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ECONOMIC ANALYSIS OF THE NATIONAL MEASUREMENT SYSTEM

Barry W. Poulson, Editor

Department of Economics
University of Colorado
Boulder, Colorado

A report from the 1972-75
Study of the National Measurement System
by the NBS Institute for Basic Standards

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U.S. DEPARTMENT OF COMMERCE, Juanita M. Kreps, Secretary
Sidney Harman, Under Secretary
Jordan J. Baruch, Assistant Secretary for Science and Technology

NATIONAL BUREAU OF STANDARDS, Ernest Ambler, Acting Director

FOREWORD

The concept of a National Measurement System has, for many years, provided a useful focus for the considerations important to physical measurements in our technology intensive economy. Dr. R. D. Huntoon, in his October 6, 1967 article in Science, emphasized the basis for a systems viewpoint in interrelated measurements activities and the idea has continued to evolve. Today, we think of the U.S. National Measurement System in terms of all the intellectual, functional and institutional activities which involve measurements throughout our society. Moreover, we seek to understand more completely the structural nature of this system and its architectural needs.

There have been a number of approaches to the study of our national system for physical measurements. The present series of studies was initiated in 1972 by Dr. Ernest Ambler, then Director of the Institute for Basic Standards. It was Dr. Ambler's purpose to organize the essential information necessary for the effective management of NBS resources and to promote the direct interaction between IBS staff members and the communities of users they serve.

This document reflects the results of the intensive studies carried out during the period from 1972 - 1975. It is important to recognize that the National Measurement System is extremely complex having widely distributed elements and impacts. The detailed analysis of this system is well beyond the state-of-the-art of econometric modeling, and therefore, any study, no matter how intensive, is necessarily incomplete. Nevertheless, the information which is now in hand provides an important addition to our capability for planning and implementing the programs of IBS. It also represents a growing foundation upon which we can continue our efforts to build a more effective structure.

A. O. McCoubrey
Director, Institute for Basic Standards
National Bureau of Standards
September 1977

PREFACE

This report summarizes several attempts over the past ten years to describe or evaluate economic aspects of the physical measurement system as seen at the National Bureau of Standards. With exceptions noted in the text, this report is a summary of several, mostly unpublished, studies done at the National Bureau of Standards. Publication of this summary provides interested persons an overview of some fragmentary work, much of which has not been critically evaluated. Hopefully, this will stimulate further scholarly work in the economic evaluation of the National Measurement System.

The authors cited in the bibliography are the basic source of data and concepts presented in this report. Assistance of the following economists who served as consultants to authors of the microstudies of the National Measurement System, conducted by the NBS Institute for Basic Standards, is acknowledged here with appreciation: Mary A. Holman, Charles T. Stewart, and James R. Barth of George Washington University; James T. Bennett of George Mason University; Bernard Udis and Charles W. Howe of the University of Colorado. Responsibility for the text of this report rests with the editor.

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September 1977

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EXECUTIVE SUMMARY

The first part of this study deals with the concept of measurement for economic analysis, the quantitative dimensions of measurement in the economy, and the relationship between measurement and economic change. Measurement goods and services yield benefits to users by extending the physical, human senses in providing information about the properties and characteristics of physical objects and phenomena. Measurement information is ubiquitous in the economy; it is used by producers and consumers and as an input at the interface between buyers and sellers. The making of measurements is resource using, the instruments, labor, and other resources needed to make measurements each have their costs and these costs represent the total cost of the national measurement system. The National Bureau of Standards has begun to study the macro economic dimensions of the national measurement system, and one approach in this study is a measure of the cost of labor and equipment used for making measurements. The cost of these resources used in making measurements was estimated at $36 billion or 6% of GNP in 1963. Each of the 78 major industrial sectors incurred substantial expenditures for measurement equipment and labor in 1963. Industries that have experienced the most rapid rates of growth and productivity advance also tend to be measurement intensive, i.e., measurement expenditures are high relative to value added by these industries. The Metric Study by the National Bureau of Standards also provided insight into the macro economic dimensions of the transition to the metric system. The cost of conversion to the metric system over the period 1970 to 1980 was estimated to equal 10% of the total cost of measurement in the economy in those years.

The second part of the study examines the measurement system from the standpoint of the private sector, including the economic rationale for measurement by producers, consumers, and in exchange between producers and consumers; and case studies of the costs and benefits of measurement in the private sector. While it is impossible to analyze the benefits of the total national measurement system, it is possible to examine benefits and costs of marginal changes in the measurement system.

The third part of the study deals with the role of government in the measurement system, incorporating an economic rationale for measurement activities by the public sector, and case studies of costs and benefits of activities by the National Bureau of Standards. Information provided by measurement is a public or collective good to the extent that the information provided by a single measurement can be given to any number of people with no one suffering a loss of the information. The production of measurement information is sometimes characterized by increasing returns; producers of measurement information often use specialized equipment and personnel who make relatively few measurements. The marginal cost of taking an additional measurement likely is less than the average cost, and the cost of disseminating the measurement information from one person to another is probably trivially small compared to the cost of making the initial measurement. Finally, measurement is accompanied by external economies in such areas as consumer protection, health and safety, international trade, and research and development. Under the above conditions the private market system may not allocate resources to the measurement system efficiently and government intervention in the national measurement system may increase the general welfare.

The role of the National Bureau of Standards in the national measurement system is based on provisions in the Constitution and on enabling legislation designed to implement those provisions. This study discusses the costs and benefits of National Bureau of Standards activities in maintaining basic standards, in conducting measurement research and development, and in providing calibration, dissemination, and publication services. The costs and benefits of selected National Bureau of Standards projects are quantified, including large force calibration, time and frequency service, coaxial connectors, standard reference materials for iron and steel, standard reference materials for metals in oil, semiconductor resistivity, and LPG meter calibration. While none of these studies satisfies the conditions of <u>rigorous</u> cost benefit or cost effectiveness analysis, they do provide insight into the economic role of the National Bureau of Standards in the national measurement system.

1. INTRODUCTION

1.1 Background and Purpose of Report

This report is a comprehensive summation of all relevant work known to NBS on the state of the art of economic analysis of the national measurement system. It is written for a mixed audience of economists and physical scientists, in an attempt to bridge a gap between economics and the physical sciences. Therefore, for the economist the economics content may seem unnecessarily tutorial, and for the physical scientist the analysis of physical measurement may appear elementary. The report will have achieved its purpose if each achieves a better understanding of the other's contributions towards understanding the economic significance of the national measurement system.

The "National Measurement System" is a concept that has developed within the National Bureau of Standards over the past decade or more [1].* Today, we use the term *national measurement system* to include all of the activities and mechanisms--intellectual and operational, technical and institutional--used by this country to produce the physical measurement data needed to create the objective, quantitative knowledge required by our society.

During the late 1960's, several studies were undertaken within NBS of the economic aspects of this system [2,3,4]. When the 1972-75 study of the national measurement system was initiated within the NBS Institute for Basic Standards, stress was placed on achieving a significant economic analysis of the system [5]. A macro economic study of the system was undertaken by NBS staff economists [6,7,8]. The NBS scientists and engineers who undertook "microstudies" of specific measurement areas were asked to develop substantial economic data regarding their areas of measurement. A group of economists was asked to review their interim reports and to suggest modifications in the studies and reports.† This present report summarizes the major results of all of these studies, within a general framework of economic theory designed to make the resulting manuscript comprehensible to both economist and physical scientist.

Following a brief introduction to the economic characteristics of measurement activity, the study is divided into four sections. Section 2 explores the economic dimensions of measurement activity in the U.S. economy. The total cost of physical measurement is estimated, and the impact of metrication on the cost of physical measurement is discussed. The relationship between measurement activity and economic change is examined in several ways: first, measurement is related to changes in the total information sector; secondly, measurement intensity by industry is related to changes in industrial output, productivity and industrial structure.

Section 3 of the study moves from a description of the macro economic dimensions of measurement activity in the economy as a whole to an analysis of the costs and benefits of specific measurement activities in the private sector. The transition from a macro economic perspective to a micro economic perspective is necessitated by the fact that it is difficult to analyze the total benefits of the national measurement system as a whole. It is possible, however, to examine costs and benefits of marginal changes in specific measurement activities in the private sector. In the private sector, measurement information is used by producers of goods and services, by consumers in satisfying their wants and needs, and in the sales transactions between producers and consumers. Case studies of some of the costs and benefits of measurement in each of these functions are taken from the micro study reports of the national measurement system study.

Section 4 shifts from the analysis of measurement activity in the private sector to measurement activity in the public sector. The economic rationale for measurement activity in the public sector is discussed. Case studies of some of the costs and benefits of measurement activities of the National Bureau of Standards are surveyed: maintaining basic standards, measurement research and development, calibration and dissemination services, the provision of standard reference materials, and publications.

The concluding Section 5 discusses some of the limitations of the existing literature on the economic analysis of the national measurement system and some suggestions for further research in this field.

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* Figures in brackets indicate the literature references at the end of this paper.

† The group of economists included Professors Charles T. Stewart, Mary A. Holman, James R. Barth, and James T. Bennett of George Washington University, Washington, D.C.; and Professors Barry W. Poulson, Bernard Udis, and Charles W. Howe of the University of Colorado, Boulder, Colorado.

1.2 Economic Characteristics of Measurement

The National Measurement System for the measurement of physical quantities is described in this series of reports as having five interacting levels: (1) conceptual system of measurement phenomena, quantities, and units; (2) basic technical infrastructure; (3) realized measurement capability; (4) dissemination and enforcement network; and, (5) organizational input-output transactions in the measurements marketplace. While these levels are interdependent, economic interest here centers in the 5th level because it is here that resources are utilized by suppliers to generate measurement goods and services for users. Essentially, the resources in question are the instruments, reference materials, and skilled manpower that constitute inputs into the measurement system. The making of physical measurement is an economic activity which, because it is resource using, is costly. The instruments, labor, and other resources needed to make measurements each have their costs and these costs represent some part of the total cost of the national measurement system.

Measurement goods and services yield benefits to users by extending the physical, human senses in providing information about the properties and characteristics of physical objects and phenomena. Reading a measuring instrument creates information and, hence, there is no doubt that such an instrument qualifies as a knowledge-producing device. If the "reader" of the instrument grasps its message and, on this basis, acts in order to influence the measured magnitude, he is what is now called a "feedback link" who detects a deviation from a standard and corrects it. It is often possible to replace the human link by a mechanical (or electrical, etc.) device which actuates the same correcting operation. For example, the human heat control operator may watch a thermometer and open a valve or manipulate a switch as soon as he notices that the room temperature has fallen below 70° Fahrenheit. The thermostat is an automatic heat-control operator, acting upon the information received from the thermometer. The point is that the measuring device transmitting the information and actuating an adjustment operation deserves to be called part of an information machine. After all, if the automatic actuator should ever stop working, say because of a break in the connection, the human operator could step in, receive the information conveyed by the measuring instrument and act to correct the observed deviation.

Viewing measurement as a form of information, we find that it is ubiquitous in the economy; it is used as an input in production, it is used in consumption by consumers, and it is used at the interface between sellers and buyers. The information provided by measurements is valuable when used as a factor of production or used by consumers because the information allows more efficient use of non-measurement resources. Information from measurement at the interface between sellers and buyers promotes efficient use of resources as well as increased equity in sales transactions.

Having noted that measurements convey information, we can go further toward defining the economic characteristics of measurement by observing that different measuring devices can be used to measure the same phenomenon and the resulting measurements are often treated differently. For example, the width of a steel block can be measured either with an ordinary ruler or with a machinist's caliper. Though both instruments measure the same attribute, we generally trust the caliper reading more than that of the ruler. Further, the caliper can probably give a reading to more accuracy and precision than can the ruler. In short, the information content of the caliper reading is higher or better than that of the ruler. Thus, it seems reasonable to consider a change from a ruler to a caliper to be a change which provides improved measurement characterized by higher quality. Further, we can expect that some people would be willing to pay a higher price for the caliper measurement than for the ruler measurement because of the better quality information. We can also note that some people would not pay a higher price; but this fact simply implies that different people do different things with the information they get from a measurement. Some people can use all the information provided to them by a caliper while other people in other circumstances would be quite satisfied with the information from a ruler. Thus, for this second group of people, the advent of the caliper is really of little consequence.

The ideas just presented reveal several economic characteristics of measurement that need further development. First, measurement information is usually expressed in the form of a quantitative statement about some physical phenomenon, as well as a related statement about the reliability of this information. Improvements in measurement then provide better information either in the statement about a physical phenomenon or in the reliability of the statement. Whereas technical improvements usually are embodied in physical capital goods, improved measurement yields better information without necessarily a physical change in the equipment used to produce the better information, although improved instruments are often the way of gaining improved measurements. The heat control operator in our earlier example may also use the same measurement instrument, i.e., a thermometer, to measure not just one temperature, but a range of temperatures over a given time period. This extended measurement set requires no technical improvement in the measuring instrument per se, but rather an amplification of labor or cost applied to the system or process of interest. In short, it is information (including certainty or reliability of that information) which is the aim of measurement activity. The latter obviously consists of theory (conceptual appropriateness of the measure), instruments or techniques, and intensiveness of labor applied.

The second characteristic of measurement revealed in the above illustration is that improved measurement may not yield benefits in an economic sense. The value of improved measurement to the user depends on whether this information provides him with a better way of reaching a given objective. It is usually assumed that consumers seek to satisfy wants through consumption; the objective is to maximize the satisfaction of wants. Producers of goods for sale in the market wish to maximize profits (total revenue less total costs). The benefits of measurement information to each will depend on the extent to which this information contributes to want satisfaction or profit maximization respectively, and the demand for measurement information is derived therefrom.

Finally, in determining both the costs and benefits of changes in measurement, it is necessary to distinguish between costs and benefits to individual users and to society--the latter may not equal the sum of the former because complex secondary effects in the economic system may exist. Furthermore, aggregate costs and benefits of changes in measurement must be determined with respect to goals of society, some of which may be economic, political, humanitarian or technological. The distinction between benefits and costs to individuals and to society is especially important in the economic analysis of changes in measurement financed in the public sector. Even when government measurement activities can be justified in terms of legislative authority and economic efficiency criteria, those activities may be inconsistent with other social goals such as the freedom of private individuals or organizations to pursue their own interests as they see them. [1,4,9,10,11,12,13].

Table 1. Measurement intensity of principal using industries, 1963
(ranked by amount and percent of value added by measurements)

Industries Ranked by Dollar Amount of Value Added			Industries Ranked by Percent of Value Added		
Rank	Industry	Value Added	Rank	Industry	Percent
1	Government (78, 79, 84)+	$11,342 M	1	Radio & TV (67)	27.0
2	Trade (69)	4,256	2	Government (78,79,84)	20.6
3	New Construction (11)	1,348	3	Aircraft Mfg. (60)	16.8
4	Elec., Gas & Water Util.(68)	1,149	4	Electronic Comp. (57)	16.5
5	Aircraft Mfg. (60)	1,106	5	Office Equipment and Computers (51)	16.4
6	Transport & Warehsg. (65)	981	6	Radio, TV and Commun. Equipment (56)	16.3
7	Radio, TV & Commun. Equipment (56)	970	7	Plastics (28)	12.2
8	Finance & Insurance (70)	817	8	Chemicals (27)	11.4
9	Telephone & Telegraph (66)	809	9	Elec. Trans. & Dist. Mfg. (53)	10.6
10	Primary Iron & Steel (37)	802	10	Textiles & Floor Cover (17)	10.3

+Numbers in parentheses denote the standard industrial sectors of the 1963 input-output tables.

Source: Howard E. Morgan, "The Economic Cost of Physical Measurement" [8]

Table 2. Value of output of measurement equipment

Producing Industry SIC Code	Industry	Total Output (million dollars)
1941	Fire Control Equipment	$ 228.0
3576	Scales and Balances	103.6
3586	Measuring and Dispensing Pumps	172.8
3611	Electric Meas. Instr. & Test Equipment	938.5
3622	Industrial Controls	819.1
3693	X-Ray Apparatus	154.6
3811	Engineering & Scientific Instr.	864.6
3821	Mechanical Meas. & Control Instr.	1279.0
3822	Automatic Temperature Controls	561.0
387	Watches and Clocks	557.0
	Total	$5678.3

Source: Howard E. Morgan, "The Economic Cost of Physical Measurement" [8]

2. MEASUREMENT IN THE U.S. ECONOMY

2.1 Economic Dimensions of the National Measurement System

2.1.1 Economic Cost of Physical Measurements

As part of the study of the national measurement system, the National Bureau of Standards attempted to estimate the cost of making physical measurements. Estimates were made of the cost of both the labor [6,7,8] and the equipment [8] used for making measurements in the industrial and governmental sectors and for the total United States economy. A number of conclusions are offered:

2.1.1.1 Expenditures for Physical Measurements

The NBS studies by Pawlik and Morgan show that the use of physical measurements is very extensive [7,8]. Approximately $35.7 billion or 6 percent of the 1963 Gross National Product (GNP) was generated by measurement related activity. Of this total measurement related GNP, $32.4 billion or 85 percent was accounted for by employee compensation; the remainder includes $2.5 billion in property type income as rents, interest, proprietors income, corporate profits and depreciation charges; $0.7 billion was a result of indirect business taxes [7,8]. In 1963 about $5.7 billion was spent for measurement related equipment [8]. The cost of this equipment cannot be summed with the above estimate of measurement related GNP because this would amount to double counting, i.e., part of the cost of this equipment is the cost of measurement related labor and capital inputs already included in the above estimate.

The making of physical measurements is pervasive throughout the economy. Each of the 78 standard industrial sectors in the American economy incurred significant expenditures for measurement related labor and equipment. Consumers, government, and private firms each spent significant amounts for measurement related equipment.

2.1.1.2 Industries Ranked in Terms of Measurement Intensity

In the NBS studies (see table 1), industries were ranked by both dollar amounts and percentages of value added by measurements [8]. In 1963 government ranked first in terms of dollar amount of value added by measurement related activity, and second among industries by percent of value added for measurement. Government spent $11.3 billion or about one-third of the total expenditures for measurement related GNP. The Federal, state, and local government share of measurement related GNP is substantially greater than their share of total GNP. This estimate is based on labor cost alone, since property type income and indirect business taxes were not included in the government's share of measurement related GNP. However, the Federal government bought $705 million worth of measurement equipment and state and local governments spent $75 million in 1963 for such equipment. It is clear that government accounts for a significant part of the total cost of physical measurements, whether we measure this as a share of measurement related GNP or in terms of expenditures for measurement related equipment.

Wholesale and retail trade ranked second ($4.3 billion) among industries in dollar value added by measurements. This apparently is due to the large number of sales transactions involving the use of weights and measures.

Construction ranked third ($1.3 billion) in dollar value added by measurements. The construction industry utilizes measurement equipment extensively in the construction of buildings, but the bulk of measurement expenditures is for labor making measurements in construction.

The NBS studies showed that the service industries in general (including government) ranked high in terms of dollar amount of value added for measurement activity. Service industries such as trade, utilities, transportation, communication, and finance each spent significant dollar amounts for measurements. Radio and TV broadcasting, and government also rank first and second, respectively, in terms of the percent of value added accounted for by measurement related activities. The other industries that spent a relatively large share of their value added for measurement are manufacturing industries that are generally regarded as industries that have experienced rapid technological change, as discussed later in this report.

2.1.1.3 Measurement Equipment

Estimates of the value of output for the measurement equipment producing industries were made in Morgan's study (see table 2) [8]. The largest of the measurement equipment industries is that making mechanical measurement and control instruments ($1.3 billion). The largest buyer for this equipment was the automobile industry, followed by aircraft manufacturers and electric/gas/water utilities.

The second most important industry is that which produces electrical measuring and test equipment ($938.5 billion). This equipment is sold primarily to federal and state governments, to the electrical utility industry, the telephone industry, and radio/TV/communications equipment manufacturers.

Producers of engineering and scientific instruments ($864.6 billion) and industrial controls ($819.1 billion) rank third and fourth respectively in value of output. The remaining producers of measurement equipment ranked considerably lower in value of output. These industries produce equipment primarily relating to the measurement of time, heat, mass, or some mixture of basic measurements.

2.1.2. Economic Impact of Metrication

2.1.2.1 Net Costs of Metrication

The only other study which provides macro economic data on the quantitative dimensions of the national measurement system is the Metric Study [14]. The Metric Study was a project by the National Bureau of Standards to determine the effect on the United States of increased world wide use of the metric system. The Metric Study investigated 14 areas where metrication was expected to have a major impact, and provides a unique insight into an impending discontinuous change in the national measurement system.

The investigations in each of the areas yielded estimates of the net costs of conversion to the metric system, i.e. total costs less benefits. In most cases the separate total costs and total benefits of conversion to the metric system were not provided, and in some cases, such as the study conducted by the Department of Defense, total costs of conversion to the metric system were estimated for a period of time longer (30 years) than that used in other studies. Nonetheless, it is possible to aggregate these costs of conversion to the metric system over the ten year period 1970-1980. This data is crude and somewhat dated since the study was conducted in 1969/70; therefore we refer to the estimates in percentage terms.

The total net cost of conversion to the metric system is estimated to be roughly equal to the annual cost of measurement activities described in the previous section [15]. If we accept these rough estimates of the macro economic dimensions of the national measurement system, we can say that the average annual costs of the conversion to the metric system over a ten year period would equal about 10% of the total cost of measurement in each of these years.

The major cost in converting to the metric system is that estimated for manufacturing industries. There, direct costs account for about 45% of the total cost of conversion to the metric system, while other costs such as maintaining dual inventories add another 5%. No estimate of the net cost of metrication was made in the original study of the non-manufacturing industries. Only 39% of these latter firms indicated that they anticipated cost changes associated with metrication and for these firms the cost is approximately 1% of value added. If we assume that the costs of metrication relative to value added for these firms are representative of non-manufacturing firms as a whole, then the cost of metrication for this sector estimated from data on value added is 5% of the total cost of conversion to the metric system.

Within the government sector, over 90% of the cost of metrication is accounted for by the Department of Defense. The cost estimated by the Department of Defense equals 33% of the total cost of conversion to the metric system; this figure is based on a 30 year conversion period because of the long life expectancy of much defense hardware and the need to retain a capability in both customary and metric units over this period of time.

The civilian agencies within the federal government conducted a rather thorough survey of the net costs of metrication, which aggregate to $0.6 billion. No metric study report was prepared for state and local government agencies. The metric study did analyze metrication in education and reported that the costs in this sector were negligible. However, other state and local government agencies are expected to incur costs associated with metrication. Assuming that these costs have the same ratio to state and local (non-educational) budgets as the ratio of metrication costs to the federal (non-defense) budget yields an estimate of $1.5 billion for the cost of metrication for state and local governments.

These estimates of the costs of metrication are subject to a wide range of error and overall we suspect that the estimates are biased upward. The Department of Defense estimate does not take into account benefits from metrication that would offset to some extent the costs; and uses a different (longer) time frame than the other studies. The costs estimated for the manufacturing sector may also be biased upward. The companies chosen for the study were not based on a random sample and the data base appears to be rather weak. For example, elimination of just two atypical companies from the 158 companies sampled would lower the estimated costs by some $0.4 billion.

The general opinion shared by those involved in the National Measurement System study is that the costs estimated in the Metric Study are too high. This feeling is supported by the British experience in metrication, where apparently there was a strong tendency to overestimate the costs. A recent survey by U.S. News and World Report adds further evidence that metrication is not only proceeding faster than expected, but that the costs of metrication in the private sector are substantially below the original estimates. For example, Everett Baugh, General Motors official in charge of metric planning, states: "When General Motors first analyzed the cost of going metric in 1966, it was about as staggering as the national debt. In 1972, we restudied the cost based on going metric only with new models as they came out. That figure was just 28 per cent of the first estimate. In 1973, another study brought it down to 19 per cent. Now, practical experience suggests that the real cost will be only 4 per cent of the original estimate" [16]. The aggregate figure also appears high relative to the total costs of measurement activity noted in the previous section. Intuitively, it is surprising that the costs of metrication should equal as much as 10% of the total costs of measurement over a 10 year period. However, given the upward biases and the crudeness of the estimating procedures, the macro economic dimensions of the measurement system suggested by the metric study are not inconsistent with the estimates for the total cost of measurement activity. For example, the share of the costs of metrication accounted for by the government sector is about 36%; the share of the total costs of measurement accounted for by the government is 35%.

2.1.2.2 Benefits of metrication

The benefits of metrication are much more difficult to identify and estimate than the costs of conversion. The Metric Study provides only fragmentary evidence on these benefits. The study estimates annual benefits in education of $0.5 billion based on labor time saved in such areas as teaching of the cumbersome customary measurement system and drilling in common fractions in mathematics. The study also estimates annual benefits in international trade of $0.6 billion resulting from the increased competitiveness of American products. This figure is probably overestimated to the extent that resources drawn into trade may result in a decline in domestic production. The estimate of $0.6 billion in trade was combined with the $0.5 billion in education to provide the only direct estimate of the benefits of metrication of $1.1 billion.

It is not possible at this point to measure directly the benefits from metrication. Given the costs of metrication cited above, it is estimated that total annual benefits required to justify conversion to the metric system are $3.5 billion. Given that the direct estimates of benefits from metrication for trade and education are $1.1 billion, then the benefits in other areas would have to be $2.4 billion to justify conversion to metrication. If metrication improves labor productivity and reduces labor measurement time by only about 5%, then the total benefits of metrication will be at least equal to that amount required to justify the conversion. This inference is not inconsistent with the direct evidence of reduced labor time in education resulting from conversion to the metric system.

In addition to the benefits of improved labor productivity, there are other potential benefits not directly estimated in the Metric Study. We expect the reduction in inventories by "rationalization of the numbers of standard sizes" to be a significant benefit subsumed under the heading of "housecleaning effect". A thorough reading of the Metric Study reports shows that metrication will probably effect such a benefit; and, although metrication is not required in order to have inventory reduction, it may very well not take place without metrication.

2.2 Economic Change and the National Measurement System

2.2.1 Measurement Activity and the Information Sector

2.2.1.1 Information or Knowledge Production and Economic Growth

In our discussion of the concept of measurement as an operational system for economic analysis, we defined measurement as part of the information sector of the economy. To understand the relationship between changes in the economy and in the national measurement system, we can begin by examining changes in the information sector. Fritz Machlup, in a seminal study on the production and distribution of knowledge or information maintains that the share of knowledge production in GNP has been increasing over the years and that in recent years knowledge production has been growing faster than GNP, implying that its share in GNP has increased [10].

However, Machlup notes that the interrelationship between knowledge or information production and economic growth is very complex The most plausible relationship is that greater knowledge leads to increased productivity of given resources and hence to faster economic growth. However, this causal chain from knowledge-production to growth of total product may also go in the opposite direction, from higher incomes to higher expenditures for knowledge.

Using the data for the mid-1950's Machlup examined rates of increase in expenditures for production in the various industries or branches of knowledge production [10]. He found that the weighted annual average growth of knowledge production was 8.8% compared with a 5.1% rate of increase of GNP per year over the same period. Over a longer period extending back into the 1940's he found that the weighted average annual growth of knowledge production was 10.6% compared with a 5.9% rate of increase of GNP. The differences in the rates appear even more impressive if knowledge production is compared with the production of everything else that is included in GNP. If knowledge-production, the sector comprising 28.7% of total GNP, increased by 8.8% (or 10.6% over the longer period) per year, an increase of total GNP by 5.1% (or 5.9%) implies that the production of other goods and services increased by only 3.7% (or 4.1% over the longer period).

Machlup notes several important reservations in these comparisons. The period examined is relatively short in terms of longer term trends in economic growth; the estimates are in current prices without adjusting for differential rates of inflation in the knowledge or information sector *vis a vis* other sectors; and no attempt is made to adjust for qualitative changes in the production of knowledge or in other goods and services. In discussing these limitations, Machlup even suggests that because of the non-measurability of the product, the consequent lack of productivity data, and the absence of market prices, one cannot even state with assurance that an increase in the expenditures for knowledge, relative to GNP, will result in more knowledge being provided to society. Nor can we say that increased knowledge necessarily causes increase in GNP.

Despite these reservations more recent evidence tends to support Machlup's suspicion that the share of knowledge production in GNP has been increasing over the years. Marc Porat has recently defined the information sector of the American economy in terms of the extent to which labor is producing output which may be classified as data, information, or knowledge, or physical outputs whose only real value lies in the data, information, or knowledge that they transmit or allow to be created [17]. Using this definition of the information sector, he finds that virtually all of the relative increase in the output of service industries in recent years is concentrated in this information sector except for a significant increase in the health care sector. He finds that approximately half of all American workers are engaged in the information sector. A recent study by the Stanford Research Institute also reveals that the demand for a number of information industries such as communications has been increasing at an accelerating rate [18].

2.2.1.2 Measurement as a Component of the Information Sector

The national measurement system produces information as part of the knowledge or information sector as defined in the above studies. Our interest in the present study is whether the production of measurement information, like the production of information as a whole, has increased relative to total economic activity.

Machlup in his original investigation of the information sector did isolate a group of industries producing measuring and controlling instruments and found that they experienced rates of growth generally higher than those found in other sectors of the economy. He found that sales of mechanical measuring instruments increased more than twenty times in the 15 years from 1939 to 1954, representing an annual growth rate of 22% [10]. Electrical measuring instruments increased approximately fifteen times; watches and clocks about four times, and scales and balances about six times over the same period.

2.2.2 Measurement Activity and Changes in Industrial Production

2.2.2.1 Measurement Intensity and Changes in Output and Productivity by Industry

In the previous section we discussed the relationship between changes in the information sector and in measurement activity at a rather high level of aggregation. In this section we attempt to disaggregate total economic activity into various industries and to explore the relationship between changes in output and productivity in these industries and in measurement activity.

One would expect greater measurement intensity to be associated with newly developed products, and with new production processes. This is true for two reasons: new processes may not yet be routinized, and new products may not have become fully standardized, so that more measurement is needed than for traditional products and processes. Also, new products and processes may be an outcome of, or take advantage of, improvements in measurement capabilities which established products and processes did not require or could not use. Thus, measurement intensity is expected to be associated with product and process improvements. In the machine tool industry, for example, new products and production processes are accompanied by a more intensive use of measurement inputs; however, once these products and processes become standardized and routinized throughout manufacturing, they may ultimately reduce measurement inputs per unit of output. While these inferences are consistent with the evidence accumulated in the micro studies, there will be exceptions and in particular instances, their validity remains to be demonstrated.

Product improvements should be reflected in growth in industry output. Process improvements should be reflected in reduction in industry cost, that is, by an increase in productivity. New products should be reflected in output growth of the industry producing them, and (as well as improved products) may result in productivity gains in other industries, using the new or improved products as inputs. The quantitative effects depend in every case on the sensitivity of demand: to lower prices, in the case of process improvements; to improved performance, in the case of product improvements; and the extent of diversion of demand from old to new products, in the case of significantly new products.

The appropriate economic indicators of the effects of measurement intensity by industry, growth in industry output and growth in industry productivity, are then only partial and indirect indicators. Some effects impact on other industries; all are modified by the characteristics of demand for the associated products; and of course measurement is by no means the only factor of production influencing industry productivity or innovation. Improvements in measurement capability, leading to the consequences indicated above, do not imply greater measurement intensity. They may permit given measurements to be performed at much lower cost. Only improvements that make new and better measurements possible are likely to be associated with greater measurement intensity. For example, the micro study for surface finish shows how improved characterization of surface finish has resulted in more intensive use of measurement, usually as a substitute for the inputs used to machine metal parts. Thus, the effects of measurement intensity are only part of the effects of measurement and of improvements in its performance. Since measurement activities are only one of many determinants of economic performance, the relation cannot be expected to be strong. Since expenditures on measurement depend on the size of an industry, it is necessary to express them as a proportion of total industry expenditures. The result is an indicator of measurement intensity.

The first attempt to explore the relationship between the growth of industrial output and productivity and measurement intensity was conducted in the National Bureau of Standards by W. H. Eskite [2]. Eskite used census data to develop indexes of measurement intensity by estimating the per cent of value added allocated to measurement activity for eighteen manufacturing industries. He then plotted index numbers of measurement intensity with rates of growth in value added for these industries. Casual observation of this data led him to conclude that there is a good deal of correlation between measurement intensity and the growth of value added in those industries.

More recently, Howard Morgan of the National Bureau of Standards estimated measurement intensity for 78 industries included in the Input-Output tables for the United States in 1963 [8]. The figures include both capital and current expenditures for measurement equipment. Measurement intensity was also estimated for the same industries in 1967, but excluding labor costs (typically the largest costs) and comparable estimates excluding labor costs were made for 1963 [47].

In table 3 the average annual rate of growth in output and in productivity for the measurement intensive industries is compared to that for all manufacturing. This evidence supports the inference that measurement intensive industries on the whole have experienced more rapid rates of growth in output and in productivity than other manufacturing industries. However, this statistical exercise was hampered by lack of data and difficulties in matching industries.

The industry structure of the Input-Output tables, from which information on measurement intensity was derived, does not match the industry structure of data on output and productivity on a time series basis. Estimates of total factor productivity by John Kendrick are on a two-digit SIC (Standard Industrial Classification) basis, and the last year of observation is 1966 in most cases [19]. Bureau of Labor Statistics man hour productivity data are on a four-digit SIC industry basis, and are available to 1971 [20]. It was not possible at this time to match Input-Output table industries with Kendrick's data, but it proved possible to match exactly with BLS productivity time series for 24 industries. The performance of measurement intensive industries (those with one per cent or more of their expenditures, excluding labor costs, allocated to measurement) compared with all manufacturing

Table 3. Productivity and output of measurement-intensive industries

	Average Annual Increase in Output		Average Annual Increase in Productivity	
	1960-66	1964-70	1960-66	1964-70
Measurement-intensive industries	11.6%	5.3%	5.5%	2.7%
All Manufacturing	8.4%	4.9%	4.2%	2.4%

Source: Charles T. Stewart, "Measurement Activity and Changes in Industrial Productivity" [47]

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is indicated in table 3. The two time periods were selected to bracket the years 1963 and 1967, for which observations on measurement intensity were available. The results are in accordance with expectations.

A more rigorous test of the relationship between measurement intensity and the rate of growth of output and productivity was attempted by a contribution to this report from the George Washington University [47] using data for the 24 individual industries. The best results were obtained for the correlation between measurement intensity (including labor costs) in 1963 and the rate of growth of output for the period 1960-66, with an R^2 of .338, significant at the one percent level. The correlation with productivity change over the same period yielded an R^2 of .263, also significant at the one percent level. Correlations were also run for other time periods, but the results were only marginally significant, with much lower R^2. Correlations were performed to test the relationships between measurement intensity (excluding labor) for 1963 and 1967, and the rate of growth of output and productivity. The signs of the coefficients were all positive as expected for 1963 and 1967 measurement intensity (but not for changes in measurement intensity between these two years). Only one relation, however, bordered on statistical significance; measurement intensity in 1963 and productivity growth between 1960 and 1966 (R^2 = .126, significant at the ten percent level). Thus this evidence is not definitive, but should be regarded as suggestive of the contribution of measurement activities to growth in output and productivity and indicative of the need for further work on identifying and measuring the relations.

2.2.2.2 Measurement Intensity and Changes in Industrial Structure

The relation between measurement intensity and changes in output and productivity can also be examined using the technical coefficients of the input-output table. These direct coefficients express in percentage terms the amounts each industry requires from its suppliers. Assume for example that a particular industry X_5 decides to increase its production by $100,000 and that its technical coefficients with respect to five industries are X_1=.11, X_2=.20, X_3=.03, X_4=.06 and X_5=.03. These technical coefficients mean that for industry X_5 to increase its production by $100,000 it must directly purchase from industries X_1, X_2, X_3, X_4 and of its own product respectively eleven, twenty, three, six and three thousand dollars worth of output. Thus changes in the final demand for goods and services are translated into change in the demand for individual intermediate or primary industries by the technical coefficients.

Technical coefficients in the input-output table may change over time due to changes in the composition of demand (product mix), changes in the relative prices on inputs, and changes in the technological alternatives available. Of these three, technological change seems to have been the most important source of variation in the technical coefficients in the American economy.

The analysis of input-output coefficients over time is particularly important in understanding changes in the national measurement system, since measurement is often embodied in intermediate inputs as opposed to goods and services produced for final demand. Working with the trends in input-output coefficients provides some insight into the relationship between changes in output and productivity and the demand for measurement inputs.

Several economists have ranked industries in terms of the rapidity of structural change as revealed by changes in input-output coefficients. Anne Carter, in a study conducted in the 1960's and Clopper Almon *et al* more recently, classified industries in terms of whether their input-output coefficients were rising, stable, or declining [21,22]. If we compare these rankings with the ranking of industries in terms of measurement intensity we can say that generally measurement intensive industries exhibit rising input-output coefficients. In other words, the demand for measurement intensive industries as intermediate inputs tended to increase more rapidly than that for other industries. There are only two major industries that are ranked as measurement intensive which fall in the category with declining input-output coefficients, i.e., construction and iron and steel. These two industries are measurement intensive in terms of dollar amount of value added, but not in terms of per cent of value added in measurement related activities.

While measurement intensive industries appear to be experiencing rising input-output coefficients, it is rather surprising to find measurement instrument industries experiencing declining coefficients. Clopper Almon shows both electrical measuring instruments and mechanical measuring devices with declining coefficients in the 1960's. The implication is that the demand for measurement instruments as intermediate inputs has not been rising as rapidly as that for other industries. Thus, we should not infer that the demand for measurement as an intermediate input has necessarily followed the pattern of demand for measurement intensive industries.

3. ECONOMIC ANALYSIS OF COSTS AND BENEFITS OF MEASUREMENT IN THE PRIVATE SECTOR

3.1 Economic Rationale for Measurement Activity in the Private Sector

3.1.1 Introduction

In this part of the study we move from a description of the economic characteristics of the measurement system to an economic analysis of measurement activity in the private sector. The transition is from a macro economic perspective to a micro economic perspective, a transition supported by the fact that an analysis of the <u>total</u> measurement system, especially in a quantitative benefit-cost mode, is bound to failure: Since a modern society could not function without a systematic way of acquiring measurement data, the value of having a measurement system is incalculable. Moreover, by focusing on specific limited measurement activities, we can assess the benefits of marginal changes in the measurement system.

While it is impossible to put a dollar value on the benefits of the national measurement system as a whole, it is possible to examine costs and benefits of marginal changes in the measurement system. Specific measurements provide information which assists people in making decisions required to reach a goal or objective. In the private sector, measurement information is used by producers, by consumers, and at the interface between producers and consumers. It is necessary to understand the role of measurement in assisting people to reach their goals in each of these situations.

3.1.2 Measurement in Production

Marginal analysis is an essential tool for examining costs and benefits of measurement in the production process. The term "marginal" refers to the last increment of some variable; for example, an increment of measurement may be defined as a single reading on an instrument, a single datum, or any observable measurement. Marginal cost is the cost attributable to that increment of measurement. The value of a unit of measurement under perfect competition equals its contribution to sales revenue, technically known as "value marginal product."

The basic condition for maximizing profit in the production process is to select the optimal combination of resource inputs, including measurement, for a given firm, in the sense that no other combination will generate greater profits. The condition simply states that inputs of measurement or any resource should continue up to the point where the last dollar spent generates exactly one dollar in sales revenue. This also requires an economically balanced combination of resource inputs for a given size of investment or firm; namely that the last dollar spent on measurement will generate the same sales revenue as the last dollar spent on each of the other resource inputs within a given budget for the firm.

An important limiting assumption subsumed by this condition is that of the independence of the various resource inputs in the analysis. If we relax this assumption, then measurement inputs can influence the use of other inputs and vice versa. Measurement inputs can be substituted for non-measurement inputs to produce a given level of output of the firm. Assuming output is constant and substitution of measurement for other resource inputs is technologically feasible, the firm will be willing to pay no more for measurement inputs than an amount equal to that saved by not using the cheapest alternative inputs.

A second assumption in the previous analysis is that the quantity of output may vary but not its quality. If we relax this assumption, then the quality of a given output of the firm may vary with different measurement inputs. For example, the use of additional measurements may permit the firm to claim higher reliability for the product or services that it sells. The value of measurements then is indicated by their contribution to additional sales revenue arising from changes in the quality of output.

3.1.3 Measurement in Consumption

Measurement affects consumers directly as consumption goods; for example, some people use pay scales or buy bathroom scales to obtain information about their weight. Measurement also affects consumers indirectly. One effect occurs when measurements are used in computing sales transactions; for example when scales and meters are used to measure the quantities purchased. Another effect occurs when measurements are used by consumers to judge the physical attributes of other goods; for example, some people using measuring devices to judge the performance of autos, hi-fi and other electronic equipment, etc. In this section we consider the effects of improved measurements on a consumer's utility when the measurement is a consumption good. In the following section, we examine the effects on the consumer's utility of improved measurement used in sales transactions.

Marginal analysis of measurement as a consumption good follows very closely the analysis in the preceding section on measurement used in production. The term "marginal utility" refers to the contribution of the last increment of a consumer good or service to the utility or satisfaction of the customer. The equilibrium condition is that for a given level of expenditures the last dollar spent for measurement goods should yield the same increment to utility as the last dollar spent for every other good or service that the consumer buys.

3.1.4 Measurement in Sales Transactions

Sales exchanges typically involve a customer agreeing to exchange some of his resources (money) for a seller's commodity. The amount of money the customer gives to the seller depends upon the unit price of the commodity and the number of units of the commodity the buyer and seller agree are transferred. Measuring instruments are often used to determine the number of units of the commodity transferred, as when a meter is used to determine the quantity of a fluid or a scale is used to determine the number of pounds sold. Improvements in measurements used in determining sales transactions can therefore be expected to affect both the buyers and the sellers. There are both efficiency effects and equity effects of these improvements.

Improved measurement in sales transactions have an efficiency effect because they reduce the transactions costs of buyers and sellers in the sale of the commodity. These transactions costs involve haggling between buyers and sellers resulting from error or uncertainty regarding the quantity or other measured characteristics of the commodity transferred. To the extent that improved measurements reduce this error or uncertainty in the quantity or quality of the commodity transferred, they reduce the range within which haggling between buyer and seller must estimate the quantity transferred. As a result, buyers and sellers can reduce the amount of time and other resources involved in consummating the transaction. This reduction in resource cost increases the net value of the goods transferred, which may accrue to either the seller or the buyer or both.

Improved measurements in sales transactions also have an equity affect because they change the bias of measurement in the transaction. An overreading or an underreading meter transfers a quantity of the commodity other than that which the consumer expects to receive per meter unit purchased. In the case of improvements in an overreading meter, real resources are transferred from seller to buyer with a consequent increase in the buyer's welfare and a decrease in seller's welfare; in the case of improving an underreading sales meter, the opposite results would obtain.

If we view sales transactions more broadly to include the search costs of a potential buyer for products with given performance characteristics, then improvements in measurement will also have efficiency effects by reducing the search costs of the buyer. A good example of this impact of improved measurement on search costs is in the use of standard reference materials. To the extent that a product embodies characteristics of a standard, this information reduces the time and resources a potential buyer must spend in determining whether a product meets his expectations. More generally, when products have measurement characteristics which refer to a standard specification known to the potential buyer, this will reduce his search costs. These examples can be generalized to any product which embodies measurement characteristics which have known value to the potential buyer. Without this measurement information, the potential buyer is either forced to spend time and resources (including measurement time and resources such as setting up his own testing laboratory, attempting to determine whether the product meets his specifications), or he avoids purchasing altogether, or he purchases a less assured product. Improved measurement by reducing these search costs will benefit the potential buyer as well as improve efficiency in the utility of the products purchased.

3.2 Case Studies of Costs and Benefits of Measurement in the Private Sector

3.2.1 Introduction

The micro studies of the national measurement system provide some insight into the costs and benefits of measurement in the private sector. They illustrate costs and benefits of measurement in production, consumption, and sales transactions. However, several qualifications must be introduced before discussing this evidence. First, the quantitative data for these costs and benefits is often hypothetical rather than actual data and, therefore, should be viewed as illustrating the qualitative discussion. Secondly, the case studies do not attempt to relate costs and benefits of measurement. While potential benefits of improved measurement are described, the costs of resources required to achieve those improvements are generally unknown. The costs and benefits of improved measurement are identified in terms of individual producers and consumers rather than the broader concept of social costs and benefits taking into account secondary impacts of these changes in measurement. Therefore, the inferences made regarding actual or recommended improvements in measurement remain untested in terms of rigorous cost benefit analysis. The case studies are taken from the micro study for that particular measurement activity as reported in this series of documents and the words used may be those of the authors in interim drafts of the reports, without editorial revision.

3.2.2 Case Studies of Measurement in Production

Surface finish [23]. Surface finish provides an example of the trade off between measurement and other resource inputs in the production process. The surface finish of a part can be overspecified, either from habit or from lack of knowledge. One source estimates that improving the surface finish of a turned surface from 50 to 25 micro inches almost doubles the turning cost. The range of surface finishes produced goes from 4 micro inch rms for roller bearings and tool components to 250 micro inch rms for noncritical component surfaces. Improved characterizing parameters are available that increase accuracy and permit the measurement of specific surface characterizing parameters most closely related to the function of the product. By using these characterizing parameters to measure surface finish, the firm can reduce the amount of materials or machining required in the production process. As an example of the use of surface measurements, tin can surfaces are smoothed to 10 micro inches to economize on the use of tin; the trade off here is between increased measurement and metal-working inputs and other material resources; namely, tin.

Humidity and moisture [24]. Oil seeds and crop grains, such as wheat, corn, soybeans, oats, and barley, must be dried to a moisture content of 13 to 15 percent or lower. This is generally done with artificial heat, usually propane, and uses energy. Too much drying is wasteful because of unnecessary use of fuel. Also, income and profits depend on moisture content. Excess moisture results in spoilage and poorer quality grains. The price of grain is reduced if the moisture content exceeds a designated value. The farmer suffers a loss if the moisture content drops below the designated value because there is more grain per bushel (by weight), without a compensating increase in price. If the measurement of the moisture content is not accurate, the farmer suffers some loss. For example, total corn production was 5.6 billion bushels in 1971. With an average price of $1.08 per bushel paid to the farmer, the total value of corn was $6.0 billion in 1971. For corn with a moisture content over 15.5 percent, the price paid to the farmer was 2 cents less per bushel for each percent of moisture. Similarly, for each percent of moisture under 15.5 percent, the price was 1.2 cents per bushel less. Data collected in 1968 for moisture meters in Iowa showed that moisture content varied by as much as 3.4 percent on the same samples. If this pattern prevailed nationally, farmers could have suffered a loss of as much as $341 million from excess moisture, or indicated excess moisture. Similarly, the loss could have been as much as $228 million from excess drying or from low moisture indication. Based on these figures, reducing the inconsistency of moisture meters from 3.4 percent to 0.5 percent would reduce the possible estimated loss to $56 million for excess moisture and to $34 million for excess drying. Similar calculations can be made for other grains.

Optics [25]. In medical radiology, subjective measurements of photographic density are made by physicians and dentists. A recent study has estimated the effect of the semi-automation of the examination of chest x-rays. Semi-automation has increased the rate of x-rays per unit of time by about 50 percent. As a result, the time saved by radiologists was estimated to be between 2.5 and 5 million hours. At an estimated cost of $30 to $40 per hour, the value of time saved amounts to between $75 and $200 million. The data suggest a significant benefit in the value of time saved relative to the cost of semi-automation. This example illustrates the trade off between improved measurement and other inputs, e.g., the radiologist's time.

Thermodynamic properties of fluids [26]. Change in capital costs is another trade off between measurement and other inputs in the production process. If measurement data are poor and subject to great uncertainty, there can be overdesign of plants and unnecessarily high capital investment. The thermodynamic micro study provides several illustrations of this trade off.

Measurement parameters are used in correlations that describe and predict thermodynamic states of gasoline components. It has been estimated that at the limits of accuracy for such predictions, specific heats can be obtained from the generalized representations that are in error by 25 per cent. Such error in specific heat can result in construction cost increases of $600,000. Another example is the effect of vapor pressure errors on the cost and operating characteristics of a process designed to remove 97 per cent of the isopentane. Isopentane is used to increase the octane rating of gasoline and thereby to reduce the amount of lead additive required in gasoline. These vapor pressure errors result in excess cost of about $65,000 out of $550,000 investment for major equipment, excess cost of about $100,000 out of $400,000 investment in energy generating equipment, and an additional $100,000 per year in operating expenses of $450,000. The data are in 1968 dollars.

These examples from the thermodynamic micro study reveal the need for improved measurement of hydrocarbon thermodynamics covering a comparative range from ambient down to -265°F for pressures from atmospheric up to 100 atm, with particular emphasis on the liquid-vapor equilibrium of complex mixtures. The study suggests that access to this improved measurement data could decrease capital and operating costs for plants built with a wide range of uncertainty in measurement data.

Ionizing radiation [27]. An important area for improving measurement of ionizing radiation is in the design and operation of nuclear power plants. Only recently, uncertainties in measuring nuclear fuel reaction rates were reduced from 20 percent to under 10 percent. What this means is that the peak operating rate compatible with avoidance of damage was formerly 20 percent below, and is still nearly 10 percent below, the power attainable if reaction rates were accurately measured.

Spectrophotometry.[31] Ability to detect differences in color and appearance is of economic value in the many industries where these qualities are important for the sale of their products. They are also important in medical diagnosis clinical tests. In the paint industry, since the range of uncertainty in reflectance is the same as the margin of error allowed in GSA specifications, considerable costs are incurred to meet specifications, and even then there are inevitable failures. Improved accuracy would permit automatic mixing and shading, would reduce costs of inventory control, would avoid much repainting for failure to match shades.

Similar considerations apply in the textile and apparel industries. Improved measurement capability would reduce the high labor costs of visual inspection of textiles. Inability to communicate color and appearance accurately results in frequent rejection and associated extra costs of handling and shipping. Automated color and appearance techniques would save much inspection, marking and associated handling, and allow automation of much subassembly work.

3.2.3 Case Studies of Measurement in Consumption

Acoustics [28]. The error and uncertainty in acoustics measurement relates to a wide range of accuracy in acoustical equipment used by the consumer. For example, in the production of sound level meters, the error in measuring noise exposure of plus or minus 5 to 10 percent might be considered good performance. The inaccuracy to be found in the technology of ultrasonic non-destructive testing is believed to be even more appreciable. A reduction in the error in acoustical measurement could improve the welfare of consumers.

One effect can be identified in the measurement processes that relate to the acoustical properties of architectural materials and systems. This is true because it is through the accurate characterization of the acoustical properties of architectural materials that noise control engineering in buildings is facilitated. Without accurate characterization of acoustical properties, the provision of an acoustically comfortable living environment for a consumer becomes less certain and more expensive. Measurements permit the development of improved noise control products. Furthermore, through publication of accurate test data, it might be possible for products with demonstrable superiority to be viable on the market and for products that are inferior to fall into disuse. Provision of accurate measurement services, along with the publication of the data, could facilitate scientific and economic progress.

Improved acoustical measurements are central to the quantitative assessment of, and protection against, noise-induced hearing loss. It has been estimated that in the United States at least 1.2 million people have severe hearing handicap. Costs of hearing disorders, although hard to verify, have been estimated to amount to $100 million annually. This estimated cost includes the direct expenditure for educating the acoustically handicapped, training of specialists, and such therepeutic costs as hearing aids. Of course, reduced earning power is another cost.

Ionizing radiation [27]. Accuracy in measurement of ionizing radiation is important for the health and safety of consumers. Radiation treatment of cancer must walk a fine line between failure to destroy the cancer and damage to healthy tissues. But only 65 percent of institutions visited in 1971, among the best hospitals doing radiation therapy, proved to have tumor dosage within an acceptable five percent error. X-rays and other ionizing radiation widely used for diagnostic purposes also increase the probability of cancer. But 34 percent of dental x-ray machines inspected in New York in 1972 were in violation of safety standards.

Although uncertainties in basic standards are not a major source of error in tumor dose for x-rays and gamma rays below 1.25 MeV, they are important for high-energy x-rays and fast neutrons. Nuclear medicine requires both primary and dosimetry standards and reliable dose-calibrator instruments. There is also a need for improved monitoring of radiation exposure of personnel.

Pressure [29]. Uncertainty in measurement by airplane altimeters may exceed 500 feet even at low elevations. The result is some risk of collision with other aircraft on approaches to airports as well as crashes when flying low. Exactly what this added probability is, and the associated loss of life and health and their value, is not known.

An alternative and more quantifiable estimate of the cost of uncertainty is the changes in air traffic regulations required to avert the possible harmful consequences of this uncertainty; greater vertical separation of aircraft, greater vertical clearance of terrain, slowing down landings, reducing the capacity of airports.

Altimeters are also used to maximize the operating efficiency of aircraft, by adjusting engine power or thrust, selecting optimal cruising speeds, and choosing minimum time routes. Greater accuracy would save on fuel and time.

Pressure measurements by tire gauges in service stations are notoriously inaccurate. Tire pressure that is too low reduces tire life. With more than 100 million cars in the nation, a measurement improvement increasing tire life by a single day is worth some three million dollars a year. Proper pressure also improves car maneuverability, contributing to safety.

Temperature [30]. Improved accuracy in the measurement of temperature can be of considerable value to health. Many diagnostic tests are temperature-dependent, in particular enzyme rate analyses which require rapid measurement of very small samples. Variations between labs, and even within labs, are often so great as to make comparisons useless. Acidity and blood gas analysis require small accurate sensors. But thermistors, widely used in medicine, are inadequately characterized. Accurate temperature measurement of tissues is important to avoid damage in the use of diathermy and ultrasonic therapy.

Spectrophotometry [31]. Spectrophotometry is used in 90 percent of clinical tests. In some, such as hormonal analyses and tests for the presence of drugs, a high rate of error could be reduced by improved accuracy. The lack of comparability of test results hampers the progress of medical research.

Fluid flow [32]. Fairfax County, Virginia, a suburb of Washington, D.C., is one of numerous jurisdictions where construction has been limited by the capacity of its water pollution control and treatment plant. The five percent uncertainty in measuring water pollution, if eliminated, would permit the construction of an additional 2,200 housing units, worth around 100 million dollars. Such additional housing would generate more than two million dollars a year in additional property tax revenue, as well as other tax revenues. But it would also impose additional costs on local governments. The net benefit to Fairfax County of eliminating measurement uncertainty would be the additional capital and operating cost of a facility that is five percent too large, plus the difference between additional revenues brought in by 2,200 households less the additional costs they impose on the county.

One area of flow measurement where improved capability is needed and would have a large payoff is the rapid measurement of variable wind velocities. A particular application is the problem of wind shear at low altitudes, which some believe accounts for as much as fifteen percent of plane crashes occuring during landing. Although no estimates are available on the probable saving in lives and other benefits, the value of even a few lives saved would justify substantial measurement improvement costs. Studies have shown a very high benefit-cost ratio for an improved wake vortex avoidance system that would allow reduction of the distance required between planes coming in for a landing. Reduced separation in turn would save airline and passenger time and economize on fuel and airport capacity.

Radiometry and photometry [33]. The accuracy realized in radiometric and photometric measurements at NBS varies from 1 to 5 percent, whereas in the field the best performance is likely to be 5 to 10 percent. There is some consensus that 1 percent accuracy is desirable in a number of uses: better weather forecasting, remote sensing, detecting improvements in the efficiency of lamps.

Lighting consumes 25 percent of the electric energy in the U.S. Sales of the lamp industry total $1 billion a year. Thus efficiency in lighting, and improvements in lamp efficiency, have large potential benefits. Gains in efficiency, with savings in electric power, come in small increments, so that accuracy is needed to accelerate improvement. The industry is hampered by lack of agreement in measurement of lumens, reducing efficiency in use of lamps. Differences of 2 to 22 percent have been observed. For light-emitting diodes, there is more than a 40 percent disagreement among manufacturers in specifications. Accuracy is also important for performance in the $5 billion a year photographic industry.

Accuracy in measurement is a factor in health. Safety in phototherapy requires a 10 percent maximum uncertainty, which is probably not available in any hospital, although well within the state of the art. Improvements in measurement are needed to evaluate the health impact of new types of lamp, with their diverse spectral characteristics.

3.2.4 Case Studies of Measurement in Sales Transactions

Fluid flow [32]. Orifice meters, among the most common used to measure pipeline flows, have uncertainty in the published values of their discharge coefficients of about 2 percent for water and other liquids and about 3 percent for gas. It is common practice for gas transmission companies to transport as much as $1 million worth of products a day across one meter station. Therefore, an improvement of only 0.1 percent uncertainty of measuring the flow rate involves a value of gas transferred equal to $1000 per day.

Long distance transfers of water are becoming important. The California water project, a major interbasin transfer of water supply between northern and southern parts of the state, has an uncertainty in flow rate measurement of about 5 percent. With charges of approximately $62 per acre-foot for irrigation water in the Los Angeles area, the uncertainty or error of flow rate can correspond to a significant sum. Efforts are currently being undertaken to reduce the error in flow rate measurement to 2 percent.

The improvements in measuring fluid flow have efficiency effects, because reductions in error or uncertainty can reduce the range within which buyers and sellers must bargain. Gas transmission companies might find it less costly to negotiate the sale of gas across metering stations and water users in southern California might negotiate water purchases with less haggling. These resources saved in the form of reduced transactions costs are a measure of the benefits of improved measurement in the efficiency of fluid transfers. These improvements in measuring fluid flow can also have equity effects because they more accurately measure the fluid transfers and can result in changes in the welfare of buyers and sellers.

Thermodynamic properties of fluids [26]. For more than a decade, the United States has been importing liquid natural gas, transported by LNG ships. Custody transfer contracts for natural gas are based on heating value, measured in BTU's. Actual transfer is based on the composition and the quantity of the material. The latter is measured by a flow meter that measures pressure, temperature, and flow rate to provide data which then is mathematically converted to a measure of the quantity of material present. It has been estimated that present uncertainties in the density of liquid natural gas could result in a cost of about $15,000 in the transfer of the custody of the contents of a typical LNG ship. If the United States eventually imports liquid natural gas from 500 ships annually, the estimated annual cost of uncertainty would amount to $8 million. That amount could be higher if gas prices continue to rise. Improvements in flow meter measurements could reduce the uncertainty regarding LNG transferred, which would have efficiency effects in reducing transactions costs between buyers and sellers. Improvement in flow meter measurements would also have equity effects to the extent that improved measurement reduced bias in flow meter measures.

Most custody transfers of ethylene take place near Houston, Texas. The critical point of ethylene is about 9.5°C, which approximates the ambient conditions in the Houston area in the winter. Temperatures near critical are therefore a usual environment for the custody transfer of ethylene. Properties of ethylene are poorly known, even several degrees above the critical temperature zone. Because of this, custody transfer is uncertain and requires increasing the temperature of the ethylene to one at which its properties are better known. Steam plants, which cost about $30,000 in 1970, are used to raise the temperature of the ethylene. The plants typically have no other function and after the ethylene has passed through the flow meter and the custody transfer has taken place, the temperature of the ethylene is lowered. In this example, improved measurement of ethylene could again have an efficiency as well as equity effect. From the view of the firm selling ethylene, improved measurement could eliminate the costs of a steam plant used to raise the temperature of the ethylene. From the standpoint of both buyer and seller, a reduction in the uncertainty in measuring ethylene transferred would reduce the transactions costs and to the extent of bias in measurement result in a shift in the real value of the ethylene transferred.

It is important to emphasize again that though the microstudies convey some idea of how improvements in measurement may benefit producers and consumers in the private sector, they do not necessarily provide the detailed justification needed to increase the allocation of resources to improving measurement. To use the example from humidity and moisture, it is clear that an individual producer might benefit from more accurate measurement of the moisture content of his crop. It is not clear that those benefits are sufficient to justify an increased allocation of the farmer's resources to improve accuracy in measuring moisture content by both farmer and elevator operator. To do this he would need to determine his improvement in revenue from improved moisture measurement capability as well as the costs of improved measurement in terms of the instrumentation and labor costs required to increase accuracy. Since both the costs and benefits of the improved measurement accrue over future time periods, he would have to discount these benefits and costs to determine the present value of the improvement in measurement. Even if the improvement in measurement were justified in terms of benefits and costs to the individual farmer, he would have to take into account secondary effects upon other decision makers. For example, the grain elevator operator may respond not only by improving the accuracy of his measurement of the moisture content of grains but also by adjusting price to recover any losses experienced in the transaction. Then the benefits of improved accuracy in measurement of moisture content may accrue in part to the grain elevator operator, in part to the individual farmer, and in part to consumers of grain which is to say to society via improved management of resources. It should be clear that a much more rigorous analysis of improved measurement of the moisture content of grains is required before one could justify an increased allocation of resources to this measurement activity from the standpoint of private benefits and costs, let alone from the standpoint of social benefits that would accrue to third parties. On the other hand, the basic social goal of equity in trade may indicate a need for action by state and local weights and measures authorities, independently of considerations of efficiency and exact cost-benefit analysis.

4. ECONOMIC ANALYSIS OF COSTS AND BENEFITS OF MEASUREMENT IN THE PUBLIC SECTOR

4.1 Government and the National Measurement System

4.1.1 Introduction

In this part of the study we move from an analysis of measurement activity in the private sector to analysis of measurement activity in the public sector, and specifically of the National Bureau of Standards' role in the system. The same caution introduced in the previous section must be repeated here; it is impossible to determine the economic costs and benefits of the total government role in the measurement system. It is possible to analyze the economic aspects of incremental changes in government activity in the measurement system. Thus, we will break down activities of the National Bureau of Standards into three major categories, maintaining basic standards, research and development, and services (i.e., calibration, dissemination and publication). Within each of these categories we have chosen examples of costs and benefits of specific projects from the micro studies. Note that these categories are meaningful from the standpoint of economic analysis; they may be less meaningful from another perspective such as that of the physical sciences. Before examining these case studies we briefly summarize the economic rationale for government intervention in the measurement system.

4.1.2 Economic Rationale for Government Measurement Activity

4.1.2.1 Measurement as a "Public Good"

In economics two major categories of goods and services can be defined--private goods and collective or "public" goods. For private goods, users are charged for what they consume with the assumption made that under conditions of pure competition, the amounts they pay measure the value to them of the item consumed. Since the consumption of the good in question by one individual precludes its consumption by another, the value of the commodity to the user is the same as its value to society. This assumption is not valid in the case of collective goods. Collective goods are defined such that each individual's consumption of such a good leads to no subtraction from any other individual's consumption of that good. Further, a decentralized pricing system may not serve to determine optimally the level of collective consumption.

Previous sections have developed the idea that measurements provide information which benefits producers, consumers, and the interaction of producers and consumers in sales transactions. Information provided by measurements may be a collective good because the information provided by a single measurement can be given to any number of people with no one suffering a loss of the information. Further, the cost of disseminating the information from measurement to another person may be trivially small. Finally, some producers of measurement information have substantial investment in equipment and specialized people who make relatively few measurements. For these producers the marginal cost of taking another measurement, i.e., obtaining another new piece of information, likely is less than the average cost of measurements.

The above facts suggest that increasing returns prevail in the production of measurement information and that the private market system will not necessarily produce measurement services up to the point where marginal cost is equal to marginal revenue. To this extent, the private market system may not allocate resources to the measurement system efficiently and general welfare is not optimum. These characteristics of measurement information begin to give a justification for possible government intervention into the area of providing measurement services to people. However, before unconditionally accepting government intervention in the provision of measurement services, we can ask under what circumstances will collective government supply be more efficient than private or noncollective supply.

In principle, resources are not necessarily misallocated because measurements, a collective good, are supplied by private sellers. Misallocation of resources could be demonstrated only if we could show that an alternative institutional method of providing measurements could be found which cost less than the present system and which provided adequate devices for signalling when resources should flow into or out of the production of measurements. Although measurement information used in production and consumption exhibits many public goods characteristics, there are no grounds, based simply on these characteristics, to assume that the supply of these measurements by the competitive market place is nonoptimal. Specific evidence is needed to establish any such conclusion. [34,35,36,37].

The following examples illustrate the public goods characteristics of measurement and suggest areas where reliance on the private sector would probably result in a misallocation of measurement resources:

4.1.2.2 Measurement and Consumer Protection

Because measurement plays a vital role in the quantity, but probably more importantly, in the quality of consumer goods, measurement technology and measurement standards require some collective or governmental supervision. Measurements can affect the consumer in at least four different ways. First, measurement standards provide technical information directly to the consumer. The consumer can use this information to understand and to select between relevant alternatives offered on the market. Measurement information also provides a means for the consumer to be aware of various kinds of nonprice competition, such as different amounts of particular ingredients in different size containers. Finally, measurement information can help the consumer to protect himself against possible fraud.

Secondly, measurement information can keep the consumer's consultants informed. Consumers necessarily purchase items that contain combinations of ingredients that are beyond their technical expertise, such as medicines and drugs. In his purchase of these commodities, the consumer usually relies on the advice of his physician or his pharmacist.

In the third place, measurement information can protect the consumer from inferior or dangerous products. To be sure, measurement information is required to establish minimum standards for the foods, drugs, and cosmetics that consumers buy. Measurement information is also the basis for the recall of products that might endanger the health or even take the life of the consumer. Recalls of products have included such diverse items as canned mushrooms, color television sets, microwave ovens, and automobiles.

Fourthly, measurement information is necessary to enforce state and federal regulations that establish minimum quality and safety standards that protect the consumer and his environment. Without measurement technology, there would be no way to enforce some of the laws and administrative rulings of such bodies as the Department of Agriculture, the Environmental Protection Agency, the Food and Drug Administration, and the Consumer Product Safety Commission.

4.1.2.3 Measurement and Health and Safety

Measurement information and the development of improved measurement technology requires federal supervision and management to promote the health and safety of the American worker. At the federal level, the Occupational Safety and Health Administration, Department of Labor, has the main responsibility for providing the worker with a safe environment. Other federal agencies, such as the Mining Enforcement and Safety Administration (Interior), the National Transportation Safety Board (DOT), the Federal Maritime Commission, and the Federal Metal and Nonmetallic Mine Safety Board of Review, also play a role in protecting the worker. In addition, there are hundreds of state and local authorities with mandates to protect workers. These governmental bodies require measurement information and measurement development to appraise the effectiveness of their standards, as well as to enforce their standards.

A federal authority with measurement responsibilities provides a valuable service both to the governmental regulators and to the business community that must comply with minimum work safety standards. Measurement information and new measurement technologies can provide the firm with an information input that can minimize the costs of compliance. This is especially true for small businesses and for other firms with low profit margins.

4.1.2.4 Measurement and International Trade

Measurement and developments in measurement technology play a large role in international political and economic relations and in the international exchange of scientific findings. Although it was not a scientific breakthrough, the July 1975 docking of the Apollo and the Soyuz spacecrafts serves as an example of the importance of measurement technology to the objectives of U.S. foreign policy. Without government provision of sophisticated measurement technologies, the Apollo-Soyuz mission could never have taken place. The development of these measurement technologies dates from the early work that the Harry Diamond Laboratories conducted in conjunction with the Department of the Army Ordnance Corps. Although there have been some private attempts to rent or to buy the remaining Saturn V vehicles for missions to the moon, it is not likely that private funds would have supported a mission such as the joint U.S./Soviet docking.

Less spectacular, but perhaps none the less important, are the day-to-day transactions in foreign trade where comparability and measurement are of the essence. Scales and instruments, specifications of weights and dimensions, in short, all quantitative international communications are cases in point. That these matters must be coordinated by governments is a point of self evidence.

4.1.2.5 Measurement Research and Development [38,39,40]

Up to now we have been considering the use of measurement information by producers and consumers. Improved measurement requires research and development expenditures to create the knowledge that underlies the supply of better measurement information to producers and consumers. The rationale for private research and development expenditures to improve measurement is the extent to which improved measurement is consistent with profit maximization of the firm (as generally discussed under 3.1.2.) A profit seeking firm will undertake research projects if the expected gains exceed the expected research costs, and if the total research and development cost is exceeded by the expected net value of the invention. When the results of applied research are predictable and relate to a specific invention desired by a firm, the opportunities for private profits through applied research may result in the optimum quantity of the society's resources directed to that invention. Obviously, however, there is a continuous spectrum of scientific activity between basic scientific research at one end and applied scientific research at the other. As one approaches the basic science end, the degree of uncertainty about results of specific projects increases and goal becomes less closely tied to the solution of a specific practical problem or the creation of a practical object. This loose defining of goals at the basic end of the research spectrum is a rational approach to the great uncertainties involved here and permits a greater expected payoff from the research dollar than if the goals were more closely defined. Thus, the direction of the basic research project may change opportunistically as the research proceeds and new possibilities appear. Applied research is usually unlikely to result in significant scientific breakthroughs except by accident, because if such important breakthroughs are needed as a prerequisite to the resolution of a particular practical problem, the likely costs of achieving these breakthroughs via direct research effort are likely to be very high.

Thus significant advances in knowledge usually require basic research but basic research efforts usually generate substantial external economies. Here private profit opportunities by themselves are unlikely to draw a sufficient quantity of resources into basic research, at least from the viewpoint of social desirability. Significant advances in scientific knowledge often have practical value in many fields, yet few firms operate in such a wide array of economic activities that they are likely themselves to benefit directly from all the new technological possibilities opened by the results of a successful basic research effort. In order to capture the value of the new knowledge in fields in which the firm is not operating or willing to enter, it must patent the practical applications and sell or lease the patent to firms in the affected industries. These significant advances in scientific knowledge are not often directly applicable to the solutions of practical problems faced by the individual firm and hence are not likely to lend themselves to quick patenting. Thus, it is unlikely that a firm will be able to capture through patent rights the full economic value created by basic research projects. If the research results cannot be patented quickly and are not kept secret by some other method, other competitors or firms producing products which use similar processes will be free to use the results as an input to their own programs. The fact that many industries have a need for new knowledge but lack the incentive to individually produce that new knowledge suggests two routes which have been used in different places at different times. One is to have government research undertake such tasks and another is to establish cooperative industrial research organizations as in the case of Great Britain.

All of the foregoing is based upon the argument of external economies which open a gap between marginal private and marginal social benefits from basic research. With respect to research and development to improve knowledge relating to measurement, we begin with substantial evidence of a viable market for knowledge about improved measurements. It is generally true that measurement users can, *a priori*, determine the value to themselves of improved measurements. It is also generally true that this knowledge can be confined with the aid of laws and regulations (such as patent laws) and therefore producers of new measurement knowledge can charge some price for the new knowledge. The revenue flowing from the sales of this new knowledge will signal resources to flow in or out of the new knowledge making business. Where the supplier of improved measurements is confronted with a conceptually knowable demand schedule, suppliers of improved measurements can estimate the returns from producing the improvements. Further, by use of the patent system or similar ownership system for knowledge, the developers of improved measurements could appropriate for themselves more of the value of the improved measurements.

But the existence of a market for improved measurements and the ability to command a price for the knowledge of improved measurements does not indicate whether the private sector allocates an optimum amount of resources to the manufacture of this knowledge. Two other elements are also important. One is the long lag that normally occurs between the start of a basic research project and the creation of something of marketable value. Firms with short run survival concerns will not be so much concerned with profits many years from now and will undervalue basic research projects compared to society, even perhaps in the absence of external economies. A second fact is that the large variance in the likelihood of profitability from basic research projects will tend to cause a risk-avoiding firm, without the resources to spread the risk by running many basic research projects simultaneously, to value a basic research project at a significantly lower level than its expected profitability and again less than its social value, even in the absence of external economies.

The production of measurement knowledge is risky and success depends on a large host of interrelated uncertainties. The usual assumption is that risky ventures, such as attempts to invent an improved measurement technique, are discriminated against by inventors. It has also been argued that a patent system cannot induce too much activity of this sort leading to patented inventions because no patenter can charge for his patent more than it is worth and most will get a good deal less. If risk aversion is the general case, the expectation is that there is under investment of resources in the production of improved measurements. In this case, there is a rationale for the government to act as a risk bearer and consciously to spend some resources on the development of improved measurements.

4.1.3 Public Production of Measurement and Improvements in Measurement

We have identified the public goods characteristics of measurement and improvements in measurement. In this section we discuss the economic rationale for decision making in the public production of measurement and improvements in measurement. As in the case of private production of measurement, we begin with the specification of the goals of the government sector. The wide range of goals of the government in producing measurement are suggested in the national measurement system study; they include improvements in science and technology, education, public health and safety, environmental quality, energy, national defense, etc. Note that some of these goals such as scientific leadership are intangible and are denied the quantitative dimensions of a dollar common denominator. Thus, the government's position is more like that of a consumer seeking to maximize satisfaction or utility, subject to a fixed budget constraint.

One technique of economic analysis that has proven useful in rational government decision making is the technique of cost benefit analysis. Assume for the moment that the government is contemplating the production of a specific measurement good or service and that the costs and benefits can be quantified in dollar terms. The condition for an optimum level of government production of measurement product or service is that the marginal cost is equal to the marginal benefit. The criterion insures that the amount spent by the government in producing measurement goods and services yields a benefit which is at least equal to the value of products or services foregone in the private sector. It also insures that government production of measurement goods and services is not expanded at the expense of other government programs which yield greater benefits. The results of benefit cost analysis are usually expressed as a ratio $B/K+O$, where B equals present value of a stream of annual benefits, K equals dollars of immediate investment, and O equals present value of all operation and maintenance costs.

The National Bureau of Standards has conducted benefit cost analysis for a small number of projects. For many government measurement programs the benefits are non-quantifiable or can be quantified only at great expense. Where benefits are difficult to estimate, it is possible to apply an alternative technique called cost effectiveness. Cost effectiveness analysis assumes that a decision has been made to achieve a given objective which may be stated in quantitative terms, even though the benefits cannot be estimated in dollar terms. For example, the National Bureau of Standards may set as an objective the achievement of a given level of accuracy in the measurement of time. A variety of social goals may be enhanced by this improved accuracy, including scientific research, economic efficiency, national defense, etc. The benefits of the enhancement of this broad range of goals may be impossible to estimate in dollar terms; therefore the decision to achieve a given level of accuracy in the measurement of time ultimately rests on the evaluation of this program relative to other competing programs in the National Bureau of Standards. Assuming that a decision is reached to pursue this program, then the improved accuracy in the measurement of time should be achieved with the least amount of cost. Using cost effectiveness analysis various alternative methods of improving the accuracy in measuring time can be compared and a choice made which achieves the objective with the least cost. [41,42,43].

4.2 Costs and Benefits of National Bureau of Standards Activities in the Measurement System

4.2.1 Introduction

In this section we examine some costs and benefits of National Bureau of Standards activities in the measurement system. To understand the role of the National Bureau of Standards, it is necessary to provide some institutional background. This institutional background defines the primary mission or goals of the National Bureau of Standards in the context of broader social goals introduced in the previous section.

The Constitution vested power in the Federal government to regulate the monetary system and the measurement system: "The Congress shall have the power. . . to coin money, regulate the value thereof, and of foreign coin, and fix the standard of weights and measures." The analogy between money and a standard of weights and measures is tied to their functions as units of measurement. Money can be considered as a common unit of measurement analogous to units such as meters used to measure linear distance, kilograms to measure weight, liters to measure liquid volume, and so on. To be a satisfactory measure of value, the monetary unit, like the physical unit, must maintain a relatively stable value. When money does not maintain a relatively stable value, the public loses confidence in money as a unit of measurement and standard of value and therefore they refuse to accept it and use it. Similarly, without an acceptable physical standard, the public lacks confidence in the goods and services that relate to that standard. They will use scarce resources to compensate for the lack of an acceptable physical standard. These resources may be in the form of labor and capital used in overmachining parts, excessive quality control and testing of products, etc., that would be unnecessary with an acceptable physical standard. The social saving that results from the adoption of acceptable physical standards is the rate of return on resources such as the above that are no longer necessary to produce goods and services that conform to the particular standard.

The direct responsibility of the National Bureau of Standards, set down as a statutory obligation in 15 US Code 272, authorizes the Secretary of Commerce to undertake: "the custody, maintenance, and development of the national standards of measurement, and the provision of means and methods for making measurements consistent with these standards, including the comparison of standards used in scientific investigations, engineering, manufacturing, commerce, and educational institutions with the standards adopted or recognized by the government." The National Bureau of Standards defines the standards for physical measurement, acts as arbitrator and policeman regarding disputes over them, and attempts to improve the operation of the national measurement system. In many cases the NBS role is complementary to that of other government agencies assigned the task of enforcing measurement standards such as the state agencies for weights and measures and the Federal Environmental Protection Agency. Measurement information provided by NBS is the basis for regulatory and enforcement functions of these agencies.

Thus, the above legislation should be viewed as enabling legislation defining the scope within which NBS can legally conduct measurement activities. The actual level of measurement activity can be evaluated in terms of costs and benefits of the activity. The following sections explore the costs and benefits of National Bureau of Standards activities in three broad areas: maintenance of basic standards; research and development to improve measurement; and dissemination, calibration, and publication activities.

4.2.2 Maintaining Basic Standards

4.2.2.1 Background

NBS responsibility for maintaining primary standards is based on the existence of a "natural monopoly" for this function. There is need for a single primary standard. Although there may be and in fact there are competing calibration laboratories in many areas of measurement, they have to establish some method of mutual standardization. This must be ultimately a single laboratory for establishing and verifying primary standards. If there were no NBS to perform this function, its equivalent would have to be created. Competition in establishing and maintaining primary standards involves duplication and waste; it is for this reason that we identify this function as a "natural monopoly." If it were not a public monopoly, it would have to be carefully regulated to perform in the public interest. But a natural monopoly situation does not exist, either in the conduct of research or in the dissemination of accurate measurement.

4.2.2.2 A Case Study of the Basic Standard for the Lumen

While a rigorous quantitative analysis of the benefits of basic standards is usually impossible, it is possible to examine some qualitative evidence on the benefits of specific basic standards by examining situations where basic standards do not exist or are inadequate. A good example of the problems associated with the lack of a basic standard is the lamp industry, where there is no agreed upon standard for the lumen for many of the newer light sources [33]. A lumen is defined as a unit of measure for the flow of light. Apparently there is absence of confidence regarding this standard between the lamp industry and the consuming manufacturers who incorporate lamps into their own products and who maintain different unit sizes. The result of no agreed-upon standard for the lumen among these firms gives some insight into the benefits of a basic standard. With the development of new high intensity discharge lamps, the absence of standards leads to a separate discharge lamp lumen for each manufacturer. Since Company A lumens differ from Company B lumens, some firms who would prefer to stock one lamp, must maintain inventories for both lamps at added expense. Because one supplier's standard for the lumen may differ from anothers the whole production of that supplier may be rejected by a consuming firm. The difficulties resulting from this problem are now so pronounced that a number of these lamp buying firms are installing new acceptance testing laboratories at great expense. From the standpoint of suppliers in the lamp industry and organizations who use those lamps the absence of an agreed upon standard for the lumen results in lower efficiency and productivity, and higher costs than would exist if there existed an agreed upon standard. Theoretically, the benefits of the hypothetical standard lumen could be estimated by the reduced costs to firms who could reduce inventories of lamps conforming to different lumen standards, and in some cases, eliminate expensive testing laboratories for lamp products.

This example of lumens also provides insight into external benefits of basic standards. The lack of an agreed upon standard for the lumen affects consumers to the extent that higher costs for lamps are passed along to the consumer. The consumer may also incur the costs of uncertainty associated with the purchase and use of lamps with a wide range of potential error in luminosity. The consumer may be the little old lady comparison shopping in the supermarket, the commercial and industrial purchaser, the original equipment manufacturer, or government purchaser. The consumer, primarily large, but also small, currently has technical problems of three types as a result of the lack of an agreed upon standard for the lumen. He has problems of equipment compatibility; he has the efficiency problem of dealing with various manufacturers employing discrepant units, and he sometimes needs to compare a commercially derived number with a natural or more precisely scientific one (e.g., comparison of artificial illumination with natural light). The existence of one agreed upon standard for the lumen would reduce or eliminate these technical problems and the general uncertainty of consumers in purchasing lamps. Again, these external benefits to consumers are not quantifiable at present, but there is abundant qualitative evidence to support their existence.

The example of the lumen also illustrates the external benefits of basic standards for international trade. The working group of the Council for Optical Radiation Measurement, in noting the lack of standards among manufacturers and users of light emitting diodes and displays, cites as an important concern the "very large market domestically and internationally." The photographic industry expressed a similar concern. "Lamps are calibrated for our associated companies throughout the world." International trade depends on the world-wide acceptability of such measurement. The working group on total flux measurement of the Council for Optical Radiation Measurement, which includes representatives of the lamp industry notes that "many purchases are made on the basis of promised performance. A difference of one or more percentage points in promised performance will, therefore, determine the business to be done, either domestic or foreign by a given manufacturer or even by an industry. This can run into millions of dollars." "One company in the lamp industry, at least, has run into the fact that their lumen levels, for some, if not all lamp types, are different by several per cent as compared to this country. Sales of our industry off-shore have been slowed down because the European lamp manufacturers are talking loudly about the inflated lumen level of the United States products. Under such conditions, especially in a competitive business, it is very difficult to grow much of a market, at least in Europe where a considerable effort has been expended." "If we are to export lamps, our foreign customers must again know that Boston lumens are the same as Paris, London, Tokyo, or Istanbul lumens." This qualitative evidence suggests that a substantial boost to foreign as well as domestic lamp sales would result from acceptance of a basic standard for the lumen.

The previous discussion points to the benefits of a basic standard for the lumen; it does not necessarily justify the National Bureau of Standard's role in providing and maintaining that standard. Presumably such an agreed upon standard could also be selected and maintained by an organization such as a standards laboratory or lamp manufacturer in the private sector, or by another government agency. Assuming that these alternative sources could provide the same quality of service in maintaining the basic standard for the lumen, the question is whether these alternative sources could maintain that standard for a lower cost. Again, in most cases it is difficult or impossible to estimate the cost of maintaining a basic standard in an alternative organization, particularly where there is no experience to provide evidence for such costs, and we are forced to rely on qualitative evidence. The lamp industry provides a good example of an industry where a basic standard has not existed and where private firms and other government agencies have not been successful in establishing an agreed upon standard. The fact is that these firms are putting pressure on the National Bureau of Standards to provide the standard. This remarkable industry interest in greater activity by the NBS in part stems from actual experience in lamp companies which have had to derive their own luminous flux assignments independently. The result on the market is deplored by all concerned. The thrust of industry concern here is not "U.S. government, stay away," but rather "NBS, please help."

The failure of private firms to establish an agreed upon standard for the lumen is a classic example of the public goods nature of basic standards. Each of the firms is attempting to capture the maximum profits in the lamp industry and each firm has its own definition of the lumen. If the definition of the lumen used by one firm were accepted as a basic standard, the sales and profits of that firm would probably increase, while that of other firms with a different definition of the lumen would decline. Under these circumstances, it is not likely that these firms will agree voluntarily to accept and use a basic standard. Yet they recognize the benefits of a basic standard for the lumen.

With respect to the adoption of a basic standard such as the lumen, it is easier to achieve agreement regarding the basic standard through cooperation between private firms and the government (NBS). Further, the maintenance costs for the basic standard are probably lower in the public sector than in the private sector. There are complementarities between the maintenance of one basic standard and other basic standards due to the existence of technical expertise, and overhead expenses in the public sector can be spread over the whole range of basic standards. These economies of scale would be lacking if each basic standard were maintained by separate organizations in the private sector.

If it is determined, as suggested above, that no other organization would be able to establish and maintain a basic standard comparable to that by NBS at lower cost, then the relevant question for NBS is whether the desired quality for the standard is maintained at minimum cost (cost effectiveness analysis). This aspect of the maintenance of basic standards is examined periodically by NBS and substantial evidence suggests that their basic standards programs conform to cost effective criteria. The concept of internal opportunity cost assessment is also apparent in their review, i.e., if a program to maintain a basic standard were dropped, what would be the best program to be picked up, and how do the benefits and costs of the latter compare to the former.

4.2.2.3 Other Basic Standards

The example of the National Bureau of Standards' role in maintaining basic standards for the lumen cannot necessarily be generalized. The micro study reports provide examples where some basic standards are maintained more efficiently in the private sector or in other government agencies. The optics micro study shows that basic standards with reference to eyeglasses were developed and are efficiently maintained by private firms in that industry. The length micro study shows that physical dimensional standards for oil field equipment were developed quite successfully by a private industrial trade association. However, the oil companies, recognizing the economies of scale in the custodial care and maintenance of those standards, then turned them over to the National Bureau of Standards. There are no basic standards for surface properties, simply because the field is relatively new and pressures have only recently emerged for the adoption of basic standards. There are no basic standards for torque measurement and apparently no pressure in the private sector for adoption of those standards. The optics micro study reveals that basic standards relating to aerial cameras were developed by the National Bureau of Standards and subsequently turned over to the U.S. Geological Survey because the expertise in this area resides primarily in the latter government agency.

The range of experience with basic standards illustrated in the micro studies suggests that there is no *a priori* way to judge whether the National Bureau of Standards should necessarily assume a role in developing and maintaining basic standards in a particular field. If the private sector is efficiently performing this function or there is no pressure for adoption of basic standards, then *no* role for NBS will be the optimum. It is possible that basic standards developed in the private sector can be more efficiently maintained in the National Bureau of Standards and vice versa. What does seem to be important is that the National Bureau of Standards continually assess its role in terms of efficiency or cost effectiveness criteria. This may require experiments to see if private or other public agencies are more efficient in fulfilling this function. In some cases, while the experiment may appear costly and inefficient, this may be the only way that NBS can determine whether the maintenance of a particular basic standard is justified. For example, the ionizing radiation micro study provides an example where the National Bureau of Standards turned a function of primary standards maintenance over to private firms with resulting chaos. Private firms were unwilling or unable to maintain an acceptable level of accuracy in the basic standard comparable to that maintained by NBS and the function was subsequently reassumed by NBS.

4.2.3 Measurement Research and Development

4.2.3.1 Costs and Benefits of Government Sponsored Measurement Research and Development

The rationale for NBS performance of basic research is the presence of externalities. The products of basic research often cannot be appropriated by the organization conducting research, or not to an extent sufficient to provide an incentive for the conduct of research by private business. Patents are a technique for legal appropriation of some of the benefits of successful research in order to provide a profit incentive for private research. However, much of the activity involved in developing and improving measurement capabilities is not patentable. Even what is may be subject to great uncertainties and long delays in economic payoff, discouraging private investment.

Furthermore, basic research not only generates externalities, it has the character of a public good: use of its findings by some does not reduce use of them by others. Although costly to generate, they are nearly costless to reproduce and disseminate. Under these conditions, it may not be in the public interest for the research performer to capture the externalities, whether by patents or by other means, even if feasible.

As noted earlier, the benefits and costs of research are among the most difficult to identify because of the public goods nature of R & D. These problems are especially evident in R & D funded by NBS to improve measurements. Note that here we are not concerned with the maintenance and dissemination of measurements of given quality, but rather with improvements in the quality and dissemination of those measurements through research.

There are some instances in examining R & D projects where it becomes legitimate to use as a measure of project benefits the cost of the best alternative way of achieving the project goals. The use of alternative cost as benefit measure really results in choosing a project or design that minimizes the cost of achieving a predetermined objective, e.g., developing and disseminating measurement of given accuracy. This approach to project or program optimization where objectives are specified in quantified non-value (e.g., physical) terms and where the attempt is then made to minimize the cost of achieving the specific physical objective, is called cost effectiveness analysis, i.e., getting the biggest bang for the buck where bang is specified in non-value terms. It must be noted that when alternative cost is used as a benefit measure, the lifetimes of the two alternatives being compared should be approximately the same. Otherwise we are trying to compare quite different benefit and cost streams. All cost effectiveness analysis should be extended to include a sensitivity analysis with respect to the values of the specified objectives. That is, the analysis must compute the rates of change of the minimum achievable project cost with respect to that goal. This computation indicates the economic cost of increasing or decreasing the goals, information that is particularly valuable when the goals have been rather arbitrarily set.

4.2.3.2 Exploratory Studies of Benefits and Costs of Selected R & D Projects of NBS

Exploratory NBS studies of benefit-cost measurement in research and development have been conducted for:

(1) high accuracy large force calibration service
(2) high accuracy time and frequency service
(3) standardization of a specialized coaxial connector
(4) standard reference materials (SRM's) in iron and steel
(5) standard reference materials metals in oil
(6) semiconductor resistivity measurement
(7) liquified petroleum gas (LPG) meter calibration

In 1968 the National Bureau of Standards conducted an investigation of the costs and benefits of the above seven R & D projects. The following summary of that study is from John T. Yates, Jr., Howard E. Morgan, and Robert D. Huntoon, Exploratory NBS Studies of Benefit Cost Measurement in Research and Development. [3]

"Table 4 contains adjusted data for each of the seven projects with benefits and costs realized through 1967 at the center and expected in the 1968-70 period at the right. Relevant time periods for each project are shown in Table 4 footnotes. Data for four projects (large force calibration, time and frequency service, coaxial connectors, semiconductor resistivity) were reported for a multi-year period from project inception through 1967; data for the LPG meter calibration project and the SRM projects are based on the experience of a single recent year. At the center of Table 4 appear annual average cost and benefit data to permit statistical comparability of data covering different time periods. Expected costs and benefits for the 1968-70 period are three-year totals and were derived from a level extrapolation of historical data, except where noted in footnotes of Table 4.

"The totals at the bottom of Table 4 indicate that, to the extent the data are admissable and comparable, the seven projects cost the NBS about $0.8 million annually and yielded benefits worth $285 million annually of which $8 million were attributed to the NBS work. Projected costs for the 1968-70 period for six projects total $1.5 million and are expected to provide $1.35 billion in total benefits, of which $25 million are attributed to the NBS efforts (estimates for the large force calibration facility were omitted due to uncertainty).

"These exploratory case studies of seven NBS research projects have suggested methods and problems in measuring the economic value of publicly funded science. The studies were intended to determine if it were possible to measure retrospectively the economic pay-off of research in the physical and engineering sciences. Emphasis was given methods rather than resulting data. The objective of the investigation was achieved. Alternate methods of measurement were developed and evaluated and suggestions have emerged to guide future studies.

"A major, and perhaps not unexpected finding, is that research projects with different technological objectives may not be comparable on economic grounds because of qualitative differences in their economic impact. Consequently, project evaluation by administrators of science programs requires consideration of technological objectives and feasibility along with the economic value to principal users. Alternate projects having a clearly defined common economic objective should be evaluated on economic as well as technological considerations.

"Essentially, this concludes that 'cost effectiveness' analysis (comparing the cost of alternate ways of reaching a common objective) may be more useful in allocating science resources than economic 'benefit-cost' analysis (comparing the economic value of alternate uses of common resources), unless projects are close technological substitutes having similar restraints and objectives. Common objectives may be macro-economic (e.g., contribution to GNP or productivity growth) or micro-economic (e.g., savings or quality improvement for a user). The impact of research on the latter is easier to measure than the former because the links between the economics of a firm and the national economy are difficult to quantify.

"Other conclusions emerging from these studies were that:

"The micro-economic effects of publicly funded research can be measured. The measurement requires tracing the technological paths leading to adoption of an innovation by users. It has been demonstrated that this can be done through a cooperative effort by physical scientist, economist, and users of research results.

"The measurement of net economic value (or macro-economic change) is not possible with the methods used in this study. An extensive case study of the indirect effects of the innovation as they are diffused in the economy may be required in addition to the use of statistical or input-output models under limiting assumptions and measurable response.

"The direct economic effect of the seven NBS projects was an apparent improvement in productivity in industry and government resulting from yield or process improvements. This supports the argument that technology is an important factor in the improvement of economic productivity.

Table 4. Summary of economic benefits and costs of selected NBS projects, 1967 [3]
(Millions of Dollars)

	Realized (through 1967)						Total Expected 1968-70[m/]		
	Total			Annual Average					
		Benefits			Benefits			Benefits	
Project	Costs	Total	NBS Share	Costs	Total	NBS Share	Costs	Total	NBS Share
Large Force Calibration	1.350	0	0	.071[a]	0	0	?	?	?
Time & Frequency Service	3.000	18.20	8.80	.405[b]	6.05[c]	2.95[d]	0.735	18.15	8.85
Coaxial Connectors	0.225[n]	0.03[e]	0.005	.019[n]	0.03	0.005	0	0.052[e]	0.009
SRM (Iron & Steel)	0.192[p]	209.30[f]	2.34[f]	.192	209.30	2.34	0.576	1,120.00[g]	5.60[g]
SRM (Metals in Oil)	0.406	1/	1/	.058	68.30[h]	1.36[h]	0.174	204.90	4.08
Semiconductor Resistivity	0.235	0.60[i]	0.54[i]	.034[k]	0.60[i]	0.54[i]	0.025	4.68[r]	4.21
LPG Meter Calibration	0.072[q]	1.10[j]	0.88[j]	.008	1.10[j]	0.88[j]	0.024	3.30	2.64
				.787	285.38	8.075	1.534	1,351.082	25.409

a/Equipment cost of $1,258,000 depreciated over 50 years plus annual average operating cost of $46,000 based on 1965-66 operating cost of $92,000.

b/Average annual cost of development of cesium beam standards 1958-67 ($1.6 mil. ÷ 10) plus capital cost of WWVL and WWVB depreciated over ten years, 1965-74, ($0.7 mil ÷ 10) plus annual average operating cost for WWVL and WWVB FY 1964-67 ($0.7 ÷ 4).

c/Sales of equipment $12.2 mil. estimated to extend from 1963 or 1964 through May 1967 or approximately 4 years ($12.2 ÷ 4) plus labor for use and maintenance for 2 years ($6.0 mil. ÷ 2).

d/NBS contribution to sales divided by 4 years ($5.8 mil. ÷ 4) plus NBS contribution to labor divided by 2 years ($3.0 ÷ 2).

e/Actual sales of connectors in 1967 and estimated potential in 1968-70.

f/Reduced cost of Mn, Ni and Cr plus reduced cost of steel production using basic oxygen process, 1966 only.

g/Based on accelerated rate of steel production using basic oxygen process.

h/Reduced maintenance cost for railroad and trucking engines plus reduced losses of aircraft due to engine failure.

i/Realized increase in yield for 12 months in FY 1965-66.

j/Value of reduction in measurement error, 1966.

k/Total FY 1961-67 costs of $235,000 divided by 7 years.

l/Totals not available; estimates are annual for selected years.

m/Expected costs and benefits are a total for the three years 1968-70 and are estimated at annual rates shown in past unless other estimates were available.

n/Based on period 1956-67.

p/1966 only.

q/1958-1966.

r/Based on historical growth rate of semiconductor materials market over past 8 years.

Table 5. Comparison of gross and net benefits and benefit-cost ratios for selected NBS projects through 1970 (annual average NBS costs and benefit contributions only)[a/] [3]

Project	NBS Costs	NBS Contribution to Benefits: Gross	NBS Contribution to Benefits: Net	Gross Benefit to Cost Ratio
	(Millions of dollars)			
Time and Frequency Service	.288	2.950	+2.662	10/1
SRM (Iron and Steel)	.192	1.980	+1.788	10/1
Large Force Calibration	.071	0	-0.071	0
SRM (Metals in Oil)	.058	1.360	+1.302	24/1
Semiconductor Resistivity	.026	1.026	+1.000	40/1
Coaxial Connectors	.015	0.004	-0.011	0.3/1
LPG Meter Calibration	.008	0.880	+0.872	110/1

a/ Annual averages based on period studied and extrapolated to 1970. See footnotes for Table 4 for dates included.

Source of tables 4 and 5: Yates, Morgan, and Huntoon, Exploratory NBS Studies of Benefit-cost Measurement in Research and Development [3]

"Results of the seven studies were largely noncomparable due to differences in:

a. Project technological objectives
b. The method and completeness of the measurement of economic value
c. Point in project life at which benefits and costs were measured
d. Present values not properly discounted over time
e. Treatment of capital costs
f. Basis for estimates of relative NBS contribution
g. Approach and judgment of different investigators

"Case studies of the economic effects of science projects may have greater value to the scientist than the administrator of science programs in that the exercise forces a careful examination of the relevance of science to the solution of practical problems." [3]

4.2.4 Measurement Services of the National Bureau of Standards

4.2.4.1 Services in the National Measurement System

Calibration, dissemination, and the provision of reference materials lack the character of natural monopoly, public goods, or externalities. The basis for a NBS role lies in the presence of economies of scale and specialization. For example, the capital required to calibrate to primary standards is costly; where the calibration process itself is time consuming or expensive, the amount of primary calibration services demanded by users may be small relative to the capacity of primary calibration facilities and personnel. A single supplier under these circumstances can lower costs as it expands its activities, and keep costs much lower than if two or more suppliers were each to provide the capital and divide up a limited market. Further down the calibration chain, the costs of calibration are smaller, the number of calibrations demanded by users much larger, so that all available scale economies can usually be attained by more than a single supplier. NBS then loses its distinctive role. Commercial laboratories sell calibration services, and many firms provide their own. Economies of scale may also occur in some types of research that recommend a single research performer. This is most likely to be the case when very expensive capital equipment is involved.

4.2.4.2 Calibration and Dissemination Services

Calibration and dissemination services of NBS generally involve rendering a service to firms, consumers, and other government agencies which is clearly identifiable and for which in some cases there exists a market test. The measure of benefits and costs for these and other services of NBS must extend beyond the market values that comprise GNP; however, the most explicit benefits from these services are the market values of the services produced. If private firms are willing to pay for measurement services from NBS such as charges for calibrating instruments, the amount they are willing to pay is at least a lower bound estimate of the value of these services. Similarly, if other government agencies are contracting with NBS for measurement services such as calibration, the revenue generated by the contract is a lower bound estimate of the value of those services.

The same situation is true for costs. The most explicit costs are those related to project inputs for which funds have to be paid out. In the case of calibration and dissemination services, this should include all of the labor, capital, material, and overhead expenses associated with the service. The problem is to select among several prices or wages to cost out these inputs, but market prices are available.

Even where a user of NBS measurement services pays a price for those services, that price may not be an accurate measure of the cost of the project. For example, in June 1970 the Comptroller General reported to Congress that fees charged by the NBS for calibration of instruments had resulted in overcharges to the Department of Defense of $806,000 during fiscal years 1966-1968 and undercharges of $713,500 to private industry [44]. The General Accounting Office recommended that the Bureau review its accounting procedures to ensure that user charges for services for private industry include depreciation of buildings and departmental overhead and to correct inequitable or inconsistent methods of allocating overhead costs in general. Following receipt of a draft of the GAO report, the Bureau revised its pricing policy for calibration and test services in July 1969 and again in April 1970, but it disagreed that there was a need for improving its accounting system in the manner recommended.

The above example illustrates a variety of problems in measuring the benefits and costs of NBS services. One problem is that the calibration services provided by NBS are so large relative to the total calibration services in the economy that they probably affect the prices of the latter, presumably lowering the price of calibration services in the private sector relative to what those prices would have been without NBS. Added to this is the problem of market imperfections in calibration services. Many companies maintain calibration service as in-house components of their production process so that prices for those services are arbitrarily set without a close relationship with costs. Therefore, it is difficult to use prices for calibration services in the private sector as a measure of the value of calibration services by NBS since that assumes competitive market prices that relate closely to costs. If the GAO charge is accurate, then the NBS was in effect providing a subsidy to private firms and a tax or surcharge to the DOD for calibration services. This differential pricing makes it difficult to use market prices to measure the benefits and costs of these services, and also suggests a misallocation of measurement resources, i.e., private firms consume measurement services in excess of that which is justified by the value of measurement resources in alternative uses, and the DOD consumes less than an optimum volume of measurement services.

We should also mention several other problems that are also relevant in estimating the costs and benefits of measurement services. One problem is that the prices paid by NBS for factor inputs may be overvalued or undervalued. This problem is extremely difficult to evaluate; some economists have charged that government agencies tend to undervalue capital equipment and especially buildings, because these capital inputs are provided to the government at subsidized rates. It is charged that government employees' wages, including fringe benefits, are in general higher than those in the private sector for comparable qualifications and job skills. If the prices of these factor inputs are undervalued or overvalued in NBS, then they are not an accurate measure of the social costs of NBS services. It should be added that in a less than full employment economy, the wages of employees and rates of return to capital may not reflect the opportunity costs of those resources, i.e., the private costs exceed the social costs. However, this problem is less relevant to NBS, which tends to employ highly skilled employees and very specialized capital equipment.

A final problem is the indirect effect of calibration and dissemination services on the economy or external benefits and costs. We should be cautious in evaluating these external benefits and costs. Any kind of expenditure, public or private, has secondary effects on other industries, i.e., input suppliers and output buyers. In a fully employed economy, expansion of NBS services causes at least a temporary contraction in those areas from which its labor and capital are drawn and also makes profitable the expansion of industries supplying processed inputs or dependent on the projects' output. Thus, whereas an NBS project is likely to have positive secondary effects on related industries, the private projects that are foregone or reduced in size because of the taxes collected to finance the project will have negative secondary effects on their related industries. There is no reason in a fully employed economy to expect the positive secondary effects of the new public project to be any greater than the negative secondary effects of reduced private spending.

As an extreme example of the above, we can examine the time of day service provided by the time and frequency group. One can point to the expansion of a number of firms in the private sector that rely on the time of day service of time and frequency through the telephone companies, but this has been accompanied by a contraction of firms in the private sector dependent on time of day service from USNO, e.g., Western Union [45].

The major problem in identifying the benefits of calibration and dissemination services in NBS is that it is usually not clear what level of services, if any, would be picked up in the private sector if NBS discontinued its services. However, there are a few examples of changes in NBS calibration services that provide some qualitative evidence of these benefits. The time and frequency division recently reduced the area of dissemination of WWVB signals significantly. There was an immediate response from users of that service to restore it at the former level. On the other hand, the optics groups has found that some of its measurement services are not essential in the sense that alternative sources of optical measurement service exist in the private sector. The optical radiation group has experienced a similar response. They find that it is conceivable that, eventually, virtually all of their calibration and testing services will be obtained from the commercial secondary standards laboratories; at present, however, the frequent discrepancies in measurements encourage many users to get calibrations from NBS. On the other hand, the ultraviolet radiometry group has found that when NBS reduces the calibration and dissemination services to the private sector, that private firms and alternative suppliers do not adequately fill the gap in the sense that the quality of measurement achieved declines. The fluid flow group also finds that private firms cannot maintain the same level of accuracy without NBS calibration and dissemination service.

4.2.4.3 Provision of Standard Reference Materials

The National Bureau of Standards has attempted to assess the costs and benefits of its standard reference materials program. The following summary is from James Bennett, The Economic Impact of Standard Reference Materials [46].

"NBS defines a Standard Reference Material as a well characterized material, produced in quantity, that calibrates a measurement system. Essentially, SRM's are samples of materials with certified chemical and physical properties (e.g., chemical composition, density, viscosity) which can be sent to the user so that measurement equipment can be calibrated on-site. The existence of SRM's obviates the need for and saves the expense of sending measurement devices to a laboratory outside the firm for periodic calibration. Basically, SRM's have two principal functions which are associated with improved efficiency in (1) industrial and research processes and (2) the specification and testing of characteristics of products.

"In this report, emphasis is given to the economic benefits which result from the use of SRM's specified in (1) above, i.e., the benefits accruing from reductions in waste and inefficiency when SRM's are employed to achieve better process control through improved measurement. This does not imply that the other function is of minimal or secondary importance. A clear definition of and basis for the measurement of performance characteristics is essential to buyers and sellers in both national and international markets. Rather, the benefits from cost reductions in process control applications are more easily identified and yield more readily to quantification than benefits such as those that are derived from the use of SRM's in research which have benefits over a much longer time scale and are difficult to assess. To the extent that these benefits are not treated in this report, the magnitude of the estimated total benefits can be regarded as understated or conservative.

"The purpose of this report was to assess the economic benefits and costs of the Standard Reference Materials program of the National Bureau of Standards and to provide indications of the extent of economic leverage of the program.

"The SRM program is extremely diverse, for about 850 well-characterized materials used for calibration in the measurement process are available. Because economic benefits arise from the use of SRM's rather than from the program per se, two generic groups of SRM's were selected for investigation: the 24 metallo-organic compounds that are employed in spectrographic analysis of lubricating oil to detect for trace metals which indicate impending engine failure and 31 ferrous metal SRM's which are used in process control in the steel industry. The ferrous metal SRM's permit the reduction in waste of expensive alloying elements, reduce the number of inaccurate measurements obtained by other (more time-consuming and expensive) means, and reduce the cost of recycling rejected production steel.

"Although these SRM's account for only 6.4 per cent of the 850 types currently in stock, total annual benefits of at least $75 million could be traced to the SOAP program which uses the metals in oil SRM's and $18.3 million to the sample of ferrous metal SRM's. A benefit-cost ratio of at least 1000:1 exists for the metallo-organic compounds. No benefit-cost ratio could be explicitly computed for the ferrous metal SRM's because some of these materials were originally introduced almost 70 years ago and cost data are not available. All evidence indicates that although the research and development costs are incurred once in the development of SRM's, the benefits resulting from their use can accumulate for years. Important sectors of the U.S. economy benefit from the SRM's reviewed in this report: the Department of Defense, the transportation sector, and the metals industry. These sectors of the economy are basic to the functioning of the economy and contribute significantly to national output and employment.

"One difficulty in calculating benefit-cost ratios is due to the question of what are the relevant costs. In considering the cost of an SRM, only the additional or marginal costs should be included - not the investment in basic research. R & D costs are one of the principal cost elements of SRM's, but these costs should perhaps be categorized as an investment in research because the Congressional mandate for NBS requires that levels of scientific competence be maintained in a wide variety of areas. Foreign counterparts of NBS do classify R & D costs of SRM's as overhead. The cost of production, obsolescence, and operations are recovered by user fees collected from the sales of SRM's. The net cost to the government of the program is very small and during the period 1969-1974, NBS appropriations have averaged only about $2 million per year.

"A second difficulty arises when one attempts to allocate the total benefits among the various factor inputs, one of which is an SRM. SRM's are used in conjunction with measuring devices and other factors. It was not possible to determine which 'share' of the total benefit should be attributed to the SRM and, obviously, the benefit-cost ratio is overstated when all benefits are allotted to the SRM. In order to correct to at least some degree for this overstatement, total benefits were estimated conservatively for only a brief period of time. All evidence indicates that the benefits will continue to accrue, perhaps for years. In any event, it is justifiable to assert that the benefits due to the SRM exceed any reasonable estimate of the cost by a very wide margin. In addition, all the uses of the SRM's are not even known and may not be known for years into the future. For these reasons the benefit-cost ratios computed here should be regarded more as indicative of order of magnitude rather than exact calculations.

"The SRM program can also have a direct impact on national goals. For example, if any of the cost savings experienced by industry is passed onto the consumer, domestic inflation is moderated. Lower cost and lower prices assist American industry to compete in world markets to improve the U.S. balance of payments. Reduction of waste of imported materials also aids the balance of payments. More effective competition in world markets also helps solve the unemployment problems in the U.S. by providing jobs to U.S. workers. SRM's are also important inputs to the research process which, eventually, results in better products and more efficient industrial processes.

"NBS is uniquely qualified to produce SRM's for a variety of reasons. First, it has a reservoir of highly competent talent which is capable of performing the research required for these materials; the development of a specialized team may not be economically feasible elsewhere - particularly in fragmented industries where firms are small in size. Second, industry-wide standards are generally needed, often from a 'neutral' supplier which guarantees continuing availability. Third, traceability to NBS of measurement systems are sometimes required by military specifications. Finally, the benefits resulting from SRM's are directly related to the speed of adoption of the measurement system. NBS has the capacity and the incentive to publicize the existence and uses of the SRM as widely as possible.

"In sum, based upon the findings of this report which investigated in depth only a small sample of SRM's, the benefits are extremely large relative to any reasonable estimate of the relevant cost. As the program expands into other areas of national concern such as pollution, health, and agriculture and serves the needs of other industries, the total benefits will probably also grow. Put another way, if every dollar of government spending produced as high a rate of return over as long a time period as SRM's, the national economy would likely be substantially improved."[46].

4.2.4.4 Publications

A final note should be added regarding the costs and benefits of publication and educational services offered by the NBS. These services are probably least amenable to any market tests. The marginal cost of disseminating such information is usually infinitesimal compared to the costs of creating that information. This public goods characteristic of measurement information is strong prima facie evidence for a significant role for publication and educational services by NBS. The qualitative assessment of these programs in the micro studies tends to be favorable; however, it would be possible to supplement this qualitative evidence with some quantitative tests. For example, when the Bureau of Domestic Commerce asked the 3,000 subscribers to its monthly "Construction Review" ($14.50 a year) to return a postcard questionnaire about the usefulness of the publication, only 250 did so. It would be interesting to test the subscriber use of NBS publications in a similar manner.

5. CONCLUSIONS

In this study we first attempted to put the national measurement system in an economic perspective. The concept of measurement was defined in economic terms, the economic dimensions of the measurement system were estimated, and the relationship between economic change and the measurement system was explored. The economic analysis of the measurement system proceeded with an analysis of the costs and benefits of measurement in the private sector and in the public sector. In each of these sections, we attempted to point out specific limitations in existing studies relating to the economic analysis of the national measurement system. In this concluding section we will discuss gaps in the existing literature and areas for further research.

This study has emphasized that measurement is part of the knowledge or information sector. Not surprisingly, this is an area where economic analysis is in its infancy. As additional theoretical and empirical work becomes available, relating to the production of knowledge, it is important to examine the relation of measurement information to the information sector.

The preliminary work on the cost of physical measurement could be updated and used to forecast future changes in demands for measurement, e.g., using the forecast for input-output tables. The instrumentation sector in particular could be examined more thoroughly. The original study on the costs and benefits of metrication could also be updated to examine the current and prospective trends in conversion to the metric system. The relationship between measurement and changes in output and productivity has been explored in a preliminary way and the results suggest that this is an important area for further research, particularly at the industry level.

The analysis of the costs and benefits of measurement in the private sector reveals a basic weakness. The perspective of the micro studies is that of the physical scientist and the specific measurement function he is concerned with, i.e., length, mass, time, etc. An alternative approach would be to focus on the user of measurement. To understand measurement in production one might choose a particular firm or industry and attempt to understand measurement problems from that perspective. For example, by focusing on the machine tool industry, one would find measurement problems that cut across most of the divisions used in the micro studies. In particular, the analysis of measurement from the standpoint of consumers has been left almost untouched in the micro studies. Again, measurement problems for the consumer probably encompass most types of physical measurement. The perspective of producers or consumers would make it easier to explore secondary impacts of costs and benefits of measurement for society as a whole.

The micro studies provide important insights into the costs and benefits of National Bureau of Standards programs. However, the studies do not necessarily provide a basis for expanded National Bureau of Standards activities. None of the studies provides evidence that would satisfy the conditions of rigorous economic analysis such as cost benefit or cost effectiveness analysis. Some of the studies suggest that the data is available or could be generated to apply more rigorous tests to provide evidence for changes in National Bureau of Standards programs.

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15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)* This report is a comprehensive summation of all relevant work known to NBS on the state of the art of economic analysis of the national measurement system. It is written for a mixed audience of economists and physical scientists. The first part deals with the concept of measurement for economic analysis, the quantitative dimensions of measurement in the economy, and the relationships between measurement and economic change. Measurement information is ubiquitous in the economy; it is used by producers and consumers and as an input at the interface between buyers and sellers. Resources used in making measurements cost about 6 percent of GNP in 1963, and all major economic sectors incurred substantial expenses. Industries with rapid rates of growth and productivity advance tend to be measurement intensive. Data from the NBS metric study provide supporting insights. The second part of the study examines the measurement system from the standpoint of the private sector, including the economic rationale for measurement by producers, consumers, and in sales transactions; and case studies of costs and benefits. The third part deals with the role of government, incorporating an economic rationale for measurement activities in the public sector, and case studies of costs and benefits of activities by NBS. Information provided by measurement may be a public or collective good, and be accompanied by external economies; under such conditions the private market system may not allocate resources efficiently and governmental intervention may increase the general welfare. While none of the case studies satisfies the conditions of rigorous cost benefit or cost effectiveness analysis, they do provide insight into the economic role of NBS in the national measurement system.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Economics; information; NBS; national measurement system.

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