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FINAL REPORT

THE ECONOMIC IMPACT OF NASA R & D SPENDING

PREPARED FOR:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
UNDER CONTRACT NO. NASW-2741
WASHINGTON, D. C.

PREPARED BY:

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APRIL, 1976

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Summary

In this study Chase Econometric Associates, Inc., has undertaken an evaluation of the economic impact of R & D spending, particularly NASA R & D spending, on the U. S. economy. The crux of the methodology and hence the results revolve around the fact that we need to consider both the demand effects of increased spending and the supply effects of a higher rate of technological growth and a larger total productive capacity. The demand effects are primarily short-run in nature, while the supply effects do not begin to have a significant effect on aggregate economic activity until the fifth year after increased expenditures have taken place.

This report is divided into two principal sections. In the first part we examine the short-term economic impact of alternative levels of NASA expenditures for 1975. The methodology used in this section is as follows:

1) We prepared macroeconomic forecasts for alternative levels of NASA spending. In these runs the level of total Federal government expenditures remained the same. Thus the improvements result solely from a shift among different types of expenditures.

2) We used INFORUM, an inter-industry forecasting model which utilizes an updated input/output table, to determine the effects of employment and output at the industry level.

3) The shifts in industry output caused by an increase in the level of NASA spending redistribute demand from low productivity industries to higher productivity industries, thereby increasing total productivity in the economy.

The principal conclusions reached in this part of the study show that a $1 billion increase in NASA spending in 1975, coupled with a $1 billion reduction of other Federal expenditures, would have the following effects:

1) A higher level of NASA expenditures would not have an inflationary impact on the U. S. economy during 1975 and would probably reduce the inflationary pressures in the economy.

2) A shift of $1.0 billion in 1971 dollars, or $1.4 billion in 1975 estimated prices, from other Federal non-defense expenditures to NASA expenditures will reduce the inflationary pressures in several key basic materials industries.

3) A shift to increase NASA expenditures will increase employment by 25,000 in the missile and ordnance and aircraft industries. While it will reduce employment in ten other industries, the net increase in the manufacturing sector will be 20,000 jobs.

4) Output will be stimulated in twenty-one industries. The principal industries which will be affected currently have considerable excess capacity and are producing at levels well below their peak years and in most cases below the average of the past five years.

5) A shift toward higher NASA spending within the framework of a constant level of total Federal expenditures creates jobs without raising the rate of inflation, and hence is more stabilizing in a recovery period than general government spending.

The second major section of the report deals with the long-term economic impact of increased levels of NASA R & D spending over a sustained period. The methodology used in this section is as follows:

1) We first developed estimates of historical series for the rate of aggregate technological progress for the postwar period.

2) We next estimated multiple regression equations relating this series to a number of variables, including NASA R & D spending, other R & D spending, gross national product, the index of capacity utilization, an industry mix variable, and an index of labor quality.

3) We calculated the increase in GNP per unit increase in NASA R & D spending which would occur taking into consideration only the "pure" productivity effects. These increments represent the expansion of the aggregate production possibility function due to a more rapid rate of technological advancement.

4) We simulated the macro model to determine how the multiplier effects of increases in NASA spending and in the rate of technological progress would affect aggregate demand and the overall economy.

The principal conclusions reached in this part of the study show that a sustained increase in NASA spending of $1 billion in 1958 dollars for the 1975-1984 decade would have the following effects:

1) Constant-dollar GNP would be $23 billion higher by 1984, a 2% increase over the "baseline", or no-additional-expenditure projections.

2) The rate of increase in the Consumer Price Index would be reduced to the extent that by 1984 it would be a full 2% lower than indicated in the baseline projection.

3) The unemployment rate would be reduced by 0.4% by 1984, and the size of the labor force would be increased through greater job opportunities so that the total number of jobs would increase by an additional 0.8 million.

4) By 1984 productivity in the private non-farm sector would be 2.0% higher than indicated in the baseline projection.

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5) Other simulations which were calculated indicated that these results would be proportional for increases of $500 million or $100 million in NASA R & D spending.

The reason for the unique combination -- for a government spending program -- of increased real GNP and a lower inflation rate is to be found in the growth of labor productivity. A growth in productivity means that less labor is needed per unit of output. The key to the growth of labor productivity is the higher rate of technological growth spurred by the increase in research and development expenditures.

Thus in this study we have found that an increase in NASA R & D spending increases the rate of technological change and reduces the rate of inflation for two reasons. First, in the short run it redistributes demand in the direction of the high-technology industries, thus improving aggregate productivity in the economy. As a result, NASA R & D spending tends to be more stabilizing than general government spending during a period of recovery. Second, in the long run, increased NASA R & D spending expands the production possibility frontier of the economy by increasing the rate of technological progress. This improves labor productivity at a faster rate, which results in lower unit labor costs and hence lower prices. A slower rate of inflation leads in turn to a more rapid rise in real disposable income, which provides consumers with the additional purchasing power to buy the additional goods and services which are being produced.

I. INTRODUCTION

The question of whether the U. S. economy can experience full employment and price stability at the same time has been one of the most thoroughly debated issues in the postwar period. Yet in spite of the great amount of resources and expertise devoted to this question, the uneducated citizen could be pardoned for observing that we seem to have accomplished just the opposite -- rapidly rising prices with unacceptably high unemployment. Repeated doses of fiscal and monetary policy have apparently resulted in long-term secular increases in both the rate of unemployment and the rate of inflation.

A complete discourse on the recent illness of the economy would have to include at a minimum chapters on the Arab oil embargo and cartel, the unexpected doubling of many food prices, worldwide shortages of many basic industrial raw materials, and the distortions caused by wage and price controls. Yet we would not do violence to the facts of the past decade if we were to summarize the causes of the current disequilibrium in the economy by stating that government policy has worked to increase aggregate demand without increasing aggregate supply. The vast majority of fiscal stimulus in the past decade has been directed toward increasing consumption, while the burden of restrictive monetary policy has fallen on reducing investment. Thus the economy has gradually been edged into a situation where shortages have developed, productivity has declined, and inflation has mushroomed. The economic "discomfort index", calculated as the sum of the rate of unemployment and the rate of inflation, reached an all-time high in 1974 and will remain at near-record levels in 1975.

We offer no simple cures for the present condition of the economy, and note that even if the optimal fiscal and monetary policies were to be followed in the future, it would take three to five years to return the economy to an equilibrium situation. Yet this relatively long adjustment time means it is even more imperative to move quickly, rather than wait until the next economic crisis is upon us. It is necessary to implement policies which increase productivity and lower the rate of inflation as well as stimulate the overall level of demand. Fiscal policy which increases aggregate demand without raising aggregate supply will not cause noticeably higher inflation this year or next, but will eventually lead to supply shortages when the economy does regain full momentum.

In general, any increase in investment spending will generate a higher level of productivity, since new capital goods will replace older ones. However, the improvement in productivity will be confined to those industries in which the additional investment is taking place. The goals of the economy would be better met if increased spending leads not only to a decline in the average age of capital but also produces increases in the level of technology which are then applicable to other industries. These spillover effects then raise the overall level of productivity even further.

It is often claimed that spending for research and development accomplishes these aims. A number of studies have shown that the rate of return on research and development is greater than is the case for other types of investment, both because technology is advanced more rapidly in the originating industry and because of the spillover effects. Not all R & D spending would be expected to have the same effect on the rate of technological growth; in particular we might expect that general-purpose R & D spending in high-technology areas would have greater spillover effects than that aimed at the development and marketing of a specific product.

The vast majority of economists who have worked in the area of productivity growth agree that R & D spending is a major contributory factor to technological progress. In the pioneering work of Abramovitz (1), Fabricant (25), Kendrick (32), and Denison (14), advances in knowledge has always been prominently identified as one of the major factors, if not the major factor, contributing to the growth in output per unit of input. Denison, for example, found that of the 1.8% growth in output per unit of input for the period 1948-1969, 1.2% was due to advances in knowledge above and beyond those increases in labor input due to improved education (p. 127).

Similarly, important work done at the micro level by Mansfield (41, 42), Minasian (48), Schmookler (60), and Nelson, Peck and Kalachek (54), has indicated high returns to R & D spending on an individual firm or industry basis. In addition, Griliches (28) has shown that the marginal social product of R & D expenditures is more than twice its private marginal return.

A number of other studies have addressed themselves directly to the question of the specific effect of R & D spending on the growth in productivity. In one such paper, Raines (59) estimated production functions for 24 two- and three-digit industries; the functions include applied R & D spending as one of the independent variables in addition to labor and capital. He found that of the average annual gain in labor productivity of 4.5% per year for those industries studied, 29% was due to R & D spending by the originating industry and another 24% was due to R & D spending by other industries (p. 40). However, the Raines work, while highly instructive, contains only a rudimentary lag structure and does not allow for time lags of greater than four years, which is almost certainly an underestimate.

In a more recent study done by Midwest Research Institute (47), an attempt was made to introduce longer lags into the relationship between R & D spending and gains in productivity. Lags of up to 18 years were used but the lag distribution was not determined empirically. Furthermore, the report states that 60% of the advance in technological progress was due to R & D spending. However, this finding was determined through a residual method and hence no direct estimation of this parameter estimate was attempted. In a very recent study, Mathematica, Inc. estimated the benefits to the national economy from applications of NASA technology (43). Here again, however, a statistical approach is not used.

Thus the methodology in this study represents a major departure from previous work designed to measure the effects and benefits of R & D spending. In generating the results in this study, we have relied heavily on the econometric and statistical approach. First, we have estimated an annual series for changes in productivity; previous work has dealt with these changes only on a decade-by-decade basis. Second, we have used a variant of Lagrangian interpolation polynomials to estimate the lag between R & D spending and changes in productivity. Third, we have used multiple regression techniques to determine the parameter estimates of the various factors influencing the rate of technological progress. Fourth, we have used large-scale macroeconomic and input-output models to determine the effects of R & D spending on the overall economy and individual industries after the interactive and dynamic multiplier effects have been taken into account.

In breaking as much new ground as is the case in this study, we admit that some of the results may be controversial. However, we have attempted to document all of the data and methodology carefully so that similar results may be obtained by other researchers. We believe that the overall results given in this study are consistent in broad form with earlier results, while introducing further elements of precision and dynamic interpretation.

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2. SHORT-TERM ECONOMIC IMPACT OF ALTERNATIVE LEVELS OF NASA EXPENDITURES FOR 1975

A. Introduction

The question which we explore in this part of the study is concerned with whether a higher level of NASA expenditures is more beneficial to the U. S. economy than a lower level of NASA expenditures during the year that the expenditures are made, holding the level of total Federal government budget constant in each case. This analysis is useful in examining the effects of altering the level of NASA expenditures as part of an overall economic stabilization policy. Thus we address the effects on several potential targets, including those of higher employment and reduced inflationary pressures.

In this regard the term "beneficial" used above is defined as having several characteristics.

1) A reduction in the direct demand pressures on industries which might be operating at high levels of capacity utilization or with tight labor markets, thereby reducing the inflationary pressures on that industry. This problem is somewhat less germane in 1975 than would ordinarily be the case, but cannot be ignored completely.

2) An increase in the demand for those industries which are currently operating with idle capacity, thereby increasing employment and output.

3) A reduction in the derived demand pressures on basic material producing industries which currently have shortages in supply, rely on imported raw materials, and are operating at high capacity utilization rates. This would

then reduce the inflationary pressures in these basic industries and the industries which they supply.

4) An increase in the demand for labor in those industries which are presently operating at levels below those of recent years.

5) The direction of expenditure away from those industries which have full utilization toward underutilized industries. This will increase employment, whereas the converse will tend to increase prices but not employment.

B. NASA Expenditure Assumptions

Two forecasts of the U. S. economy for 1975 were developed using alternative levels of NASA expenditures. These forecasts were termed NASAHI and NASALO. No assumption of the model used other than the level of NASA expenditure was altered between the NASAHI and the NASALO forecasts.

The NASALO forecast assumes an expenditure by NASA of $1.35 billion for goods and services (excluding NASA employee wages) during calendar 1975. These expenditures and all other data in this section of the study are expressed in terms of constant 1971 prices, except as specifically noted, because our initial focus is to examine the effect on real economic activity, i.e., adjusted to eliminate the effects of price changes. We then examine the effects on prices separately.

The NASAHI forecast assumes an expenditure by NASA of $2.35 billion during calendar 1975. The $1.0 billion addition to NASAHI is obtained by reducing general Federal non-defense expenditures by $1.0 billion, leaving the level of total Federal government expenditures unaltered. NASAHI may be described as involving a redistribution of $1.0 billion of government expenditures to NASA from other Federal government programs.

The $1.0 billion shift in Federal government expenditures is equivalent approximately to a $1.4 billion shift in Federal government expenditures in estimated 1975 prices. The exact price index to be used depends, of course, on whether the funds are spent in NASA programs or other Federal programs.

Because the level of total Federal government expenditure was not altered between NASAHI and NASALO, the amount of the shift in expenditure was only $1.4 billion in estimated 1975 prices, and only the first-year impacts are being measured, the aggregate economic impact shown for this shift will necessarily be small. It is desirable, however, to analyze the microeconomic impact across a broad range of industries to determine whether this shift affects the differential performance and employment in particular industries. Of greatest concern is whether the inter-industry effects are beneficial as described above.

In order to measure the differential industrial effect of the NASAHI and NASALO expenditure levels, we utilized the INFORUM Inter-Industry Forecasting Model. This model, which was developed by the Interindustry Forecasting Project of the University of Maryland has been expanded and modified by Chase Econometrics and has been linked to the Chase Econometrics Macroeconomic Forecasting Model to provide consistent economic forecasts for the industries included in the model. This method links the techniques of input-output analysis with the regression techniques utilized in constructing a macroeconomic model. While regression techniques provide the behavioristic equations required for macroeconomic forecasting, inter-industry shifts are best examined in a more deterministic framework, such as an input-output model, providing that the input-output model includes a degree of flexibility in its structure.

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C. Input-Output Economics

Basic Elements

Aggregate econometric models seldom account for production in any way other than as aggregates of final output. All of the consumption goods sold to consumers are added up under the heading of consumer durables, nondurables and services; all of the products sold to companies for plant and equipment are added up and classified accordingly. Most of these models tend to obscure the existence of a very large number of transactions between companies throughout the economy. The production of products which are to be used in the making of other products is a major part of economic activity. When we are considering the production of such large complex pieces of machinery as a launch vehicle, or a space shuttle, we must explicitly recognize that there are a large number of products that are inputs to these products, and moreover, these inputs originate in a very large number of industries. One major aspect of all of this is the methods of production that are to be used; in other words, how various inputs are combined to produce outputs.

Input-output analysis is a method of accounting for these industry-to-industry transactions. The salient feature of input-output analysis is the industry-by-industry specification of the dollar's worth of specific inputs that are required to produce a dollar's worth of different outputs. In some respects, an input-output table is an existing technology map. It provides a starting point for diagnosis and for examination.

Another major feature of input-output analysis is that the table of transactions among industries -- usually termed intermediate transactions to distinguish them from final transactions that cover the sales to final users -- is integrated with the National Income Accounts. Consequently, one can still maintain consistency with the data for consumption, investment, government expenditure, etc.

For purposes of illustration, Table 2.1 contains a highly condensed example of an input-output flow table. In this illustration, there are four producing sectors (whereas in the model that we have used for analysis purposes in this report, there are 185 industries). The units in Table 2.1 may be read as millions of constant dollars -- flows of dollars in the period of a year. The magnitudes used here are purely illustrative.

Reading across the first row of Table 2.1 we find that Agriculture sells 15 units to itself. This can be simply enough explained by noting that it is necessary to plant wheat to grow wheat. Consequently, in any one year, a certain amount of the output of Agriculture must be retained by Agriculture for the purpose of generating next year's crop.

The second column of the first row shows the sale of 100 units by Agriculture to Manufacturing I. Similarly, sales by Agriculture to Manufacturing II of 75 units and sales of 40 units to Services are shown. There is no entry in the Imports column. This is because a sale of agricultural products to other countries would result in an export, and exports are included in Final Demand. The Total Intermediate column is simply the sum of the sales by Agricultural to itself, both Manufacturing sectors and Services.

The next column is Final Demand. This column contains sales to consumers, sales of plant and equipment products to investors, sales to government, and sales to exports.

The Total Output column is again simply the sum of the Total Intermediate plus Total Final Demand. Consequently, although Agricultural is shown to produce a total output of 450 units, only 220 are sold into final demand and the balance is sold into other industries to become a part of the products that they manufacture.

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Each of the three following rows in Table 2.1 -- Manufacturing I, Manufacturing II, and Services -- may be interpreted in the same fashion. The import row requires a slightly different interpretation. Sales of imports into agricultural, manufacturing and services may be interpreted in the same fashion as the earlier rows. On the other hand, imports are treated as a negative in final demand. Consequently, the sum of the total intermediate plus the total final demand results in a zero total output.

The next row is termed Value Added. This is a catchall term for the payments by each column industry for non-material inputs. In other words, Value Added includes the payments by each industry to labor, capital (depreciation), profits, rents, net interest, etc. Another way of expressing value added is in terms of income; value added payments are those payments generally treated as income in the National Income Accounts: wages, salaries, profits, rents, net interest, etc. A similar interpretation of value added is valid for each of the column industries.

The last row, Total Inputs, is simply the sum over the column. It should be noted that the figure in the Total Inputs row must equal the figure in the total output column for each industry. Another way of looking at this is in the standard accounting income statement format. The elements in each row, for instance, the figures in the row for Agriculture refer to the sales by, or revenues accruing to agriculture. These total 450 units. Those 450 units are in turn disbursed amongst a number of uses. That disbursement is shown in the Agriculture column where 15 units are paid to other firms in the Agricultural industry, five units are paid to manufacturing -- for example, for inputs of fertilizer and agricultural chemicals; 20 units are paid for the purchase of services -- and these are explicitly non-labor services (one example would be the rental of aircraft for spraying of pesticides and herbicides).

The figure in the imports row indicates that agriculture is paying out 10 units for imported products. Similarly, the 400-unit entry in the value added is the total of wages, salaries, profits, depreciation, rents, etc. that are paid out. Since the column contains all disbursements and the row contains all revenues for the year then the totals must equal. A similar interpretation applies to each of the industries listed.

Moving now to the right hand side of the table, the sum down the column of Total Intermediate transactions simply provides an adding-up of all of the dollar's worth of exchanges between industries.

The sum over the Final Demand column provides an adding-up of all of the dollar values of products and services that are sold as consumers goods, plant and equipment, and products sold to government. This is equivalent to Gross National Product. Gross National Product can, of course, be defined in two ways: as the dollar value of all goods and services purchased in the economy, or the dollar value of all income spent in the economy. It is therefore not surprising to note that the sum across the row labeled "value added" also adds up to the same value as the sum over the column of final demand.

Consequently, in the lower right hand corner of Table 2.1, we find that the total of intermediate transactions within this sample economy is 1220 units, the total GNP is 1080 units, and the sum of these two -- generally termed Total Gross Output -- is 2300 units.

Table 2.1: SAMPLE OF A COMPRESSED INPUT-OUTPUT TABLE

PURCHASES BY:

SALES BY:	Agriculture	Manufac-turing I	Manufac-turing II	Services	Imports	Total Intermediate	Final Demand	Total Output
Agriculture	15	100	75	40	-	230	220	450
Manufacturing I	-	50	200	100	-	350	400	750
Manufacturing II	5	170	35	140	-	350	250	600
Services	20	30	40	20	-	110	390	500
Imports	10	100	50	20	-	180	-180	-
Value Added	400	300	200	180	-			
Total Inputs	450	750	600	500	-	1220	1080	2300

Table 2.2 shows the direct input relationships that are derived from this input-output table shown in Table 2.1. The method of deriving this table is simply to divide every element in each column by the total output of the industry represented by that column. Consequently, one would divide the first column in Table 2.1 by 450. The resulting coefficients are termed the direct, or technical coefficients of production. To produce one unit of output, the Agricultural sector must purchase .0333 units from itself. Similarly, to produce a unit of output, Agricultural must purchase .0111 units of the output of Manufacturing II and .0444 units of the output of Services. Similarly, it requires .0222 units of imports. Addition of .8889 units' worth of labor, management, financial services, etc. rounds out the ability of the Agricultural sector to produce one unit of output.

While these tables tend to appear most complex when presented in their full detail, they are in fact relatively simply in concept. Their primary purpose is to allow one to get into the nuts and bolts of production. When these tables are integrated into forecasting models they allow one to explore the effects of changing the distribution of demand. They also allow the analyst to explore the impact of explicit changes in the ways the products are made -- regardless of whether these changes originate in technological changes or in a simple substitution caused by change in relative prices. In some instances, these methods allow us to explore the impact on the economy of the construction of new products. In the past we have analyzed the impact on the U. S. economy of the B-1 bomber production program (10). A similar analysis could be undertaken of the production program for the space shuttle vehicle, or the introduction of any major new product line; be it government sponsored or a strictly private business development.

Table 2.2: MATRIX OF DIRECT REQUIREMENTS COEFFICIENTS

	Agriculture	Manufac-turing I	Manufac-turing II	Services	Imports	Total Intermediate	Final Demand	Total Output
Agriculture	.0333	.1333	.1250	.0800				
Manufacturing I	-	.0667	.3333	.2000				
Manufacturing II	.0111	.2267	.0583	.2800				
Services	.0444	.0400	.0667	.0400				
Imports	.0222	.1333	.0833	.0400				
Value Added	.8889	.4000	.3333	.3600				
Total Inputs	1.000	1.000	1.000	1.000				

Input-Output Models

Input-output, or interindustry analysis, is a method of determining detailed industry outputs which is much more powerful than pure regression techniques. An equation relating electronic components to GNP may have worked well enough in the past; coupled with a projection of potential GNP, it may produce a forecast which time will prove to be more accurate -- or more lucky -- than one made with input-output. But it remains basically an inscrutable forecast. When we want to take a "long, hard look at it", there is nothing to look at but a graph of how well it has done in the past. A major advance would be to utilize our knowledge about the myriad products incorporating electronic components -- instruments, home entertainment goods, biomedical equipment, military hardware, etc. But then we need forecasts of instrument output, radio-TV output, defense spending, and investment by the medical and health care industries. The last item depends, in turn, upon a varied set of federal and regional government policies and a host of other variables. When faced with a problem of such rapidly increasing complexity it is no wonder that business forecasters have turned to various short-cut methods. Input-output, however, provides both a means of coping with this complexity, and a method of incorporating a wide variety of specific information.

The input-output framework contains a complete set of relationships between any industry and all of the markets for its product (the provision of a service is also called a "product"). The portion of output sold to other industries for further processing is called intermediate product, for it is used by the purchasers as a current input in their production processes. The remainder of output is by definition sold to final demand. These final demand customers fall into the familiar Gross National Product (GNP) Accounts categories, that is, personal consumption, investment in plant, equipment and inventory, government and foreign trade.

The entire I-O accounting framework can be expressed as a simple set of equations, one for each industry:

(1) Output = Consumption
+ Investment
+ Government
+ Net Foreign Trade
+ Intermediate Sales

"Intermediate Sales" is the only category normally omitted from GNP, since it would lead to many instances of double counting. A calculation of GNP does not count the value of wheat in flour if it has already accounted for wheat production elsewhere.

The most important contribution of I-O is the method of computing these intermediate sales. We have 185 industries in our system, leading to an astonishing 34,225 ($=185^2$) possible intermediate sales to other industries, including sales made completely within one industry. Presently, 14,000 contain non-zero entries. This matrix has actually been estimated for the United States economy by the Bureau of Economic Analysis (BEA) for the years 1958, 1963, and 1967. Presently, through a process of updating, our matrix is based on 1971 data.

With this matrix of transactions, we then have a shopping list of inputs for each industry, and we can derive a set of direct or technical coefficients (a_{ij}) giving us the weight of the i^{th} item in the list for the j^{th} industry. More precisely, a_{ij} is the value of the i^{th} product used as input to produce one dollar's worth of product j. For example, in 1967 the Motor Vehicle industry required \$0.0206 worth of rubber, \$0.071 worth of iron and steel, and \$0.0571 worth of metal stampings as direct input to each dollar of motor

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vehicle output. If we assume that the j^{th} industry's demand for each item on the list is proportional to its own output, then we can solve equation (1) simultaneously with similar equations for every other industry.* In this way we obtain industry outputs that are in balance with current input requirements and with final demands.

The system outlined above is a good one for evaluating such problems as the current period impact upon all industries of a change in automobile sales. We can easily trace the resulting changes in the purchases of steel, rubber, glass, plastic, and other items on the auto industry's shopping list. But this is only a <u>static</u> application of the input-output <u>table</u>. It does not, for example, evaluate the income effects of this change in auto demand, nor does it tell us anything about resulting changes in investment plans by the auto and steel industries, which in turn would each have further effects on the steel industry.

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*For those a bit familiar with matrix algebra, let A be the matrix of all the a_{ij}'s, and F be the vector of total final demands for each product. If Q is the vector of total output, then:

$$Q = F + AQ, \text{ the solution for which is:}$$

$$Q = (I-A)^{-1}F$$

where I is the identity matrix, and $(I-A)^{-1}$ is called the "Leontief Inverse" or the matrix of direct and indirect requirements per dollar of delivery to final demand.

D. INFORUM: Beyond Input-Output Tables

INFORUM, on the other hand, is a consistent dynamic forecasting model. This means that industry outputs are determined year by year on the basis of forecasts for all product markets, the building of sufficient capacity to produce those outputs, and the availability of labor. Thus no industry is allowed to grow faster than the sum of all its markets. While the I-O matrix plays quite an important role in this model, it should be clear now that it helps us to forecast only one of the several types of markets to which any product is sold. Hundreds of forecasting equations using various regression techniques are used to forecast final demands, productivity and other series in INFORUM.

An integral part of this procedure is the estimation of coefficient change, since few, if any, production processes will remain exactly the same over the medium to long term.

1) The Input-Output Table in INFORUM

The basic structure of the input-output coefficient matrix in INFORUM is, at present, derived from the detailed 480 industry 1963 input-output matrix produced by BEA. Work on implementing the 1967 BEA table, including comparing the estimated 1967 table with the actual, is now underway. The reader should note that the complete BEA tables are much more detailed than the aggregated versions published in the *Survey of Current Business* and in *Scientific American*.

Two major differences exist between the most recent published table and the one actually used in INFORUM. The first comes about because the published BEA matrix is defined in terms of sales by establishments and purchases by product; this matrix is definitionally hybrid -- an "establishment-product"

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matrix. The INFORUM matrix, on the other hand, has been "purified". This means that the secondary products of an establishment are reassigned from the industry where it was produced to the industry where its production is primary. For example, lumber produced in a plant whose primary product is furniture is transferred back to the lumber industry. Along with this reassignment of outputs, it is necessary to reassign those inputs necessary for the production of that secondary output. The basic assumption used for reassigning inputs to secondary production is that a given product is made by the same process, no matter what kind of establishment makes it.

The result of this "purification" is to transform the input-output matrix from an "establishment-product" hybrid to a "product-product" purified matrix. Consequently, INFORUM's input-output data are defined in terms of products. This is in direct contrast to other I-O models that produce output data in terms of outputs by establishments, and allows INFORUM to incorporate meaningful coefficient change procedures.

The second alteration made to the BEA matrix is to update it to the most recent complete set of data available. Currently we are using a matrix which has been "balanced" to 1971 row controls (outputs) and column controls (total inputs). Soon we will be using the 1967 BEA matrix, purified and then updated to 1972 controls largely derived from the 1972 Census of Manufacturers.

2) Coefficient Change

The problem of coefficient change has been approached by analysts from many different directions. We avoid the approach made in many models, where coefficient change is treated as a residual to be explained away. These models make no attempt to determine exactly what individual coefficient changes are implied or whether they are reasonable. More important, they are incapable of producing the consistent details of INFORUM's unique Matrix Listing during forecast years.

In INFORUM, and particularly in the Chase Econometrics version, we take the more direct approach. In those industries where coefficient change is expected, we have undertaken to examine the actual paths of the coefficient over time. Reasons for this change may be the introduction of new technologies, or changes in laws (witness changes due to environmental regulations), preferences, or relative prices. The time-series data that are used for this analysis do not come from the I-O tables. As is well known, the government produces the tables once every five years or so, and then usually with a five to six year lag. Consequently we use data from other parts of government, from a host of industry associations, and from various trade publications.

We use three basic methods to project the value of input-output coefficients into the future.

1) Assumption of a constant coefficient. We might think at first that all very small coefficients should be randomly tossed into this category. But even these must be examined. An example may suffice to show why. During the last decade the coefficient for sales of integrated circuits to electronics would have been very small -- a minor input to electronics, but to project such a coefficient into the future at a constant level would be absurd. All told, less than 10% of our coefficients remain constant.

2) Ex Ante forecasting. Ex ante forecasting is essentially a process of (a) taking estimates, usually from engineers, of the technical input structure for some product in a future year, (b) translating this structure into a numeric framework compatible with input-output analysis, and (c) depending

upon assumptions about the timing of introduction of this new technology, incorporate the new column of technical coefficients in the I-O structure.

3) Determine the historical pattern of movement in a coefficient, and fit that pattern to an S-shaped logistic curve. The method then gives a non-linear extrapolation of the historical path of the coefficient. This method is an improvement over both the assumption of constant coefficients and of linear extrapolation. Using logistic curves we can more realistically forecast the use of new technologies whose rate of growth will inevitably level off after several years. In many cases, these logistic paths have been shown to approximate closely the likely path of the coefficient derived from ex ante forecasts and engineering information. We are in the process of improving the procedure by including other relevant variables, such as relative prices, into the logistic formulation. Among other things, this will greatly facilitate Chase Econometrics' ongoing research into the direct and indirect effects of commodity inflation and the energy crisis.

E. Macroeconomic Impacts

Before analyzing the inter-industry impacts of the NASAHI and NASALO expenditure levels, it is necessary to prepare a macroeconomic forecast using each of these alternatives. The results of these alternatives on the aggregate economy are shown in Table 2.3. While the results are not dramatic, they do indicate that the direction of change in economic activity from an increase in the level of NASA expenditure is positive and beneficial. The magnitudes are small because the total Federal expenditure has not been altered and these improvements result solely from a shift within total Federal expenditures. Nonetheless, these results do indicate that NASA expenditures are less inflationary than other Federal government expenditures, and that a shift toward higher NASA spending with a constant Federal expenditure is not inflationary in the present economy. Conversely, it would follow that a shift away from NASA to other Federal programs could be relatively inflationary in the present economy. Further, the employment effect of NASA expenditures is beneficial, although not large for this small change, and thus both goals of higher employment and lower rates of inflation would be hindered by a lower level of NASA expenditure.

TABLE 2.3

MACROECONOMIC IMPACT OF NASAHI AND NASALO EXPENDITURES

	NASALO 1975	NASAHI 1975
Gross National Product	1529.9	1530.1
Gross National Product (1958$)	820.7	820.8
Consumer Price Index (% change)	10.5	10.5
Disposable Personal Income	1084.9	1085.0
Wholesale Price Index (% change)	15.5	15.6
Federal Government Deficit	17.0	16.9

All figures are in billions of dollars except where indicated otherwise.

NASAHI = NASA expenditures during 1975 of $2.35 billion in 1971 dollars.

NASALO = NASA expenditures during 1975 of $1.35 billion in 1971 dollars.

The changes that are presented between the NASALO and NASAHI expenditure levels are not large, all being in the last digit or changes of $0.1 billion, except for GNP where the change is $0.2 billion. Since these gross aggregates are inadequate to examine the full impact of this small change, we now turn to the microeconomic results of utilizing the INFORUM model.

F. Industry Impacts

1) Employment

We first examine the manufacturing sector. As shown in Table 2.4, employment is increased by 20,000 jobs in total manufacturing. While the statistical significance of the magnitude of this change is questionable, it is nonetheless evident that NASAHI creates jobs rather than destroying jobs. This is particularly important for 1975 when the U. S. economy will be attempting to recover from the longest recession in the post-World War II period.

Aggregate U. S. employment as estimated in the INFORUM model increases by 7,000 jobs in 1975 under the NASAHI assumption as compared with the NASALO assumption. This change also confirms that NASA spending creates rather than destroys jobs.

2) Output

Manufacturing output in 1975 (measured in 1971 constant-dollar terms) is 0.1% higher under NASAHI than under NASALO. This increase of $847 million in output results only from a redistribution of government spending from other Federal government expenditures to NASA expenditures. It is also important to note that the manufacturing sector will be slowest to recover during 1975 because of the secondary effects of the severe recession in the automobile industry, and that again the effect of this shift will be stabilizing.

3) Productivity

The shifts in industry output caused by an increase in NASA spending redistribute some demand in addition to creating new demands. This redistribution of demand tends to shift spending from traditionally low productivity industries to higher productivity industries, thereby increasing the aggregate productivity in the economy. While the change, as with employment, is once again rather small, it adds to the preponderance of evidence that NASA spending tends to be more stabilizing in a recovery period than general government spending. The increase in productivity, which is measured in thousands of dollars of output per man-year, is shown in Table 2.4.

TABLE 2.4

TOTAL MANUFACTURING OUTPUT, EMPLOYMENT, AND PRODUCTIVITY FOR 1975

	NASAHI	NASALO	Ratio
Output (billions 1971 dollars)	$ 789.340	$ 788.493	1.001
Employment (millions of jobs)	20.061	20.041	1.001
Productivity (thousands of dollars per man-year)	39.347	39.344	1.0001

G. Inter-Industry Effects

1) Employment

In the 94 industry disaggregation of the U. S. economy for which the INFORUM model computes employment forecasts, the NASAHI assumption results in higher employment than the NASALO during 1975 in four industries and in lower employment in six industries. The remaining industries were unchanged by varying this assumption. While only four industries were aided, this resulted in an aggregate increase of 28,000 jobs, primarily in the aircraft and ordnance industries. The aggregate loss of jobs in the six manufacturing industries affected totaled 7,000 jobs, with no individual industry showing a large change. Table 2.5 presents the employment results for the affected industries.

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TABLE 2.5

EMPLOYMENT BY INDUSTRIES AFFECTED BY A NASA SPENDING SHIFT

EMPLOYMENT BY SELECTED INDUSTRIES			HI (thousands)	LO	DIFF
Industry Number	Industry	SIC Code			
5	Missiles and Ordnance	19	154	142	+12
59	Machine Shop Products	359	191	190	+ 1
67	Communication Equip.	366	404	402	+ 2
71	Aircraft		501	488	+13
	Total				+28
22	Logging and Lumber	241, 242	307	308	- 1
25	Furniture	25	543	544	- 1
27	Paper and Products	26 (ex 265)	501	502	- 1
30	Printing & Publishing	27	688	689	- 1
31	Industrial Chemicals		295	296	- 1
72	Shipbuilding	373	169	171	- 2
	Total				- 7
	Net gain in Manufacturing Employment (thousands of jobs)				+20 *

2) Output

Of 185 industries of the U. S. economy for which the INFORUM model prepares total shipments forecasts, the NASAHI assumptions increase demand for 21 industries, reduce demand for 130 industries, and have no output effect on 34 industries. As was shown in Table 2.4, the aggregate manufacturing output was increased, but it is particularly important to examine the major

* Round-off error

industries affected, particularly in areas where supply conditions have persistently caused bottlenecks, and in which these constrained supply conditions have caused severe inflationary pressures.

We first examine the basic materials industries in Table 2.6. The demand for all of these materials, excepting aluminum, is decreased slightly by the shift in spending from NASALO to NASAHI. Of course, NASA expenditures will continue to utilize all of these materials, but the net change as compared with the average of other Federal government programs results in reductions in demand in these industries. This result is due to the large equipment component of NASA expenditures and probably results from the significant intermediate demands placed on these industries by other government programs.

These small reductions in demand pressure would, at the margin, contribute to relief in terms of inflationary pressures on these industries. It is also important to note that several of these industries depend heavily on imported raw materials and should therefore benefit the U. S. balance of payments position slightly.

TABLE 2.6

SHIPMENTS OF BASIC INDUSTRIES

	NASAHI	NASALO	DIFF
Copper	6260	6267	- 7
Industrial chemicals	20662	20682	- 20
Steel	34931	34933	- 2
Zinc	515	515	0
Lead	546	547	- 1
Aluminum	8010	7985	+ 25
Structural metal products	14391	14399	- 8
Computers	11302	11323	- 21
Petroleum refining	30658	30685	- 27

All figures are in millions of 1971 dollars.

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The effect on NASA's major supplying industries is even more dramatic than the effects on basic materials industries. Table 2.7 indicates the change in shipments by each of NASA's major supplying industries. It is noted that the aggregate change in shipments by these industries is greater than the $1.0 billion change in expenditure between NASAHI and NASALO assumptions. This additional increase occurs because the redistribution in government spending has some feedback effects in the economy during the first year of expenditure and these multiplier effects themselves increase demand in these industries.

TABLE 2.7

SHIPMENTS BY MAJOR NASA SUPPLYING INDUSTRIES

	I-O Category	NASAHI	NASALO	DIFF
20	Guided Missiles	2890	2324	+566
127	Communications Equipment	13576	13500	+ 76
134	Aircraft	8019	7880	+ 39
135	Engine	3198	3080	+ 18
136	Aircraft Parts, etc.	5097	4768	+329
			Total	1028

All figures are in millions of 1971 dollars.

Considering the possible inflationary effects of a demand increase in these industries, we must first attempt to get an estimate of capacity in these industries. Because no accurate measure of physical capacity exists for these industries, we have used employment data as a proxy. Both production worker and total employment was examined for peak years and for an average of pre-Vietnam and post-Vietnam years to conclude whether resources should be available in the economy to permit an increase in output in these industries without increasing factor costs significantly. Table 2.8 indicates that employment in three of these industries has declined substantially both from peak years of 1966 for Electronic Components and Guided Missiles and 1968 for Aircraft. Additionally, each of these three categories has declined on average during the post-peak Vietnam period, indicating a substantial margin of slack capacity in these industries. Only Instruments has seen a growth in employment from 1968 to 1973. There should not be any resultant supply difficulties in these industries which account for virtually all of NASA spending, and it is therefore unlikely that this demand increase will affect the overall rate of inflation in the U. S. economy.

TABLE 2.8

EMPLOYMENT IN MAJOR NASA SUPPLYING INDUSTRIES

	1966	1968	1973	1969-1973 average	1960-1964 average
Aircraft	417	489	275	333	328
Guided Missiles	159	150	95	99	157
Instruments	431	462	495	466	359
Communication Equipment	468	523	438	468	415

(thousands of jobs)

It should be noted in particular that in addition to only one industry, instruments, having employment above its prior peak year, only instruments has a level of employment above its 1969-1973 average, showing a secular trend which must leave substantial idle capacity in these industries.

3) Productivity

Just as in total manufacturing there was no statistically significant change in productivity during 1975 as the result of a higher level of NASA spending for individual industries, there are also few productivity changes. Of 87 industries for which output per man-year is calculated, increases were shown in only two industries, ordnance and aircraft, both of which would be expected. In neither case was the increase significant. Only one industry showed a reduction in productivity as a result of the NASAHI assumption; this change was insignificant and was in the service sector.

H. Conclusions

In this section of the study, we have shown that a shift to NASA expenditures from other Federal government spending will stimulate the economy without raising prices. In particular, we found the following effects of a shift of $1 billion in 1971 dollars.

1) A higher level of NASA expenditures would not have an inflationary impact on the U. S. economy during 1975 and would probably reduce the inflation pressures in the economy.

2) A shift of $1.0 billion in 1971 dollars, or $1.4 billion in 1975 estimated prices, from other Federal non-defense expenditures to NASA expenditures will reduce the inflationary pressures in several key basic materials industries.

3) A shift to increase NASA expenditures will increase employment by 25,000 in the missile and ordnance and aircraft industries. While it will reduce employment in six other industries, the net increase in the manufacturing sector will be 20,000 jobs.

4) Output will be stimulated in twenty-one industries. The principal industries which will be affected currently have considerable excess capacity and are producing at levels well below their peak years and in most cases below the average of the past five years.

5) A shift toward higher NASA spending within the framework of a constant level of total Federal expenditures creates jobs without raising the rate of inflation, and hence is more stabilizing in a recovery period than general government spending.

3. THE LONG-RUN ECONOMIC IMPACT OF ALTERNATIVE LEVELS OF NASA R & D SPENDING

A. Introduction

While the set of short-run simulations were instructive, they were severely limited in scope. There is little question that it is important to determine whether increases in NASA spending would or would not contribute to inflation in the short run, since we are warned almost daily of the inflationary impact of increased government spending even when the unemployment rate exceeds 9%. Yet most observers would agree that if R & D spending does have a beneficial effect on the economy, it occurs primarily through an increase in the rate of technological progress, both in the originating industry and through spillover effects. These changes clearly do not work their way through the economic system during the year in which the R & D spending is originated, and in general have little effect for at least two years. Thus if we are going to explore the effects of R & D spending on the economy, we need to move to a long-run simulation scenario for that reason alone.

Yet there is an even more important reason why we need to consider the long-run implications of higher R & D spending. An increase in the rate of technological progress leads to an expansion of the production possibility frontier because more output can be produced with the same amount of input. However, this increase is not automatically transferred into a rise in aggregate demand. Instead, improvements in technology lead to lower prices, which raise real disposable income. Consumers can then spend the additional disposable income on more goods and services, including but certainly not limited to new products fashioned from the new techhology. It is this boost in real income which leads to the higher level of demand, output, and employment which we find in our simulations. This process also takes time to work through the system. As a result, the major effects of increased R & D spending are not felt until several years from the date of original expenditures. When these occur, however, they are likely to be very significant.

Thus we need to consider both the demand effects of increased spending and the supply effects of a higher rate of technological growth and hence a larger total productive capacity. Since R & D spending increases the rate of technological progress, it permits a greater rate of capacity expansion and also lowers the rate of inflation, hence increasing the real purchasing power of consumers. In the absence of technological progress, wage rate increases could not be offset by productivity gains, and thus prices would increase by the same proportion. This actually reduces real disposable income, since consumers are faced with a progressive tax schedule which is denominated in current prices. Higher prices also result in inadequate accumulation of capital consumption reserves, since these reserves are based on historical rather than replacement costs. Thus significant long-range benefits accrue to all sectors of society when the rate of productivity gain is increased.

In this section of the report we first describe the macroeconomic approach to measuring the rate of technological progress, hereafter referred to as γ. We then relate γ to a number of factors which represent the determinants of increases in productivity, including R & D spending. We next use the regression coefficient for NASA R & D spending in this equation to determine the historical rate of return with respect to supply effects which has been realized. Finally, we simulate the effects of increased (or decreased) NASA R & D spending on the U. S. economy over a ten-year period.

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B. The Macroeconomic Approach to Estimating the Rate of Technological Progress

The macroeconomic approach to estimating γ has often been criticized. In a well-written and frequently-referenced article, M. I. Nadiri (51) states the case thus:

> Aggregation is a serious problem affecting the magnitude, the stability, and the dynamic changes of total factor productivity ... that the use of the aggregate production function gives reasonably good estimates of factor productivity is due mainly to the narrow range of movement of aggregate data, rather than the solid foundation of the function. In fact, the aggregate production function does not have a conceptual reality of its own; it emerges as a consequence of the growth processes at various microeconomic levels and is not a causal determinant of the growth path of an economy.

What say we to these charges?

The problem of aggregation in economics is a thorny one about which relatively little is known even today. Yet this has not hampered the development of theoretical and empirical research in other areas of economics. It has often been shown that one cannot logically proceed from an individual Engel curve to an aggregate consumption function, but this has not stopped the flow of work in this area. The concept of aggregate and industry investment functions is almost meaningless in this day and age of the multi-product, multi-division, and multi-national firms, yet no attempt has been made in the literature to trace empirical shifts in the investment pattern of a given firm among various products, industries or even countries as expected rates of profit change. The aggregate wage rate function, usually referred to as a Phillips curve, is governed primarily by inter-industry shifts; Lipsey (35) tried to develop this concept at an early stage but it has received virtually no support in the past fifteen years. Yet the aggregate consumption, investment and wage rate functions have become established as the cornerstones of macroeconomic analysis. One wonders why the admitted difficulties of the aggregation problem are focused almost exclusively on the production function.

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We can shed some light on this question by examining in skeleton form the historical development of work on the aggregate production function and growth in factor productivity; the literature is reviewed in greater detail in Appendix A. Paul Douglas (20), in his pioneering work, argued strongly for the existence of an aggregate production function of the form

$$X = AL^{\alpha}K^{1-\alpha} \tag{3.1a}$$

where α = the elasticity of labor with respect to output.
X, L, and K stand for output, labor input and capital input respectively. This is universally known as the Cobb-Douglas production function.

Douglas defended his position on the grounds that the relative shares of labor and capital have remained constant over long periods of time. He also estimated functions of the form

$$X = AL^{\alpha}K^{\beta} \tag{3.1b}$$

and found that $\alpha+\beta$ was not significantly different from unity. The use of an exponential trend, written as

$$X = AL^{\alpha}K^{\beta}e^{\gamma t} \tag{3.1c}$$

was popularized by Solow in 1957 (61), who also reported that $\alpha+\beta$ was close to but slightly less than unity.

Two main flaws were perceived in this approach. First, the size of the residual γ appeared to be much too large to be ascribed strictly to random or exogenous events. Furthermore, it contained significant long-run fluctuations. The first major work to point this out was that of Abromowitz and Fabricant (1, 25); the bulk of the more recent work has been done by Denison (14, 15) and Kendrick (32). Thus research in the past twenty years has centered on alternative forms of the aggregate production function.

The large residual element measured by γ suggested a number of problems with the simple aggregate production function. One problem is clearly the possibility of omitted variables, such as those influencing the quality of labor or capital inputs. Another problem arises from the heterogeneity associated with the inclusion of vastly different industries in an aggregate function and the nature of the inputs themselves. A third problem is that the resources devoted to technological change may well be endogenously determined, or at least should be separately identified and not simply lumped into the residual category. Fourth, the Cobb-Douglas function essentially incorporates a static approach, whereas improvements in technology filter through the economy only after many years. Fifth, changes in relative factor prices may result in changes in factor demand and hence different growth rates in technology. This list could be extended almost indefinitely, but these areas represent the major criticisms of the Cobb-Douglas approach.

We deal with the last point first, since it has generated the most voluminous outpouring of discussion. The Cobb-Douglas function assumes that the elasticity of substitution between factors, usually denoted by σ, is unity. This follows directly from the assumption that α and β are equal to factor shares under the assumptions of perfect competition and cost minimization. However, a more general class of production functions for which the elasticity of substitution can take any (constant) value was developed by Arrow, Chenery, Minhas and Solow (4) in 1961. Such a function, known universally as a CES function, is derived from the equation

$$(3.2) \quad \log\left(\frac{X}{L}\right) = \alpha + \sigma \log\left(\frac{w}{p}\right)$$

where w is the wage rate and p the price of output.

If we impose the constraints of pure competition and cost minimization, this function can be transformed to

$$(3.3) \quad X = \gamma\left[\delta K^{-\rho} + (1-\delta)L^{-\rho}\right]^{-\mu/\rho}$$

where

γ = efficiency parameter (scale factor)

δ = distribution parameter

ρ = substitution parameter

μ = degree of returns to scale

The elasticity of substitution $\sigma = \frac{1}{1+\rho}$ clearly tends to unity as $\rho \to 0$.

It would not be useful in this report to discuss the hundreds of estimates of σ which have been calculated; some of these are cited in Appendix A. However, we can summarize these findings by saying that in the vast majority of cases, the estimated values for σ are less than unity, suggesting that the Cobb-Douglas function is invalid. Yet the estimates of σ have turned out to be extremely sensitive to the method of estimation and specification. Furthermore, we cannot ignore the fact that factor shares have remained relatively constant over long periods of time.

One of the major problems in estimating production functions, whether Cobb-Douglas, CES or any other variety, is the assumption that firms are satisfying their cost-minimization criteria at all times. As a practical matter, firms almost never manage to accomplish this because they are unable to predict ahead with perfect certainty. Thus they continually find themselves in disequilibrium situations which result in underutilization of one or more factor resources. As a practical matter, firms would not adjust the number of employees for every change in output even if these were known in advance because of the substantial costs of hiring and firing. Thus when we use actual data, as opposed to only those points along the production function, it is small wonder that we obtain estimates of $\sigma < 1$. In fact, if we were to shorten the unit time period used in estimation from annual to quarterly or monthly, we would find the values of σ decreasing to zero.

The range of problems which we have just been discussing bears a striking resemblance to early work done in the area of the consumption function, where it has long been determined that (a) the cross-section estimates of the marginal propensity to consume (mpc) are smaller than the time-series estimates, and (b) the mpc decreases as the time period is shortened. Both these problems were solved by the introduction of the concept of the permanent income hypothesis, which in its empirical formulation results in a distributed lag for the income term. While some questions have been raised about the strong version of this hypothesis, namely that the long-run mpc = apc, almost no one questions the dynamic nature of the consumption function itself.

Yet virtually no attempts have been made to introduce dynamic structure into the production function. The only attempts have been by Murray Brown (9), who has used a distributed lag on factor prices. Such an equation is usually known as a variable elasticity of substitution (VES) function; many other versions of VES functions have also been formulated. However, this idea has not been adequately explored on an empirical basis. Thus even though the CES function admits the possibility of different values of σ, it has never been transformed into a dynamic equation. The emphasis has instead been spent on varying σ with respect to factor intensities but not with respect to time.

The other problem with the CES function is the question whether the firm is actually on its cost-minimization function. In this case, one way to handle the problem is to deal with full-employment equivalents of outputs and inputs. This is by no means a trivial task, as witness the large variation in series of full-capacity output which are available. However, well-defined criteria can be used to construct these series. This is the methodological approach which is used in this study.

If we estimate an aggregate production function under either of these approaches -- distributed lags or use of full-capacity data -- we indeed find that the elasticity of substitution does return to unity in equilibrium conditions. Thus the Cobb-Douglas function does represent a useful empirical

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approximation to an aggregate production function under these criteria. This suggests that most of the mountains of work on the CES function has been a red herring. For all of the other complaints levelled at the Cobb-Douglas function are equally applicable to the oversimplified two-factor static CES function as well.

These other complaints cannot be dismissed simply by including distributed lags or moving to full-capacity measures, however, and deserve our further attention. Thus we first turn to the methodology used to construct full-capacity estimates of γ, and then return to the question of other variables which could be included as determinants of γ.

C. Estimating a Time Series for γ

It is thus our contention, based on the foregoing discussion, that a Cobb-Douglas function with constant returns to scale accurately represents the relationship between labor, capital and output providing that full-capacity measures of inputs and output are substituted for actual values. Thus

(3.4) $X_c = AL_c^{\alpha}K^{1-\alpha}e^{\gamma t}$ and hence

(3.5) $\log X_c = \log A + \alpha \log L_c + (1-\alpha) \log K + \gamma t$

In these equations K refers to actual capital in place and hence is the same whether we consider actual or full capacity output. Since we will be referring to full-capacity measures throughout this section, we drop the subscript c. Differentiating (3.5) with respect to time, we then have

(3.6) $\frac{\Delta X}{X} = \alpha \frac{\Delta L}{L} + (1-\alpha) \frac{\Delta K}{K} + \gamma.$

Our task now is to find adequate measures of X, L, and K. We can easily estimate α from factor share data, and find it to be 2/3, as has been reported elsewhere.

We turn first to the estimates of L and K, which are reasonably straightforward. We have:

$$(3.7) \quad L = \frac{E}{\left(1 - \frac{UN}{100} - \frac{UN_H}{100}\right)} * h_{max}$$

E = total employment including self-employed and agricultural workers

h_{max} = index of maximum hours of work per week

UN = rate of unemployment, %

UN_H = rate of hidden unemployment, %

$$(3.8) \quad UN_H = \sum_{i=1}^{4} \left\{ \left[\left[\alpha+\beta t\right]_i - \left(\frac{LF}{POP}\right)_i \right] * \left(\frac{LF_i}{LF}\right) \right\} * 100\%$$

where

$\alpha+\beta t$ is a trend line through peak points of labor force participation rates by each age-sex classification. As t increases the value of the expression, $\alpha+\beta t$ also increases indicating that labor force participation rates increase over time.

LF_i = labor force by age-sex classification

POP_i = population by age-sex classification

i = 1, ..., 4; groups are
- males aged 16-24
- females aged 16-24
- females aged 25-54
- total aged over 55

We assume no secondary workers in males aged 25-54.

The weakest link in this definition is the use of the measured unemployment rate. For a number of reasons, a given level of unemployment now implies a tighter labor market than was formerly the case. The principal reasons are as follows: *

1) The definition of unemployment in general excludes the self-employed. Thus as this group declines in relative importance, a constant unemployment rate implies a declining rate for wage and salary workers.

* This section follows Denison (16) pp. 95-96.

This can be seen by a simple example. Assume there are 100 workers in the labor force each year. In year 1, 80 are classified as employees and 20 are classified as self-employed; 10 employees are out of work. Thus the stated rate of unemployment is 10%, but the rate for wage and salary workers is $\frac{10}{80}$ or 12.5%. In year 2, the composition of the labor force shifts so that 90 are now classified as employees and 10 as self-employed; 10 employees are still out of work. The stated rate of unemployment remains at 10%, but the rate for wage and salary workers declines to $\frac{10}{90}$ or 11.1%.

2) Secondary workers in the labor force usually have lower marginal productivity. Thus as the percentage of these workers in the labor force increases, a constant unemployment rate indicates a declining labor reserve measured in terms of effective labor input. It is this effect which we try to measure through the use of the hidden unemployment term, which has declined secularly over the past twenty years.

3) Secondary workers are in general not close substitutes for primary workers. Hence changes in unemployment in secondary worker categories will have very little effect on the supply of labor. This term is also reflected to a certain extent in the hidden unemployment term.

4) Unemployment compensation insurance and welfare benefits have reduced the mobility of unemployed labor resources.

All of these factors tend to work in the same direction, which is that the reported unemployment rates have recently been overstated and hence our estimate of L increases too rapidly. Inasmuch as the secular trend is significant, this method ascribes too much contribution of the growth in output to L and too little to γ. In other words, the series which we produce for γ could actually understate the true residual growth in the absence of offsetting factors. However, this is probably offset by our method of measuring K, as we see next.

The calculation of K is simply given by

$$(3.9) \quad K = \sum_{i=0}^{N_1} \lambda_1^{\,i} (I_{pe})_{-i} + \sum_{i=0}^{N_2} \lambda_2^{\,i} (I_{ps})_{-i} + \sum_{i=0}^{N_3} \lambda_3^{\,i} (I_h)_{-i} + \sum_{i=0}^{N_4} \lambda_4^{\,i} (I_{gs})_{-i}$$

where

I_{pe} = purchases of producers durable equipment

I_{ps} = purchases of nonresidential structures, private sector

I_h = purchases of residential structures, private sector

I_{gs} = purchases of nonresidential structures, public sector

The λ_j are determined so that each $\lambda^N = 0.05$, representing the approximate scrappage value in each case. We choose $N_1 = 15$, $N_2 = 20$, $N_3 = 30$ and $N_4 = 20$ years.

The principal comment to be made about this formulation is that we use the economic equivalent of the capital stock rather than the physical equivalent. This is known as embodied technical change. The physical value of any particular capital good after one year is almost identical to its value when it was new, since physical depreciation or breakdown after one year is most unlikely. However, economic obsolescence may be considerable in a year when new capital goods become available which can produce the same output with less labor input. Thus inasmuch as we use the geometric lag formulation, we may be understating the effectiveness of the capital stock and hence overestimating γ. On balance the biases to γ caused by our methods of measuring L and K are likely to balance out.

We now turn to the question of estimating full-capacity output. The main problem in this task, it turns out, is removing the cyclical fluctuations in the output series. Methods which start with actual output and then try to "blow up" the series to full-capacity levels in general give unacceptable results. This is particularly true if the unemployment rate is used for the blow-up series. As we mentioned above, any method which relies on using the unemployment rate as a measure of the gap between actual and maximum output gives poor results, since it fails to take into account hidden unemployment, shifts in the age-sex composition of the labor force, or the declining share of the self-employed. Series which use capacity utilization were similarly found to be unsuitable. Here the major problem is that capacity utilization is generally available only for the manufacturing sector, which is only about 1/3 of the total economy. Thus when actual output is divided by capacity utilization the resulting series has cyclical bulges in recession years. An example of this is given in Table 3.1, where it can be seen that the potential GNP series calculated by the CEA unemployment method has very large increases either in recession years or the years following--witness 6.7%, 6.3%, 5.6% and 6.4% for 1954, 1958, 1961 and 1971 respectively. Thus we have little trouble discarding this approach.

A much more sophisticated approach has been used by Denison (16). We do not discuss Denison's method in detail; the interested reader is referred to the cited reference, pp. 86-91 and Appendix Q. However, we mention briefly that Denison does define potential national income as

> ... the value that national income would have taken if (1) unemployment had been at 4 percent; (2) the intensity of utilization of employed resources had been that which on the average would be associated with a 4 percent unemployment rate; and (3) other conditions had been those which actually prevailed in that year.

Clearly (2) is the key adjustment which must be made, and Denison performs a large number of data manipulations to handle this problem.

Table 3.1

Measures of Potential GNP

		CEA Trend			CEA Unemployment			Denison		
	Actual GNP	Gap	Poten-tial	% Change	Gap	Poten-tial	% Change	Gap	Poten-tial	% Change
1954	407.0	-17.0	424.0	3.5	-20.2	427.2	6.7	-17.5	424.5	2.8
1955	438.0	- 0.8	438.8	3.5	- 5.5	443.5	3.8	0.6	437.4	3.0
1956	446.1	- 8.1	454.5	3.5	- 1.9	448.0	1.0	- 4.0	450.1	2.9
1957	452.5	-17.5	470.0	3.5	- 3.9	456.4	1.9	-10.9	463.4	3.0
1958	447.3	-39.1	486.4	3.5	-40.1	487.4	6.8	-30.8	478.1	3.2
1959	475.9	-27.6	503.5	3.5	-22.4	498.3	2.2	-13.3	489.2	2.3
1960	487.7	-33.4	521.1	3.5	-23.9	511.6	2.7	-20.2	507.9	3.2
1961	497.2	-42.1	539.3	3.5	-42.8	540.0	5.6	-27.3	524.5	3.3
1962	529.8	-28.4	558.2	3.5	-26.1	555.9	2.9	-12.4	542.2	3.4
1963	551.0	-27.6	578.6	3.6	-29.4	580.4	4.4	-12.1	563.1	3.9
1964	581.1	-19.2	600.3	3.7	-21.9	603.0	3.9	1.2	579.9	3.0
1965	617.8	- 5.0	622.8	3.8	-10.3	628.1	4.2	12.0	605.8	4.5
1966	658.1	11.0	647.1	3.9	4.4	653.7	4.1	19.1	639.0	5.5
1967	675.2	2.2	673.0	4.0	3.2	672.0	2.8	6.0	669.2	4.7
1968	706.6	6.7	699.9	4.0	9.5	697.1	3.7	4.9	701.7	4.9
1969	725.6	- 2.2	727.8	4.0	11.4	714.2	2.5	- 8.2	733.8	4.6
1970	722.5	-34.5	757.0	4.0	-21.7	744.2	4.2	-27.4	749.9	2.2
1971	746.3	-41.0	787.3	4.0	-45.9	792.2	6.4	-32.1	778.4	3.8
1972	792.5	-26.3	818.8	4.0	-42.8	835.3	5.4	-23.3	815.8	4.8
1973	839.2	-12.3	851.5	4.0	-27.7	866.9	3.8	-16.7	852.5	4.5
1974	821.2	-64.4	885.6	4.0	-44.3	865.5	-0.2	-66.3	887.5	4.1

All GNP figures are given in billions of 1958 dollars.
% change refers to the change in potential GNP for each category.

We had originally planned to use Denison's series, but encountered difficulties when we began empirical testing. The problem was both in the cyclical properties and the secular trend. In particular, we believe that the Denison series (16 , p. 97) underestimates the growth in potential GNP somewhat in the early 1960's. In particular it is hard to believe that the economy was already at overfull capacity by 1964; most accounts, and we concur, tend to date the period of overfull capacity utilization as beginning in 1966.

A problem also exists in the cyclical pattern. It is usually argued that technological progress moves only in the forward direction; that knowledge, once obtained, is irreversible. Following this argument, we would expect that γ would be positive in all years. We note, however, that the series for γ derived from both the Denison and CEA measures of X contain negative elements.

After further consideration, we could reasonably expect γ to be negative in years of full or overfull employment. During such years, inefficiencies develop as shortages and bottlenecks occur, labor works longer hours and more untrained personnel are used, and relatively inefficient capital equipment is reactivated to produce the marginal goods. Hence the calculation of γ overstates the contribution of labor and capital, since we continue to assume that the elasticities of labor and capital remain at 2/3 and 1/3 respectively. The amount which output "should" rise according to the Cobb-Douglas function is greater than the actual increase, and hence γ appears to be negative. Of course γ need not be negative in these years, but a plausible case could be made for a declining technology in these years, whereas it would be unrealistic elsewhere.

In the Denison-based series, we find negative values of γ for 1956, a boom year; 1957, the beginning of a recession; 1967, a boom year; and 1970, a recession year. This pattern does not fit our hypothesis very well and also excludes

1966, when capacity pressures were most severe. The CEA-based series, on the other hand, has negative values in 1956, 1965, 1966, and 1967, all definitely boom years. This evidence strongly suggests that this series is more representative of true movements in γ.

The major drawback with the CEA series is that it is based on a series for potential GNP which is almost a straight line trend with no yearly variance. Hence it is possible that errors of measurement in L and K account for the majority of the variance in γ, since it is measured as a residual. We do not think this argument is very powerful, since while the measurement technique for L and K may contain biases, they are the type of biases which are probably trendlike in nature and are not apt to flip-flop from one year to the next. The CEA trend series probably does exaggerate the smoothness of the potential GNP series, but is clearly preferable to a series which introduces a spurious cyclical factor. However, because we are cognizant of these possible shortcomings, we have estimated all of the regression equations for γ using the series calculated from both the Denison and the CEA estimates of potential output.

The calculations of labor input used by Denison and incorporated in our work and his adjustments for quality of labor have generally been accepted as satisfactory. However, no adjustment was included for changes in the quality of capital. This has led Jorgenson and Griliches (31) and Christensen and Jorgenson (11) to argue that the traditional measures of productivity growth have been overstated because they fail to adjust for improvements in the quality of capital. However, this approach confuses inputs with outputs; it assumes that because advancements in knowledge have taken place, they must somehow be considered as quality improvements in capital. Denison (13) has effectively rebutted this approach in a lengthy article covering virtually every facet of the Jorgenson-Griliches findings. He states that "there is an advantage in matching growth sources with the reasons that income changes ... [but] confusion is hard to avoid if the consequences of advances in knowledge are classified as contributions of capital ... Such a classification is an invitation to misinterpretation." (p. 27) In other words, in their work Jorgenson and his colleagues arbitrarily reclassify factors contributing to improvements in productivity as if they were factors augmenting the capital stock without providing documentation or empirical application of these transfers. In view of Denison's effective rebuttal, we do not consider the Jorgenson-based measures of capital stock.

Thus the series which we actually chose as our preferred choice for X is the Council of Economic Advisors (CEA) series based on trend; these figures are also given in Denison (16 , p. 97) and have been updated by us through 1974. Further experimentation which we did failed to provide a more realistic series for trend output. The series for labor and capital are as described earlier; we did not think it relevant to recompute X or γ on the basis of the capital stock series employed by Jorgenson et al.

The estimates of γ based on Denison's estimates (γ_D) and CEA estimates (γ_C) of potential GNP are given in Table 3.2. It should be mentioned that the γ_D series might or might not be identical to such a series derived by Denison, since our estimates of labor and capital input are not identical. We then proceeded to utilize both series for γ in regression analysis, although the principal conclusions are based on the γ_C estimates. The specific methodology used for the Denison-based series is discussed in greater detail in Appendix B.

Table 3.2

Estimates of γ for the period 1954-1974

	γ_D Based on Denison's estimates of X	γ_C Based on CEA estimates of X
1954	1.12	1.73
1955	0.54	1.21
1956	-0.27	-0.25
1957	-0.24	0.98
1958	2.00	2.81
1959	0.75	1.73
1960	1.51	1.54
1961	1.96	2.19
1962	0.50	1.48
1963	1.73	1.58
1964	0.40	1.04
1965	1.14	-0.05
1966	0.53	-1.42
1967	-0.32	-0.19
1968	0.76	0.57
1969	0.59	0.21
1970	-0.44	1.36
1971	2.34	2.58
1972	2.21	1.35
1973	1.23	0.68
1974	1.17	1.10

All figures are given in percentage terms.

D. The Determinants of γ

We now proceed to develop those factors which will serve as explanatory variables of γ. These can be conveniently summarized as follows:

1A) Labor Quality

1B) Economies of Scale

2) Industry Mix Variable

3) R & D Expenditures

4) Dynamic Structure

We can draw a close relationship between these factors and the five principal reasons, noted in Section B, for the general rejection of the aggregate production function approach. Of these five reasons, we have already evaluated the argument about factor prices. To review briefly, the other four are as follows:

1) Missing Variables
2) Heterogeneity of Inputs and Outputs
3) Endogenous or Other Specific Factors
4) Dynamic Framework

In a general sense, category (1) covers all the other categories, for if we were able to specify the equation perfectly, then clearly nothing could be omitted. However, in a narrower sense, the following variables are usually thought to be included under category (1); here we follow the earlier Denison (14).

a) Age mix of the work force
b) Sex mix of the work force
c) Education level of the work force
d) Health level of the work force
e) Length of the work week
f) Economies of scale

Category (2) can be treated by introducing an industry mix variable to measure fluctuations in output caused by changes in relative shares of output by various industries. We have already examined the effect of such a shift in

Chapter 2 of this report and discuss it in greater detail later in this section. Category (3) is usually taken to refer to spending for research and development. Category (4), which represents much of the work in this study, is discussed in later sections of this chapter.

Labor Quality

We now return to category (1) (a)-(e), which taken together are often referred to as an index of labor quality. We can dismiss the inclusion of the latter two variables on a priori grounds. While we can plausibly argue that better health care would lead to a more productive labor force, it does not necessarily follow that a greater percentage of GNP devoted to health care increases productivity. In fact, inasmuch as proportionately more resources are devoted to health care for those not in the labor force, they are diverted from other productive sectors of the economy in a full-employment situation. Thus while social utility and welfare may be increased, the rate of technological growth is diminished.

Little doubt exists that a substantial decline in the work week, say from 60 to 40 hours, would materially improve output/manhour. However, the slight decline which has occurred during the past twenty years has served primarily as an impetus for a larger proportion of the labor force to obtain a second job. Thus a decline in this series does not necessarily imply that the average labor force participant is working fewer hours per week.

We now consider the first three labor quality variables, using the general approach followed by Denison. Of these variables, we would expect the educational level of the work force to be the most important. The only realistic way one can calculate quantitative indexes for age and sex mix is to assume that workers are paid their marginal value product and that discrimination and failure to provide equal pay for equal work are not significant. In view of recent developments in labor relations and discrimination suits, this assumption is undoubtedly not very robust.

In preliminary calculations, we found that none of the three variables had parameter estimates which were significantly different from zero. We also tried combining the age mix and sex mix variables, but still found that they routinely had t-ratios which were less than 1.5; a similar finding was reported for the education variable. The actual data series used and method of construction are given in Appendix E.

While these variables have been found to be significant in other studies, a number of points may be considered here. First, our method of obtaining full-employment labor force estimates included the use of a hidden unemployment variable, which does take into account shifts in the age-sex composition of the labor force. Second, over a significantly longer time period, the amount of education and training received by the labor force would show a much greater variance than it has over the 1956-1974 period. Since all of these variables do change slowly over time, we may also be reflecting our inability to measure these changes in a foreshortened sample period.

Economies of Scale

The term "economies of scale" can refer either to the national output or that of individual firms; we consider the aggregate case first. Until recently, it was considered plain common sense to argue that increasing the size of the market led to greater efficiency of production; this line of reasoning stems all the way back to Adam Smith. Greater specialization was possible only as the total market increased, which was often accomplished by international trade as well as expanding domestic consumption. Vast expenditures for infrastructure could clearly be utilized more efficiently if they were to carry greater volumes of goods and services. Thus Denison could write in 1962, "I believe we can rule out not only decreasing returns to scale but also constant returns without loss of general assent." (14 , p. 174).

In the past few years this point of view has been completely reversed, spearheaded by such organizations as the Club of Rome. According to their point of view, we can continue to enjoy a rising standard of living only if we begin to use less resources rather than more. While we believe that this argument is greatly overstated and even distorted, the "general assent" of which Denison spoke is no longer anywhere in sight. In the present stage of maturity of the U. S. economy, the evidence we have been able to gather supports the position that economies of scale are no longer a contributing factor to the rate of technological progress.

When we turn to the case of individual firms, the argument for economies of scale carries even less weight. We do not argue this case at length, needing only to refer to a comment which Denison quotes from The Economist that "Railroad consolidation would cut costs; a saving of as many as 200,000 employees is possible." Those who are in need of further convincing are referred to Pan American, Lockheed, and the large auto companies. We do not include economies of scale as a determinant of technological progress in this study.

In the interests of clarification, we should mention that economies of scale would probably be quite important for a study of the U. S. economy over much longer periods of time, such as 1900-1975, or for other countries which are in a less mature stage of development than the U. S. Similarly, economies of scale might be significant in examining technological change in a rapidly developing industry. However, we feel fully justified in arguing that the U. S. infrastructure has deteriorated rather than improved over the past twenty years, and that increases in the total size of the U. S. market since 1954 have not been in the region of increasing returns to scale.

Industry Mix Variable

We now turn to the other variables which we have identified as determinants of γ . In terms of our previous nomenclature, these could be summarized as industry mix variables, R & D expenditures, and the dynamic framework. The latter category in turn can be subdivided into time lags and cyclical fluctuations. We consider each of these variables in turn.

The industry mix variable reflects the fact that the aggregate rate of increase in technology may change simply because of a shift in the relative proportion of GNP accounted for by high- and low-technology industries. This can be shown by a simple example in which, for purposes of exposition, we assume only two industries in the economy with technology increasing at 1% per year in industry A and 5% per year in industry B. Then if in year 1 industry A and B both account for 50% of GNP but in year 2 industry B accounts for 60%, we see the following shift in the aggregate level of technological growth:

	Year 1			Year 2		
	γ	% of GNP	Contribution to γ	γ	% of GNP	Contribution to γ
Industry A	0.01	50	0.005	0.01	40	0.004
Industry B	0.05	50	0.025	0.05	60	0.030
Total Economy - level of γ			0.030			0.034

Thus γ has increased from 3.0% to 3.4% per year simply because Industry B has increased its share of GNP. The simplified macro approach has often been criticized because it fails to take into account these inter-industry shifts. However, we have constructed a variable specifically to handle these shifts, which we have called the industry mix variable. A full description of this variable is given in Appendix C. However, we can briefly describe it here as follows:

$$IM_t = \sum_{i=1}^{N} \omega_{it} \left[\frac{(XIP_i)}{(XIP_m)} \right]_t$$

where

IM_t = industry mix variable at time t

ω_{it} = average level of productivity (output/man-hour) for each of i industries in the t^{th} year

XIP_{i_t} = index of industrial production for the i^{th} industry in year t, 1967=100.0

XIP_{m_t} = index of industrial production for the manufacturing sector in year t, 1967=100.0

In other words, IM in any given year is equal to a weighted average of the shifts in industrial production by industry, where the weights are the average levels of output/man-hour by industry classification. When output shifts toward these industries with greater technological progress, IM_t will rise; conversely, if output shifts toward industries with slower technological progress, IM_t will decline.

The w_{it} are based on calculations which are included as part of INFORUM the input-output model which was described in the previous chapter of this report. They are derived from series on output, employment and labor productivity which form an integral part of this model. The series for industrial production are taken directly from the Survey of Current Business.

The industry breakdown used incorporates the two-digit disaggregation for the manufacturing sector; there are twenty such industries. Some of these industries are quite broad, such as chemicals or nonelectrical machinery; others such as tobacco or furniture are fairly narrowly defined. The industry data and nomenclature are also given in Appendix C.

R & D Expenditures

We now turn to expenditures for R & D. Since the numbers form a critical part of the study, we list them here in Table 3.3 as well as in Appendix D. These numbers are given in current dollars, and also as a proportion of GNP, which is the way they are entered in the regression equations. As indicated, we have subdivided total R & D spending into NASA R & D and other R & D categories.

Several reasons exist why we disaggregated R & D spending in this manner. It might occur immediately to some readers that NASA R & D spending was treated separately because this study was performed under contract to NASA. While this may have been a contributing factor, it certainly was not the overriding consideration. In fact, inasmuch as a broader class of R & D expenditures were

Table 3.3

Expenditures for R & D, 1961-1974

	Billions of Dollars				% of GNP $	
	Tot R & D	(annual) NASA R & D	Other R & D	GNP $	Tot R & D %	NASA R & D %
1961	14.50	0.37	14.13	520.1	2.79	0.07
1962	15.67	0.72	14.95	560.3	2.80	0.13
1963	17.37	1.62	15.75	590.5	2.94	0.27
1964	19.22	2.81	16.41	632.4	3.04	0.44
1965	20.44	3.65	16.79	684.9	2.98	0.53
1966	22.27	4.37	17.90	749.9	2.97	0.58
1967	23.64	4.61	19.03	793.9	2.98	0.58
1968	25.12	4.22	20.90	864.2	2.91	0.49
1969	26.17	3.74	22.43	930.3	2.81	0.40
1970	26.55	3.26	23.29	977.1	2.72	0.33
1971	27.34	2.81	24.53	1054.9	2.59	0.27
1972	29.21	2.63	26.58	1158.0	2.52	0.23
1973	30.63	2.46	28.17	1294.9	2.37	0.19
1974	32.10	2.33	29.77	1396.7	2.30	0.17

shown to have similar effects, this report might have been viewed as being of interest to a wider spectrum of organizations supporting R & D spending. In any case, the severe statistical and data limitations precluded using other combinations of R & D data; we discuss these next.

1) From a statistical point of view, it would not have been possible to include several different classes of R & D spending because of the paucity of observations in the sample period and the lag structures associated with each variable. Possibly the list could have been extended to encompass one more class of R & D spending, but as we will see, even extending the study to include two categories caused some statistical problems.

2) NASA R & D spending is relatively homogeneous, since a large part of the total R & D budget was directed toward space exploration, and nearly all of it was undertaken in the area of high-technology industries. Thus when estimating the coefficient of this particular problem, we are not saddled with the problem of adding apples and oranges.

3) It has been suggested that R & D spending by the Department of Defense (DOD) might be considered to be similar to NASA spending. However, we find that at least from the point of view of this study, the differences are as great as the similarities. The critical difference is that much DOD research is classified, and hence the improvements in technology which result from that spending are not fully available to the private sector. As we have already discussed, the spillover effects of R & D spending are the primary contribution to increases in γ.

4) R & D spending in the health sciences, while it may be extremely valuable in terms of prolonging life and reducing illness, does not have a noticeable effect on γ. We have already discussed this on page 54, where we noted that increases in expenditures on health primarily benefit those who are not in the labor force. Hence the cost-benefit analysis of these types of expenditures must be analyzed using different techniques. In particular, it is neither possible nor even desirable to value everything in dollars when working in these disciplines.

5) R & D spending in the private sector is quite variegated and in many cases not strictly relevant for inclusion in these figures. While some private sector firms do engage in meaningful R & D spending, a significant proportion of so-called R & D spending by individual firms relates to marketing of new products rather than true research. This often reflects the fact that firms feel that it improves their image among prospective investors if they can appear to show an active interest in spending for research and development. In addition, the spillover effect which is so important in Federally funded R & D is less apparent from the private sector, since firms have an interest in keeping these new developments secret in order to maximize profit-making opportunities.

For these reasons, we have chosen to treat NASA R & D and other R & D as the two separate components of this type of spending. As we will see later, the effect of NASA R & D spending on γ is approximately four times as large as other R & D spending, ostensibly for reasons (3)-(5) given above. We examine the statistical evidence later in this chapter.

Dynamic Structure

As we mentioned earlier, one of the peculiarities we found in both macroeconomic and industry work on production functions is the use of a static time frame, which amounts to the assumption of instantaneous adjustment. A major proportion of the theory of investment has been devoted to an examination of lag structures, reflecting the fact that business decisions take time to implement. Thus we certainly should expect work on the decisions to hire factor inputs and introduce innovations to include the relevant lag structure.

The work which relates R & D expenditures to increases in the rate of technological progress has not been similarly shortsighted, and has noted that very long lags do occur between the time of innovation and increases in technology and profitability. However, much of this work has been noneconometric in nature and the discrete lag structure has not been stated explicitly. In addition, much of the value of econometric work has been negated because of use of questionable statistical methods. We need to consider a number of points with respect to these problems.

1) The form of the dependent variable may be a critical determinant of the results which are obtained. Some studies have used the level of technology, a series which increases almost monotonically over time and hence includes a very strong time trend. For example, if we used the level of technology instead of the rate of increase, the series would look like this:

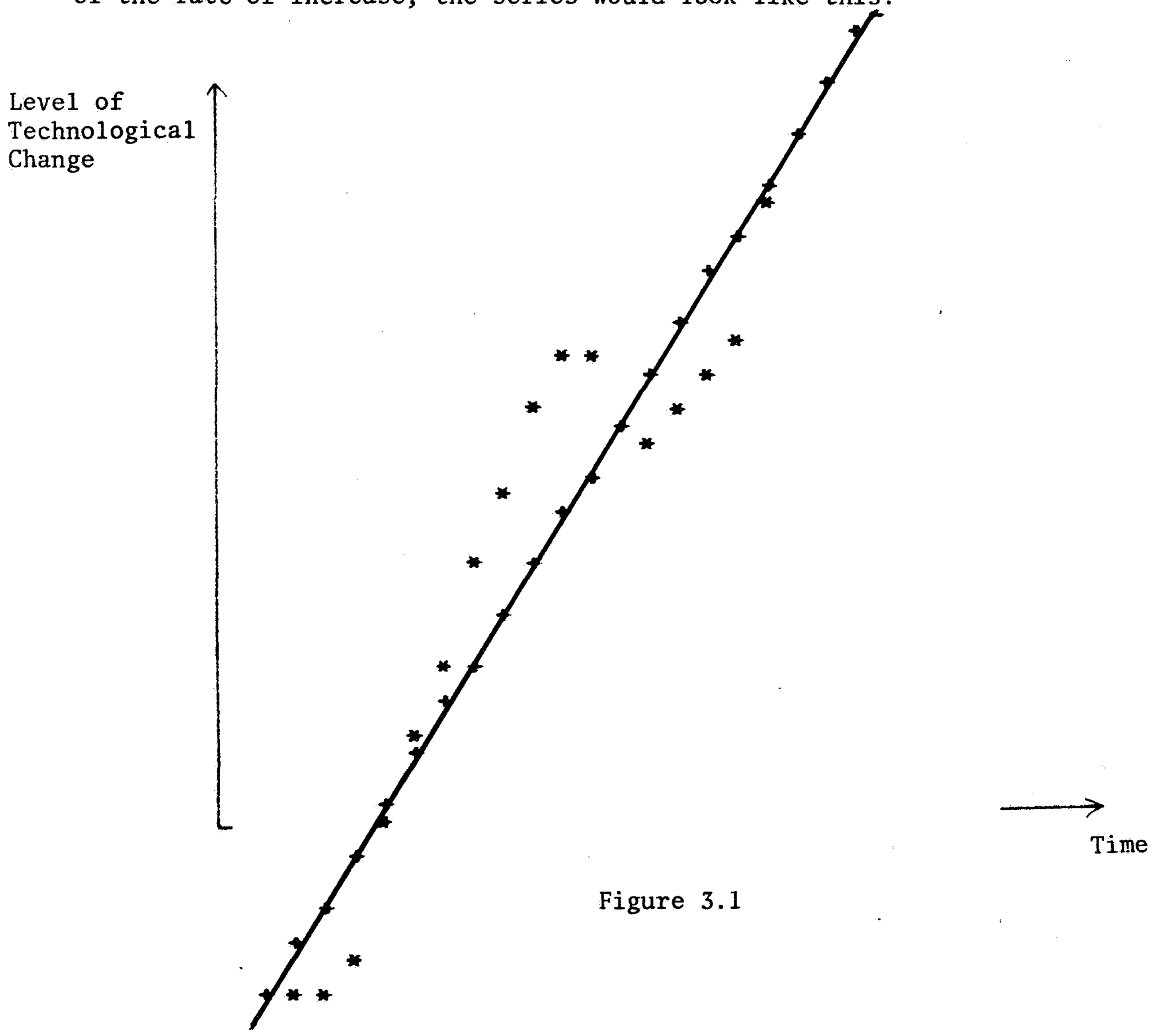

Figure 3.1

If this series were correlated with only a simple time trend, we would obtain $\bar{R}^2 = 0.92$, which means that 92% of the variance in that series could be explained simply by extrapolating a time trend. Similarly, high correlations could be obtained by relating the level of technology to any series with a strong time trend, whether or not that series had anything to do with technological advancement.

We have removed the trend from our technological advancement series by using the rate of change of technological progress, (γ), which is the first difference of the trend series given above in Figure 3.1. This series, already given in Table 3.2, has a slight nonsignificant correlation with a time trend. We thus eliminate the problem of spurious correlation and common trends among the variables in the equation.

2) Since we are working with a trendless series for γ, we need to include independent variables which also do not contain trends. Thus it would be inappropriate to use the level of R & D spending without further adjustment. We solved this problem by taking the ratio of R & D spending to total GNP. This also solves the problem of dealing with inflation, since we are interested in magnitudes of real growth; this implicitly assumes that the GNP deflator is the correct one for R & D spending. If R & D spending doubles in nominal terms but prices have also doubled, the net effect on the real growth rate should be zero.

3) We must determine the lag structure between expenditures for R & D and changes in γ. The most straightforward way to do this would be simply to calculate a regression using a large number of lags for R & D spending and then choosing the cutoff point where the weights became negative. In other words, we would estimate

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(3.10) $\gamma = a_0 + a_1\ NRD_{-1} + a_2\ NRD_{-2} + \ldots + a_j\ NRD_{-j} + b_1\ ORD_{-1} + b_2\ ORD_{-2}$

$+ \ldots + b_k\ ORD_{-k}$

where

NRD = NASA R & D (in millions) divided by GNP (in billions)

ORD = other R & D (in millions) divided by GNP (in billions)

-1, -2 etc. indicate lags in years

j, k are $\cong$ 10

This method presents two insurmountable obstacles. First, we have only twenty observations in the sample period; thus it would be statistically impossible to estimate this equation because the number of coefficients to be estimated would be greater than the number of observations. Second, even though we have removed the common trend from the variables in the equation, the use of variables as closely related as NRD_{-i}, NRD_{-i-1}, NRD_{-i-2}, etc. inevitably results in distorted parameter estimates and nonsensical results.

Thus it was necessary to consider another method which would solve both these problems. The method which is most commonly used is formally known as the technique of Lagrangian interpolation usually referred to as Almon lags*; these are discussed in Appendix D. Basically this method assumes that the general lag structure follows some low-order polynomial curve (e.g., quadratic) and that the points of the lag distribution lie along this curve. The researcher then has to determine (a) the shape of the lag distribution, (b) the total length of lag, and (c) the period in which the lag first becomes important.

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* Named after work done by Shirley Almon in her Ph.D. thesis (2) in which she correlated investment with appropriations using a variant of Lagrangian interpolation polynomials.

We have taken the position that the exact lag distribution and length will be determined empirically, which is to say they will depend in large part on which lag structure is most closely related to the actual data. We do, however, admit some a priori constraints before we start the estimation procedure. We would expect, for example, that the effect of R & D spending would not be felt immediately, would start slowly at first, would become more important as the inventions stemming from R & D spending become more widely disseminated, and finally would level off as new inventions stemming from the original spending ceased. In other words, the general pattern would be as follows:

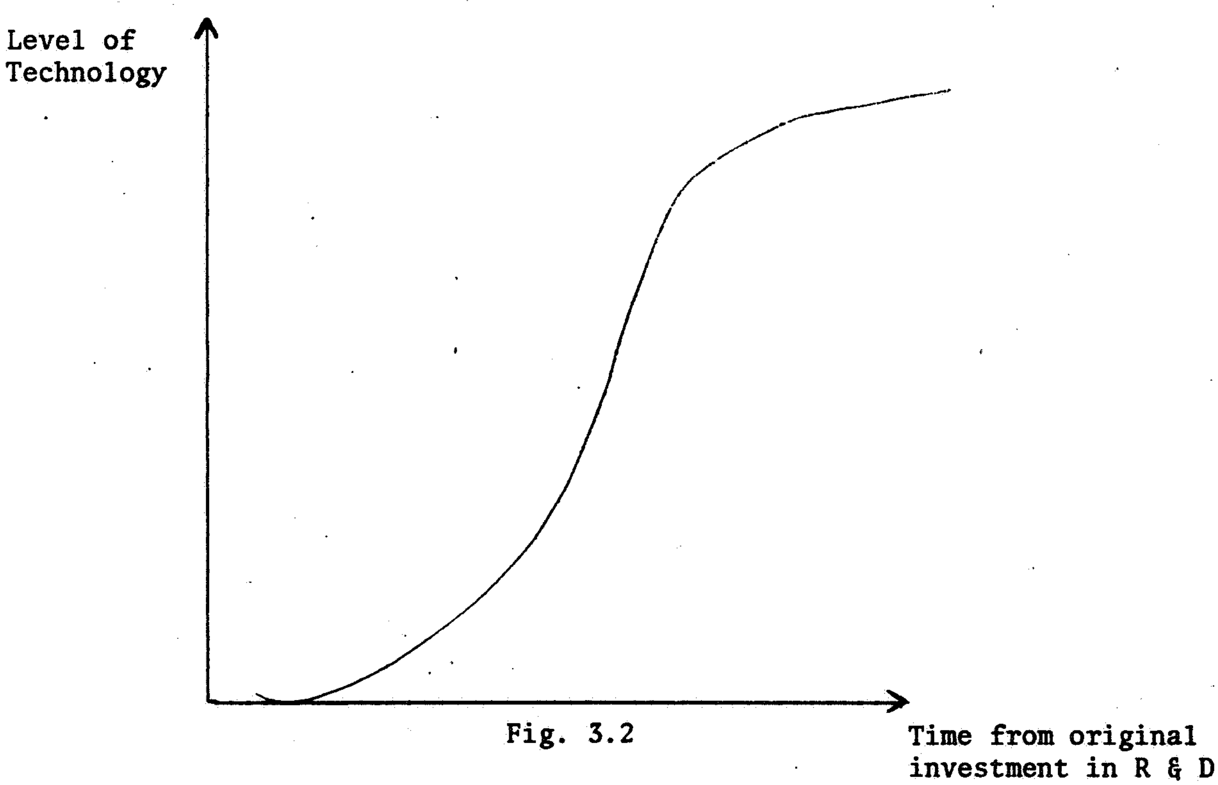

Fig. 3.2

We are explaining γ, which is the first difference of the level of technology. In the continuous case this is equivalent to the first derivative of the above curve, or

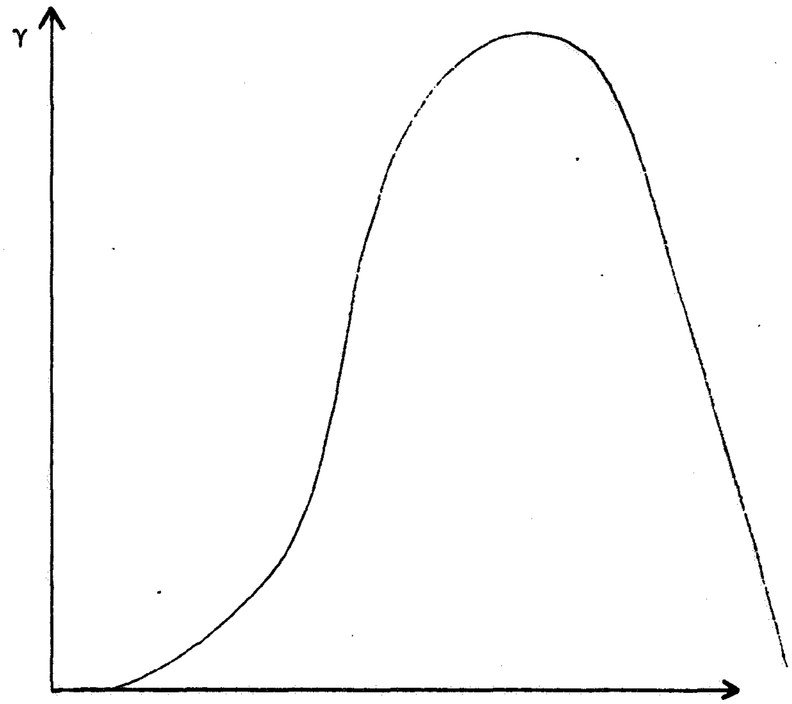

Fig. 3.3

This is in fact the shape which we obtain.

The Almon lag procedure need not have generated this shape of polynomial. For example, we could have had

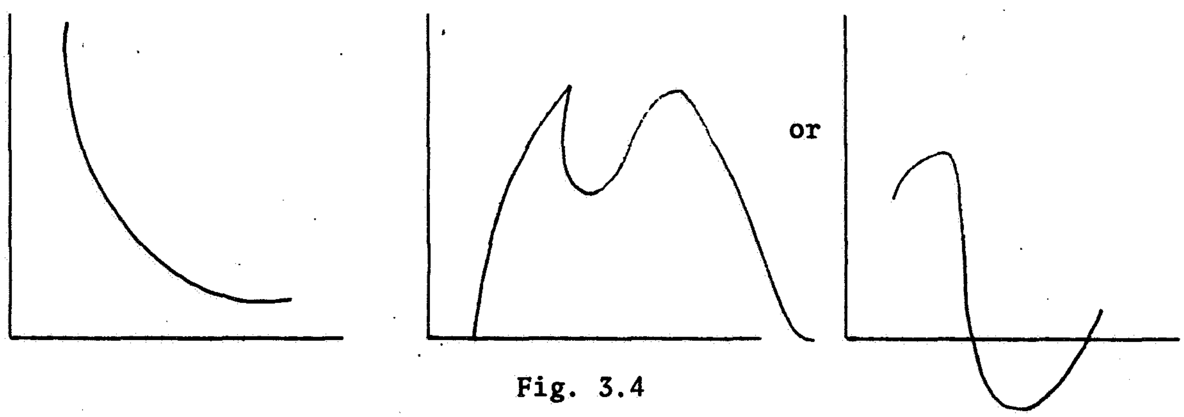

Fig. 3.4

We did in fact obtain some of these alternative shapes under different assumptions about lag structures and variables included in the equation. This suggested reasonable boundaries on our experimentation.

In general we found that the weights remain positive for several years but then turn negative if the lag structure was continued for eight or more years. We also found that the results were approximately the same if we started the distribution with a lag of one or two years. As discussed later, the two-year lag resulted in a slightly lower rate of return to NASA R & D spending, but made more sense intuitively, so we chose the conservative approach by using a two-year initial lag.

One other point about the lag structures deserves discussion. We have superimposed the same lag structure on both NASA and other R & D spending. When we tried to estimate an equation with separate Almon lags on both NASA R & D and other R & D, plus the other variables included in the equation, we did not obtain reasonable results. While sufficient degrees of freedom existed from a statistical point of view, from an economic point of view we found that the exercise reduced to one of curve-fitting. When we experimented with each variable separately, we found that the lag structure of the coefficients was very similar. Thus we decided that the most reasonable approach would be to use the same Almon lag pattern for both R & D variables.

Capacity Utilization

The last point we consider in this section is the question of cyclical variables. It is certainly reasonable to argue that an increase in R & D spending would have a larger effect on the economy during periods of slack employment of factor resources than it would during a period when the economy was at full employment. In that case increased R & D spending -- or any increase in spending, for that matter -- could occur only if resources were drawn away from production of other goods and services. Furthermore, as we have already mentioned in the previous section, productivity growth tends to be very low or even negative during periods of full employment and capacity as shortages develop, labor efficiency declines, and older less efficient machines are used for production. Thus adding additional expenditures to an already overheated economy would produce a smaller rate of return.

We have entered Cp, the index of capacity utilization, in the equation for γ in two different ways. First, we multiplied R & D spending by (1-Cp). Cp is defined as a ratio between 0 and 1 and has averaged 84.6% over the 1954-1974 sample period. If Cp were 100%, this argument would imply that additional R & D spending would have no effect on γ in that year. However, the ratio which we used never exceeded 93.2% on an annual basis during the sample period. Second, as we had mentioned above, gains in productivity, no matter what the source, are lower when the economy approaches full capacity; this is true whether R & D spending is increasing or decreasing. Thus we have also included Cp as a separate term and would expect it to enter with a negative sign.

E. Empirical Estimates of the Equation for γ

Our empirical investigation has so far led to the following interim conclusions:

1) The lag structure for R & D spending should first enter the equation with a two-year lag and should extend back an additional five years.

2) The distributed lag weights follow the general shape of an inverted U-distribution, as given in Table 3.4.

3) The independent variables should include NASA R & D spending, other R & D spending, an industry mix variable, and the index of capacity utilization. As shown in Table 3.13, the results for the educational level of the labor

Table 3.4

Distributed Lag Weights for R & D Spending

Time Lag (Yrs.)	Proportional Weight
0	0.0
1	0.0
2	0.061
3	0.164
4	0.220
5	0.232
6	0.200
7	0.123
8 and later	0.0

force or the age-sex classification were mixed and generally not significant. Hence we have concluded that they are not important for the particular time horizon we have chosen and have excluded them from the first equation.

The generalized form of the equation which we estimated is then:

$$\gamma = f\left(\sum_{i=0}^{7} A_i \, NRD_{-i}\,,\ \sum_{i=0}^{7} A_i \, (ORD)_{-i} * (1-Cp),\ IM,\ Cp,\ LQ\right)$$

where

NRD = $\frac{\text{NASA R \& D}}{\text{GNP}}$

ORD = $\frac{\text{OTH R \& D}}{\text{GNP}}$ This term was entered with and without being multiplied by (1-Cp).

NASA R & D = NASA R & D spending, millions of dollars

OTH R & D = Other R & D spending, millions of dollars

GNP = gross national product, billions of dollars

IM = industry mix variable, fraction

CP = index of capacity utilization, percent

LQ = indexes of labor quality--educational attainment and age-sex classification

Before selecting our final equation, we set out to test the stability of the parameter estimates by truncating the sample period at both ends to see if major changes would occur in the coefficients. We were not able to perform extensive testing because of the relatively short sample period. We did find that omitting years at the end of the sample period made little difference. However, at the beginning of the sample period we noted a major increase in the coefficient for NRD if the sample period started in 1960 instead of earlier years. Since NASA R & D spending did not become significant until 1960, it seemed sensible to utilize the 1960-1974 sample period for our final results. However, we also performed a number of calculations with the sample period extended back to 1956. A more complete discussion of the final equation is given in Appendix E.

The Derived Equation

The final equation, based on the 1960-1974 sample period, is given below. For purposes of comparison we have also included the equation based on the 1956-1974 sample period.

$$\gamma = -1.81 + \underset{(3.9)}{0.426} \sum_{i=0}^{7} A_i (NRD)_{-i} + \underset{(2.0)}{0.074} \sum_{i=0}^{7} A_i (ORD)_{-i} \frac{(1-Cp)}{(1-\overline{Cp})}$$

$$+ \underset{(4.5)}{0.031} (IM-\overline{IM}) - \underset{(3.1)}{0.157} (Cp-\overline{Cp})$$

$\bar{R}^2$ = .883
DW = 1.95
Sample Period 1960-1974

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$$\gamma = -0.94 + \underset{(5.4)}{0.318} \sum_{i=0}^{7} A_i (NRD)_{-i} + \underset{(2.4)}{0.046} \sum_{i=0}^{7} A_i (ORD)_{-i} * \frac{(1-Cp)}{(1-\overline{Cp})}$$

$$+ \underset{(4.3)}{0.029} (IM-\overline{IM}) - \underset{(3.7)}{0.158} (Cp-\overline{Cp})$$

$\bar{R}^2 = .883$
DW = 1.94
Sample Period 1956-1974

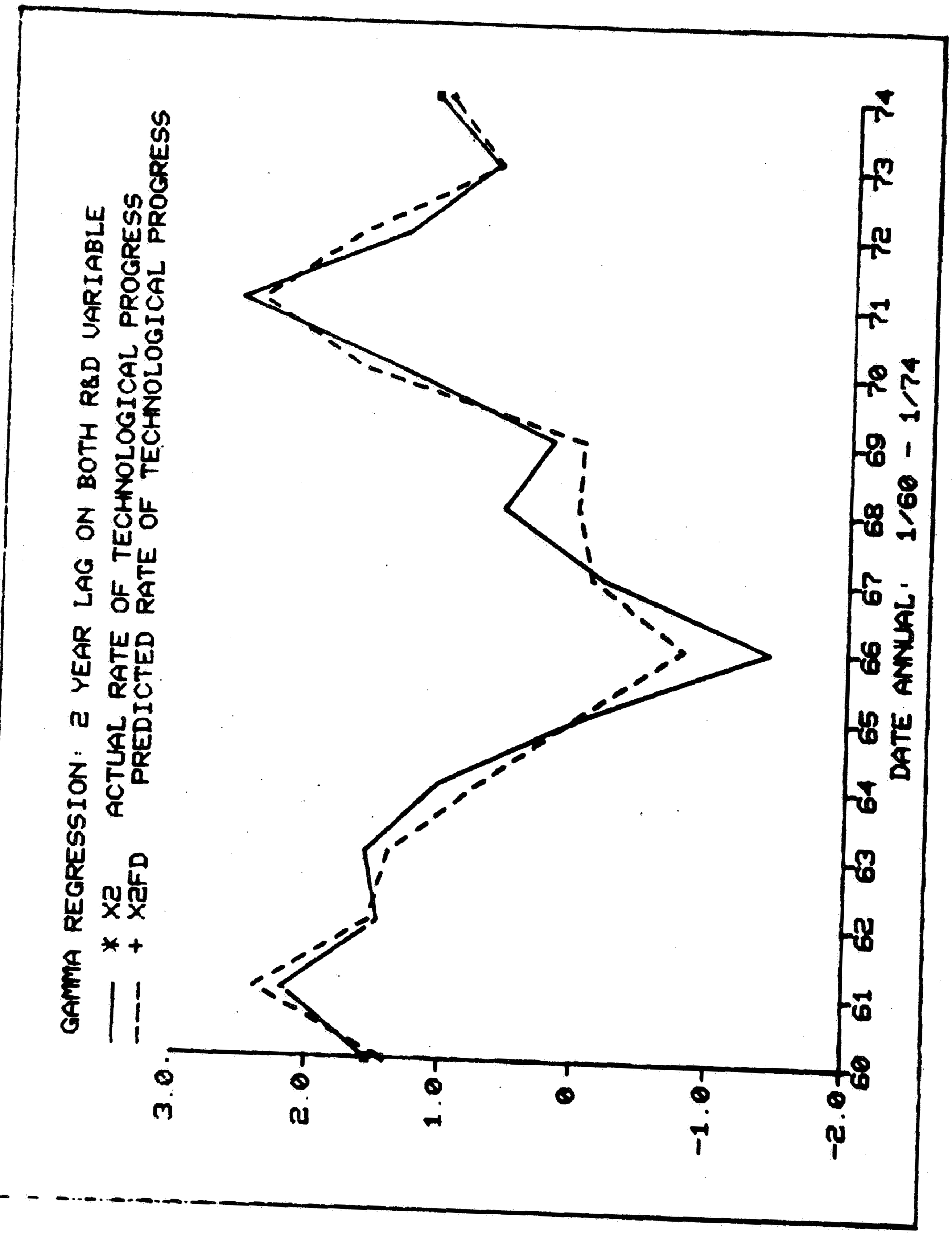
where all symbols are previously defined.

The preceding equations for γ for both sample periods exhibit the behavior one would expect for the relationships considered. The coefficients of the principal variables have the correct algebraic signs and the statistical measures--$\bar{R}^2$, the adjusted multiple coefficient of correlation, DW, the Durbin-Watson statistic, and the t-ratios for all of the coefficients--all were acceptable values and suggest highly significant relationships.

Figure 3.5 shows a plot of the actual versus predicted values for γ for our primary equation estimated for 1960-1974 using a two-year lag, no (1-Cp) term for NRD, and no labor quality variables. Graphs for some of the other equations for 1956 and 1960 are given in Appendix E.

In examining the graph shown in Figure 3.5 it becomes obvious that there are two peak periods of technological growth: 1960-62 and 1970-72. It is much more than a coincidence that these periods correspond, with the proper lag, to the large increase in R & D spending (a) following Sputnik and (b) associated with the Apollo expenditures of the mid to late 1960's. In order to verify this hypothesis, we show the contributions of each of the various independent variables to the explanation of γ. We have used deviations from the mean values of IM and Cp, since it is meaningless to

Fig. 3.5


GAMMA REGRESSION: 2 YEAR LAG ON BOTH R&D VARIABLE
* X2 ACTUAL RATE OF TECHNOLOGICAL PROGRESS
+ X2FD PREDICTED RATE OF TECHNOLOGICAL PROGRESS
3.0
2.0
1.0
0
-1.0
-2.0
60
61
62
63
64
65
66
67
68
69
70
71
72
73
74
DATE ANNUAL 1/60 - 1/74

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talk about zero values of these variables. One cannot even attach a great deal of meaning to zero spending on R & D, since some low level of spending would undoubtedly continue even in the absence of any Federal funding for R & D expenditures. Similarly, a zero level of expenditures for NASA R & D spending probably neglects the fact that before NASA funding began some R & D spending in these areas was taking place under the aegis of other agencies. Even so, there is little quiestion that the bulge in γ in the early 1960's is closely related to the peak in other R & D spending with the appropriate lag, while the bulge in the early 1970's is closely related to the peak in NASA R & D spending, again with the appropriate lag structure. These figures are given in Table 3.5.

Calculating the Historical Rate of Return

We are now in a position to ask the following question. How much higher would real GNP have been per dollar of increased NASA R & D spending during the period 1960-1974?

To answer this question we need to undertake a two-step approach. First, we need to determine how much γ would have risen with higher R & D spending. Second, we need to translate this into an increase in real GNP.

Because of the time lags involved, we would expect the increase in γ, and hence in GNP, due to higher spending to be zero for the first few years, increase rapidly for the next few years, and then level out, following the curve shown in Figure 3.2.

If we expand the equation for γ by inserting all the Almon lag distribution terms and concentrate only on the NRD term, we have

Table 3.5

Causes of Variation in γ Over the Sample Period

Date	γ	Due to $0.426\ \Sigma A_i\ (NRD)_{-i}$	$0.074\ \Sigma A_i\ (ORD)_{-i}\ (\frac{1-Cp}{1-\overline{Cp}})$	$0.031\ (IM-\overline{IM})$	$-0.157\ (Cp-\overline{Cp})$
1960	1.54	0.00	2.06	1.08	.68
1961	2.19	0.01	2.31	1.50	.87
1962	1.48	0.04	2.59	1.02	.24
1963	1.58	0.11	2.71	.90	-.08
1964	1.04	0.26	2.64	.34	-.45
1965	-0.05	0.52	2.40	-.09	-.77
1966	-1.42	0.91	2.15	-.77	-.90
1967	-0.19	1.36	1.80	-.87	-.24
1968	0.57	1.80	1.48	-.78	-.32
1969	0.21	2.13	1.34	-1.03	-.23
1970	1.36	2.25	1.30	-.49	.72
1971	2.58	2.17	1.42	.11	.80
1972	1.35	1.96	1.66	.04	.08
1973	0.68	1.67	1.89	-.37	-.56
1974	1.10	1.38	1.95	-.64	.16

$\overline{IM}$ and $\overline{Cp}$ denote sample period averages of these variables. The figures given in columns (2)-(5) are equal to the actual values of the variables used in the regression equation times the coefficients given at the top of each column. The actual data are given in Appendix E. Each row of numbers in columns (2)-(5) sum to a figure which is greater than γ, indicating a negative constant term in the equation. However, as noted above, a zero level of R & D spending has little economic meaning.

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$$\gamma = 0.426\ (0.0\ NRD + 0.0\ NRD_{-1} + 0.061\ NRD_{-2} + 0.164\ NRD_{-3} + 0.220\ NRD_{-4} + 0.232\ NRD_{-5} + 0.200\ NRD_{-6} + 0.123\ NRD_{-7})$$

We must work with the NRD variable, which is not NASA R & D spending as such but rather that spending as a proportion of GNP.* Over the 1960-1974 sample period, real GNP in 1958 dollars averaged $663.5 billion. Thus during this period increasing NASA spending by $1 billion or $1000 million would raise γ by an average amount of

$$\frac{1000}{663.5} * 0.426 = 1.51 * 0.426 = 0.643.$$

However, this total effect will occur only over a seven-year period. The increase in γ on a year-by-year basis for a $1 billion increase in NASA R & D spending is as given in Table 3.6. These figures are calculated by multiplying 0.643 by the weights given in Table 3.4.

* NRD equals NASA R & D (millions) divided by GNP (billions)

Table 3.6

Increases in γ for a $1 billion increase in NASA R & D Spending

Year	Incremental Effect
0	0
1	0
2	0.040
3	0.105
4	0.141
5	0.149
6	0.129
7	0.079
8 and later	0

We must now recall that γ is the rate of change of technological progress. In order to get the new level of technological progress, we must cumulate these figures over time. Thus the new level of technological progress following a $1 billion increase in NASA R & D spending would be increased by the amounts given in Table 3.7.

Table 3.7

Cumulative Effects on the Level of Technological Progress Stemming from a $1 Billion Increase in NASA R & D Spending

Year	Cumulative Effect
0	0
1	0
2	0.040
3	0.145
4	0.286
5	0.435
6	0.564
7	0.643
8 and later	0.643

We still must translate these changes into increases in GNP. This translation requires two steps. The first one, which is relatively straightforward, consists of a direct conversion of changes in γ to changes in GNP on the supply side. The second step, which is much more complicated, involves the simulation of the macroeconomic model in order to determine the interactive and dynamic effects which higher levels of productivity have on prices, income, outputs, and employment. As we demonstrate in the next chapter, the actual change in GNP will be considerably larger once we include the effect of the dynamic demand and supply multipliers.

We now consider the first of these two steps, which measures only the "pure" productivity effects. In other words, it does not include the demand effects of higher government spending or the secondary effects in the overall economy stemming from an increase in real disposable income and hence greater

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consumer spending. These particular results reflect only the increase in the production possibility frontier which is made possible by increased levels of technology.

Recall from (3.6) that we have written

$$\frac{\Delta X}{X} = \alpha \frac{\Delta L}{L} + (1-\alpha) \frac{\Delta K}{K} + \gamma$$

Thus for no change in ΔL or ΔK, which is precisely the supply case we are considering here, $\frac{\Delta X}{X} = \gamma$. Since we have been measuring γ in percentage terms, the figures in Table 3.9 need to be divided by 100. If we use the average GNP figure of 663.5 and multiply that by 0.00643, we end up with the result that a $1 billion increase in NASA R & D spending eventually leads to a $4.26 billion increase in GNP.

We still must make one more adjustment to the time sequence, however. For reasons which are explained in the next chapter, the effect of an increase in technology on real GNP occurs only with an additional lag of two more years. This represents the additional time it takes for the improvements in technology to be transferred into increases in aggregate supply via effective demand. We thus find that the time pattern of annual increases in real GNP does not begin until the fifth year after the increase in NASA R & D spending. The estimated time sequence is given in Table 3.8.

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Table 3.8

Increase in GNP Per Unit Increase in NASA R & D Spending -- "Pure" Productivity Effects Only

Year	Cumulative Change in GNP
1	0
2	0
3	0
4	0
5	0.26
6	0.96
7	1.90
8	2.88
9	3.74
10	4.26

We can then use the usual method of calculating the rate of return for a \$1 increase in spending. We have

$$\frac{0.26}{(1+r)^5} + \frac{0.96}{(1+r)^6} + \frac{1.90}{(1+r)^7} + \frac{2.88}{(1+r)^8} + \frac{3.74}{(1+r)^9} + 4.26 \left[\frac{\left(\frac{1}{1+r}\right)^{10}}{1 - \frac{1}{1+r}} \right] = 1.00$$

where r is the rate of return.

Solving this equation yields r = 43% to the nearest percent. If we re-solve the equation by substituting $\frac{4.26}{(1+r)^{10}}$ for the last term, thus not assuming an infinite life, we find the rate of return diminishes to 38%.

Thus an increase of $1 billion in NASA R & D spending in any given year would increase productivity and total capacity of the U. S. economy by $4.26 billion in the tenth and each succeeding year.

A number of commentators have suggested that the lag structure we have estimated is too short, even though the effects of increased NASA R & D spending on productivity do not begin to be felt until five years. To be sure, one can always find isolated instances of spillover effects which occurred ten or even twenty years after the original expenditure for R & D; this is exactly why we have included an infinite stream of returns. Yet we have independent evidence that our lag structure is not too short and if anything may be overstated. In the 17th Annual McGraw-Hill Survey of Business Plans for New Plants and Equipment (44), businessmen were specifically asked "How soon do companies expect R & D expenditures to result in large scale production?" (Table XVI). The results are given below.

	- Years -				
	1-2	3-5	6-9	10 & over	weighted* average
Basic Research	10	28	26	36	8.6
Applied Research	21	49	23	7	5.0
Development	39	51	8	2	3.5

* using 1.5, 4, 7.5, and 15 years as the weighting factors.

If we use conservative estimates of 20% for basic research, 30% for applied research, and 50% for development, we find the total weighted average is 5.0 years, which is indistinguishable from our results.

Thus these are not our results alone. The McGraw-Hill conclusions, which are underlined, state that (p. 12)

> Thus, while industry is spending increasingly large sums on R & D, it is also expecting the reward to be forthcoming in the near term. It is readily apparent why the bulk of R & D is devoted to applied research and development -- here is where the quick rewards are.

It should be stressed that all the calculations which we have considered so far stem from a $1 billion increase in spending followed by a return to previous levels. If spending were to remain $1 billion higher indefinitely, the pure supply effects -- disregarding interactive and dynamic multipliers -- would clearly be much larger. These figures are given for the standard case in Table 3.9.

Table 3.9

Cumulative Effect on GNP of a Sustained Increase
in NASA R & D Spending -- "Pure" Productivity Effects Only

Year	Change in GNP		
1			
2			
3			
4			
5	0.26	=	0.26
6	0.96 + 0.26	=	1.22
7	1.90 + 0.96 + 0.26	=	3.12
8	2.88 + 1.90 + 0.96 + 0.26	=	6.00
9	3.74 + 2.88 + 1.90 + 0.96 + 0.26	=	9.74
10	4.26 + 3.74 + 2.88 + 1.90 + 0.96 + 0.26	=	14.00

As indicated earlier, the actual results will be significantly larger because of the demand and multiplier effects calculated by simulating the Chase macroeconomic model. In the following chapter we turn to a detailed discussion of the methodology and results of these simulations.

F. Sensitivity of the Equation for γ to the Assumptions

The general comment of those who have seen these results is that they are "too good" in that they explain a surprisingly large proportion of the variance in γ. In addition, the rate of return of over 40% on NASA R & D spending has impressed many commentators as being too high. Furthermore, as shown in Table 3.9, fluctuation in the independent variables appear to account for a very large proportion of the total variability in productivity growth over the sample period. Thus the charge is issued that the results are highly sensitive to the particular choice of γ and the exact choice of independent variables used in the equation.

In view of the results which we obtained and the importance which is attached to NASA R & D spending, it is perhaps not surprising that these points were raised. In order to explore their validity, we carried out a sensitivity analysis of the various assumptions employed in deriving the equations for γ; the main ones are as follows:

(1) length of sample period

(2) length of lag at the beginning of the distribution--one or two years

(3) whether to multiply NRD and ORD by (1-Cp)

(4) inclusion of separate term for Cp

(5) inclusion of labor quality variables

(6) the choice of γ--based on CEA or Denison measures of maximum potential output

Length of Sample Period

We first consider the different length of sample period for the case of γ_C, (1-Cp)*ORD, 2-year lag, separate Cp and no labor quality variables; we then turn to the other criteria. The change in the coefficients of all the terms and t-ratios of the NRD and ORD term are given in Table 3.10.

Table 3.10

Variability of Estimates for Different Sample Periods, 2-Year Lag

	NRD Coeff.	Coeff. t-ratio	ORD Coeff.	Coeff. t-ratio	IM Coeff. Value	CP Coeff. Value	$\bar{R}^2$	DW
1956	0.318	5.4	0.046	2.4	0.029	-0.158	0.883	1.94
1957	0.283	4.6	0.026	1.1	0.030	-0.134	0.888	1.88
1958	0.299	3.8	0.031	1.1	0.030	-0.137	0.887	1.89
1959	0.312	3.5	0.031	1.1	0.031	-0.131	0.861	1.87
1960	0.426	3.9	0.074	2.0	0.031	-0.157	0.883	1.96

$\bar{R}^2$ is the multiple coefficient of correlation adjusted for degrees of freedom. DW is the Durbin-Watson statistic, which can be used to test for serial correlation. A DW value of 2.0 implies no serial correlation; significant correlation exists for DW < 1.4 or DW > 2.6. All the values shown here are unusually close to 2.0.

Length of Lag at the Beginning of the Distribution--One or Two Years

If we use a one-year initial lag for R & D spending, the coefficients of the NRD and ORD terms actually increase, as can be seen from the comparison given in Table 3.11.

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Table 3.11

Variability of Estimates for Different Lag Structures

	NRD Value	Coeff. t-ratio	ORD Value	Coeff. t-ratio	IM Coeff. Value	CP Coeff. Value	$\bar{R}^2$	DW
1956, 2 yr lag	0.318	5.4	0.046	2.4	0.029	-0.158	0.883	1.94
1956, 1 yr lag	0.330	4.4	0.045	1.9	0.029	-0.157	0.867	1.79
1960, 2 yr lag	0.426	3.9	0.074	2.0	0.031	-0.157	0.883	1.96
1960, 1 yr lag	0.591	3.6	0.099	2.0	0.029	-0.163	0.863	1.98

However, we felt that on an a priori basis a one-year lag seemed too short; in addition the equations did not explain the data quite as well, although the differences are very small. We mention once again that we have used the conservative approach in choosing the parameter estimate of NRD.

Whether to Multiply NRD and ORD by (1-Cp)

When we multiplied NRD by (1-Cp) thereby treating it the same way as ORD, the coefficient actually increased, as shown in Table 3.12.

Table 3.12

Variability of Estimates for Different Treatment of (1-Cp)

	NRD Value	Coeff. t-ratio	ORD Value	Coeff. t-ratio	IM Coeff. Value	CP Coeff. Value	$\bar{R}^2$	DW
1956, NRD	0.318	5.4	0.046	2.4	0.029	-0.158	0.883	1.94
1956, NRD $\left(\frac{1-Cp}{1-\overline{Cp}}\right)$	0.492	5.2	0.041	2.1	0.029	-0.164	0.875	1.88
1960, NRD	0.426	3.9	0.074	2.0	0.031	-0.157	0.883	1.96
1960, NRD $\left(\frac{1-Cp}{1-\overline{Cp}}\right)$	0.542	3.2	0.043	1.2	0.029	-0.158	0.853	1.69

We have divided ORD by the scale factor $(1-\overline{Cp})$, the sample period average, which is .1356 for 1950-1974 and .1248 for 1960-1974. This allows us to compare the coefficients directly by working with them in the same magnitude. We have also divided the NRD (1-Cp) term by $(1-\overline{Cp})$.

Perhaps this point deserves some further clarification. In the ORD term, we actually have

$$0.592 * \Sigma A_i (ORD)_{-i} * (1-Cp)$$

Suppose ORD rises by \$1 billion (\$1000 million) and assume GNP for that time period is \$600 billion. Then γ would rise by

$$0.592 \left(\frac{1000}{600}\right) * (1-Cp) \text{ percent.}$$

The effect will vary depending on the value of Cp, which is what we expect. However, suppose Cp is at its average value, 0.8752. Then γ rises

$$0.592 \left(\frac{1000}{600}\right) * 0.1248.$$

Clearly another way to write this term would be

$$\left[0.592 * 0.1248\right] \frac{1000}{600}$$

Now suppose Cp is not 0.8752; in general we can write

$$(0.592 * 0.1248) \frac{1000}{600} * \frac{1-Cp}{(1-\overline{Cp})}$$

which is the way we have treated this term. Thus in the alternative equations we have transformed the coefficient of the ORD term in the same manner.

Other Assumptions

In order to investigate the validity of the results and their sensitivity to the variables further, we calculated sixty additional regression equations in which we experimented with different measures of γ, different treatments of Cp, and the inclusion of the indexes of labor quality. A summary of these results is given in Table 3.13.

Alternative Specifications of the Equation for Technological Change

		$\sum_{i=0}^{7} A_i\,(NRD)_{-i}$	$\sum_{i=0}^{7} A_i\,(ORD)_{-i}$	$\sum_{i=0}^{7} A_i\,(ORD)_{-i}\frac{(1-CP)}{(1-\overline{CP})}$	IM	CP	ΔIE	ΔIAS	Rate of Return	$\bar{R}^2$
γ_C	56-74	.318		.046	0.029	-.158			39	.88
	60-74	.426		.074	0.031	-.157			43	.88
γ_D	56-74	.383		.031	0.039	.040			42	.45
	60-74	.294		-.037	0.042	.135			38	.37
γ_C	56-74	.227	.066		0.033	-.140			34	.88
	60-74	.259	.101		0.037	-.124			36	.86
γ_D	56-74	.327	.041		0.041	.049			39	.45
	60-74	.365	-.079		0.038	.132			41	.38
γ_C	56-74	.392	-.007		0.048				42	.78
	60-74	.383	.008		0.045				42	.79
γ_D	56-74	.270	.067		0.036				37	.47
	60-74	.233	.020		0.029				35	.30
γ_C	56-74	.376		-.008	0.048				41	.78
	60-74	.386		.002	0.045				42	.79
γ_D	56-74	.368		.046	0.034				41	.48
	60-74	.330		.039	0.030				39	.31
γ_C	56-74	.135	.087		0.026	-.177	.096	1.97	28	.90
	60-74	.179	.080		0.029	-.140	.072	2.09	31	.88
γ_D	56-74	.327	.066		0.044	.019	.114	-2.96	39	.52
	60-74	.361	.072		0.046	.057	.096	-2.37	41	.27
γ_C	56-74	.187	.083		0.031	-.164	.074		32	.88
	60-74	.203	.175		0.036	-.178	.103		33	.87
γ_D	56-74	.249	.072		0.037	0	.146		36	.47
	60-74	.332	-.035		0.038	.100	.061		40	.32
γ_C	56-74	.193	.066		0.030	-.144		1.64	32	.89
	60-74	.206	.011		0.028	-.097		2.61	33	.88
γ_D	56-74	.396	.042		0.048	.058		-3.35	42	.52
	60-74	.399	-.021		0.044	.115		-1.68	42	.33
γ_C	56-74	.398	-.009		0.048		-.043		42	.77
	60-74	.383	-.006		0.044		-.044		42	.78
γ_D	56-74	.249	.072		0.037		.146		36	.51
	60-74	.231	.066		0.033		.144		34	.34

Table 3.13
(continued)

	$\sum_{i=0}^{7} A_i\,(NRD)_{-i}$	$\sum_{i=0}^{7} A_i\,(ORD)_{-i}$	$\sum_{i=0}^{7} A_i\,(ORD)_{-i}\frac{(1-CP)}{(1-\overline{CP})}$	IM	CP	ΔIE	ΔIAS	Rate of Return	$\bar{R}^2$
γ_C 56-74	.370	-.010		0.046			1.30	41	.78
60-74	.265	-.094		0.029			3.81	36	.84
γ_D 56-74	.325	.073		0.042			-3.21	39	.52
60-74	.329	.103		0.042			-3.10	39	.30
γ_C 56-74	.269		.055	0.024	-.173	.048	1.76	37	.89
60-74	.283		.044	0.026	-.133	.029	2.08	37	.88
γ_D 56-74	.429		.037	0.043	.030	.075	-3.12	43	.50
60-74	.356		-.004	0.042	.091	.067	-1.60	41	.27
γ_C 56-74	.310		.055	0.028	-.165	.031		39	.88
60-74	.422		.090	0.030	-.160	.010		43	.87
γ_D 56-74	.357		.037	0.036	.016	.104		41	.45
60-74	.249		-.040	0.039	.111	.081		36	.33
γ_C 56-74	.285		.052	0.026	-.162		1.60	37	.89
60-74	.311		.049	0.028	-.128		1.88	39	.89
γ_D 56-74	.454		.033	0.046	.048		-3.37	44	.52
60-74	.420		.008	0.046	.103		-2.06	43	.33
γ_C 56-74	.356		-.009	0.046		-.028	1.25	41	.76
60-74	.182		-.045	0.034		.001	3.54	31	.82
γ_D 56-74	.414		.048	0.040		.088	-3.03	43	.53
60-74	.424		.057	0.037		.086	-2.59	43	.30
γ_C 56-74	.383		-.007	0.048		-.037		42	.77
60-74	.415		.011	0.045		-.048		43	.78
γ_D 56-74	.350		.043	0.034		.111		40	.48
60-74	.253		.015	0.029		.122		36	.32
γ_C 56-74	.350		-.010	0.046			1.34	40	.78
60-74	.184		-.045	0.034			3.53	32	.84
γ_D 56-74	.435		.051	0.040			-3.30	44	.54
60-74	.523		.084	0.041			-3.38	47	.34

The principal conclusions to be drawn from the myriad of results in Table 3.13 are as follows:

(1) The goodness-of-fit statistics ($\bar{R}^2$) are substantially worse for γ_D (the Denison-based measure) than for γ_C (the CEA-based measure). The γ_D series evidently contains a larger random component than does γ_C. This is probably not too surprising because the series for γ_C was derived from a straight-line estimate of the potential GNP, while γ_D was taken from a GNP series for which the yearly rates of change showed significant variations. However it is most significant to note that the average coefficient of NRD from the thirty regressions with γ_D is 0.348, <u>significantly higher than the average of 0.301 obtained from the γ_C equations</u>. In other words, substituting the Denison-based measure of γ actually raises the coefficient of the NRD term. If we convert this to a rate of return on NASA R & D spending as discussed previously, it averages 40% based on the coefficients for γ_D and 38% for γ_C.

(2) All of the regressions with γ_D have positive signs for the Cp term, as opposed to the negative sign which is found in the γ_C regressions and which we would expect on theoretical grounds. This does suggest the possibility of some spurious negative correlation between γ_C and Cp. This result might have arisen as follows. We have $\gamma_C \cong \frac{\Delta X}{X} - \alpha \frac{\Delta L}{L} - \beta \frac{\Delta K}{K}$, and $\frac{\Delta X}{X}$ is almost constant. During years of expansion in the economy, $\frac{\Delta L}{L}$ and $\frac{\Delta K}{K}$ would on average increase faster than usual, so γ_C would rise more slowly than usual. During these same years, it is likely that capacity utilization would also be above average levels, hence the negative correlation. In our opinion, this is not an entirely spurious relationship, since as the economy nears full capacity it uses labor and capital resources which are not as efficient.

Labor resources are used which are not as highly skilled, not as thoroughly trained, or less efficient because of overtime work. Capital resources are used which are obsolescent and are pressed into action only when they can be justified by higher product prices. One would expect these arguments to hold for γ_D as well, and the fact that Cp is always zero or positive in the γ_D regressions does cast some doubt on their validity. On the other hand, it may be that Denison's calculations for potential GNP fail to take into account the less efficient labor and capital inputs near full capacity, a view toward which we are inclined.

On balance we would probably admit that some spurious correlation does exist by including Cp in the γ_C functions. However, even without this term the $\bar{R}^2$ averages around 0.8, which is still unusually high for this type of first difference equation. Furthermore, the average of the NRD coefficients in the equations with Cp is 0.330, which is slightly higher than the 0.318 average without Cp. Thus our results do not change significantly whether we include the Cp term separately or not.

(3) Another controversy has arisen over the fact that the term for other research and development (ORD) has been multiplied by (1-Cp). The suggestion has been made that this enhances the value of the NRD coefficient and has been included for that reason. There is little doubt that the use of ORD*(1-Cp) does improve the coefficient of the NRD term; it averages 0.376 in those equations which include ORD*(1-Cp), compared to 0.272 in those equations with just ORD. This is the largest pairwise spread for any set of variables tried. Furthermore, the use of the (1-Cp) term with ORD enhances that coefficient as well, raising it from an average of 0.026 to 0.037.

This result can be interpreted in a number of ways. One possibility is that the addition of the (1-Cp) term is a very meaningful one, and that these results suggest very strongly that R & D spending has a greater effect in the economy during periods of slack capacity. Such a viewpoint agrees with the conclusions found in Chapter 2, where we noted that a shift toward higher NASA spending is more stabilizing in a recovery period than general government spending. However, we realize that these results could be interpreted as further evidence of the spurious negative correlation between γ_C and Cp which has already been discussed. Thus we consider using the ORD term without (1-Cp) in our "least favorable" case discussed below.

(4) We also experimented with including the indexes of labor quality for education (IE) and age-sex classification (IAS). The latter term adds virtually nothing to the equation; it is positive in every single equation for γ_C and negative in every single equation for γ_D. The reason for this appears to be that Denison gives greater weight to changes in age-sex classification in computing potential output and labor input than we did. In any case, the use of IAS in the γ_D equation tends to raise the coefficient for NRD, and we do not consider it further.

The coefficient for IE is positive in the great majority of cases (25 out of 30) and does tend to decrease the NRD coefficient; the average is 0.290 for equations with IE and 0.358 for those without. This finding is not too surprising, since level of educational attainment and R & D spending are undoubtedly highly correlated.

We thus consider a "least favorable" case, which has the following characteristics:

(1) We use γ_D instead of γ_C

(2) The Cp term is omitted

(3) ORD is not multiplied by (1-Cp)

(4) IE is included in the equation

We should make it perfectly clear that we do not consider this a satisfactory equation, and present it only as a possible lower bound for the estimate of the rate of return on NASA R & D spending.

In our opinion, the Cp term has important theoretical significance both by itself and in conjunction with the ORD factor. The γ_C series represents, we believe, a more accurate description of changes in productivity over the past twenty years than does γ_D. While we find no theoretical reason for excluding IE, the coefficient associated with this term falls far below standard significance levels, a point which would undoubtedly be raised in capital letters if it applied to the NRD term. Nevertheless, we find that the rate of return on NASA R & D spending is still estimated to be 36% for the 1956-1974 period and 34% for the 1960-1974 period, compared to the estimates of 39% and 43% respectively for the preferred equations. Thus in spite of using the least favorable case for this regression, we still obtain relatively high rates of return for NASA R & D spending. The conclusions of the report would not be materially altered even if we were to select this least favorable case as the preferred alternative.

The "least favorable" equations for the two sample periods are as follows:

$$\gamma_D = -1.37 + \underset{(2.9)}{0.249} \sum_{i=0}^{7} A_i (NRD)_{-i} + \underset{(1.8)}{0.072} \sum_{i=0}^{7} A_i \, (ORD)_{-i} + \underset{(4.5)}{0.037} \, (IM - \overline{IM})$$

$$+ \underset{(1.5)}{0.146} \, \Delta IE$$

$\bar{R}^2 = 0.510$
DW = 2.81
Sample period 1956-1974

$$\gamma_D = -1.57 + \underset{(2.0)}{0.231} \sum_{i=0}^{7} A_i (NRD)_{-i} + \underset{(0.5)}{0.066} \sum_{i=0}^{7} A_i (ORD)_{-i} + \underset{(2.4)}{0.033} (IM - \overline{IM})$$

$$+ \underset{(1.3)}{0.144} \Delta IE$$

$\bar{R}^2 = 0.338$
DW = 2.85
Sample period 1960-1974

It is of considerable interest to note that the rate of return diminishes only slightly if we use the coefficients in some of the alternative equations we have estimated. In some cases the estimates are even higher. If we refer to some of those alternatives which are given in Tables 3.10 - 3.12 we can calculate the following alternative rates of return. We have excluded the calculations for those equations which incorporate only a one-year lag, since the rate of return there seems to be unrealistically high. These estimates are given in Table 3.14.

Table 3.14

Alternative Rates of Return for NASA R & D Spending

			Rate of Return	
Equation Characteristic	Table #	NRD Coeff.	Infinite Life	First 10 yrs. only
Standard	All	0.426	0.43	0.38
Standard, 1956-74	3.10	0.318	0.39	0.33
NRD (1-Cp) 1960-74	3.12	0.542	0.47	0.42
NRD (1-Cp) 1956-74	3.12	0.492	0.45	0.40

We can also calculate the rate of return for other R & D spending. The coefficients of these terms are always much lower, and the effects are not nearly as spectacular. Even so, we find a respectable 21% rate of return for other R & D spending in our standard equation, with other estimates not far from this figure (for the infinite life case). Summary statistics are given in Table 3.15.

Table 3.15

Alternative Rates of Return for Other R & D Spending

Equation Characteristic	Table #	ORD Coeff.	Infinite Life	First 10 years
Standard	All	0.074	0.21	0.11
Standard, 1956-74	3.4	0.046	0.17	0.05
NRD (1-Cp) 1960-74	3.11	0.043	0.16	0.04
NRD (1-Cp) 1956-74	3.11	0.041	0.16	0.04

4. Macroeconomic Impacts of NASA R & D Spending

A. Advantages of the Macroeconomic Approach

In Chapter 3 we discussed the various charges which have been levelled against the macroeconomic approach to estimating γ. However, the reader should be reminded that there are several advantages of using this method. First, the aggregate measures of γ include all of the spillover effects which cannot be captured at the micro level unless one performs an excrutiatingly large number of individual studies. Second, the micro approach by necessity ignores the economic environment in which these expenditures are made and fails to account for the interactive and dynamic effects which are caused by increased spending. Third, complete macro model simulations take into account both the demand effects of higher spending and the supply effects of greater productivity. Fourth, simulations with a complete macro model permit one to evaluate the relative long-run efficacy of alternative government programs which provide, for example, funds for public service jobs instead of increases in spending for R & D.

A number of studies, including work by Mansfield (41, 42), have been shown that the social rate of return on R & D spending is often at least twice as great as the private rate of return. In other words, the benefits to society in terms of greater output and higher productivity far exceed the benefits accruing to the firm or organization which originally spent the money for R & D. This is particularly true in the area of high-technology R & D spending, where the major benefits often stem from inventions and in areas which were not originally considered to be even remotely connected with this spending. Yet microeconomic studies which are designed to measure the rate of return in a single industry cannot capture the magnitude of these benefits.

The increase in the aggregate rate of technological progress logically represents the summation of all industries which are affected by a given change in spending on R & D. While the microeconomic effect can certainly probe the effects within a given industry in more detail, the overall result is necessarily incomplete. The optimal strategy would be to combine the microeconomic and macroeconomic effects, a task which is beyond the scope of this study.

We have already indicated that the economic impact of R & D spending will vary depending on the stage of the business cycle during which these expenditures are made. Expenditures made during periods of full or over-full employment of factor inputs will result in a smaller net addition to productivity and real growth than those undertaken during periods of slack capacity. Microeconomic studies invariably ignore this point.

In addition to the macroeconomic benefits deriving from the spillover effects, the higher level of real output will also give rise to increases in labor productivity through increases in the capital/labor ratio. These increases are not considered in the calculations of γ, which measures the residual growth in technology after the contributions of labor and capital have been removed. Yet an increase in labor productivity leads to higher real wages and hence higher levels of consumer spending, output, and employment. These contributions to social benefits certainly should be included in an overall calculation of the rate of return, yet are omitted from microeconomic studies by their very nature.

The social rate of return should include the increase in output which stems from a higher level of real income and aggregate demand. An increase in productivity will lead to greater production with the same factor inputs,

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hence resulting in lower unit costs of production. This will eventually result in lower prices, which will raise real disposable income. This will permit consumers to purchase more with each dollar of nominal income, which will lead to an increase in consumption, output, and employment. In other words, increasing the rate of technological progress raises the level of output in two distinct ways. First, it expands the production possibility frontier through the introduction of new inventions and innovations. Second, it increases aggregate demand by raising the level of real income and consumer spending. Microeconomic studies consider only the former.

Finally, only by simulating a complete macro model can we measure the effects of alternative government programs on the overall economy. Such simulations can be used to measure not only the effect on aggregate demand, but the effects on productivity, employment, unit labor costs, and hence inflation. Nowadays economists are no longer concerned only with the level of unemployment and real output; alternative programs must be carefully weighed for their contributions to higher or lower rates of inflation. Thus we find that a $1 billion increase in NASA spending has approximately the same effect on aggregate demand and employment during the first two years as would a similar increase in other purchases of goods and services by the government, although the multiplier effects are larger than those which we obtain for tax cuts or increased transfer payments. However, the differences over a ten-year span are much different. While most types of government spending add to aggregate demand without increasing aggregate supply, and hence eventually contribute to inflationary conditions, spending for R & D actually increases productivity and aggregate supply a sufficient amount so that the rate of

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inflation is lowered. While we have shown that this is also true to a smaller extent for other types of R & D spending, it is not true for those types of spending which do not increase productivity at all. Once again, these types of simulations can be calculated only with the macroeconomic approach.

B. The Chase Econometrics Macro Model

It is likely that the macroeconomic results which we have obtained in this study are broadly similar to those which would have been found with other macro models; on the other hand, each macro model has its own particular features. It would not be appropriate in this report to include a full description of the macro model, but perhaps we might indicate its general nature. After that we consider some of the dynamic features which lead to the results which we have obtained.

The Chase Econometrics macro model is a complex large-scale econometric model which contains 125 stochastic equations and approximately 200 endogenous variables. The first major block of the model contains equations for consumption, investment, foreign trade, and government spending. The consumption sector consists of fourteen categories; the principal independent variables are disposable income in constant dollars, income distribution, relative prices, credit conditions, and (for durable goods) existing stocks. The disposable income and income distribution terms contain lags of up to 16 quarters, representing the fact that consumer spending patterns adjust slowly over time to changes in income. The investment sector is disaggregated into components for producers durable equipment, various types of nonresidential construction, housing starts, and inventory investment. While a variety of independent variables are used, the key elements are disposable income or industrial production, relative prices, and credit conditions. These include both the standard interest rates and the Chase Econometrics index of credit rationing, which measures the non-price component of credit availability. The export and import equations include various measures of income both for the U. S. and on a worldwide basis, cyclical variables, and relative prices. Most of the components of government spending are exogenous, but they enter the model in current dollars, which means that a higher rate of inflation leads to lower spending in real terms, and hence less output and employment in the overall economy.

The second major block of the model is the monetary sector. Equations are provided for all major interest rates, components of the money supply, deposits at financial intermediaries, business loans, and the index of credit rationing. Interest rates are determined primarily by Federal Reserve action, demand for funds from the private sector, demand for funds from the government sector (the surplus or deficit), and price expectations. The equations for assets and liabilities of banks are structured in current dollars, so that an increase in the price level results in higher interest rates and tighter money unless the Fed takes offsetting action. These variables then feed back as independent variables in the aggregate demand equations in the consumption and investment sectors.

The third major block of the model deals with income distribution, and as such includes equations for employment and unemployment, labor force, wage rates, nonwage personal income, profits, depreciation and taxes. Employment is a function of output in constant prices, previous capital stock, and the rate of technology. This section also contains the equations for maximum capacity in the economy, which we adjust when we increase the rate of technological progress through higher R & D spending.

The other equations in the section are denominated in terms of current prices. Wage rates are a function of previous levels of unemployment and changes in the consumer price index. The various income distribution terms depend primarily on aggregate measures of income and output and relative prices, which in this case include factor as well as product prices.

The fourth major block in the model explains prices. This part of the model contains almost 30 equations, since we explain the deflators for all the components of aggregate demand, plus several components of the wholesale price index. These equations are highly nonlinear in form and contain as principal variables unit labor costs, the index of capacity utilization, and various input prices of key materials such as food and fuel. The equations also include interest rates which represent another cost of doing business, and a number of cyclical demand variables for various sectors.

The principal dynamic features of this model are somewhat different than other macro models which are more linear in nature, do not contain as much simultaneity, and do not include the variety and scope of relative price terms which we have included. First, the demand multipliers stemming from a unit increase in aggregate demand are not monotonic, but contain a definite cyclical effect, due in part to the stock-adjustment principle. Second, an increase in productivity lowers unit labor costs and hence prices, leading to further increases in aggregate demand. In the next section we turn to a discussion of these dynamic factors.

C. Dynamics of the Macroeconomic Model

As suggested in the previous section, the Chase Econometrics macro model is a very complex and fully simultaneous model with many asymmetries and non-linearities. One of the key factors is the interaction between the real and monetary sectors. We discuss this in terms of an increase in prices, since that is the way in which the argument is usually presented. The effect of a decrease in prices due to lower costs is symmetrical.

A rise in prices will decrease real output (and vice versa) through several distinct channels:

a) A higher rate of inflation, cet. par., raises the personal savings rate.

b) Higher rates of inflation lead to higher interest rates and tighter credit rationing, thus reducing investment.

c) Higher prices lead to less investment because of the increased cost, particularly in housing.

d) Higher prices lead to a worsening of the net export position.

e) Higher prices lead to a lower constant dollar government spending for the same current dollar figure. If the current dollar figure is raised, there are still some offsetting effects through an increase in taxation or higher interest rates due to a larger budget deposit -- unless, of course, the Federal Reserve System expands the money supply at the same time. We now discuss each of these in more detail.

The positive relationship between the savings rate and the rate of inflation is one of the most misunderstood in all of economic literature. Occasional empirical attempts to determine whether this relationship does in fact exist have too often been restricted to a set of simple relationships in which consumption (or savings) is regressed against income and prices. Such overly simplistic experiments usually give statistical results which are not significant enough to support either point of view. Even if they did, however, they would miss the real question by a wide margin. For the answer, even on a theoretical level, depends on the type of inflation which one specifies.

Neutral inflation occurs when all product and factor prices rise by the same amount. An extreme case of such an inflation (or deflation) occurs when a country simply alters its unit of exchange, such as the conversion of 100 old francs to 1 new franc. Under such conditions the savings rate is completely unaffected. This is well known as the homogeneity condition for consumption. However, it is clear that we are not considering this type of inflation for the purposes of the U. S. economy in the 1970's.

Hyperinflation occurs when the expected rate of inflation next period is greater than the actual rate of inflation in this period. When this happens, consumers rush to change their money for goods as quickly as possible. During such times, the *ex ante* savings rate goes to zero. Clearly this is not the type of situation which is of interest in the present simulations. The savings rate in 1975.2 will reach a postwar high, which is completely inconsistent with fears of hyperinflation.

Normal inflation occurs when neither of the two above conditions holds. Therefore, some prices are rising faster than others but they are expected to rise less rapidly next period. Even within the broad group of normal inflation we can distinguish several sub-varieties. However, it will be sufficient to deal in this context with the actual type of inflation witnessed in the U. S. economy during the postwar period, which in every case has been sparked by excess demand, at least in its initial phases.

During the type of inflation which we have been witnessing, two major shifts take place. First of all, prices of goods and services with high income elasticities rise relatively faster than those with low income elasticities, although they still rise more slowly in absolute terms. This can best be clarified with an example. Assume that during a year of low inflation, consumer prices rose 2%, with durable goods rising 0% and services rising 4%. In a year of high inflation (say 8%) it is likely that durables prices would rise 6% and service prices 10%. While durable prices are still rising at a somewhat lower rate than service prices, the incremental rate of change has been greater. Thus there is a relative decline in durable purchases (which are assumed to have a high short-term income elasticity) which is not balanced by the slightly higher spending on services (which have a low short-term income elasticity). This argument is strictly supportable on a theoretical basis only if the goods with high income elasticities also have high price elasticities, and analogously for low elasticities, but this seems eminently reasonable. In any case the argument is easily supportable on an empirical basis.

This, however, is not the most important link by which a rise in the rate of inflation increases the savings rate. According to the permanent income hypothesis, the marginal propensity to consume is lower for variable incomes than it is for fixed incomes. Yet it is almost a truism that inflation penalizes those on fixed incomes at the expense of those on variable incomes. Thus during inflation the decline in consumption by those on fixed incomes is not nearly matched by the increase in consumption by those on variable incomes -- even if we assume that the income changes are the same -- and thus the savings rate rises. This result, which has long been supported by careful theoretical

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analysis, has never before been shown to operate empirically, mainly because the critical parameter estimates for income distribution and relative price terms can be uncovered only at a fairly detailed level of disaggregation. While other studies have divided consumption into many more categories than are predicted in the Chase Econometrics model, they have all been aimed at determining long-run trends and have excluded short-run cyclical effects due to inflation.

The other channels by which a rise in prices lowers real output are much more straightforward and do not require nearly as much detailed exposition. For a given nominal money supply, it is clear that higher prices lead to a lower real money supply and hence an increase in interest rates unless there has been a specific offsetting shift in the liquidity preference function. In addition, the investment functions in the Model for both residential and nonresidential investment contain relative price terms. Hence when the cost of capital goods rises more than the general price level for goods -- which invariably happens during booms because of the relatively inelastic supply curve for all types of construction -- the constant-dollar demand for fixed investment at a given level of output is decreased. This effect is considerably stronger for residential construction than other types of investment, since the home is being sold (or rented) directly to the final consumer, who has a more elastic demand curve than the businessman who is renting industrial or commercial space. The relative price effect on equipment, while still significant, is smaller than it is for either type of construction.

It should come as no surprise that an increase in domestic prices for a given level of foreign prices leads to a deterioration in the net foreign balance. We have found that the price elasticity for both imports and exports of finished goods is greater than unity, thus making the problem one of a potentially serious nature. Finally it should be pointed out that a government budget which is fixed in current dollars will clearly buy less goods and services and generate less employment if prices increase. It is true that governments faced with this dilemma often raise their current-dollar expenditures enough so that real purchases remain constant. For a given nominal money supply, however, this will result in higher interest rates and tighter credit, thus reducing aggregate demand in the private sector. Only if the Federal Reserve System agrees to follow a "neutral" or passive monetary policy and create as much additional money as is necessary will there be no initial rise in interest rates. Yet if the economy is at full employment, this move is eventually the most inflationary of all, since it increases the ex ante demand for resources without changing the supply, and thus will eventually result in higher inflation than would be the case if the Fed did not finance the deficit. It is clear, then, that a rise in prices will reduce aggregate demand and raise unemployment. Similarly, a decline in costs and prices will increase aggregate demand and lower unemployment.

We now return to the factors which result in cyclical behavior in the demand multiplier. Under ordinary circumstances an increase in aggregate demand would lead to higher prices through (a) higher levels of capacity utilization and (b) lower rates of unemployment, which would lead to higher wage rates and hence higher unit labor costs. However, these forces are offset in the case of higher NASA R & D spending by an increase in productivity caused by the switch to higher-technology industries.

We still observe, however, a significant cyclical pattern in the demand multipliers stemming from a change in exogenous spending. The incremental change in real GNP peaks in the second year and then declines gradually until the supply effect begins to raise output. This is due to what is commonly known as the stock-adjustment principle. This factor is a significant determinant of levels of purchases for consumer durables, plant and equipment spending, housing, and inventory investment, although with differing lag structures. Within the confines of business cycle analysis, the most marked effect occurs in inventory investment.

The general principal operates in the same manner for all of the categories of aggregate demand mentioned above. We assume an equilibrium position exists at some time when the ratio of stocks to the relevant aggregate demand variable (income, output, or sales) is in equilibrium. This equilibrium value in general depends both on institutional variables, such as turnover ratios, on demographic factors, such as population or age distribution, and on economic variables, such as the cost and availability of credit. We then increase GNP by one unit. If stocks are to remain in equilibrium, they must rise proportionately to the increase in income. During this time we witness an acceleration of demand. After stocks have reached the new equilibrium level, however, the extra demand which was caused by the augmenting of stocks recedes. This would then tend to reduce the multiplier effects of an exogenous increase in aggregate demand in later years.

The simple stock adjustment case can be represented as follows.

(4.1) In equilibrium $K_t = \alpha X_t$

where K_t is the capital stock of a particular good and X_t is the relevant aggregate demand variable.

If we now increase X_t to a new level X_{t+1} eventually K_t will move to a new level K_{t+j} which is equal to αX_{t+1}. However, in the meantime the change in K_t will be proportional to the difference between actual and desired levels of capital stock, so that

(4.2) $\Delta K_{t+1} = \delta(\alpha X_{t+1} - K_t)$

In the next period $K_{t+1} > K_t$ because of the positive value of ΔK_{t+1}. If we assume $X_{t+2} = X_{t+1}$, then

(4.3) $\Delta K_{t+2} = \delta(\alpha X_{t+2} - K_{t-1})$

The increment ΔK_{t+2} will be smaller than ΔK_{t+1} because the gap between actual and desired levels of capital stock has diminished. Eventually this gap will close altogether.

In actual simulations, of course, the dynamics are much more complicated. Since ΔK = investment, and investment is part of GNP, X_{t+2} is usually not equal to X_{t+1}. Furthermore, inasmuch as α depends on financial variables, it too will vary over the business cycle. However, the general principle is an important one in understanding the dynamics of macro models.

The change in income or output will affect the stock of business fixed investment and housing only with a very substantial lag, so that a complete stock adjustment for these categories of aggregate demand usually spans more than one business cycle. The cycle is shorter for consumer durables and shorter still for inventory investment, where adjustment often occurs within a few months. This results in an inventory sub-cycle which usually occurs at least twice in every regular (40-month) business cycle.

We have thus far discussed the dynamic effects of a $1 billion increase in NASA R & D spending both from the point of view of the demand side and the supply side. One more factor must be considered, and that is the lag structure on the supply side. We have already noted the existence of a two-year lag between the original expenditure of R & D funds and any increase in γ. We now note an additional two-year lag between the time γ increases and any incremental change in aggregate demand occurs. The mere fact that the production possibility frontier has expanded does not by itself guarantee that aggregate demand will rise. Instead, it must work through the structure of the economy through a lower price level, as indicated in the previous pages. Higher productivity will lead to lower unit labor costs, which will in turn lead to lower prices. This will increase consumer real income which will lead to higher levels of consumption. This in turn will cause sales and output to increase, which will increase the demand for labor and hence employment. Finally investment will increase, since output and capacity utilization has risen. This process takes an additional two years before it gets underway, and thus the supply effects from increased NASA R & D spending influence real GNP only with a four-year lag.

D. Simulation Results

In order to prepare these results, we first simulated the Chase Econometrics macro model out ten years under baseline forecasts; this represents our standard ten-year forecast. A copy of these latest forecasts is included as Appendix F to this study. We do not need to go into detail about this forecast, except to note that it predicts an average unemployment rate of 9% this year and 8% next year, an increase in the rate of inflation to the 9% range in 1977 and 1978, and another major recession in 1978-79. After that things improve somewhat, but the rate of unemployment does not dip below 6% until after 1980. Because of this significant slack in the economy, the multiplier effects of increased R & D spending are somewhat higher than they would be if the economy were at full employment.

We then superimpose on this run a $1 billion increase in NASA R & D spending. We have measured this $1 billion in constant (1958) dollars, since all the calculations have been in terms of the real rate of increase in technological progress. We assume that NASA R & D spending is increased by this amount at the beginning of 1975 and the incremental increase remains in force throughout the next decade. This means that the current-dollar level of the NASA spending increase factored into the model is equal to 1.00 times the implicit GNP deflator for GNP in each year. The increases in current-dollar NASA spending for each year are given in Table 4.1. The incremental values for the other factor which we changed in the model, namely γ, are also given in this table.

Table 4.1

Increases in Current-Dollar NASA R & D Spending and in γ

Used in the Macroeconomic Simulation

	NASA Spending [a]	Cumulated Values of γ [b]
1975	2.3	0
1976	2.4	0
1977	2.6	0.040
1978	2.8	0.185
1979	3.1	0.471
1980	3.3	0.906
1981	3.6	1.470
1982	3.8	2.113
1983	4.1	2.756
1984	4.4	3.399

(a) Entered in the model through changes in the level of Federal non-defense spending.

(b) Entered in the model through changes in the level of total capacity in the economy.

In this simulation we did not assume that the $1 billion increase in NASA R & D spending was offset by a decrease in any other Federal spending or an increase in taxes, so we have assumed the expansionary effect of deficit spending. However, by the end of the decade, government receipts have increased by $3.7 billion due to the higher level of economic activity, so the actual increase in the Federal budget deficit is only $0.3 billion.

Before turning to the actual results, we first distinguish between the demand and supply effects. A $1 billion increase in NASA spending will have an immediate effect on real GNP, raising it approximately $2.1 billion the first year and $2.5 billion the second year. In succeeding years the multiplier is reduced slightly due to stock adjustment effects, which are centered in inventory investment and purchases of consumer durables. These cyclical effects are not dominant in our simulation, but they cannot be ignored; as we have recently seen once again, the business cycle is not likely to pass out of existence in the near future.

The demand multiplier effects which we have obtained are not markedly different than those which would have occurred for a similar increase in other purchases of goods and services by the government sector or for release of funds to the private sector for construction projects. They are, however, substantially higher than the effects which would be obtained from a $1 billion increase in transfer payments or decrease in taxes. In particular we have found that the real multiplier is smallest and the increase in inflation is largest per unit change in transfer payments.

We discussed in Chapter 3 the magnitude of increase which will occur in the productive capacity of the economy for an increase in NASA R & D spending. However, there is no automatic increase in demand which will occur just because total supply is now higher, and even those increases which do happen do not occur immediately. Greater R & D spending leads to an increase in productivity, primarily in the manufacturing sector. As a result of this increase, less labor is needed per unit of output. This in turn lowers unit labor costs, which leads to lower prices. Yet this decrease is not immediately transferred into higher output and employment. As prices are lowered (or grow at a less rapid rate), real disposable income of consumers increases at a faster rate. Consumers can then purchase a larger market basket of goods and services, which in turn are now available because the production possibility frontier has moved outward. These decisions are not instantaneous and frictionless, as they would be in an oversimplified static model. We do not see significant effects of increased technology on aggregate demand until 1980.

The actual simulation results for a $1 billion increase in NASA R & D spending, which are given in Table 4.2, indicate clearly that the demand elements predominate for the first five years. The only major difference between this run and a typical multiplier analysis of government spending is that prices do not rise at all; this is due to the aforementioned switch to higher-technology industries which occurs when NASA spending rises. The stock-adjustment principle is noticeable in the results; more so for the index of industrial production, since inventory investment and consumer durables comprise a larger proportion of the manufacturing sector than they do of total GNP, which contains a large service component.

During the first five years of the simulation, all the changes in the economy are rather modest. The consumer price index and rate of inflation stay at virtually the same level in both the baseline and NASA high simulations. The unemployment rate declines by approximately 0.1%, and the number of jobs increases by 0.13%, or 110,000 jobs. The changes in industrial production follow the changes in real GNP, while labor productivity increases at virtually the same rate.

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Table 4.2

Change in Selected Variables With a Sustained Increase in NASA R & D Spending of $1 Billion Per Year

	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
Gross National Product, Billions of 1958 Dollars										
Base	788.1	834.0	869.6	859.8	868.5	922.4	977.7	1012.2	1059.6	1090.8
NASA	790.2	836.5	871.7	862.1	871.7	928.6	988.0	1035.0	1077.4	1114.1
Change	2.1	2.5	2.1	2.3	3.2	6.2	10.3	13.8	17.8	23.3
% Change	.3	.3	.2	.3	.4	.7	1.1	1.4	1.7	2.1
Consumer Price Index, 1967 = 100.0										
Base	161.1	173.9	188.4	204.9	219.4	232.0	244.2	257.0	270.9	286.5
NASA	161.0	173.8	188.4	204.7	219.0	231.0	242.2	254.0	266.9	280.7
Change	-0.1	-0.1	0.0	-0.2	-0.4	-1.0	-2.0	-3.0	-4.0	-5.8
% Change	0.0	0.0	0.0	-0.1	-0.2	-0.5	-0.8	-1.1	-1.5	-2.0
Rate of Inflation, %										
Base	9.1	7.9	8.3	8.7	7.1	5.8	5.2	5.2	5.4	5.8
NASA	9.1	7.9	8.3	8.6	7.0	5.5	4.9	4.9	5.0	5.3
Change	.0	.0	.0	-.1	-.1	-.3	-.3	-.3	-.4	-.5
Unemployment Rate, %										
Base	9.0	8.2	7.4	8.6	9.9	9.2	8.0	7.1	6.5	6.0
NASA	8.9	8.0	7.3	8.5	9.8	9.1	7.7	6.8	6.1	5.6
Change	-.1	-.2	-.1	-.1	-.1	-.1	-.3	-.3	-.4	-.4
Employees on Payrolls, Millions										
Base	76.9	79.9	82.8	83.3	83.2	85.3	88.1	90.5	92.5	94.3
NASA	77.0	80.0	82.9	83.4	83.3	85.5	88.4	90.9	93.1	95.1
Change	.1	.1	.1	.1	.1	.2	.3	.4	.6	.8
% Change	.1	.1	.1	.1	.1	.2	.3	.4	.6	.8
Index of Industrial Production, Manufacturing Sector, 1967 = 100.0										
Base	109.1	120.2	129.6	125.3	122.4	132.6	145.3	154.6	162.2	168.6
NASA	109.9	121.2	130.5	126.3	123.5	134.3	148.1	158.1	166.5	174.0
Change	.8	1.0	.9	1.0	1.1	1.7	2.8	3.5	4.3	5.4
% Change	.7	.8	.7	.8	.9	1.3	1.9	2.3	2.7	3.2
Index of Labor Productivity, 1967 = 100.0										
Base	110.2	112.1	113.3	112.5	115.2	120.1	123.9	126.9	129.9	132.0
NASA	110.3	112.2	113.4	112.7	115.5	120.8	125.1	128.6	132.0	134.7
Change	0.1	0.1	0.1	0.2	0.3	0.7	1.2	1.7	2.1	2.7
% Change	0.1	0.1	0.1	0.2	0.3	0.6	1.0	1.3	1.6	2.0
Change in Labor Productivity, %										
Base	-.4	1.7	1.1	-0.7	2.4	4.3	3.2	2.4	2.4	1.6
NASA	-.3	1.7	1.1	-0.6	2.7	4.6	3.6	2.7	2.7	2.0
Change	.1	.0	.0	0.1	.1	.3	.4	.3	.3	.4

Base = baseline projection with current estimates of NASA R & D spending for next decade.

NASA = an increase of $1 billion in 1958 dollars in NASA R & D spending.

Change = NASA - Base

% Change = $\frac{\text{NASA - Base}}{\text{Base}}$. Since the unemployment rate is already given in percentage terms, we do not calculate this item for unemployment.

Once the linkages from aggregate supply to aggregate demand have been established, which occurs after the fifth year, the difference in real growth between the two simulations begins to increase at a much more rapid rate. In particular, we find that the growth in real GNP is about $4 billion per year faster than would be the case under the baseline simulation which does not include increased NASA R & D spending. Thus constant-dollar GNP is $6 billion higher in 1980, $10 billion in 1981, $14 billion in 1982, $18 billion in 1983, and $23 billion higher in 1984. If we were to continue this simulation farther into the future, we would find that the gap between GNP in the two simulations would continue to increase at approximately $4 billion per year -- $27 billion in 1985, $31 billion in 1986, and so on.

As greater productivity is translated into higher aggregate demand, we find that the economy can produce more goods and services with the same amount of labor. This has two beneficial effects. First, unit labor costs decline, hence lowering prices. Second, lower prices enable consumers to purchase more goods and services with their income, hence leading to further increases in output and employment.

We find that the consumer price index grows at a slower rate with higher NASA R & D spending than without, and is a full 2% lower by 1984 than would otherwise be the case. Once again, this change does not occur in the early years of the simulation, but begins to become important in 1980.

One of the major effects of the higher level of real GNP and aggregate demand is the reduction in the unemployment rate of 0.4% by 1984. Since the labor force will be approximately 100 million strong by that date, this indicates, as a first approximation, an increase of 400,000 jobs. However, if we take into account the increase in the size of the labor force, the total will rise to 800,000 new jobs. The increase in the labor force will occur for three principal reasons. First, the derived demand for labor will be greater because the marginal productivity of labor has increased. Second, the supply of labor will rise because the real wage has increased. Third, and probably most important, the increase in aggregate demand will reduce the amount of hidden unemployment as more entrants join the labor force.

It is also important to note that labor productivity rises substantially as a result of the increased NASA R & D spending. The index of labor productivity for the private nonfarm sector grows at a rate of 3.1% during the 1980-1984 period, compared to an average annual rise of 2.8% with no increase in spending. By 1984 the level of labor productivity is 2.0% higher than the baseline projection. Further details and comparisons are given in Table 4.2 for a $1 billion increase in NASA R & D spending.

We also calculated alternative simulations in which we raised NASA R & D spending by $0.5 and $0.1 billion in order to test for nonlinearities at different levels of expenditures. However, we found that in most cases these results were proportional to the $1 billion case. Thus, for example, by 1984 we found that in the $0.5 billion run, real GNP is $11.3 billion higher, compared to $23.3 billion in the $1 billion run. Similarly, the rate of inflation is reduced by 1.0%, compared to 2.0%. Unemployment is reduced by 0.2%, compared to 0.4%, and the number of employees increases by 400,000, compared to 800,000. The index of industrial production is 1.6% higher, and labor productivity increases by 1.0%; the comparable figures are 3.2% and 2.0% in the $1 billion case.

The figures for the $0.1 billion case are also proportional, although in some cases the results differ slightly due to rounding error. Once again taking the 1984 period as a basis for comparison, we find that real

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GNP is $2.0 billion higher, the rate of inflation is .3% lower, and the rate of unemployment is less than .1% lower. The increase in the number of employees is 60,000, in the industrial production index is .3%, and for labor productivity .2%.

A number of other simulations which we performed also indicated that decreases in the NASA R & D budget of $1.0, $0.5, or $0.1 billion would have approximately the same negative effect on the rate of growth, inflation, and employment. Changes larger than $1.0 billion would have less than proportional effects, particularly if these incremental changes were made in relatively short periods of time. However, within the range of modifications likely to be made to the NASA R & D budget during the next few years, we find that the economic impact is proportional to the size of the budget change.

Table 4.3

Change in Selected Variables With a Sustained
Increase in NASA R & D Spending of $0.5 Billion Per Year

	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
Gross National Product, Billions of 1958 Dollars										
Base	788.1	834.0	869.6	859.8	868.5	922.4	977.7	1021.2	1059.6	1090.8
NASA	789.3	835.6	870.8	860.9	870.0	925.6	983.0	1028.0	1068.3	1102.1
Change	1.2	1.6	1.2	1.1	1.5	3.2	5.3	6.8	8.7	11.3
% Change	.2	.2	.1	.1	.2	.3	.5	.7	.8	1.0
Consumer Price Index, 1967 = 100.0										
Base	161.1	173.9	188.4	204.9	219.4	232.0	244.2	257.0	270.9	286.5
NASA	161.0	173.8	188.4	204.8	219.2	231.5	243.2	255.5	268.9	283.7
Change	-0.1	-0.1	0.0	-0.1	-0.2	-0.5	-1.0	-1.5	-2.0	-2.8
% Change	0.0	0.0	0.0	0.0	-0.1	-0.2	-0.4	-0.6	-0.8	-1.0
Rate of Inflation, %										
Base	9.1	7.9	8.3	8.7	7.1	5.8	5.2	5.2	5.4	5.8
NASA	9.1	7.9	8.3	8.7	7.0	5.7	5.0	5.0	5.2	5.6
Change	.0	.0	.0	.0	-.1	-.1	-.2	-.2	-.2	-.2
Unemployment Rate, %										
Base	9.0	8.2	7.4	8.6	9.9	9.2	8.0	7.1	6.5	6.0
NASA	8.9	8.1	7.4	8.5	9.9	9.1	7.8	7.0	6.3	5.8
Change	-.1	-.1	.0	-.1	.0	-.1	-.2	-.1	-.2	-.2
Employees on Payrolls, Millions										
Base	76.9	77.9	82.8	83.3	83.2	85.3	88.1	90.5	92.5	94.3
NASA	77.0	80.0	82.9	83.4	83.3	85.4	88.3	90.7	92.8	94.7
Change	.1	.1	.1	.1	.1	.1	.2	.2	.3	.4
% Change	.1	.1	.1	.1	.1	.1	.2	.2	.3	.4
Index of Industrial Production, Manufacturing Sector, 1967 = 100.0										
Base	109.1	120.2	129.6	125.3	122.4	132.6	145.3	154.6	162.2	168.6
NASA	109.6	120.8	130.1	125.8	122.9	133.5	146.7	156.4	164.3	171.3
Change	.5	.6	.5	.5	.5	.9	1.4	1.8	2.1	2.7
% Change	.5	.5	.4	.4	.4	.7	.9	1.2	1.3	1.6
Index of Labor Productivity, 1967 = 100.0										
Base	110.2	112.1	113.3	112.5	115.2	120.1	123.9	126.9	129.9	132.0
NASA	110.3	112.2	113.4	112.6	115.4	120.5	124.5	127.7	130.9	133.3
Change	0.1	0.1	0.1	0.1	0.2	0.4	0.6	0.8	1.0	1.3
% Change	0.1	0.1	0.1	0.1	0.2	0.3	0.5	0.7	0.8	1.0
Change in Labor Productivity, %										
Base	-.4	1.7	1.1	-0.7	2.4	4.3	3.2	2.4	2.4	1.6
NASA	-.3	1.7	1.1	-0.7	2.5	4.4	3.4	2.6	2.5	1.8
Change	.1	.0	.0	.0	.1	.1	.2	.2	.1	.2

Base = baseline projection with current estimates of NASA R & D spending for next decade.

NASA = an increase of $0.5 billion in 1958 dollars in NASA R & D spending.

Change = NASA - Base

% Change = $\frac{\text{NASA - Base}}{\text{Base}}$. Since the unemployment rate is already given in percentage terms, we do not calculate this item for unemployment.

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Table 4.4

Change in Selected Variables With a Sustained Increase in NASA R & D Spending of $0.1 Billion Per Year

	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
Gross National Product, Billions of 1958 Dollars										
Base	788.1	834.0	869.6	859.8	868.5	922.4	977.7	1021.2	1059.6	1090.8
NASA	788.4	834.0	869.6	860.0	868.8	923.4	979.1	1022.6	1061.4	1092.8
Change	.3	.0	.0	.2	.3	1.0	1.4	1.4	1.8	2.0
% Change	.0	.0	.0	.0	.0	.1	.1	.1	.2	.2
Consumer Price Index, 1967 = 100.0										
Base	161.1	173.9	188.4	204.9	219.4	232.0	244.2	257.0	270.9	286.5
NASA	161.1	173.9	188.4	204.8	219.3	231.8	243.9	256.6	270.4	285.9
Change	.0	.0	.0	-.1	-.1	-.2	-.3	-.4	-.5	-.6
% Change	.0	.0	.0	.0	.0	-.1	-.1	-.2	-.2	-.3
Rate of Inflation, %										
Base	9.1	7.9	8.3	8.7	7.1	5.8	5.2	5.2	5.4	5.8
NASA	9.1	7.9	8.3	8.7	7.1	5.7	5.2	5.1	5.4	5.7
Change	.0	.0	.0	.0	.0	-.1	.0	-.1	.0	-.1
Unemployment Rate, %										
Base	9.0	8.2	7.4	8.6	9.9	9.2	8.0	7.1	6.5	6.0
NASA	9.0	8.1	7.4	8.6	9.9	9.2	7.9	7.1	6.5	6.0
Change	.0	-.1	.0	.0	.0	.0	-.1	.0	.0	.0
Employees on Payrolls, Millions										
Base	76.9	79.9	82.8	83.3	83.2	85.3	88.1	90.5	92.5	94.3
NASA	76.9	79.9	82.8	83.3	83.2	85.3	88.2	90.5	92.6	94.4
Change	.0	.0	.0	.0	.0	.0	.1	.0	.1	.1
% Change	.0	.0	.0	.0	.0	.0	.1	.0	.1	.1
Index of Industrial Production, Manufacturing Sector, 1967 = 100.0										
Base	109.1	120.2	129.6	125.3	122.4	132.6	145.3	154.6	162.2	168.6
NASA	109.2	120.2	129.7	125.4	122.5	132.8	145.7	155.0	162.6	169.1
Change	.1	.0	.1	.1	.1	.2	.4	.4	.4	.5
% Change	.1	.0	.1	.1	.1	.2	.3	.3	.2	.3
Index of Labor Productivity, 1967 = 100.0										
Base	110.2	112.1	113.3	112.5	115.2	120.1	123.9	126.9	129.9	132.0
NASA	110.2	112.1	113.3	112.5	115.2	120.2	124.0	127.1	130.1	132.2
Change	.0	.0	.0	.0	.0	.1	.1	.2	.2	.2
% Change	.0	.0	.0	.0	.0	.1	.1	.2	.2	.2
Change in Labor Productivity, %										
Base	-.4	1.7	1.1	-0.7	2.4	4.3	3.2	2.4	2.4	1.6
NASA	.4	1.7	1.1	-0.7	2.4	4.4	3.2	2.5	2.4	1.3
Change	.0	.0	.0	.0	.0	.1	.0	.1	.0	.0

Base = baseline projection with current estimates of NASA R & D spending for next decade.

NASA = an increase of $0.1 billion in 1958 dollars in NASA R & D spending.

Change = NASA - Base

% Change = $\frac{\text{NASA - Base}}{\text{Base}}$. Since the unemployment rate is already given in percentage terms, we do not calculate this item for unemployment.

5. CONCLUSION

In this report we have evaluated the effect of an increase in NASA R & D spending on the U. S. economy. While the actual process is fairly complex, it can be subdivided into two main parts: relating NASA R & D spending to changes in the rate of technological growth, and determining the effect of these changes on the overall economy.

One does not need an econometric model to show that an increase in government spending will raise GNP and lower unemployment. We learned many years ago that it is easy to spend our way out of a recession if no other constraints are involved. Yet having just recently come from the realm of double-digit inflation and the first postwar decline in labor productivity, it is clear that alternative policies must be examined not only from the point of view of their effect on demand and employment but on the real growth rate and the rate of inflation as well.

NASA R & D spending increases the rate of technological change and reduces the rate of inflation for two reasons. First, in the short run, it redistributes demand in the direction of the high-technology industries, thus improving aggregate productivity in the economy. As a result, NASA R & D spending tends to be more stabilizing in a recovery period than general government spending.

Second, in the long run, it expands the production possibility frontier of the economy by increasing the rate of technological progress. This improves labor productivity further, which results in lower unit labor costs and hence lower prices. A slower rate of inflation leads in turn to a more rapid rise in real disposable income, which permits consumers to purchase the additional goods and services which are being produced.

Turning to the specific figures, a \$1 billion sustained increase in NASA R & D spending will raise real GNP \$23 billion by 1984, raise labor productivity by 2.0% and lower the level of the consumer price index by 2.0%. The unemployment rate will decline by 0.4%, and an additional 0.8 million new jobs will be created because of a more rapid expansion of the labor force. It should be noted that the demand component of increased spending results in only a \$2 billion increase in real GNP by the tenth year, with the remaining \$21 billion due to the permanent improvement in the level of technology. For the entire ten-year period, the cumulative increase in real GNP is \$83.6 billion. Furthermore, these results are approximately linear when we changed NASA spending by \$0.5 billion or \$0.1 billion over the same time frame. Similarly a decrease in NASA R & D spending of \$1 billion would have reverse effects of the same magnitude on growth, inflation, unemployment and other facets of economic activity.

As a final word, a number of caveats should at least be mentioned. First and foremost, although we have taken great care to include the relevant determinants of γ, one cannot ignore the fact that we have used the macroeconomic approach. A more thorough examination of the effect of increased NASA R & D spending on the rate of technological progress still must come at the industry level. In particular, we need to determine whether a properly weighted average of γ's at the industry level would produce results which are consistent with our findings at the macro level. Such an approach would have to take into effect all the spillover and cross-correlation factors which exist between R & D spending in industry j and increased productivity in industries K_1, K_2, ..., K_n.

A second factor which needs to be considered in greater detail is the actual determinants of γ. Perhaps different results would be obtained if

R & D spending were subdivided differently; NASA and defense R & D might each be entered separately, or a distinction might be made between public and private R & D spending. We found that variables representing the quality of labor and economies of scale were not important; these variables might prove to be significant determinants of γ on the industry level. Furthermore, these variables might become more important if a longer sample period were available for empirical testing.

Third, we have not fully explored the rate or the level of tangible investment as a determinant of technological change. On an econometric basis we have excluded the contributions of labor and capital from the measurement of γ, but we should not overlook the possibility that the level of R & D spending in the private sector is directly related to the level of investment. Thus the relationship between growth in output/man-hour, investment and technological change should be examined in greater detail, both at the macroeconomic and industry level.

Fourth, further work still needs to be done in estimating the lag structure between changes in R & D spending and γ, and between changes in γ and the level of aggregate demand. While we calculated numerous regression equations and simulations, the pattern and length of the lag structure need to be fortified by further analysis at the industry level.

In spite of these areas where further research is indicated, the macroeconomic model approach should be viewed as a very powerful tool for policy simulations, both on an ex post and an ex ante basis. For example, the macro model can be used to evaluate the effect of alternative government spending programs on unemployment, inflation, and real growth. Simulations can be calculated to indicate how the economy would have performed during the past decade under different levels of spending for the major components of the Federal budget; this could provide insight into how best to deal with the severe economic problems which face the U. S. economy in the mid-1970's.

One fact is clear: the rates of productivity and technological change in the U. S. economy have diminished rapidly in recent years. Disposable income and real wages have fallen by unprecedented amounts in the current recession, and productivity declined in 1974 for the first time in the entire postwar period. Per capita income in the U. S. has moved from a strong first to a weak fifth in the ranking among major nations, as the rate of technological progress in the United States declines below all of our major competitors. While the double-digit rate of inflation last year was due primarily to the quadrupling of oil prices and a doubling of many food prices, the continuing high level of inflation is a direct reflection of rapidly rising unit labor costs, as rapidly rising wage rates cannot be offset by sluggish increases in technological progress.

One might take issue with the high rates of return for NASA R & D spending reported in this study, and prefer to wait for additional corroboration from future industry studies. Yet there is little doubt that increases in the amount of spending by NASA R & D do have a significant impact in raising the rate of technological change. While increases in virtually all types of government spending raise aggregate demand and reduce unemployment, most public spending programs eventually add to inflationary pressures because they increase aggregate demand without increasing aggregate supply. Increased spending for NASA R & D, however, expands the production possibility frontier by increasing the rate of technological change, and hence leads to a lower rate of inflation as well as higher output and employment.