "related science and technological activities" (RSTA) — a critical step in S&T metrics, as these features are indeed essential to the functioning of an S&T system. UNESCO published two reports that included information about RSTA, but they did not include actual measures. UNESCO did not have the resources to continue these efforts beyond the early 1980s.[11] This report makes a similar attempt to close the gap and reintegrate RSTAs and S&T.

Since only a handful of metrics are offered, the analysis might be construed as suggesting that a single model of RSTA investment exists within the S&T-advanced countries. In fact, the different countries have quite different RSTA structures. Public, private, and academic sectors take different roles within the various systems. This diversity of approaches leads to the question of whether one or another national RSTA system possesses some optimal structure or competitive advantage over another. However, the diversity of approaches suggests another explanation: that initial conditions for the growth of institutions varied widely. As they evolved, the systems took on different characteristics. The path dependency of the system resulted in multiple outcomes, each of which works within its own environment, even as some pressures exist to harmonize at the international level.

Among the differences we found is that support for S&T infrastructure is sometimes offered directly—provided with the explicit goal of supporting S&T—and sometimes indirectly—provided to meet other goals, but with the effect of supporting S&T. While it is difficult to decouple the two functions, to the extent they can be identified, this paper focuses on the activities that are directly related to supporting S&T. This is done because these facilities are often provided by the public sector. Indirect activities will be discussed, but in less detail. Table 1 presents a list of the various infrastructure and support mechanisms that serve S&T. Each support item is placed in a box indicating the sector (public or private) that generally provides these services or supports. An indication of whether the activity is a capital investment or a service is also included.

Table 1

Types of RSTA Investment and Principal Investor

		Type of RSTA Investment	
		Direct	Indirect
Principle Investor	Public or NGO Sector	***Capitalisation of laboratories*** ***Technology extension ctrs*** **Training & education** **Metrology services** **Drug certification** **Information dissemination** **Patent licensing**	Tax breaks for R&D Tax breaks for capital investment Competition policy Intellectual property protection Standards-setting support Trade relations Regulation
	Private Sector	***Capitalisation of laboratories*** ***Testing & quality assurance*** **Funding academic R&D** **Training** **Standards-setting**	Training programmes Grants to academe Other philanthropy Shared investment in physical infrastructure

Italics=physical plant
Bold=services

Direct, Public Sector Investment in S&T Infrastructure

Public investments into specific S&T capability often require different approaches based upon the nature of the investment being made. Capital investments, infrastructure, services, direct and indirect costs are different types of investments that require different decision-making tools. This section will delineate the metrics associated with investments in research and development, in infrastructure (such as laboratories), in services (such as metrology), and in training. Each of these S&T features present different challenges in terms of public commitment and metrics. These metrics are summarized and presented in Table 2.

Table 2

Summary of S&T Infrastructure Metrics

Infrastructural Component or Function	***Sub-component***	**Metric range in S&T-advanced countries**
S&T laboratories		2 - 9 S&T institutions per 100,000 inhabitants
	S&T laboratory equipment	R&D funds require an additional 20 percent spent on equipment
	S&T laboratory space	Between 25 and 180 sq meters is allocated per research staff member
	Public spending on research	R&D spending of ~$60 million (GERD) per 100,000 population
	Government share of academic research	Government funds 60-70 percent of university-based research
	Government share of business research	Government funds more than 6 percent of business-based research
	Industrial contribution to academic research	Industry funds ~6 percent of academic research
Standards, testing, and metrology services		Governments spend $150,000 per 100,000 inhabitants on standards, testing, and metrology
Extension services, technology transfers and information collection		Governments contribute close to $200,000 per 100,000 inhabitants on manufacturing extension services
Metrics for the following infrastructural components were not estimable with available data		
Intellectual property protection	Government provides legal framework; public sector grants and litigates IP rights; patent offices often self-funded	*Companies in many countries tend to patent in the US, Europe, and/or Japan to gain broad market protection*
Vocational education and training	Government (national, regional, local), private sector provide training opportunity; spending ranges considerably; difficult to estimate	*Governments are generally highly committed to vocational and technical training*
Regulatory and compliance services	Governments (national, regional, local) create regulations and offer compliance services; businesses also provide compliance services; spending difficult to estimate	*Different countries have quite a different mix of regulations and services; the responsible party (public or private) also differs considerably among countries*

Scientific and Technical Institutions

Scientific and engineering institutions are the backbone of capability among the S&T-advanced countries. Among the infrastructural functions studied, this one had the most data available. Institutions that conduct and teach science, engineering, and technology are considered one of the most important features of S&T capacity among advanced countries. In the 16 countries that demonstrate an advanced position in the Science and Technology Index for 2002, data from the World Bank show that these countries have, on average, approximately 2.4 scientific or technical institutions per 100,000 inhabitants[12]. The figure represents a wide range among these countries, from only 0.174 institutions per 100,000 inhabitants in Japan, to 9.175 in Canada, which averages to 2.4 scientific or technical institutions per 100,000 inhabitants. The size of the institution is not accounted for, however, so the Canadian number may represent a large number of small institutions. (An interesting metric that is not reported is how these institutions are spread across a country's geographic space.) In addition, the functional role of institutions may vary considerably from one country to another because of the country's social and economic structure.

Within the S&T-advanced countries, the share of public funding for research and development at relevant institutions varies widely. Overall, on average, the S&T-advanced countries committed an average of US$ 59 million to GERD per 100,000 inhabitants.[13] GERD as a percentage of GDP among these countries was an average of 2.37 in 2000.

In general, the funds dedicated by governments to research are spent in three sectors: 1) government laboratories; 2) industrial laboratories; and 3) academic laboratories. In general, the funds provided for R&D by governments are designed to pay for salaries and operating costs. As a result, most of the R&D funds do not contribute to RSTA. There is an exception to this, and that is the amount of R&D funds that are allowed to contribute to "overhead," which can be used in to maintain capital equipment and buildings. This figure is often negotiated between donors and research institutions at the time a grant or contract is let.

As part of R&D spending, governments commit funds to university research through contracts and grants, averaging about 70 percent of the funding of university-based research across the S&T-advanced countries. These funds are provided in addition to direct funding to higher education that may be part of government's contribution. Among the S&T-advanced countries, the percentage of higher education R&D funds that is contributed by government is very high indeed. In 2000, government share of higher education R&D funds among the S&T-advanced countries averaged 78 percent. The average cost of maintaining a researcher for one year within the S&T-advanced countries is difficult to estimate because of the varying costs of living across these countries as well as the differences of costs among the fields of science themselves. Within the United States, this number has been estimated at between US$ 180,000 and US$ 250,000 a year per researcher.

Governments also contribute to industrial research within the S&T-advanced countries, although at a much lower percentage than with university research. On average among the S&T-advanced countries, in 2000, government contributed about 7 percent to business R&D activities. (This is generally provided for the conduct of research, not to provide infrastructure, although, as noted above, some percentage may be spent on overhead, which often includes maintenance of physical plant and equipment.) Industrial research is largely self-funded.

Within the S&T-advanced countries, industry contributes significant amounts of its own funds to research, development, testing, and standardization. Industry spending on R&D among the S&T-advanced countries was, on average, about US$ 100 million in 2000, of which an average of 84 percent was self-funded according to the OECD. In addition, industry invests heavily in RSTA for its own uses and purposes, although the extent of the investment is very difficult to calculate with accuracy. Industry also funds both R&D and RSTA at universities. In 2000, among the S&T-advanced countries, industry funded 5.5 percent of higher education R&D.

Governments provide funds to purchase scientific and technical equipment. Within the United States' research system, it is estimated by the National Science Foundation that government provided 58 percent of the expenditures on academic research instrumentation in 2000.[14] When awarding research grants, the National Science Foundation allows an allocation of 5 percent of the funds to be spent on equipment. Recent studies (including one by NSF) estimate that equipment expenditures are a considerably higher share of research costs than is reflected in the 5 percent allocation. A RAND study estimated that facilities and administration for research is about 31 percent of the total grant. Even if we assume that the cost of equipment falls between 5 and 30 percent, this still suggests that the conduct of R&D needs an allocation of about 20 percent of funds over and above the R&D funding to be dedicated to infrastructure. (Indeed, the National Science Foundation devotes 22 percent of its overall budget to infrastructure.[15])

Governments also provide capital funds for the building of research laboratories. The federal government can be expected to fund 100 percent of the costs of its own research laboratories. In addition, governments provide funds to universities to build laboratory space. In 2000, the United States federal government contributed 9 percent of the total construction costs of academic research laboratories.

Another way to assess the construction needs of research and development laboratory space is to find the number of assignable square meters within the S&T-advanced countries. According to the National Science Foundation, the net assignable square feet of research space in the United States was 155 million square feet (14.4 million square meters). In a study of major research universities in the United States, a private consulting group[16] found that, on average, academic researchers were allocated an average of 2,019 square feet (187.6 square meters) for Principal Investigators and 273 square feet (25.4 square meters) for project researchers.[17] This puts the average for research space in the S&T-advanced countries at between 25 and 180 square meters per research staff member.

Standards, Testing, and Metrology

Standards, testing, and metrology are extremely important to the economies of advanced industrialized economies. The scope and extent of these activities is vast, and the benefits that accrue to economies are wide-ranging. Successful industries are able to assure clients that their products meet standards for quality, interoperability, or functionality. Standards, testing, and metrology are becoming more important as world trade becomes increasingly interdependent.

This paper is too short to cover all the areas of standardization that are important to S&T: other literature has made these connections both clear and imperative.[18] Nevertheless, we can draw some lessons from the extent of the investment in these capabilities among the S&T-advanced nations. The worlds of standards-setting, testing, and assurance are complex: organizations that set standards and those that conduct testing are often in the private or quasi-public sector. Some governments become directly involved in standards-setting for both the private and government sectors; some governments stay out of private-sector standards-setting, getting involved only in determining their own specifications. In many cases, governments accept private standards into the public regime. In some cases, standards are set *de facto*: in the marketplace. In other cases, standards are set *de jure*: by a decision-making group.

In all S&T-advanced countries, at least one institution is given responsibility for legal metrology, which is the regulation of weights and measures. In addition to these national institutes of measurement, groups of individuals representing both public and private bodies organize to set standards. These are called standards-setting groups, and they are often international in character. Industry representatives are often active participants in these groups.

Accreditation institutions are also important features of the economies in S&T-advanced countries, offering third-party quality assurance guarantees for tradable goods. These groups ensure a degree of accuracy, trace-ability, and service for a fee. The services offered include calibration, testing, certification, and inspection and verification. These groups are often privately established and operated, although a number of international bodies exist to help ensure the consistency of accreditation procedures.[19]

The European Union (15) spends more than €83 billion per year, or nearly 1 percent of EU GDP, on measurement and standardization, according to an EU study.[20] Adding in social spending on health, environmental regulations, safety testing, and anti-fraud projects raises this figure considerably: EU countries spend more than Euro 13 billion on measurement in health services, for example, and Euro 5 billion on safety and emissions testing. The EU study estimates that the standards, testing, and metrology activities within the EU generates €230 billion of directly estimable benefits through application and from the impact that measurement has on technology growth. The benefit is estimated at an equivalent of 2.7 percent of EU (15) GDP.[21] They further estimate that every euro spent on measurement activity generates €3 of direct benefit.

Standards and measurement services often require industry to pay a fee. Within the EU, for example, the internal cost of measurement to industry was estimated at €3.4 million in 2000.[22] Industry bears a great deal of the costs and fees of standardization and metrology in the S&T-advanced countries. Governments generally provide what Tassey called "infratechnologies,"[23] and industry works on specific products that require standardization and measurement. Within the EU (15), the total funding for National Measurement Institutes (NMIs) was €552 million in 2002, according to an EU study.[24] Of this, government contributed 64 percent of the total or €353.

The U.S. government, through the National Institute of Standards and Technology (NIST), (an agency of the Department of Commerce) has an operating budget of about US$ 848 million for fiscal year 2005. NIST appropriations provide US$ 373.4 million for measurement and standards research in the NIST Laboratories as well as other smaller programmes. NIST appropriations in 2003 included US$ 73 million for renovation and repair of facilities. (These funds are not counted as R&D within the U.S. federal budget.) In addition, NIST receives about US$ 45 million in fees for reimbursable services such as calibrations, measurement standards, and laboratory accreditation. Other federal agencies support an estimated US$ 118 million of research in the NIST Laboratories.

According to the OECD, the 2002 budget of the Japanese Industrial Standards Center for safety, metrology, and standards was approximately US$ 110.3 million. Together with the figures from the EU and the U.S., added to spending by Japan and divided by population puts average government spending on standards, testing, and metrology at about US$ 150,000 per 100,000 inhabitants.

Extension Services, Technology Transfer, and Information Collection

Many of the S&T-advanced countries offer extension and technology transfer services to aid industry with research, development, testing, and evaluation. Governments contribute close to US$ 200,000 per 100,000 inhabitants on manufacturing extension services. These activities can take the form of science shops, such as those funded by the government of the Netherlands, to provide knowledge transfer from universities to industry. The government of Japan provides support through Kohsetsushi engineering centers throughout the country to aid industry with technology and engineering adaptation. Many countries have provided support to the creation of a science and technology park—offering low-cost land, building loans and tax breaks to companies that establish growth-based businesses within these centers. Other services offered can be incubator centers that provide support to small technology-based start-ups, such as the St. Petersburg Science & Technology Center in Russia.

One type of aid to industry is manufacturing extension services, which are offered in many S&T-advanced countries. The Japanese Kohsetsushi engineering centers received approximately US$ 500 million (US$ 400,000 per 100,000 inhabitants) in cumulative funding during FY 1988.[25] In the United States, manufacturing extension services receive approximately US$ 230 million per year (US$ 78,000 per 100,000 inhabitants) from federal and state funding.[26] In Germany, technology transfer centers had a budget of approximately US$ 95 million (US$ 116,000 per 100,000 inhabitants) in 1995.[27]

These programs are begun by governments at the federal or regional (state or province) level to encourage economic development and value-based business growth. Often, some cost-sharing in the form of user fees is required of those taking advantage of the services. These programs are established to promote business networks, strategic alliances, and joint ventures to improve competitiveness. (Youtie and Shapira 2000)

Governments also collecting and make available technical information for the private sector about the capabilities of foreign research centers. These types of services range widely in size and in the depth of information made available, but they constitute a type of intelligence gathering that can be very valuable to users at a very low unit cost. Perhaps the most highly developed of these services is offered by the Japan Science and Technology Agency (a government-funded agency), that collects and analyses technical information from around the world. (http://www.jst.go.jp/EN/) These agencies often collect user fees from industry, so total government funding is difficult to estimate.

Note: The next three sections report on government activity to support S&T infrastructure, but data were not available to allow an estimate of measurement similar to that offered in the earlier sections.

Intellectual Property Rights Protection

The ability of government to provide Intellectual Property Right (IPR) protection plays an important role in the development of S&T. Patents are designed to encourage invention by preventing others from making, using, selling, or importing your invention or an identical one for a period of years, normally twenty years in most countries. Although there are several different types of property rights over intangible assets such as trademarks, copyrights, design, and patents, the latter is by far the most important for stimulating innovation. Unless inventors can be assured that they will obtain exclusive rights over an invention for a limited period of time (generally 20 years from filing) during which they can recover innovation costs, they are unlikely to risk major investment in R&D.[28]

Patents are only valid in the country in which they are granted and are subject to national laws. However, the most valuable inventions are generally filed with the European Patent Office (EPO), the US Patent and Trademark Office (USPTO), and the Japanese Patent Office (JPO). These are the three major offices and an invention that has been patented in all three (called a "triadic" patent) has wide protection.

In order to improve international comparability of patent-based indicators and to identify valuable patents, the OECD has developed a set of indicators based on "triadic" patent families. A triadic patent family is defined as a set of patents taken at the EPO, JPO and the USPTO that shares one or more priorities[29]. According to the OECD, in 2000 there were approximately 44,000 patent families of which 34.3 percent originated in the US, 31.4 percent in the EU, and 26.9 percent in Japan.[30] There is a strong positive correlation between the level of industry-financed R&D expenditure and the number of triadic patent families.[31] In 2000, France, Germany, Japan, the United Kingdom, and the United States accounted for 83 percent of the triadic patent families. The number of triadic patents originating in large, non-OECD countries such as China, India, and Brazil increased rapidly during the 1990s, although their share of the total number of triadic patent families is still very small (less than 0.1 percent each).[32]

Between 1992 and 2002, the number of patent applications filed with the EPO, USPTO and JPO increased by more than 40 percent.[33] This corresponds to a 15 percent increase at the JPO and a doubling of the number of applications at EPO and USPTO. Although nearly every technology field experienced patent growth during the 1990s, two particular fields showed disproportionate growth: biotechnology and Information and Communications Technology (ICT).[34] Between 1991 and 2000, all EPO patent applications increased by 6.9 percent, while biotechnology and ICT patent applications increased by 10.9 percent and 9.5 percent respectively.[35] The fact that the greatest increase in patenting occurred in new technology areas suggests that patent numbers reflect trends in innovation.

There appear to be few available indicators regarding the cost of patent protection. Although government must initially make a large investment in the creation of a legal and organizational IPR framework, the goal is for patent offices to be eventually self-sustaining. The US Patent and Trademark Office receives no money from the U.S. Treasury: it is funded entirely through user fees.[36] Moreover, various national approaches to IPR complicate efforts to develop consistent metrics. Patent offices are often funded through filing and maintenance fees. Over the lifetime of a typical patent, they can total about US$ 8,000. Although fees paid by small entities and individuals are lower, they are still significant, averaging approximately US$ 4,000.

Although IPR protections are intended to spur innovation and have been very successful in the advanced, industrialized countries, the effects of IPR on developing countries incur controversy. Because developing countries are rarely on the leading edge of technological innovation, IPR raises the cost of technology access and restricts their ability to adopt and learn through processes such as reverse engineering.[37] In the short term, it should be acknowledged that countries with very low levels of development are unlikely to benefit from strong IPR protection. If the weakness of the intellectual property protection framework simply reflects the fragility of the overall technology system, government should primarily focus on reaching higher levels of technological development while strengthening IPR over time as resources permit. However, there are several reasons that even developing countries should implement strong IPR when possible. First, the Trade Related Intellectual Property (TRIPs) Agreement within the context of the World Trade Organisation (WTO) requires that all signatories reform their IPR regimes. Second, investors are seeking destinations at a global level: an effective IPR regime may attract larger flows of investment by trans-national companies.[38]

Vocational and Technical Training

Most of the S&T-advanced countries have agencies and technical institutions offering a range of vocational and technical training. These education opportunities are often offered at the post-secondary school level to students who are not interested in or able to obtain a university education. However, vocational training and technical education offered can range widely, as evidenced by the extent of services offered in France:

- Technical classes offered within the basic public education system
- Vocational training of young people from age 15
- Continuing training of adults
    - Private-sector employees
    - Civil servants
    - The self-employed
    - Jobseekers
- Services for teachers and trainers of vocational training
- The funding of continuing vocational training
    - Central government
    - Enterprises

- Training, skills audit and information providers
    - Public and quasi-public training agencies
    - Private agencies
    - Skills audit agencies[39]

France emphasizes school-based learning and technical institutes that combine academic subjects with technology instruction and hands-on training. France's neighbour and chief industrial partner, Germany, is renowned for its rigorous commitment to training via a "dual system" of education and apprenticeships that yield nationally recognized qualifications. In the UK, where the majority of students leave school at or around the age of 16, the emphasis is on prolonging education and providing apprenticeship training funded by local and national government with private-sector support.[40]

These services are offered by national agencies, by regional and local governments, and by the private sector. The services offered in S&T-related subjects range so widely and are offered by so many different groups, that it is difficult to estimate how much is being spent on these services in the S&T-advanced countries. In 2005, the United States federal government allocated US$ 1.3 billion to national and state vocational and technical training programmes. Then, according to the National Governors' Association, in 1999, overall state-level spending for jobs training totalled US$ 600 million. In addition to public spending, private sector companies also provide technical and vocational training to help build the workforce.

Experience that is perhaps closer to the needs of the developing countries is provided by Singapore's dedication to vocational and technical education and other human resources development. In the 1990s the Government concentrated on post-secondary and tertiary education to develop the skills needed for high technology and knowledge intensive products and services. The Government's plan for post-secondary education was that the proportion of each cohort proceeding to post-secondary education and training institutions should be 25 percent for technical institutes of the Institute of Technical Education, 40 percent to the polytechnics, and 25 percent to pre-university junior colleges.[41]

In 1992 the Institute of Technical Education was established to take over the functions of the Vocational and Industrial Training Board and to provide technician training for secondary school leavers with "O" and "N" level qualifications. Its three existing institutes were upgraded and seven new institutes were built. With 10 institutes, the Institute of Technical Education was able to enroll about 10,000 to 11,000 secondary school leavers, or about 25 percent of each cohort. The Institute of Technical Education upgraded its courses to make it more appropriate for secondary school students. Total budgets for these activities were not available for this report.

Regulatory Agencies and Compliance Services

The ability of a government to certify the safety of certain products supports the system by intervening between the outputs and uses of science and technology. As such, regulatory agencies and compliance services do not directly support S&T; rather, they help to assure the users that the outputs of S&T are safe. Thus they would fall under RSTA services of standards and quality assurance in Table 1.

Regulations governing the outputs of certain S&T-based industries, such as food and health, are generally determined by public agencies within S&T-advanced countries. (There are also cases where the private sector actively participates in establishing regulations by conducting clinical trials or other safety testing.) Regulatory agencies generally seek to govern privately-provided goods and services with a strong public-goods component: these include food and food service equipment; medicines, drugs, and medical equipment; materials worthiness. Regulatory agencies also implement standards of clean air and water that are often determined through some public discourse function.

Compliance agencies provide assurance that public standards and regulatory requirements are met by privately-produced products. They also help to certify products for the purposes of international trade by assuring that products being imported or exported meet the standards required in the foreign market. Depending upon the country and the sector involved, compliance services can be provided by either a public or a private sector institution.

The types of regulatory and compliance services, and the sector providing the service, differ considerably among the S&T-advanced countries. In some countries, regulations are set at the national level, and public compliance agencies provide testing and assurance services. In other countries, standards are set and compliance assured at the local level. (Building safety and materials worthiness standards, for example, are very often set at the local level.) In some cases, private-sector companies provide compliance testing and assurance for both national and tradable goods. Because of the very different regulatory and compliance structures, this paper explores only one case study as within RSTA: food safety, testing, and compliance.

Case Study: Food Safety, Testing, and Security

Food safety, testing, and security are functions of government that have science and technology components. Following a series of food scares in the 1990s (e.g. BSE, dioxins) which undermined consumer confidence, food safety, testing, and security became a higher priority for governments in S&T-advanced countries. The breadth of public activities makes it difficult to assess the extent of or spending on these activities.

Within the European Union, in addition to agencies and regulations at the level of the member states, a new European-level scientific body was charged with providing independent and objective advice on food safety issues associated with the food chain. The agency is the European Food Safety Authority (EFSA). Its primary objective as set out in the White Paper on Food Safety is to: "...contribute to a high level of consumer health protection in the area of food safety, through which consumer confidence can be restored and maintained."

Set up provisionally in Brussels in 2002, EFSA provides independent scientific advice on all matters linked to food and feed safety - including animal health and welfare and plant protection — and provides scientific advice on nutrition in relation to Community legislation. EFSA's risk assessments provide risk managers (consisting of EU institutions with political accountability, i.e. European Commission, European Parliament and Council) with a scientific basis for defining policy-driven legislative or regulatory measures required to ensure a high level of consumer protection with regards to food safety. The EFSA had a budget of US$ 10 million (€8.3 million) in 2003, half of what was requested for full operations.

In addition to EFSA activities, each of the EU member states has its own food testing and safety agency. The agencies responsible for food safety within the European Member States range widely across possible applications. Table 3 below shows a sample of European States' agencies and responsibilities related to food safety and assurance.

Table 3

European Agencies Responsible for Food Safety

Belgium **L'Agence fédérale pour la Sécurité de la Chaîne alimentaire (AFSCA)** since 2000	Regroups control activities, Scientific advice (but limited) and communication to general public ; no management of legislation
Italy **Instituto Superiore de la Sanita.**	Independent body advises Ministry of Health. Risk assessment and risk communication, scientific research. Plans for a broader agency in the past but not so far under this government.
France **Agence française de sécurité sanitaire des aliments (AFSSA)** formed in 1999	Primarily risk assessment and communication. Accountable to Ministries of Agriculture, and Consumer Affairs and Health.
United Kingdom **Food Standards Agency** since1999	Answerable to a Management Board. Risk assessment, control (policy and actual enforcement), Rapid Alert System, risk communication and management. Codex Alimentarius and other international work. Reports ultimately to Minister of Health.
Ireland **The Food Safety Authority of Ireland** formed in 1999	A science-based consumer protection agency accountable to the Minister of Health. Involved in risk assessment, risk communication and risk management. Co-ordinates enforcement of food legislation via service contracts, for a standard and level of food safety activity with the range of agencies and government departments that are responsible for supervising different segments of the food chain and which together make up the National Inspectorate.
Spain **Agencia de Seguridad Alimentaria (AESA).** Agency Established by law 11/2001 of July 2001	Responsibilities: promote co-ordination of food safety administrations, coordination in crises, planning and co-ordination of the control activities, central point of reference for the assessment of food risks. Will be the contact point of the EFSA.
Portugal AQSA, is the newly formed (2003) **Portuguese Agency for Quality and Food Safety,**	Responsible for risk assessment and risk communication.
Lux Ministère de la Santé, Lab National de Santé.	Risk management, control, risk assessment, surveillance research.

Germany **New Federal Agency: BVL** (Bundesamt für Verbraucherschutz und Lebensmittelsicherheit)	Coordination and risk management only; the EFSA interlocutor.
Netherlands Since 1st January 2004, the **Food and Consumer Product Safety Authority (VWA)**	Formally under the Ministry for Agriculture, Nature and Food Quality, but the VWA still fulfills an important advisory task for the Ministry of Health, Welfare and Sport. The main tasks of the VWA are risk assessment scientific research and risk communication activities.
Denmark **Danish Veterinary and Food Administration** formed 1997. Part of MFAF.	Responsible for regulations, co-ordination, research and development controls and risk communication.

Within North America, a range of public and private agencies at a number of levels (local, state, and federal) handle food security and assurance. The Canadian Food Inspection Agency, which coordinates food safety in Canada, had a 2003 budget of US$ 316 [million?] (Canadian, US$ 257 [million?]) for food safety. Within the U.S. federal government, four regulatory organizations have primary responsibility for national food and water safety and security, not including trade-related efforts. These are: the Department of Health and Human Services' (DHHS) Food and Drug Administration (FDA), the U.S. Department of Agriculture's (USDA) Food Safety and Inspection Service (FSIS) and Animal and Plant Health Inspection Service (APHIS), and the Environmental Protection Agency (EPA).

These four agencies comprise a comprehensive system of domestic food safety assurance, each playing a different role. The mission of the FDA is to protect consumers against impure, unsafe, and fraudulently labeled food in those areas that are not regulated by FSIS. FSIS is responsible for ensuring that meat, poultry, and egg products are safe for consumption and accurately labeled. The goal of APHIS is to protect U.S. agricultural health against plant and animal pests and disease. The EPA is charged with protecting public health by reducing the risks from pesticide residues in food and eliminating the use of pesticides on food that do not meet standards. No food or animal feed item may be legally sold in the U.S. if it contains a food additive or drug residue not permitted by FDA or a pesticide residue that does not comply with EPA standards. FDA, FSIS, APHIS, and EPA also use existing food safety and environmental laws to regulate plants, animals, and foods that are the results of biotechnology. The approximate budget of each organization for improving food safety in FY 2003 is shown in Table 4.

Table 4

Budgets of U.S. Federal Government Agencies Responsible for Food Safety

	US Dollars (millions)
FDA[42]	41
FSIS[43]	905
APHIS[44]	1,083
EPA[45]	110
Total	2,139

In addition to the four primary organizations, many other U.S. agencies contribute to the goal of improving food safety through their research, education, prevention, standard-setting, and/or outbreak response activities.[46]

Japan also recently implemented greater food safety action at the federal level. In 2002, the Council of Cabinet Ministers Concerning Food Safety Policy was established. In July 2003, the Food Safety Committee was established in the Cabinet Office to implement risk assessment and comprehensive risk communication. Further, the Ministry of Agriculture, Forestry and Fisheries (MAFF) and the Ministry of Health, Labor and Welfare (MHLW) promote information/opinion exchange (risk communication) between relevant parties as well as risk management under each jurisdiction.

The Food Safety Commission is an independent body made up of seven commissioners, four full-time and three part-time, who have been selected for their expertise in fields such as toxicology, microbiology, organic chemistry, and sanitary science, which will serve as the basis for evaluating the effect of foods on health and deciding what action should be taken in the event of a crisis. (There were calls for consumers to be represented on the Commission, but the idea was turned down on the grounds that "the Commission is not a forum for settling conflicts of interest between sectors.") Producers and consumers will be represented on the specialist research committees reporting to the Commission on various issues. Ensuring transparency is important to the Commission's operations. Total budget requirements of the Commission were not available at the time of this report.

RSTA within a Larger S&T and Innovation System

The ability of a nation to participate in the global knowledge economy[47] depends to some extent on its capabilities in science and technology.[48] Economists increasingly find a relationship between economic performance and the useful knowledge created by S&T.[49] Spending on research and development (R&D) is positively correlated to economic growth in the advanced industrialized countries.[50] Moreover, it is clear that a number of capabilities, such as health care, agricultural production, national security, and environmental sustainability depend upon knowledge derived from S&T and related activities in research, development, and engineering.

Science and technology have features suggesting they are transferable across cultures and over time.[51] Acquired knowledge is often published; practitioners can recreate experimentation in another time and place, hoping for the same results. Knowledge can be passed through time (as in the contemporary use of the work of Newton or Einstein) and through space (scientists in India can understand and recreate experiments created in Europe). Yet, as economic historian Joel Mokyr has pointed out, differences in knowledge creation alone cannot explain the gaps in income between countries.[52] Some countries excel at knowledge creation, while others excel at knowledge exploitation. Efforts to transfer knowledge from advanced to developing countries have a poor record. The fact that S&T has not fulfilled expectations of being transferable from richer to poorer countries suggests that infrastructure and cultural factors[53] play a larger role than has been assumed in the past. Just as the biological argument of nature versus nurture swings between one and the other, the analytic pendulum swings between attributing growth to knowledge accumulation on one hand,[54] and physical investment and culture on the other.[55]

The Co-evolution of RSTA and S&T

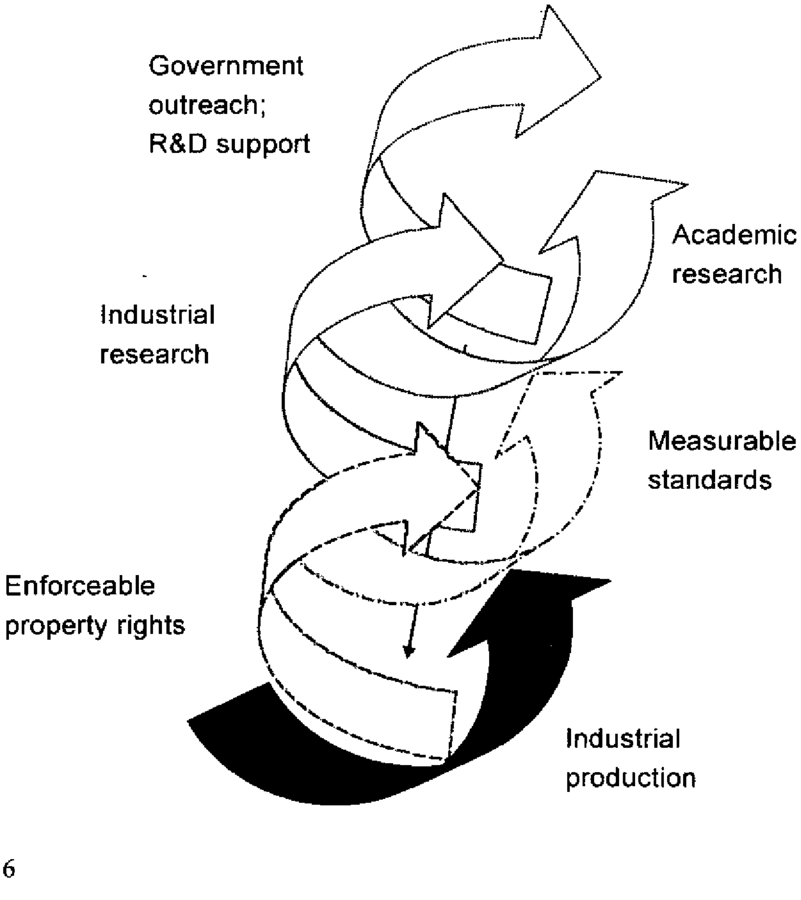
The development of the advanced industrialized economies suggests that S&T emerges as a specialized knowledge system once an economy reaches a certain threshold of industrial capability.[56] The knowledge derived from S&T is embedded in people, institutions and infrastructure. The knowledge creates a virtuous cycle of growth, experience, codification, and retention of learning over time. Freeman suggests that the divergence in economic growth among nations over the past two centuries can be attributed to social capability for institution-building and institutional change.[57]

The combination of knowledge, institutions, and economic growth has been referred to as a "national system of innovation."[58] While it is arguable that the system is bound [?] at the nation, a number of *interlocking* systems exist at the sub-national and international levels. It has been convincingly argued that, at least within the past four decades, national institutional systems enable and constrain the innovations created within the business sector.[59] In this line of argument, innovation influences the conduct, scale and scope of governing institutions. As these institutions adapt to market conditions, they in turn influence the system of innovation. In evolutionary terms adopted by economists, institutions form part of the "selection environment" within which innovation occurs, and it in turn influences that environment, in a co-evolutionary pattern.

Taking an historical perspective, an S&T base often begins with the development of a process to standardize a system of weights and measures, enabling greater precision in the use of chemical processing and later in automation.[60] Following this, industries invest in S&T to solve problems that arise within the manufacturing process. Investment in academic and government research follows with public investments in those areas that show under-investment in the private sector. Governments often establish outreach and adjudication functions within the emerging system to transfer knowledge within and across sectors. These activities did not happen in a lock-step or linear process, but successive steps grew from and fed back into the earlier institutions and functions.

Figure 2

The Emergence of an S&T-based Knowledge System



As RSTA evolves, feedback loops develop to provide information from one sector to another. Institutions change and grow as information flows within the innovation system. The feedback among sectors, and the resulting changes in the institutions, is part of the function of emergence and co-evolution of S&T. This emergence has been called the "triple helix" or "Sabato's triangle" of change among knowledge-creating institutions in industry, academe, and government.[61] The best ways to encourage this type of emergent behaviour in economies is to create the incentives for people to form supporting institutions, and remove constraints on the scale and scope of organization.

Lessons Learned and Areas for Further Research

This paper suggests that six functions offer direct infrastructural support to a science and technology system. The functions that have been explored are: scientific and technical institutions (public and academic); agencies dedicated to standards, testing, and metrology; extension services, technology transfer, and information collection; intellectual property protection agencies; vocational training; and regulatory agencies and compliance services. To the extent possible, this report has suggested metrics for these functions.

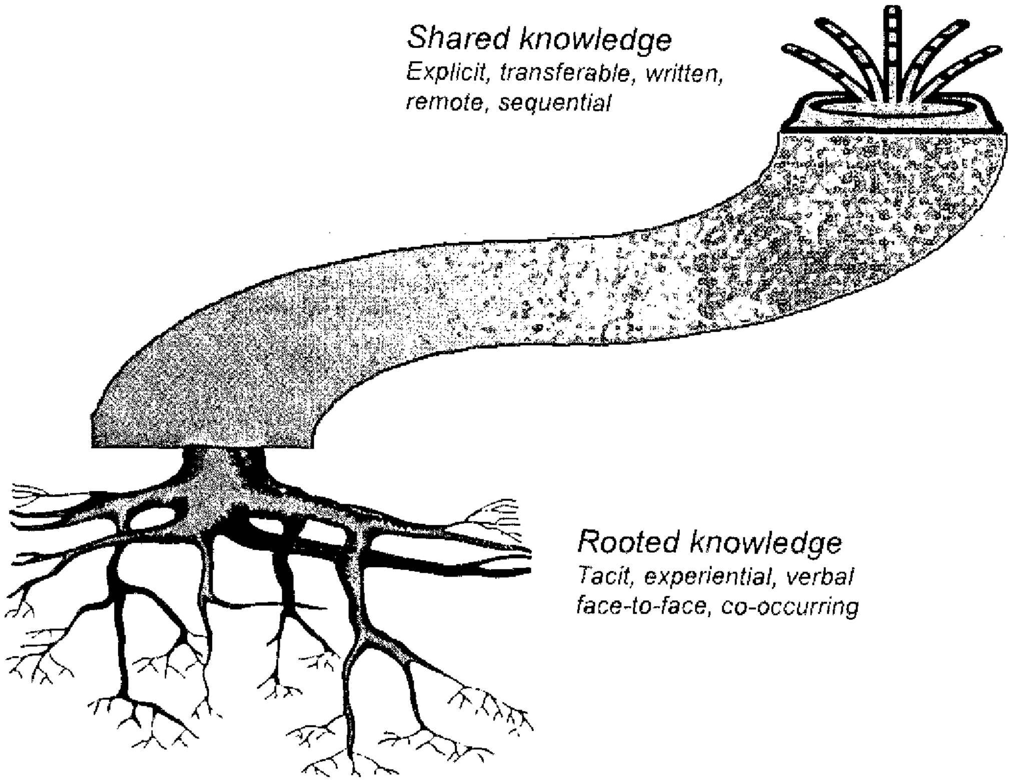
The RSTA metrics have been presented in a way that enables a discussion outside the boundaries of a national system. This is done for several reasons. One is that nations vary widely in size, and the institutional functions of RSTAs can serve as a barrier to very small countries as they try to develop an S&T system. In some cases, teaming up to provide or create RSTAs would make sense. The second reason is more profound and also more confounding: the challenge in a globalizing world is to find the conditions for the evolution of supporting institutions that can adapt, through changes and assimilations occurring at a number of levels (local, national, regional and global). Such a system is not yet defined for developing countries; whatever system emerges may look quite different from those created for 20th century, nationally-based industries. Offering metrics based upon the system that emerged within the S&T-advanced countries in the 20th century may not be the right model.

Rethinking RSTA

As they become more important potent sources of knowledge, science and technology are viewed as increasingly important elements of an economy. However, it is unclear how the S&T system will be supported in the future, since the national models of the past will almost surely not operate in the future. It is clear, however, that the investment would be more efficiently made based upon scale, scope, and location of expertise than on national borders. The second thing that is clear is that the RSTA functions discussed in this paper will likely remain the same. Since they involve the scale of research, how it is shared and protected, how it is codified and disseminated, and how it is regulated, these features can be expected to remain part of the system.

The central question is this: at what level should S&T infrastructure be provided? Each of the RSTA functions has features that suggest a framework for the level of infrastructure. The framework for making decisions about the location of RSTA should be guided by the extent to which the knowledge involved is tacit or rooted in experience (what Eric von Hippel (1994) calls "sticky" knowledge) or easily shared, transferable knowledge (what von Hippel calls "slippery" knowledge) Figure 3 presents a schematic drawing of types of knowledge supported by RSTA.

Figure 3
Aspects of Knowledge within the Technical System



Research has immobilities associated with it: Laboratories, equipment, markets, and other factors cannot be easily moved. This type of "rooted" research can also require working side-by-side with others to understand the processes. Rooted or highly tacit RSTAs can include activities in:

- laboratories,
- extension services, and
- vocational training.

These are cases where local infrastructure is clearly needed and there is no substitute for proximity.

In cases of "slippery" knowledge which is easily transferred and can be shared among a knowledgeable group, the issue of *where* the knowledge originates and what constitutes the local tie should be re-thought in a highly interconnected era. Slippery knowledge can pass quickly within a network of interconnected people. These shared aspects of the knowledge system can include:

- aspects of standards setting,
- metrology,
- information collection and dissemination,
- technical training manuals, and
- compliance testing.

As an example, standards and metrology may be suited to a grid-based, virtual system accessed electronically. Standards questions might be answered through the Internet by access to an expert system. This would provide developing countries with access to world-class technical knowledge. With this knowledge, they could join the standards-setting process on an equal footing. In these cases, being tied into the global network may be very important, and making a smaller local investment that taps this knowledge may be possible.

Levels of Decision-making

The main obstacle in creating RSTA at the level of functionality and efficiency, with full use of on-line connection and expertise, is the question of the level of political decision making and control. Even if they are just considered at the national level, there are issues associated with the level of decision-making for RSTA investments. Within S&T-advanced countries, the best practices associated with investment generally involve multiple partners in determining investment and control. Installing responsibility and oversight close to the user is generally a good strategy, and best practice suggests that in fact some RSTA are built and monitored at a local level by relevant officials. This is certainly the case with vocational training and for some parts of regulation and compliance.

In other cases, the large scale or scope of the investment required also needs consonant political will to make a long term and expensive investments. These decisions often need to take place at the national level, not because this is the natural scale for the RSTA, but because national treasuries have access to the kinds of funds required. Thus investments in laboratories, in metrology centres, and in regulatory systems often take place at the national level. In these cases, close coordination with industry and other levels of government, and through careful planning with tools such as Foresight, RSTA investments can be fruitfully made.

In addition to coordination with industry and with levels of government, other best practices that can be derived from actions of governments and agencies within the S&T-advanced countries include:

- Alignment with national or regional goals in which investments are made to support the growth and development of specific sectors, such as investment in semiconductor materials metrology to support the electronics industry
- Partnership between various sectors where a number of groups share responsibility for creating or overseeing RSTA service, such as private-sector responsibility for assuring the safety of equipment to standards set in the public sector.
- Open versus closed systems where interested groups can share information and can "see" the decision-making process for RSTA investments and provide input to this, such as seeking consumer input on food safety issues.

Areas for Future Study and Action

Given the fact that RSTA has received scant attention from those studying and measuring the S&T system, it is clear that more research is needed into its role in new knowledge creation and economic growth. To what extent do different parts of RSTA provide social and economic goods that have direct benefit to taxpayers? To what extent do these services substitute for or complement private investment? To what extent can the responsibilities for RSTA be shared with other countries or other providers? These questions need further attention to fully understand how to make RSTA investments truly cost-effective for developing countries seeking to grow a science and technology base.

References

Archibugi, D. and A. Coco, *Measuring Technological Capabilities at the Country Level: A Survey and a Menu for Choice.* 2004, Italian National Research Council: Rome, Italy.

Carnegie Commission on Science, Technology, and Government, *Science, Technology, and Government for a Changing World.* 1993.

European Commission, *Innovation Policy in Six Candidate Countries: the Challenges.* 2001.

Freeman, C. "Continental, national and sub-national innovation systems—complementarity and economic growth," Research Policy, 31, 2002, pp. 191-211.

Fukuda-Parr, S., *Human Development Report 2003.* 2003, New York: Oxford University Press.

Godin, B., *Measurement and Statistics on Science and Technology: 1920 to the Present.* 2005, Routledge Studies in the History of Science, Technology and Medicine.

--Neglected Scientific Activities: The (Non) Measurement of Related Scientific Activities," Project on the History and Sociology of S&T Statistics, Paper No. 4, 2001.

High Level Group, *Increasing Human Resources for Science and Technology in Europe.* 2004.

Kleinknecht, A., K.V. Montfort, and E. Brouwer, *The Non-Trivial Choice Between Innovation Indicators.* Econ. Innov. New Techn., 2002. 11(2): p. 109-121.

Leydesdorff, L., *A Sociological Theory of Communication: The Self-Organization of the Knowledge-Based Society*, Universal Publishers, 2001.

Linde, E.v.d., et al., *A preliminary survey of future requirements for outfitting public scientific research in the Netherlands: Towards a co-ordinated investment portfolio.* 2002, RAND Europe.

Mokyr, J. *The Gifts of Athena: Historical Origins of the Knowledge* Economy, Princeton University Press, 2002.

Noble, David F., The wedding of science to the useful arts, in: *America by Design. Science, Technology and the Rise of Corporate Imperialism* (New York: Knopf, 1977), pp. 3-19.

National Commission on Entrepreneurship, *American Formula for Growth: Federal Policy & the Entrepreneurial Economy, 1958-1998.* 2002.

National Science Board, *Federal Research Resources: A Process for Setting Priorities.* 2001.

National Science Board, *Science and Engineering Infrastructure For the 21st Century: The Role of the National Science Foundation.* 2003.

Nelson, R. "On the uneven evolution of human know how," *Research Policy,* July 1, 2002.

Organisation for Economic Co-operation and Development, *Science and Innovation Policy: Key Challenges and Opportunities.* 2004: Paris.

Sommers, P. and D. Heg, *Spreading the Wealth: Building a Tech Economy in Small and Medium-Sized Regions.* 2003, The Brookings Institution Center on Urban and Metropolitan Policy.

Tassey, G., *Methods for Assessing the Economic Impacts of Government R&D.* 2003, National Institute of Standards & Technology.

--*Standardization in Technology-Based Markets*. 1999, National Institute of Standards and Technology.

--*Technology Infrastructure and Competitive Position*. 1992, Kluwer Academic Press.

--United Nations Millennium Development Task Force on Science, Technology, and Innovation, *Innovation: input to development*. UN Development Program, 2005.

Von Hippel, E. *"Sticky Information" and the Locus of Innovation*, MIT Sloan School of Management Working Paper, April 1994.

Wagner, C.S., et al., *Science and Technology Collaboration: Building Capacity in Developing Countries?*. 2001, RAND Science and Technology.

Wagner, C.S., E. Horlings, and A. Dutta, *Can Science and Technology Capacity be Measured?*. 2001.

Wagner, C.S. and S.W. Popper, *New Foundations for Growth: The U.S. Innovation System Today and Tomorrow*. 2001, Science & Technology Policy Institute, RAND Corporation.: Washington D.C., U.S.A.

Williams, G., *The Assessment of the Economic Role of Measurements and Testing in Modern Society*. 2002, European Commission: Oxford.

Notes

[1] B. Godin (2005) Measurement and Statistics on Science and Technology: 1920 to the Present. *Routledge Studies in the History of Science, Technology and Medicine.*

[2] Ibid.

[3] http://www.worldbank.org/data/countrydata/countrydata.html

[4] The S&T system as it is discussed here is considered to be separate from but partly contributing to the innovation system. Some parts of S&T, such as astrophysics, contribute little to economic innovation. Some parts of the innovation system, such as trade policy, have little impact on S&T.

[5] Authoritative reports with metrics on S&T include the OECD (France) publication Main Science and Technology Indicators (MSTI); the Science & Engineering Indicators published by *the National Science Board of the National Science Foundation* (US); *the UN Development* Project's Human Development Report; and the World Economic Forum's Global Competitiveness Report; and the United Nations Industrial Development Organization (UNIDO) Industrial Development Report.

[6] Cited in B. Godin, op.cit.

[7] Cited in B. Godin, op. cit.

[8] Ibid.

[9] National Science Board, 2001.

[10] Z. Gostkowski, *Integrated Approach to Indicators for Science and Technology,* CSR-S-21, Paris: UNESCO, 1986, p. 2, quoted in B. Godin, op cit.

[11] B. Godin, op. cit., provides more information on UNESCO's efforts to collect data on S&T infrastructure.

[12] World Bank.

[13] GERD is gross expenditures on research and development, including government, business, and academic spending.

[14] NSB 2002 report

[15] NSB 2002 report

[16] Harley Ellis/HERA/Spectrum benchmark study, 1999.

[17] This estimate was made for three fields: chemistry, engineering, and internal medicine.

[18] David, P. 1994

[19] EU standards study

[20] EU standards study

[21] Ibid.

[22] EU, p. 30

[23] G. Tassey (1992) Technology Infrastructure and Competitive Position, Kluwer Academic Publishers.

[24] Assessment of the Economic Role of Measurements and Testing p. 10

[25] Kohsetsushi, Japanese industrial research centers - Report

[26] Philip Shapira, personal communication

[27] Technology Infusion: Assessing Current and Best Practice Programs, p.104

[28] OECD Patents and Innovations: Trends and Policy Challenges

[29] OECD Compendium of Patent Statistics, p. 11

[30] Ibid, p. 6

[31] Ibid, p. 24

[32] Ibid, p.15

[33] OECD Patents and Innovations: Trends and Policy Challenges, p. 11

[34] Ibid, p.13

[35] OECD Compendium of Patent Statistics, p. 6

[36] USPTO document

[37] National Industrial Systems in Africa, p. 20

[38] Ibid.

[39] Source: International Labour Office

[40] Ibid.

[41] "Human Resource Development for Continued Economic Growth The Singapore Experience," Paper presented at the ILO Workshop on Employers' Organizations in Asia-Pacific in the Twenty-First Century, Turin, Italy, 5-13 May 1997.

[42] http://www.fda.gov/oc/oms/ofm/budget/2004/Tables/aptba.htm

[43] Ibid.

[44] http://www.usda.gov/agency/obpa/Budget-Summary/2003/2003budsum.htm#fun

[45] http://www.epa.gov/ocfopage/budget/2003/2003bib.pdf

[46] These subsidiary organizations include DHHS's Centers for Disease Control and Prevention (CDC) and National Institutes of Health (NIH); USDA's Agricultural Research Service (ARS); Cooperative State Research, Education, and Extension Service (CSREES); Agricultural Marketing Service (AMS); Economic Research Service (ERS); Grain Inspection, Packers and Stockyard Administration (GIPSA); the U.S. Codex office; and the Department of Commerce's National Marine Fisheries Service (NMFS).

[47] David P. and D. Foray, 2002. "An Introduction to the Economy of the Knowledge Society," *International Social Science Journal* 171, March. Also see chapters on the knowledge base by D. Foray & B.-A. Lundvall, and by M. Abramowitz & P. A. David, 1996, in *Employment and Growth in the Knowledge-Based Economy*, Paris: OECD.

[48] A large literature addresses the question of the contribution of science and technology to economic growth and knowledge creation. Among these are M. Gibbons et al., *The New Production of Knowledge: The Dynamics of Science and Research in Contemporary Societies*, London, England: Sage Publications, 1994 and Richard R. Nelson, 2000, The Sources of Economic Growth, Cambridge: Harvard University Press. This question is also discussed in the RAND study, referenced in note 3.

[49] National Academy of Sciences, 2003

[50] Ibid.

[51] J.J. Salomon (1971) has said that, "Because of its objectivity, science is considered to be supracultural, untrammeled by conflicts of values...Even the idea of national scientific communities is contradictory..."

[52] Mokyr 2002, p. 2.

[53] Nelson 2002 has noted the importance of cultural factors in the transfer of technical knowledge.

[54] In a 1991 report, the World Bank cited knowledge accumulation as more decisive in post-World War II growth than investment in physical capital.

[55] Freeman 2002, citing List (1841) and Smith (1776), shows that the discussion about wealth accumulation and the respective roles of knowledge and physical capital in it have a long history.

[56] The process took as long as 120 years in the United States if one counts 1800 as the beginning of a systemic economy and 1920 as the point where the current national economy can be said to have taken shape. This is addressed in Freeman 2002.

[57] Freeman 2002, p. 192.

[58] Lundvall 1992; Nelson 1994

[59] Nelson and *Wionter 1982; Dosi 1988; Lundvall 1992; Gilsing* and *Nooteboom 2004.*

[60] Noble 1977.

[61] Leydesdorff and Etzkowitz 2000.

Appendix 1. Defining Science and Technology Capacity

In order to detail the RSTA needed to support it, it is useful to develop a definition of science and technology capacity. It is defined for the purpose of this paper as the ability of a country to absorb and retain specialized knowledge and to exploit that knowledge to create innovative products and services.[a] The ability to use specialized knowledge emerges from the interactions among institutions and people as they respond to specific problems and opportunities. The institutions, regulatory agencies and funding schemes that give rise to S&T themselves grow and change over time. Because indicators can represent some features of the system, it is possible to measure S&T capacity from a broad perspective using both direct and indirect measures.

The indicators used to measure S&T capacity are:

- Infrastructure to support economic and research activities, measured by per capita gross domestic product in purchasing power parity dollars by the U.S. Development Project Human Development Report 2002; it is presented as a proxy for basic infrastructure.
- Tertiary education, represented by the gross tertiary science enrolment ratio from the UNDP HDR 2002.
- Number of scientists and engineers in the R&D per million inhabitants from the UNDP HDR 2002.
- Number of research institutions per million inhabitants from the World Bank's World Development Indicators.
- Research and development spending by public and private sources as a percentage of GDP from the UN HDR 2002.
- Stock of embedded knowledge measured by patents and by journal articles per million inhabitants.
- Connectivity with the larger technical world measured through a comparative share of each country's internationally co-authored papers for 2000.

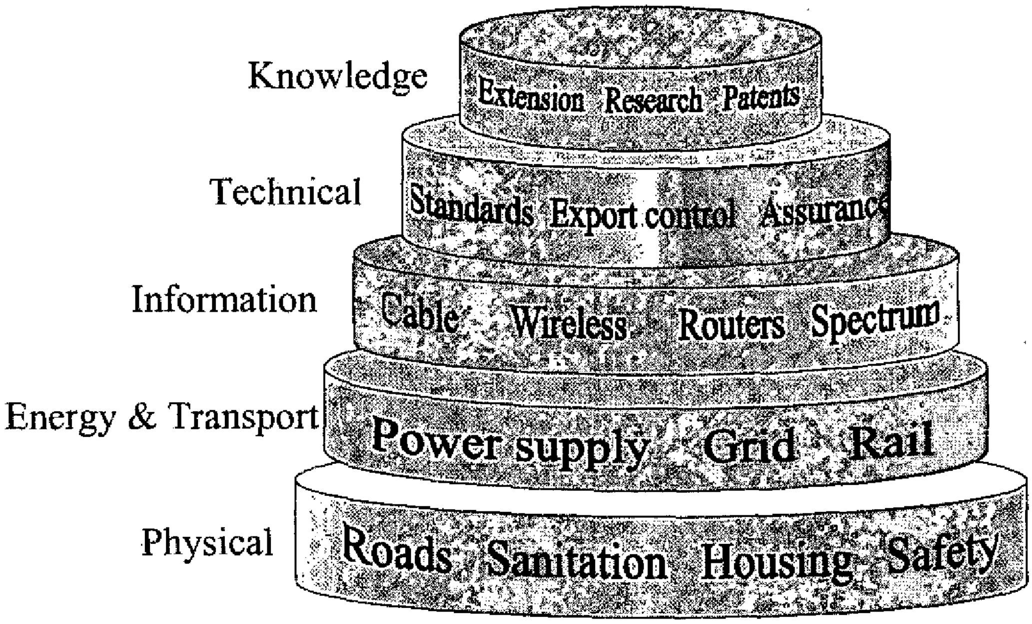
It can be argued that some features are *sufficient* to support S&T, while other features are *necessary* to support it. The necessary features are 1) scientists and engineers, 2) institutions for research, and 3) funds for research and development. These three variables were judged to relate directly to S&T capacity. Indeed, these are the variables that are most often measured in the current statistical reports on S&T activities. The other variables either define the boundary conditions for S&T, or reflect the results of its application and production. Finally, it is clear that some features provide only indirect support to S&T. With this understanding of the features of S&T capacity, we can now turn to the infrastructure supporting these features.

---

[a] Wagner, Horlings, and Dutta, 2005, forthcoming.

Appendix 2. Basic Infrastructure as a Condition for S&T Growth

If, instead of taking an historical approach, we consider S&T support systems as a snapshot in time, it can be assumed that it depends on a basic physical infrastructure of roads, electricity, water, and transportation. As illustrated below the systems have dependencies, with each level dependent upon other more basic infrastructure capabilities. S&T cannot exist as a knowledge system without a certain level of physical and industrial infrastructure. In the U.N. Millennium Report, "Innovation: applying knowledge in development," says "One of the problems that hinders the reduction of poverty in the development world-and the achievement of other Goals-is the lack of adequate infrastructure services." (p. 78) The U.N. report provides the following definition:



The Interlocking Infrastructures of Capacity

> "...infrastructure is the facilities, structures, and associated equipment and services that facilitate the flows of goods and services between individuals, firms, and governments. It includes public utilities (electric power, telecommunications, water supply, sanitation and sewage, and waste disposal); public works (irrigations systems, schools, housing, and hospitals); transport services (roads, railways, ports, waterways, and airports); and R&D facilities." (p. 184).

Industrial Development Report 2005 Background Paper Series

Interpreting Ireland's Economic Growth

Nicholas Crafts

Catching up: What are the Critical Factors for Success?

Jan Fagerberg and Martin Srholec

Historical Patterns in the Co-evolution of Higher Education, Public Research, and National Industrial Capabilities

Roberto Mazzoleni

The Role of Knowledge-Based "Public Goods" in Economic "Catch-Up": Lessons from History

David C. Mowery

The Pillars of Progress: Metrics for Science and Technology Infrastructure

Caroline S. Wagner and Martina S. Reed

Measuring the Demand of Trade-Related Technological Public Goods in Argentina

Gabriel Sánchez and Inés Butler

Formation and Growth of Sectoral Innovation Systems—"Functional Analysis" as a Tool for Policy Makers in Identifying Policy Issues

Staffan Jacobsson

Food Safety Capacity-Building Needs: The Argentine Food Industry

Gerardo Garguilo

Standards, Technical Change and IPRs: Lessons from Industrialized Countries for Developing Countries

Knut Blind

Science, Technology and Innovation in Developing Countries: Some Elements for Defining Policies and Assigning Resources

Judith Sutz and Rodrigo Arocena

Printed in Austria
V.05-89006—November 2005—100

About the cover illustration:
The graph on the cover, generated by means of fractal geometry model, simulates a pattern formed by three ring vortices playing catch up with one another (also called 'chaotic leapfrogging').

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Telephone: (+43-1) 26026-0, Fax: (+43-1) 26926-69
E-mail: unido@unido.org, Internet: http://www.unido.org