MANUFACTURING PRODUCTIVITY AT THE FIRM LEVEL IN THE US DEFENSE INDUSTRY

by

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(ABSTRACT)

This thesis will develop measures of labor productivity for a Government owned and operated manufacturing facility that produced military products to unique customer order. The methodology used to calculate labor productivity is the recently revised Bureau of Labor Statistics (BLS) labor productivity program. The revised BLS program incorporate changes to the techniques for constructing the output measures which are used in conjunction with input measures to derive output per hour measures. The motivation of this research is to explore the labor productivity of a particular Government owned and operated firm through a detailed examination of historical labor input data, manufacturing cost data, the firm's cost structure, and annual output. To date, no productivity analyses at the firm level have been published by the BLS in the Monthly Labor Review magazine due in part to a lack of required factor input data. These data are often proprietary in nature and do not lend themselves readily to public scrutiny. In order to maintain the confidentiality of the

proprietary data used herein, neither the firm nor its products are identified. Generic labels, such as product 1, product 2, etc., are used as placeholders in lieu of actual product names. Nevertheless, all mathematical derivations employed in the construction of the output and input index series used to calculate labor productivity are explicitly identified, as are the specific equations that comprise the BLS technique.

Dedication

I would like to dedicate this thesis to my loving wife Theresa. Her patience, encouragement and understanding during its completion will always be appreciated and never forgotten. In addition, the efforts of my parents and Delores McElroy were instrumental in providing me the time to dedicate to this work.

Acknowledgments

This thesis is submitted to complete the requirements for the Master of Arts degree in Economics from the Virginia Polytechnic Institute and State University.

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1. Introduction

This study of labor productivity for a firm engaged in manufacturing military products to unique customer order involves the collection and analysis of historical manufacturing cost data, output, and factor input data. The analytical foundation of the theory and methods used to conduct this investigation is the US Department of Labor, Bureau of Labor Statistics productivity guidelines originally published in the BLS Handbook of Methods in 1992[1] and recently revised in a 1995 publication[2]. The BLS frequently publishes research on manufacturing productivity at the sector and industry level. BLS researchers draw their source data primarily from the National Income and Product Account (NIPA) data published by various government agencies. Research into manufacturing productivity at the firm level by the BLS has been hindered by a lack of data for the labor, capital, factor input prices, output costs, and demand data required to conduct an analysis. In this paper I am able to overcome these data discrepancies and structure an analysis of labor productivity at the firm level using the applicable BLS tools and techniques.

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1 BLS Handbook of Methods, U.S. Department of Labor, Bureau of Labor Statistics, September 1992, Bulletin 2414.

2 Gullickson, William Measurement of productivity growth in U.S. manufacturing, Bureau of Labor Statistics, Monthly Labor Review, July 1995, pp. 13-28

The overall purpose of the analysis is to examine the behavior of a single producer engaged in military manufacturing from the perspective of measuring labor productivity for the years 1977-95. Productivity analysis is an important subset of micro-economic analysis because it provides a window from which to measure and observe the producer's behavior regarding factor input allocation, output, and product cost. Furthermore, productivity growth is often used as a benchmark for assessing the firm's relative performance within its industry. The focus of this analysis is on the firm level, using labor productivity theory and measurement and reporting techniques currently utilized by the BLS to evaluate one particular firm's behavior.

The firm examined in this study is a Government owned and operated manufacturing facility of military equipment. This organization (firm) produces output for unique customer order, generally in the form of annual work orders for complete products or spare components. Like most manufacturing firms today, this organization has undergone radical technological and business process change to its productive base in the form of multi-million dollar capital improvements in facilities, machinery, equipment, and CAD/CAM manufacturing technologies. The capital investment took place between the years 1978-86. During this time the Government initiated a multi-million dollar capital investment program to improve productivity, plant capacity, product quality, and to reduce manufacturing costs.

Given the availability of economic data spanning the 1977-95 time frame and recognizing that this period contains nine years worth of multimillion capital investment, derivation of labor productivity growth rates should provide insight into how efficiently the firm utilized these new investments to produce products during and after the investment period. While the BLS employs an alternative technique known as multifactor productivity, which is designed to capture more explicitly the capital investment components of output growth, this study does not attempt to develop such measures. Problems with data availability and data consistency preclude a full examination of multifactor productivity of the firm at this time.

My ex-ante expectations are that labor productivity (i.e., output per hour) should have grown in the years following the nine-year capital investment. We should observe the index of output per hour to be increasing during and after the capital investment. Further, examining the relationship between trends in annual output and the components of labor productivity (i.e. output produced and employee hours expended) will provide the necessary evidence to document the sources of productivity changes throughout the entire 1977-95 period.

In the 1988 time frame, an official of the firm commented on the potential impact that the multimillion dollar capital investment program would have on the firm's manufacturing efficiency. In his words,

... "the overall modernization benefits include a reduction in the number of machines on the shop floor by one-third while doubling capacity and a productivity improvement of 22 percent" .[3]

The economic data to support an examination of labor productivity analysis of this firm are available. A historical profile of the unit and total manufacturing costs and annual production data have been compiled, for the majority of products produced by the firm during the 1977-1995 time frame. The firm's factor input costs have been examined by observing trends in such cost elements as direct manufacturing labor hours, direct manufacturing labor cost, overhead manufacturing labor cost, fixed and variable overhead manufacturing cost, Other Direct Cost (ODCs) and material costs for each product. According to plant representatives, the nominal cost value of these products represents approximately 85% of the total output value for the firm over these years. In other words, the annual manufacturing cost data collected and analyzed represent 85% of the annual total product of the firm in each of the years investigated.

This introduction has presented an overview of the *motivation* behind this study, the theory and methodology to be applied, and the expectations for the results. In Section II, the theory behind labor productivity is further developed in order to provide a foundation for the methodology implemented in constructing the productivity measures.

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[3] Internal DoD correspondence, 1988

Four themes are developed in this section to establish a solid understanding of the economic meaning of labor productivity. They include 1) how labor is productivity defined, 2) how it is measured, 3) how it is reported and 4) how it is interpreted. In Section III, the actual derivation of labor productivity indexes are presented. The methodology discussion includes a review and presentation of how the firm's output and factor inputs were measured, and how labor productivity was calculated. Also discussed are profiles of annual individual product output along with profiles of output by product group. In Section IV the results of this investigation are presented both with tabular statistics and graphical illustrations of the trends in labor productivity. Section V presents an interpretation of the observed trends and concluding comments. The paper concludes with a bibliography, and author's Vita.

2. Productivity Overview

Productivity at the firm level is important because a firm's ability to generate wealth relies on its ability to produce more output with fewer inputs. The same principle applies at the national level, where a significant source of potential national income lies in the ability of U.S. industries to produce more goods and services by making labor more efficient, as opposed to requiring a proportional increase in labor time. The BLS produces two measures of productivity for the United States: labor productivity and multifactor productivity. The BLS's labor productivity research has focused on developing growth rates of output per hour since the early 1900's. Most recently, the BLS modernized its industry labor productivity program by revising its methods for constructing growth rates of output per hour. (See Kunze et al. for a complete discussion of how the BLS modernized its industry labor productivity program.) In addition, the BLS's Monthly Labor Review magazine has dedicated more attention recently to the concept of multifactor productivity through the publication of numerous articles. The principal article that outlines the BLS's latest policy for computing the indexes of multifactor productivity for two-digit manufacturing sectors is presented by Gullickson.[4]

4 Gullickson, William, "Measurement of productivity growth in U.S. manufacturing", Monthly Labor Review, July 1995. pp. 13-28.

Other insightful articles which demonstrate the measurement and interpretation of the multifactor productivity concept are Kern, et al., which covers the utility industry and Glaser, which discusses the metal stamping industry. We turn our attention now to the development of a broader understanding of labor productivity by discussing four important issues: how it is defined, how it is measured, how it is reported and how it is interpreted. This discussion is intended to provide the reader with a foundation for the formal development and presentation of measurement methodologies implemented for the firm under investigation.

2.1. Labor Productivity: How is it defined?

The BLS defines labor productivity as a "partial" productivity measure which relates output produced to the labor resources consumed in generating that output. The BLS refers to labor productivity as a "measure of the efficiency with which labor is being utilized in production." Labor productivity is often referred to as a single measure of productivity defined as <u>output per hour of all persons engaged in production</u>. It is a single measure of the value of goods and services expressed in constant prices. It addresses only one input expended in the production of output. The BLS uses labor productivity indexes to show the change in output relative to changes in labor input. However, they acknowledge that labor productivity, as currently measured, represents a view of economic efficiency for an industry, sector, or a firm, which reflects "not only improvements in techniques and organization of production—technical change—but also the effects of substituting other inputs such as capital and intermediate purchases for labor in the production process."[5] Thus the official BLS definition of labor productivity is ... "labor productivity refers to the relationship between output and the labor time used in generating an output or outputs. Another name for this type of productivity measure is output per hour.

2.2. Labor Productivity: How it is measured

The BLS original measures of labor productivity (i.e., output-per-hour indexes) were devised to measure the effects of productivity on jobs. Kunze, et al. point out that during the 1940's the BLS was frequently called upon to answer these types of questions:

> "What relative volumes of labor times are required to produce a given composite of products at different times?" and "What relative volumes of production of a given composite of products are obtainable at different times with a given amount of labor time?."[6]

An index series is a simple way to express, in percentage terms, the change in some variable from a given point in time to another point in time. Output per hour was

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5 BLS Industry Labor Productivity Home Page, Internet, Authored by Clayton Waring, August 1995.

6 Kunze, Kent, Jablonski, Mary and Klarquist, Virginia, "BLS modernizes industry labor productivity program" Monthly Labor Review, July 1995. p. 4.

calculated by dividing an index series for output by an index series for employee hours. Of course, several questions arise from this simple definition, such as how was output expressed for a sector or industry and how were different products aggregated into one output measure for an entire industry? Moreover, “the output measure in the numerator of the original labor productivity ratio used unit employee hour weights for combining the various categories of output of an industry." Because the weights used were related to fixed periods, “changes in the relative quantities of the various outputs did not affect the productivity indexes." Rather, according to Kunze, et al., “the indexes were affected only by changes in unit labor requirements of the individual products."

It is apparent from the above discussion, that such a simple matter of output per hour involves some complex mathematical calculations and underlies some important economic principles. Derivation of index numbers, and application of appropriate weighting schemes to the output and input index number ratios are time-consuming efforts for the BLS in its calculation of industry labor productivity measures. Considerable effort has been spent by BLS to modernize its original labor productivity measure by introducing a revised weighting scheme based on the Tornqvist index, a so-called superlative index number. The decision to change its labor productivity measure was based on a coordinated review of applicable economic production function theory by a senior panel of BLS economists in 1993. As a result of incorporating Tornqvist indexes of output, BLS labor productivity today provides a measure of the efficiency in an industry, whereas the original series on output per hour was only designed to measure the employment effects of productivity changes in individual industries.

Today's measurement of labor productivity, promulgated by the BLS, is based on underlying notion that "productivity should be measured and analyzed in the context of the neoclassical theory of production and costs."[7] The production function which is a derived mathematical relationship between output and the inputs that comprise it, is the foundation for the revised BLS labor productivity measurement techniques. One type of production function in particular, the translogarithmic production function, is considered by the BLS to be more flexible than the Cobb-Douglas type. Thus, "because changes in output consistent with the translogarithmic production function are exactly measured by changes in Tornqvist index,"[8] the BLS's revised measures of labor productivity include Tornqvist indexes of output. The following discussion will outline the BLS's latest labor productivity index measurement methodology. The source of data for this discussion is Kunze, et al..

Because the Tornqvist index plays such a prominent role in the theory and practical application of the BLS's labor productivity measure, it is worth discussing the subject in-depth prior to presenting the algebraic formulations. A Tornqvist index of

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7 Ibid, p. 4
8 Ibid, p. 4

either output or input aggregates the growth rates of all the products or inputs between two periods, using a weighting scheme based on the products' or inputs' shares in industry value of production. The individual weights used for each product or input is equal to its average value share in the two periods. The usefulness of the Tornqvist methodology is that it overcomes the inherent problem with aggregation using a fixed weighting scheme, as demonstrated in the BLS's original labor productivity measures. Under the fixed weighting scheme, the resulting output per hour measure did not "fully allow for the possibility that relative prices and the mix of products being produced can change from the base period to the current period ."[9] It should be readily apparent that under the fixed weighting scheme, a given market basket of goods produced in a given year for an industry could be quite different from the base period. Hence, the use of weights tied to the base period given in the composition of the market basket of goods could yield a measure of output that is different from one based on values in the current period. The solution adopted by the BLS was the use of the superlative or Tornqvist type index which supported the "construction of an output aggregate in which the weights incorporate changes in prices and quantities occurring between the two periods." [10]

The methodology for calculating the BLS's revised labor productivity index is outlined below. The source of these formulations is Kunze, et al.. The new labor

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9 Ibid. p. 5
10 Ibid p. 5

productivity indexes measure the changes in the relationship between output and the hours expended in producing that output. The formula for calculating the labor productivity index is shown in Equation 1.

Eq. 1 $$P_t = \frac{\frac{Q_t}{Q_0}}{\frac{L_t}{L_0}}$$

Where P_t = the index of output per hour in the current year,

t = the current year,

0 = the base year,

$\frac{Q_t}{Q_0}$ = the index of output in the current year, and

$\frac{L_t}{L_0}$ = the index of labor input in the current year.

Calculations of the output and input indexes for industries or firms which produce a single uniform product or service is straightforward. The output index is simply the ratio of the number of units produced in the current year divided by the number of units produced in the base year. Likewise, the employee hour index is calculating by dividing the hours expended in the current year by the hours expended in the base year. Of course, this methodology does not apply to a firm or an industry which supplies more than one type of differentiated product. As in the case of the government firm producing a basket of military goods, the output must be calculated using the Tornqvist formula provided in Equation 2.

Eq. 2 $$\frac{Q_t}{Q_{t-1}} = \exp\left[\sum_{i=1}^{n} W_{i,t}\left(\ln\frac{q_{i,t}}{q_{i,t-1}}\right)\right],$$

Where

$\frac{Q_t}{Q_{t-1}}$ = the ratio of output in the current year (t) to output in the previous year (t-1)

n = the number of products

$\ln\frac{q_{i,t}}{q_{i,t-1}}$ = the natural logarithm of the ratio of the quantity of product i in the current year to the quantity in the previous year, and

$w_{i,t}$ = the average value share weight for product i.

The BLS computes the average value share weight for product j as expressed in Equation 3.

Eq. 3 $w_{j,t} = \left(S_{j,t} + S_{j,t-1}\right) \div 2$

where

$$S_{j,t} = P_{j,t}Q_{j,t} \div \sum_{i=1}^{n} P_{i,t}Q_{i,t} \text{ and}$$

$P_{i,t}$ = the price of product i at time t.

Because the Tornqvist methodology calculates the ratio of output in a given year to that in the previous year, the ratios must be chained together to form a series. Kunze et al provide a simple example. If

t = 3 and the base year is denoted by 0, then

$$\frac{Q_t}{Q_0} = \frac{Q_3}{Q_0} = \left(\frac{Q_3}{Q_2}\right)\left(\frac{Q_2}{Q_1}\right)\left(\frac{Q_1}{Q_0}\right)$$

This chained output index, $\frac{Q_t}{Q_0}$, is used directly in the labor productivity formula. The employee hour index for an industry or firm with multiple products is calculated in the same manner as in the single-output case. In other words, regardless of how many different types of products a firm or industry produces, "the employee hour index equals hours expended in the current year divided by hours expended in the base year."[11]

To conclude this section on the definition of labor productivity, it would be prudent to reiterate a theme discussed throughout the majority of published research and BLS policy on productivity research. Measures such as labor should be interpreted as quantifying the contribution of the particular input, or combined inputs, to production. In other words, labor productivity measures output per hour. It relates one input, labor time, to output. It does not measure the specific contribution of labor, capital, or any other factor of production. Official language from the BLS, puts the idea this way... "changes over time in the output, labor input, or combined input measures underlying these productivity indexes may reflect the influence of other factors including variations in the characteristics and efforts of the work force, changes in the management skill, changes in the organization of production, and new technology."[12]

2.3. Labor Productivity: How it is reported

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11 Ibid p. 5

12 Bureau of Labor Statistics, BLS Handbook of Methods, U.S. Department of Labor, September 1982, Bulletin 2414, p. 81.

The actual change in the growth rate of manufacturing output per hour worked is usually expressed as a average annual percent change either from year to year, quarter to quarter, or over the course of several years. As indicated earlier, labor productivity is the ratio of output divided by labor hours expended in producing that output. The value is usually indexed to a base year. Multifactor productivity is also displayed in the form of an index ratio of output to input, where input is an aggregate of labor, capital, intermediate purchases, and energy.

2.4. Labor Productivity: How it is interpreted

Average annual rates of growth in output per hour, expressed in some base year, are the most convenient and frequently used expression of labor productivity in BLS and scholarly research. In an important article published in Monthly Labor Review which documents the comparative manufacturing productivity and unit labor costs between the US and 12 other nations, Greiner[13], et al., present several interesting metrics for productivity and related measures. These include output per hour, output, total hours, employment, hourly compensation, unit labor costs (national currency and US dollars), and exchange rates. What is noteworthy about this work is that it demonstrates the importance of presenting productivity analysis within a broader framework of

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[13] Greiner, Mary. , Kask, Christopher and Sparks, Christopher. "Comparative manufacturing productivity and unit labor costs, Monthly Labor Review, February 1995. p. 31.

manufacturing economics. Framed by easy-to-grasp metrics like output, wage rates, hours worked and others, the concept of productivity is more easily understood. Viewed in such a manner, observations in the relative trends in output per hour between the U.S. and one or more other nations may be fully examined and interpreted in light of the total manufacturing experience. Borrowing from the research of Greiner et.al, one gains good insight into how economists interpret productivity data. For example,

> " In the 1990-93 period, U.S. productivity rose 2.5 percent per year and several other countries rebounded to post higher productivity gains than in the previous period.... Productivity gains recorded in the 1979-93 period resulted from *a combination of increasing output and decreasing labor input* in all of the economies except Japan.... During the 1990's, the composition of productivity growth in manufacturing has become much more heavily weighted toward *reducing labor input, rather than increasing output.* Between 1990 and 1993, the United States was the only country in which an overall rise in output contributed as much to productivity growth as reductions in labor input. In the 11 other countries, *virtually all productivity growth was accomplished by reducing the number of hours worked.*"[14] (italics added)

Multifactor productivity is quite frequently displayed as an average annual rate of growth defined as output per unit of combined inputs of capital, labor, energy, materials, and purchased business services. Of course, there are many structural, and/or behavioral reasons explaining changes in manufacturing output per hour at the firm or industry level. For example, I shall attempt to demonstrate that, for the government firm under investigation, changes in output per hour are influenced by perturbations in annual

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[14] Ibid. p. 31

military demand, changes in the direct manufacturing and overhead workforce. Additionally, like many privately owned manufacturing concerns, this government owned and operated supplier has opportunities for swings in output per hour over time resulting from changes in the labor force composition, the amount of capital per unit of labor, introduction, adaptation and diffusion of new manufacturing equipment, and managerial methods. In the end, economists are left with the charter of interpreting the myriad of potential influencing factors on output per hour by utilizing a rate of change in a simple ratio of output to input.

3. Derivation of Labor Productivity Indexes for the Firm

3.1. Measuring the Firm's Output

3.1.1. BLS Techniques

A Tornqvist index of output aggregates the growth rates of all the products between two periods, using a weighting scheme based on the products' shares in the value of production. The individual weights used for each product is equal to its average value share in the two periods. Thus the superlative or Tornqvist type output index supports the "construction of an output aggregate in which the weights incorporate changes in prices and quantities occurring between the two periods." [15] The algebraic formulas for calculating the output index for this government firm was previously expressed in Equation 2. The following section will discuss the specific data collected from the firm and used in calculating the firm's output index.

The firm's output index is a measure of the change in the firm's output over time. It was developed using a deflated value technique. The firm's military products were organized into four distinct groups based on function, mechanical complexity, and end use. Price changes were removed from the current dollar value of each year's production

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[15] Ibid p. 5

using Department of Defense Deflator indexes. The application of specific military deflator indexes is akin to a researcher normalizing the value of shipments of various product classes for a particular industry using the appropriate BLS Producer Price Indexes.

3.1.2. The Firm's Output Database

The firm's database for output produced between 1977-95 consists of four product groups. Each group comprises a variety of products similar in performance and function. The aggregate product demand history is presented in Figure 1. Individual product group demand histories are displayed in Figure 2.

3.1.3. Establishing a Quantity Index of the Firm's Output

A quantity index of the firm's output index was established using the BLS technique. As required by the BLS approach, data for the quantity produced on an annual basis along with the price of the product is required to derive the average value share weight for each product. Tables 1 through 4 present the annual quantities produced for individual products under each of the four product groups.

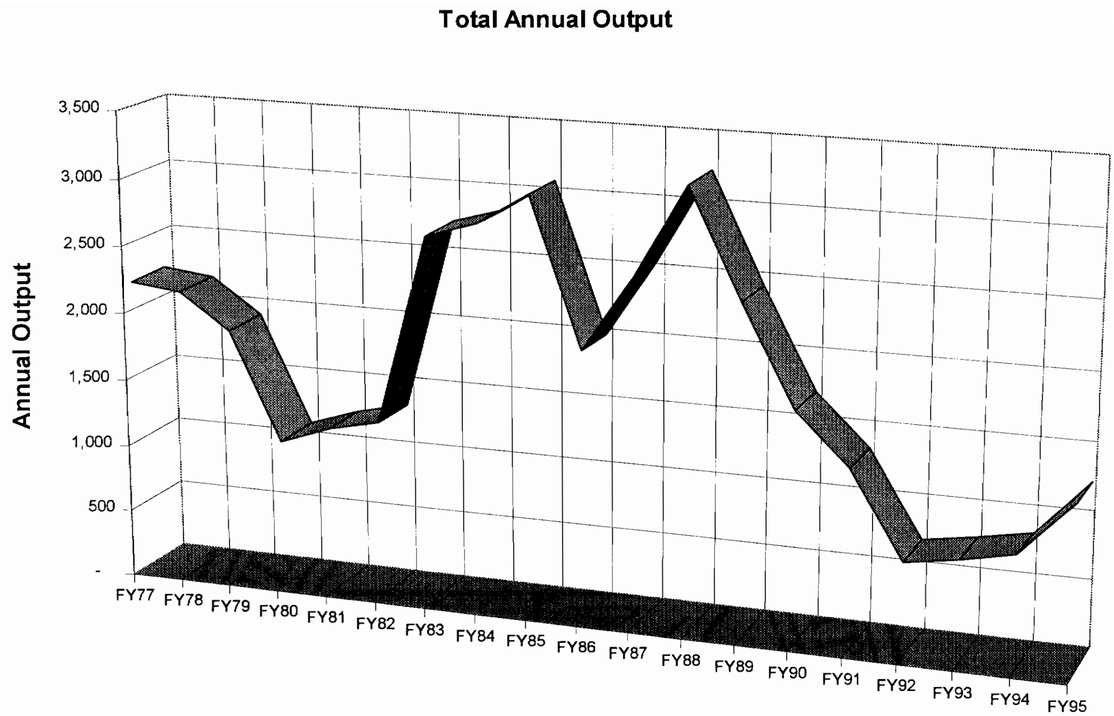

Figure 1 Total Annual Output

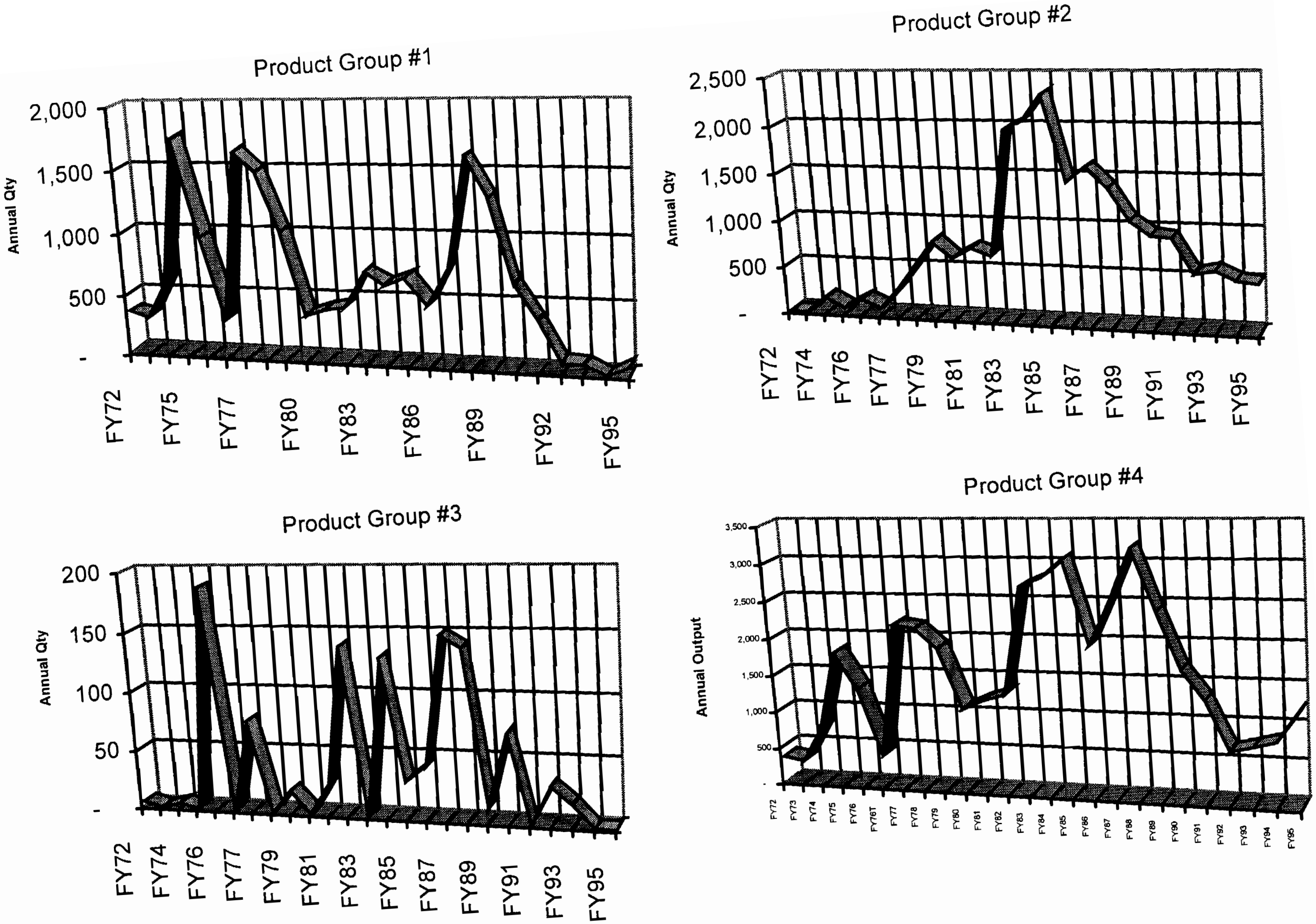

Figure 2 Annual Quantity by Product Group

Table 1. Product Group 1 Annual Output

Product Group 1	FY77	FY78	FY79	FY80	FY81	FY82	FY83	FY84	FY85	FY86	FY87	FY88	FY89	FY90	FY91	FY92	FY93	FY94	FY95
Total Quantity	**1,650**	**1,496**	**1,028**	**370**	**420**	**450**	**725**	**636**	**698**	**480**	**789**	**1,633**	**1,325**	**678**	**392**	**82**	**80**	**-**	**79**
Product 1	281	271	157	95	169	118	47	82	56	30	31	73							
Product 2		9	17	21	18	50	88	194	20	4	64	214	63						
Product 3		70	44		23	169	2					5	4						
Product 4									3	31	108	170	266	281	281	68	32		51
Product 5														5	5	14	48		28
Product 6	1,369	1,146	810	254	210	113	588	360	619	415	586	1,171	992	392	106				

Table 2. Product Group 2 Annual Output

Product Group 2	FY77	FY78	FY79	FY80	FY81	FY82	FY83	FY84	FY85	FY86	FY87	FY88	FY89	FY90	FY91	FY92	FY93	FY94	FY95
Total Quantity	**302**	**556**	**819**	**650**	**765**	**695**	**1,982**	**2,078**	**2,337**	**1,471**	**1,626**	**1,420**	**1,099**	**960**	**943**	**587**	**634**	**542**	**519**
Product 1	199	104	283	174	358	335	191	167	347	229	265	127		129	179	136	73	121	100
Product 2		19	15	98	215	186	330	205	165	219	35	78	196	52		14	34		
Product 3				172	53	100	27	45		12	6	10							
Product 4	103	433	521	206	139	36	129	18		34		20							
Product 5														6	59		59	115	42
Product 6															11	3	50	49	167
Product 7						38	1,305	1,643	1,546	254	329	363	114	80					
Product 8									237	147	47								
Product 9									42	576	944	822	789	693	694	434	418	257	210

Table 3. Product Group 3 Annual Output

Product Group 3	FY77	FY78	FY79	FY80	FY81	FY82	FY83	FY84	FY85	FY86	FY87	FY88	FY89	FY90	FY91	FY92	FY93	FY94	FY95
Total Quantity	**77**	**-**	**19**	**-**	**25**	**140**	**-**	**131**	**31**	**44**	**150**	**140**	**12**	**73**	**-**	**32**	**18**	**-**	**-**
Product 1										19	50	34	12	73					
Product 2																32	18		
Product 3	77		19		25	140		131	31	25	100	106							

Table 4. Product Group 4 Annual Output

Product Group 4	FY77	FY78	FY79	FY80	FY81	FY82	FY83	FY84	FY85	FY86	FY87	FY88	FY89	FY90	FY91	FY92	FY93	FY94	FY95
Total Quantity	**179**	**117**	**41**	**91**	**26**	**38**	**20**	**-**	**13**	**-**	**-**	**36**	**1**	**-**	**-**	**-**	**33**	**298**	**650**
Product 1	179	117	41	91	26	38	20		13			36	1						
Product 2																	33	298	650

The information used to calculate the firm's output index is presented below in Table 5 through Table 9. In conjunction with the methodology prescribed by the BLS for calculating labor productivity, the following tables display the data utilized. The notation used to describe an individual product is (i) and the variable used to describe an individual fiscal year is (t). Thus, Table 5 presents The Price of Product i at Time t. This matrix displays the total manufacturing cost for each product in each year. Manufacturing cost consists of direct labor cost, indirect labor cost, material cost and ODCs. Table 6 presents the Average Value Share Weight for Product i at Time t. This matrix displays the results of Equation 3 as it was applied to the data set in Table 5. Table 7 presents the Annual Quantities of Product i at Time t. The matrix illustrates the actual quantities of each product produced in each year between 1977 and 1995. This quantity matrix is used in the derivation of the natural logarithm of the ratio of the quantity of product (i) in the current year to the quantity in the previous year. Table 8 displays the Natural Logarithm of the Ratio of Quantities for each product in each fiscal year. The final set of calculations utilized in the derivation of the index of output in the current year is displayed in Table 9, Ratio of Output in Current Year to Output in Previous Year. The value of each cell of this matrix displays the result obtained by Equation 2.

Table 5 The Price of Product i at Time t

Total Price	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Product 1	$15,300	$ 8,249	$20,935	$12,500	$24,736	$21,090	$11,209	$10,088	$22,194	$15,473	$16,947	$ 8,465		$ 9,414	$12,251	$10,417	$ 6,478	$10,263	$10,213
Product 2	$10,389	$ 6,934	$ 2,387	$ 4,932	$ 2,231	$ 1,917	$ 909		$ 578			$ 1,883	$ 49						
Product 3	$ 8,677	$ 7,136	$ 4,537	$ 2,567	$ 4,132	$ 3,099	$ 1,098	$ 1,928	$ 1,205	$ 713	$ 938	$ 1,646							
Product 4		$ 2,503	$ 2,033	$ 7,788	$13,634	$11,225	$18,226	$10,119	$ 9,101	$12,253	$ 2,493	$ 4,542	$12,243	$ 3,241		$ 1,393	$ 2,781		
Product 5		$ 384	$ 507	$ 575	$ 518	$ 1,470	$ 2,193	$ 4,587	$ 473	$ 140	$ 1,592	$ 5,396	$ 1,574						
Product 6				$20,638	$ 6,253	$11,184	$ 3,519	$ 5,217		$ 1,381	$ 902	$ 1,509							
Product 7	$19,849	$58,518	$68,344	$24,531	$15,774	$ 5,470	$12,775	$ 1,861		$ 3,910		$ 2,291							
Product 8		$ 7,101	$ 3,727		$ 1,531	$13,373	$ 279					$ 377	$ 328						
Product 9														$ 2,930	$ 7,094		$ 7,733	$13,727	$ 5,719
Product 10										$ 984	$ 2,391	$ 1,334	$ 451	$ 2,704					
Product 11									$ 8,410	$54,042	$74,728	$62,652	$56,420	$49,335	$44,758	$31,471	$32,707	$24,757	$18,664
Product 12									$ 197	$ 1,010	$ 3,558	$ 5,352	$ 7,539	$ 7,971	$ 2,595	$ 2,019	$ 886		$ 1,789
Product 13																$ 1,041	$ 592		
Product 14															$ 670	$ 386	$ 3,938	$ 5,273	$14,765
Product 15														$ 108	$ 107	$ 307	$ 1,266		$ 718
Product 16	$ 1,154		$ 272		$ 455	$ 2,199		$ 2,003	$ 522	$ 335	$ 1,559	$ 1,952							
Product 17						$ 1,450	$41,148	$45,776	$40,283	$ 8,918	$10,540	$10,964	$ 4,273	$ 2,635					
Product 18	$24,900	$16,846	$12,436	$ 3,687	$ 3,690	$ 1,668	$ 8,431	$ 4,859	$ 7,389	$ 5,902	$ 8,910	$17,536	$14,820	$ 6,682	$ 2,012				
Product 19									$11,761	$ 7,818	$ 2,776								
Product 20																	$ 3,309	$12,952	$15,912

Table 6 Average Value Share Weight for Product i at Time t

Wi,t	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Product 1	0.30	0.13	0.13	0.17	0.25	0.31	0.20	0.11	0.17	0.18	0.14	0.10	0.03	0.06	0.14	0.20	0.17	0.13	0.15
Product 2	0.13	0.10	0.04	0.04	0.05	0.03	0.02	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Product 3	0.09	0.09	0.05	0.04	0.04	0.05	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Product 4	0.00	0.01	0.02	0.06	0.14	0.17	0.17	0.15	0.10	0.10	0.06	0.03	0.08	0.08	0.02	0.01	0.04	0.02	0.00
Product 5	0.00	0.00	0.00	0.01	0.01	0.01	0.02	0.04	0.03	0.00	0.01	0.03	0.03	0.01	0.00	0.00	0.00	0.00	0.00
Product 6	0.00	0.00	0.00	0.13	0.18	0.12	0.09	0.05	0.03	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Product 7	0.16	0.40	0.57	0.46	0.27	0.14	0.10	0.07	0.01	0.02	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Product 8	0.00	0.03	0.05	0.02	0.01	0.10	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Product 9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.07	0.05	0.06	0.17	0.14
Product 10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.02	0.02	0.00	0.00	0.00	0.00
Product 11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.28	0.53	0.54	0.54	0.58	0.61	0.66	0.61	0.46	0.32
Product 12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.04	0.06	0.09	0.07	0.04	0.03	0.01	0.01
Product 13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.00
Product 14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.07	0.15
Product 15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01
Product 16	0.01	0.01	0.00	0.00	0.00	0.02	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Product 17	0.00	0.00	0.00	0.00	0.00	0.01	0.22	0.47	0.46	0.24	0.08	0.08	0.07	0.04	0.02	0.00	0.00	0.00	0.00
Product 18	0.31	0.23	0.13	0.08	0.05	0.04	0.05	0.07	0.06	0.06	0.06	0.10	0.15	0.12	0.05	0.01	0.00	0.00	0.00
Product 19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.09	0.05	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Product 20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.12	0.21

Table 7 Annual Quantities of Product i at Time t

Annual Quantities	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Product 1	199	104	283	174	358	335	191	167	347	229	265	127		129	179	136	73	121	100
Product 2	179	117	41	91	26	38	20		13			36	1						
Product 3	281	271	157	95	169	118	47	82	56	30	31	73							
Product 4		19	15	98	215	186	330	205	165	219	35	78	196	52		14	34		
Product 5		9	17	21	18	50	88	194	20	4	64	214	63						
Product 6				172	53	100	27	45		12	6	10							
Product 7	103	433	521	206	139	36	129	18		34		20							
Product 8		70	44		23	169	2					5	4						
Product 9														6	59		59	115	42
Product 10										19	50	34	12	73					
Product 11									42	576	944	822	789	693	694	434	418	257	210
Product 12									3	31	108	170	266	281	281	68	32		51
Product 13																32	18		
Product 14															11	3	50	49	167
Product 15														5	5	14	48		28
Product 16	77		19		25	140		131	31	25	100	106							
Product 17						38	1305	1643	1546	254	329	363	114	80					
Product 18	1369	1146	810	254	210	113	588	360	619	415	586	1171	992	392	106				
Product 19									237	147	47								
Product 20																	33	298	650
	2208	2169	1907	1111	1236	1323	2727	2845	3079	1995	2565	3229	2437	1711	1335	701	765	840	1248

Table 8 Natural Logarithm of the Ratio of Quantities

lnQi,t/Qi,t-1	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Product 1	0.91	-0.65	1.00	-0.49	0.72	-0.07	-0.56	-0.13	0.73	-0.42	0.15	-0.74	0.00	0.00	0.33	-0.27	-0.62	0.51	-0.19
Product 2	1.72	-0.43	-1.05	0.80	-1.25	0.38	-0.64	0.00	0.00	0.00	0.00	0.00	-3.58	0.00	0.00	0.00	0.00	0.00	0.00
Product 3	1.92	-0.04	-0.55	-0.50	0.58	-0.36	-0.92	0.56	-0.38	-0.62	0.03	0.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Product 4	0.00	0.00	-0.24	1.88	0.79	-0.14	0.57	-0.48	-0.22	0.28	-1.83	0.80	0.92	-1.33	0.00	0.00	0.89	0.00	0.00
Product 5	0.00	0.00	0.64	0.21	-0.15	1.02	0.57	0.79	-2.27	-1.61	2.77	1.21	-1.22	0.00	0.00	0.00	0.00	0.00	0.00
Product 6	0.00	0.00	0.00	0.00	-1.18	0.63	-1.31	0.51	0.00	0.00	-0.69	0.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Product 7	3.03	1.44	0.19	-0.93	-0.39	-1.35	1.28	-1.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Product 8	0.00	0.00	-0.46	0.00	0.00	1.99	-4.44	0.00	0.00	0.00	0.00	0.00	-0.22	0.00	0.00	0.00	0.00	0.00	0.00
Product 9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.29	0.00	0.00	0.67	-1.01
Product 10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.97	-0.39	-1.04	1.81	0.00	0.00	0.00	0.00	0.00
Product 11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.62	0.49	-0.14	-0.04	-0.13	0.00	-0.47	-0.04	-0.49	-0.20
Product 12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.34	1.25	0.45	0.45	0.05	0.00	-1.42	-0.75	0.00	0.00
Product 13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.58	0.00	0.00
Product 14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-1.30	2.81	-0.02	1.23
Product 15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.03	1.23	0.00	0.00
Product 16	0.00	0.00	0.00	0.00	0.00	1.72	0.00	0.00	-1.44	-0.22	1.39	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Product 17	0.00	0.00	0.00	0.00	0.00	0.00	3.54	0.23	-0.06	-1.81	0.26	0.10	-1.16	-0.35	0.00	0.00	0.00	0.00	0.00
Product 18	1.61	-0.18	-0.35	-1.16	-0.19	-0.62	1.65	-0.49	0.54	-0.40	0.35	0.69	-0.17	-0.93	-1.31	0.00	0.00	0.00	0.00
Product 19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.48	-1.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Product 20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.20	0.78

Table 9 Ratio of Output in Current year to Output in Previous Year

Wi,t*ln(Qi,t/Qi,t-1)	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Product 1	0.28	-0.09	0.13	-0.08	0.18	-0.02	-0.11	-0.02	0.12	-0.07	0.02	-0.07	0.00	0.00	0.05	-0.05	-0.10	0.07	-0.03
Product 2	0.22	-0.04	-0.04	0.03	-0.06	0.01	-0.01	0.00	0.00	0.00	0.00	0.00	-0.03	0.00	0.00	0.00	0.00	0.00	0.00
Product 3	0.18	0.00	-0.03	-0.02	0.03	-0.02	-0.02	0.01	-0.01	-0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Product 4	0.00	0.00	0.00	0.11	0.11	-0.02	0.10	-0.07	-0.02	0.03	-0.12	0.02	0.07	-0.11	0.00	0.00	0.03	0.00	0.00
Product 5	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.03	-0.07	0.00	0.02	0.03	-0.04	0.00	0.00	0.00	0.00	0.00	0.00
Product 6	0.00	0.00	0.00	0.00	-0.21	0.08	-0.12	0.02	0.00	0.00	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Product 7	0.49	0.57	0.11	-0.42	-0.11	-0.20	0.13	-0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Product 8	0.00	0.00	-0.02	0.00	0.00	0.20	-0.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Product 9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.11	-0.15
Product 10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	-0.01	-0.01	0.03	0.00	0.00	0.00	0.00	0.00
Product 11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.73	0.26	-0.08	-0.02	-0.08	0.00	-0.31	-0.02	-0.22	-0.07
Product 12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.03	0.00	0.00	-0.06	-0.02	0.00	0.00
Product 13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	0.00	0.00
Product 14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	0.10	0.00	0.18
Product 15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00
Product 16	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	-0.02	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Product 17	0.00	0.00	0.00	0.00	0.00	0.00	0.76	0.11	-0.03	-0.43	0.02	0.01	-0.08	-0.01	0.00	0.00	0.00	0.00	0.00
Product 18	0.49	-0.04	-0.05	-0.09	-0.01	-0.02	0.09	-0.03	0.03	-0.02	0.02	0.07	-0.02	-0.11	-0.07	0.00	0.00	0.00	0.00
Product 19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.04	-0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Product 20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.17

The information in Table 9 expresses the ratio of output in the current year (t) to output in the previous year (t-1). It should be pointed out that the firm's actual production history, for which information is available for select products, begins in 1972. Between Government fiscal years 1976 and 1977, however, there was a change in the month which starts the fiscal year. Thus, work orders from the firm actually show items produced in FY76, FY76T (Transition) and FY77. Due to the erratic behavior of production during the transition year and uncertainty in the exact mechanism for combining the transition yearly production totals into FY76 of FY77, it was decided, after consultation with economists at the BLS, to start the labor productivity analysis in FY77.

The index of output in the current year referred to earlier in Equation 1 as $\frac{Qt}{Q0}$ was calculated as a Tornqvist index, where the ratio equals the output in a given year divided by that in the previous year. The ratios are chained together to form a series. For example, if FY77 is the base year, and the current year is FY95, then the chained output index used to calculate the index value for FY95 is:

$$\frac{Qt}{Q0} = \frac{Q95}{Q77} = \left(\frac{Q95}{Q94}\right) \times \left(\frac{Q94}{Q93}\right) \times \left(\frac{Q93}{Q92}\right) \times \ldots \left(\frac{Q78}{Q77}\right)$$

Table 10, The Index of Output in the Current Year, presents the array of chained output index calculated for the firm between 1977 and 1995.

Table 10. The Index of Output in the Current Year.

	Output Index
1977	1.00
1978	1.48
1979	1.62
1980	1.02
1981	0.95
1982	1.00
1983	1.52
1984	1.38
1985	1.40
1986	1.70
1987	2.10
1988	2.13
1989	1.94
1990	1.49
1991	1.70
1992	1.11
1993	1.11
1994	1.39
1995	1.55

3.2. Measuring the Firm's Index of Labor Input

Measuring the firm's index of labor input, according to the BLS, requires the creation of an employee hour index. In this particular case, employee hours were examined for direct manufacturing workers (production workers) and overhead manufacturing workers (nonproduction workers). Calculation of the employee hour index for a firm that produces multiple products is calculated exactly as if the firm produced a single product. Following the BLS techniques, the employee hour index for a firm producing a single product is defined as the hours expended in the current year divided by the hours expended in the base year. Tables 11 through 14 tables are used to illustrate the data utilized in the derivation of the firm's input index. Indirect labor costs reported in Table 11 were utilized in conjunction with indirect labor rates in order to derive the indirect labor hours displayed in Table 12. The direct labor hours presented in Table 13 were provided by the Government. Total hours for product (i) in year (t) is the result of summing the indirect labor hours for product (i) in year (t) from Table 11 and the direct labor hours for product (i) in year (t) from Table 13.

The index of labor input which was derived from the total labor hours presented in Table 14 is shown in Table 15, Index of Labor Input in the Current Year.

Table 11 Indirect Labor Costs of Product i at Time t

Indirect Labor Costs																			
FY96$k	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Product 1	4,702	2,381	6,869	4,502	8,975	7,946	4,194	4,000	7,817	6,507	7,655	4,057		5,030	6,762	5,359	3,525	6,383	6,680
Product 2	3,685	2,379	819	1,996	649	744	367		258			972	29						
Product 3	1,836	1,790	1,159	722	1,332	934	328	645	395	271	293	808							
Product 4		542	462	2,491	5,261	4,229	6,796	4,049	3,368	5,162	984	2,094	6,063	1,783		428	1,302		
Product 5		101	168	185	160	365	638	1,350	135	30	542	2,059	693						
Product 6				6,677	2,224	3,747	1,043	1,601		453	273	632							
Product 7	4,546	15,817	19,872	7,947	5,265	1,383	4,215	653		1,456		1,121							
Product 8		1,382	864		458	3,658	33					148	120						
Product 9														480	4,057		4,880	9,374	3,689
Product 10										423	904	625	234	1,586					
Product 11									2,771	19,878	28,572	26,808	26,021	25,618	21,480	15,475	18,414	14,173	11,927
Product 12									38	304	1,162	1,954	2,924	3,666	946	812	425		913
Product 13																596	377		
Product 14															379	101	2,249	2,695	9,983
Product 15														56	59	162	588		476
Product 16	455		111		159	840		781	173	156	731	965							
Product 17						366	14,720	17,272	15,704	3,055	4,527	5,641	2,386	1,520					
Product 18	5,231	3,769	3,450	1,157	933	481	2,481	1,571	2,468	2,027	3,286	7,832	7,730	3,530	1,092				
Product 19									4,742	3,247	1,119								
Product 20																	881	7,682	6,919

Table 12 Indirect Labor Hours of Product i at Time t

Indirect Labor Hours	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Product 1	95,563	49,706	143,403	95,794	193,433	167,286	85,238	79,673	156,964	120,277	129,968	64,499	-	66,450	91,004	73,210	35,319	57,975	49,705
Product 2	74,894	49,664	17,090	42,460	13,996	15,655	7,467	-	5,185	-	-	15,447	415	-	-	-	-	-	-
Product 3	37,319	37,372	24,194	15,366	28,696	19,661	6,657	12,857	7,936	5,011	4,971	12,844	-	-	-	-	-	-	-
Product 4	-	11,315	9,649	52,996	113,390	89,027	138,122	80,659	67,620	95,408	16,710	33,288	88,388	23,548	-	5,844	13,043	-	-
Product 5	-	2,098	3,511	3,943	3,438	7,678	12,970	26,892	2,707	558	9,194	32,736	10,104	-	-	-	-	-	-
Product 6	-	-	-	142,070	47,940	78,884	21,201	31,894	-	8,372	4,630	10,043	-	-	-	-	-	-	-
Product 7	92,404	330,203	414,866	169,085	113,467	29,114	85,663	13,015	-	26,904	-	17,814	-	-	-	-	-	-	-
Product 8	-	28,842	18,040	-	9,867	77,021	678	-	-	-	-	2,353	1,752	-	-	-	-	-	-
Product 9	-	-	-	-	-	-	-	-	-	-	-	-	-	6,342	54,596	-	48,899	85,142	27,448
Product 10	-	-	-	-	-	-	-	-	-	7,815	15,340	9,930	3,415	20,946	-	-	-	-	-
Product 11	-	-	-	-	-	-	-	-	55,633	367,427	485,098	426,207	379,319	338,420	289,101	211,410	184,507	128,726	88,743
Product 12	-	-	-	-	-	-	-	-	761	5,616	19,720	31,057	42,618	48,431	12,735	11,092	4,258	-	6,795
Product 13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8,148	3,782	-	-
Product 14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5,096	1,377	22,532	24,475	74,278
Product 15	-	-	-	-	-	-	-	-	-	-	-	-	-	741	787	2,219	5,887	-	3,538
Product 16	9,250	-	2,307	-	3,427	17,682	-	15,556	3,482	2,874	12,414	15,342	-	-	-	-	-	-	-
Product 17	-	-	-	-	-	7,697	299,177	344,062	315,343	56,464	76,864	89,682	34,778	20,081	-	-	-	-	-
Product 18	106,328	78,680	72,030	24,622	20,105	10,125	50,417	31,288	49,551	37,469	55,796	124,515	112,682	46,625	14,703	-	-	-	-
Product 19	-	-	-	-	-	-	-	-	95,223	60,018	18,993	-	-	-	-	-	-	-	-
Product 20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8,832	69,768	51,479
Total	415,759	587,879	705,091	546,335	547,759	519,830	707,590	635,896	760,405	794,214	849,698	885,757	673,472	571,584	468,022	313,299	327,057	366,086	301,987

Table 13 Direct Labor Hours of Product i at Time t

Direct labor Hours	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Product 1	75,184	37,426	108,032	72,280	147,153	136,229	71,517	74,816	149,904	110,378	119,515	54,102	-	62,049	88,247	69,360	41,391	49,127	48,700
Product 2	58,923	37,396	12,875	32,032	10,647	12,749	6,266	-	4,888	-	-	14,112	384	-	-	-	-	-	-
Product 3	29,361	28,140	18,226	11,593	21,830	16,010	5,586	10,742	7,112	4,620	4,247	10,220	-	-	-	-	-	-	-
Product 4	-	8,520	7,269	39,087	86,261	72,500	115,889	78,310	57,255	87,600	14,875	30,654	78,204	23,140	-	5,544	15,538	-	-
Product 5	-	1,580	2,645	2,974	2,615	6,252	10,882	23,576	2,345	482	7,910	24,005	7,670	-	-	-	-	-	-
Product 6	-	-	-	107,197	36,471	64,239	17,785	30,105	-	8,196	4,296	8,370	-	-	-	-	-	-	-
Product 7	72,699	248,631	312,537	127,580	86,320	23,708	71,875	12,078	-	24,344	-	15,400	-	-	-	-	-	-	-
Product 8	-	21,717	13,590	-	7,506	62,722	569	-	-	-	-	1,897	1,398	-	-	-	-	-	-
Product 9	-	-	-	-	-	-	-	-	-	-	-	-	-	5,550	50,606	-	55,342	82,340	28,980
Product 10	-	-	-	-	-	-	-	-	-	8,398	14,700	9,146	3,216	20,002	-	-	-	-	-
Product 11	-	-	-	-	-	-	-	-	48,196	347,328	437,072	373,188	351,894	305,613	299,114	199,206	191,444	142,635	127,260
Product 12	-	-	-	-	-	-	-	-	660	4,650	16,740	23,067	32,328	35,922	10,331	8,681	3,785	-	6,164
Product 13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7,904	3,611	-	-
Product 14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4,884	1,479	22,900	25,284	78,657
Product 15	-	-	-	-	-	-	-	-	-	-	-	-	-	648	729	2,086	6,960	-	3,864
Product 16	7,278	-	1,738	-	2,607	14,400	-	13,637	3,016	2,486	10,680	13,263	-	-	-	-	-	-	-
Product 17	-	-	-	-	-	6,268	251,020	303,955	295,286	58,928	70,077	80,586	28,044	17,120	-	-	-	-	-
Product 18	83,653	64,808	54,263	18,578	15,295	8,245	42,302	24,480	42,092	32,785	46,880	96,022	89,280	34,888	11,766	-	-	-	-
Product 19	-	-	-	-	-	-	-	-	84,135	56,742	19,646	-	-	-	-	-	-	-	-
Product 20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7,569	63,250	47,415
Total	327,098	448,218	531,175	412,221	416,705	423,322	593,691	571,699	694,889	746,937	766,638	754,032	592,418	504,932	465,677	294,260	348,540	362,636	341,040

Table 14 Total Labor Hours of Product i at Time t

Total Labor Hours	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Product 1	170,747	87,132	251,435	168,074	340,586	303,515	156,755	154,489	306,868	230,655	249,483	118,601	-	128,499	179,251	142,570	76,710	107,102	98,405
Product 2	133,817	87,060	29,965	74,492	24,643	28,404	13,733	-	10,073	-	-	29,559	799	-	-	-	-	-	-
Product 3	66,680	65,512	42,420	26,959	50,526	35,671	12,243	23,599	15,048	9,631	9,218	23,064	-	-	-	-	-	-	-
Product 4	-	19,835	16,918	92,983	199,651	161,527	254,011	158,969	124,875	183,008	31,585	63,942	166,592	46,688	-	11,388	28,581	-	-
Product 5	-	3,678	6,156	6,917	6,053	13,930	23,852	50,468	5,052	1,040	17,104	56,741	17,774	-	-	-	-	-	-
Product 6	-	-	-	249,267	84,411	143,123	38,986	61,999	-	16,568	8,926	18,413	-	-	-	-	-	-	-
Product 7	165,103	578,834	727,403	296,665	199,787	52,822	157,538	25,093	-	51,248	-	33,214	-	-	-	-	-	-	-
Product 8	-	50,559	31,630	-	17,373	139,743	1,247	-	-		-	4,250	3,150	-	-	-	-	-	-
Product 9	-	-	-	-	-	-	-	-	-	-	-	-	-	11,892	105,202	-	104,241	167,482	56,428
Product 10	-	-	-	-	-	-	-	-	-	16,213	30,040	19,076	6,631	40,948	-	-	-	-	-
Product 11	-	-	-	-	-	-	-	-	103,829	714,755	922,170	799,395	731,213	644,033	588,215	410,616	375,951	271,361	216,003
Product 12	-	-	-	-	-	-	-	-	1,421	10,266	36,460	54,124	74,946	84,353	23,066	19,773	8,043	-	12,959
Product 13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	16,052	7,393	-	-
Product 14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9,980	2,856	45,432	49,759	152,935
Product 15	-	-	-	-	-	-	-	-	-	-	-	-	-	1,389	1,516	4,305	12,847	-	7,402
Product 16	16,528	-	4,045	-	6,034	32,082	-	29,193	6,498	5,360	23,094	28,605	-	-	-	-	-	-	-
Product 17	-	-	-	-	-	13,965	550,197	648,017	610,629	115,302	146,941	170,268	62,822	37,201	-	-	-	-	-
Product 18	189,981	143,488	126,293	43,200	35,400	18,370	92,719	55,768	91,643	70,254	102,676	220,537	201,962	81,513	26,469	-	-	-	-
Product 19	-	-	-	-	-	-	-	-	179,358	116,760	38,639	-	-	-	-	-	-	-	-
Product 20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	16,401	133,018	98,894
Total	742,857	1,036,097	1,236,266	958,556	964,464	943,152	1,301,281	1,207,595	1,455,294	1,541,151	1,616,336	1,639,789	1,265,890	1,076,516	933,699	607,559	675,597	728,722	643,027

Table 15. Index of Labor Input in the Current Year

	All employee Hours Input Index
1977	1.00
1978	1.39
1979	1.66
1980	1.29
1981	1.30
1982	1.27
1983	1.75
1984	1.63
1985	1.96
1986	2.07
1987	2.18
1988	2.21
1989	1.70
1990	1.45
1991	1.26
1992	0.82
1993	0.91
1994	0.98
1995	0.87

4. Calculating Labor Productivity for the Firm

Deriving the index of output per hour in the current year is simply a matter of dividing the index of output in the current year by the index of labor input in the current year. This ratio was previously identified and defined in Equation 1. The resulting index of output per hour for the firm, along with the indexes of output and employee hours are presented below in Table 16, Labor Productivity: Index of Output per Hour..

In the late 1970's production at the firm was largely handled by machines of Korean War vintage. These machines were entering their economic as well as physical lives. Production planners recognizing the critical importance to modernize both the facilities and the machinery initiated a multi-million dollar capital investment program in 1978. Throughout the next eight years the Government invested more than 300 million dollars to modernize the plant and improve the capacity and reduce manufacturing costs. Despite these efforts, we observe that output per hour indexed to 1977 had one modest increase followed by ten straight years of negative productivity growth relative to 1977 levels. It is not until 1989 that we observe the output per hour index break the 1977 1.0 mark.

Table 16. Labor Productivity: Index of Output per Hour.

1977=100	Output per employee hour *Output per Hour*	Output *Gross Output Index*	All employee Hours *Input Index*	Production worker Hours	Nonproduction worker Hours
1977	1.00	1.00	1.00	1.00	1.00
1978	1.06	1.48	1.39	1.37	1.41
1979	0.98	1.62	1.66	1.62	1.70
1980	0.79	1.02	1.29	1.26	1.31
1981	0.74	0.95	1.30	1.27	1.32
1982	0.79	1.00	1.27	1.29	1.25
1983	0.87	1.52	1.75	1.82	1.70
1984	0.85	1.38	1.63	1.75	1.53
1985	0.71	1.40	1.96	2.12	1.83
1986	0.82	1.70	2.07	2.28	1.91
1987	0.97	2.10	2.18	2.34	2.04
1988	0.96	2.13	2.21	2.31	2.13
1989	1.14	1.94	1.70	1.81	1.62
1990	1.03	1.49	1.45	1.54	1.37
1991	1.35	1.70	1.26	1.42	1.13
1992	1.35	1.11	0.82	0.90	0.75
1993	1.22	1.11	0.91	1.07	0.79
1994	1.42	1.39	0.98	1.11	0.88
1995	1.79	1.55	0.87	1.04	0.73

Output per hour during the 1979-1988 time period is below the 1977 level of 1.0 because the employee hour index is larger than the gross output index in those years. But why? Perhaps the answer lies in the treatment of labor as a "quasi" fixed factor of production. This phenomenon is common in trades producing highly technical products to unique customer order. The military and commercial aircraft industry is a good example which has many similarities with this firm. Production requires the talents of many highly skilled workers, both direct labor and overhead labor. Considering the enormous investment these firms make in training such a workforce, it is perfectly consistent that they would hoard workers during period of demand slumps in order for a viable workforce to be available for anticipated demand surges. This is especially true of the government manufacturing facility where the pressure to optimize workforce composition was not particularly severe during the early years of the 1980 Reagan military buildup. The firm's reluctance to downsize its workforce naturally means that the products produced during the years of reduced demand have to absorb a larger proportion of overhead, depreciation, and business operating costs than products made during periods of high volume and production rates.

We do observe output per hour steadily improving beginning in 1989 until 1995, with two declines in years 1990 and 1993. For each of these years, the magnitude in production worker hours outweighed the magnitude in nonproduction workers. The largest productivity gains occur between 1991 and 1995, despite a slip in productivity in 1993. These gains were precipitated by a reduction in the employee hour index below the 1.0 1977 level in conjunction with a similar downward trend in the index of weighted output.

In order to better illustrate the meaning of the above productivity trends, five graphical displays were created in order to visualize the firm's manufacturing experience between 1977 and 1995. Figure 3 shows the trend line in the firm's labor productivity with 1977 as the base year. We observe a slight increase immediately following 1977. This is followed by three successive years of productivity declines. The next three years show improved productivity, yet productivity which lags behind the 1977 starting point. In 1985, we observe the firm's all time low in terms of output per hour- a value of 71% relative to 100% for 1977. Beyond 1985, the trend in labor productivity is constantly increasing. Two significant dips occur in 1990 and again in 1993. The last year labor productivity was measured for the firm, i.e. 1995, we observe an all time peak in labor productivity of 1.80 relative to the base year 1977 =1.

Clearly there are significant forces at work driving the annual perturbations in labor productivity for the firm between 1977 and 1995. In total, the downward trends in labor productivity are most pronounced shortly after the 1977 time frame, while the three remaining low years, 1985, 1990, and 1993 all demonstrate rather sharp declines followed by immediate improvements.

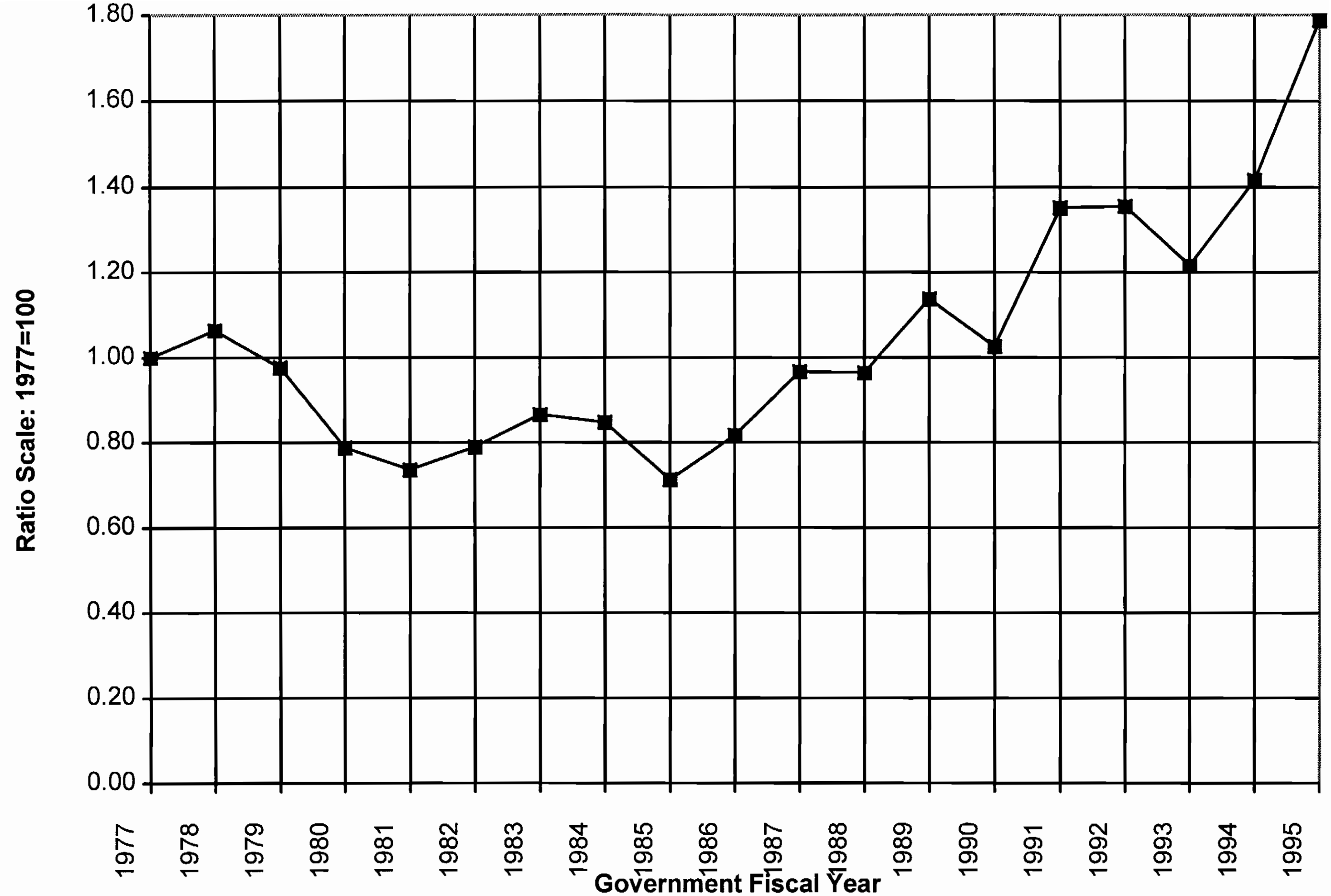

Figure 3 Labor Productivity: Output Per Unit of Labor Input

In order to determine the sources of these peaks and troughs in labor productivity, Figure 4 attempts to explain the trends by comparing labor productivity against an unweighted annual output display. Several patterns in labor productivity are evident when viewed simultaneously with annual output. First, there are **three** instances where productivity declined in a year in which the volume of output for that year is less than the output in the previous year.. This occurs in 1979, 1980, and 1990. Conversely, there are **five** instances where productivity declined in a year in which the volume of output for that year is greater than the output in the previous year. This occurs in 1981, 1984, 1985, 1988, and 1993. Productivity increases accompanied by decreases in the volume of output in a given year relative to the previous year occurred **four** times. The years where this occurred include 1978, 1986, 1989, and 1991. The total number of years in which productivity increases were accompanied by increases in the volume of output was **five**. The years in which this occurred were 1982, 1983, 1987, 1994 and 1995. There was **one** occurrence in which productivity remained the same between two consecutive years despite a decrease in annual demand. This occurred in 1992.

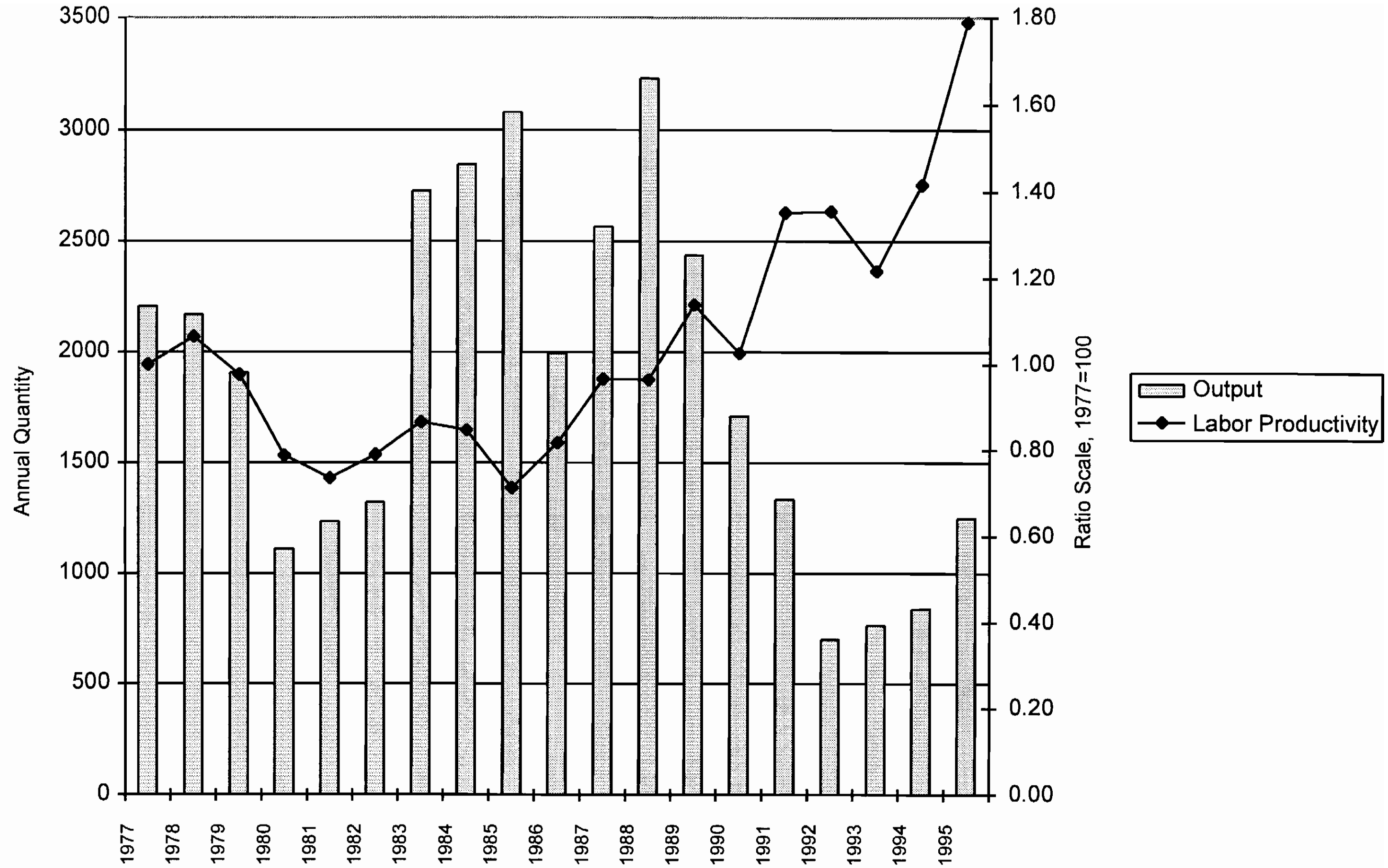

Figure 4 Labor Productivity and Unweighted Annual Output

It is interesting to observe that in the top four years of peak output, 1983, 1984, 1985, and 1988, productivity was below the 1977 level. These four years all had annual production levels in excess of 2,500 units, while the 1977 level was around 2,200. Also, we note that the top five highest productivity levels occurred in years in which annual output was at the lowest annual levels in the entire nineteen year period. Clearly, volume does not drive productivity at this firm.

Another technique to explain these productivity trends is presented in Figure 5. Figure 5 presents the trend in the index of weighted output in the current year versus the unweighted annual output. The weighted output trend line tends to follow the general pattern of peaks and valleys depicted by the bars illustrated the unweighted annual outputs. Unlike the labor productivity or output per hour trends illustrated in Figure 3, where there was a noticeable period of negative productivity relative to the base year, the index of weighted output is practically always above the 1977 base year level. Because this index displays the growth rate of the constant dollar value of gross output originating from the firm it is a good measure of the swings in manufacturing cost for all products produced by the firm. Most noticeable is how the trend lines crosses the bar in certain years such as 1983, 1984, 1985 and 1988 while in other years appears far above the bar's peak. Obviously, the composition of products coupled with the average value share weighting utilized within the Tornqvist index number methodology yields a clear picture of the trends in real resources expended in manufacturing.

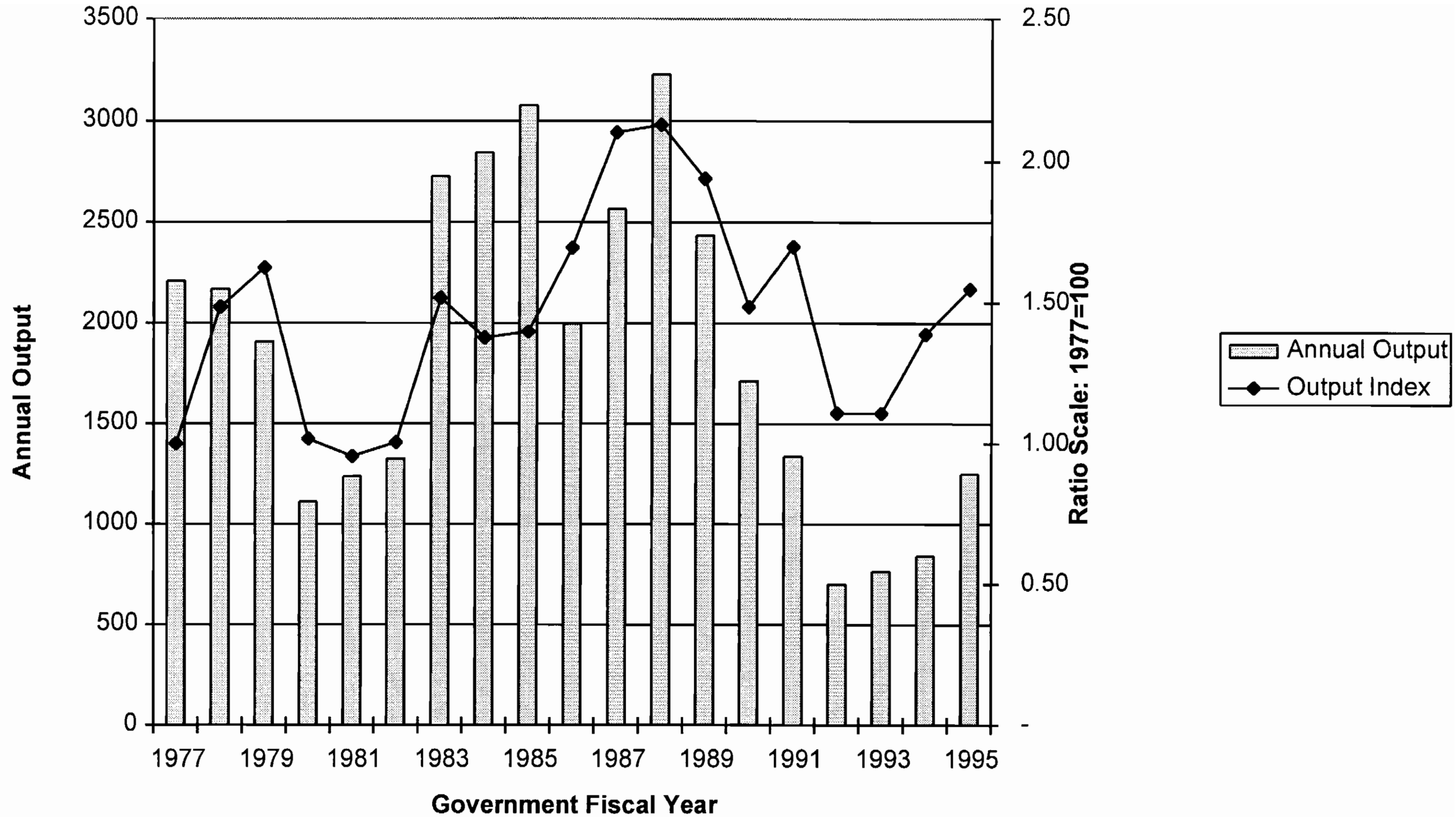

Figure 5 Index of Weighted Output in the Current Year versus Unweighted Annual Output

Figure 6 displays the index of labor input in the current year versus the unweighted annual output. The purpose of this figure is to illustrate the relationship between the rate of growth in total employee hours expended annually in production and annual output. Beginning in 1978, the pattern of employee hour usage is not consistent with swings in annual demand. For example, in 1979 annual demand dropped approximately 400 units while employee hours increased. Likewise, in 1986 annual demand was approximately 1200 units below the previous year, yet employee hour usage increased. It is not until the peak year of 1988 when the trend in employee hours began a steady decline reaching a floor value in 1992 below the threshold of the 1977 base year value of 1.0 This rapid decline in the index of labor input is consistent with employment data available for the firm. Since the 1988 time period, the firm has faced pressure to reduce both direct and indirect personnel in light of the drastic reductions in annual demand accompanying the early 1990's. The firm today is operating at an all-time low level of total employment. It is interesting to observe that the quantity of products produced in 1995 consumed relatively less employee hours than the two previous years, despite the fact of a nearly 400-unit increase in quantity produced. It appears that production technology, and managerial adjustments to the composition of the labor force today provide the firm with increased potential for continued productivity gains relative to recent years experience.

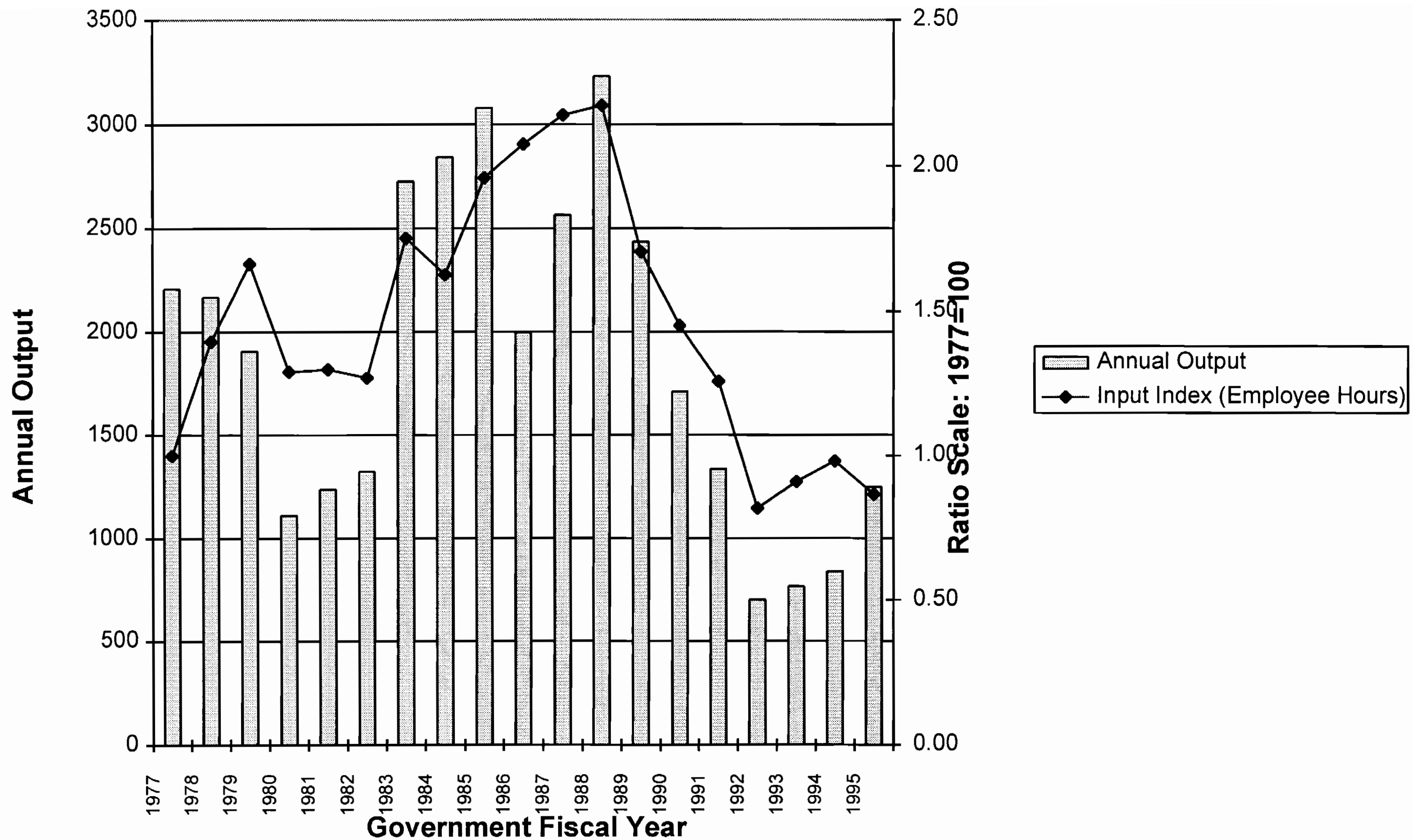

Figure 6 Index of Labor Input in the Current Year versus Unweighted Annual Output

A final visual illustration of the trends in the factors driving productivity change at this firm is presented in Figure 7. The figure shows the composition of the total manufacturing hours expended on an annual basis to be the sum of direct and indirect hours. Indirect or overhead manufacturing hours always represents a larger portion of the annual total than direct hours. This should not be surprising given the tendency of the firm to maintain a surge workforce during the Reagan military buildup years of the 1980's. Similarly, we may observe the gap closing between the indirect and direct hours beginning around 1989 and continuing to 1992 where the two appear to equalize. The ratio remains very close and appears to begin to widen in the opposite direction in 1995. In 1995, the direct hours represents a larger portion of the total hours expended than indirect hours.

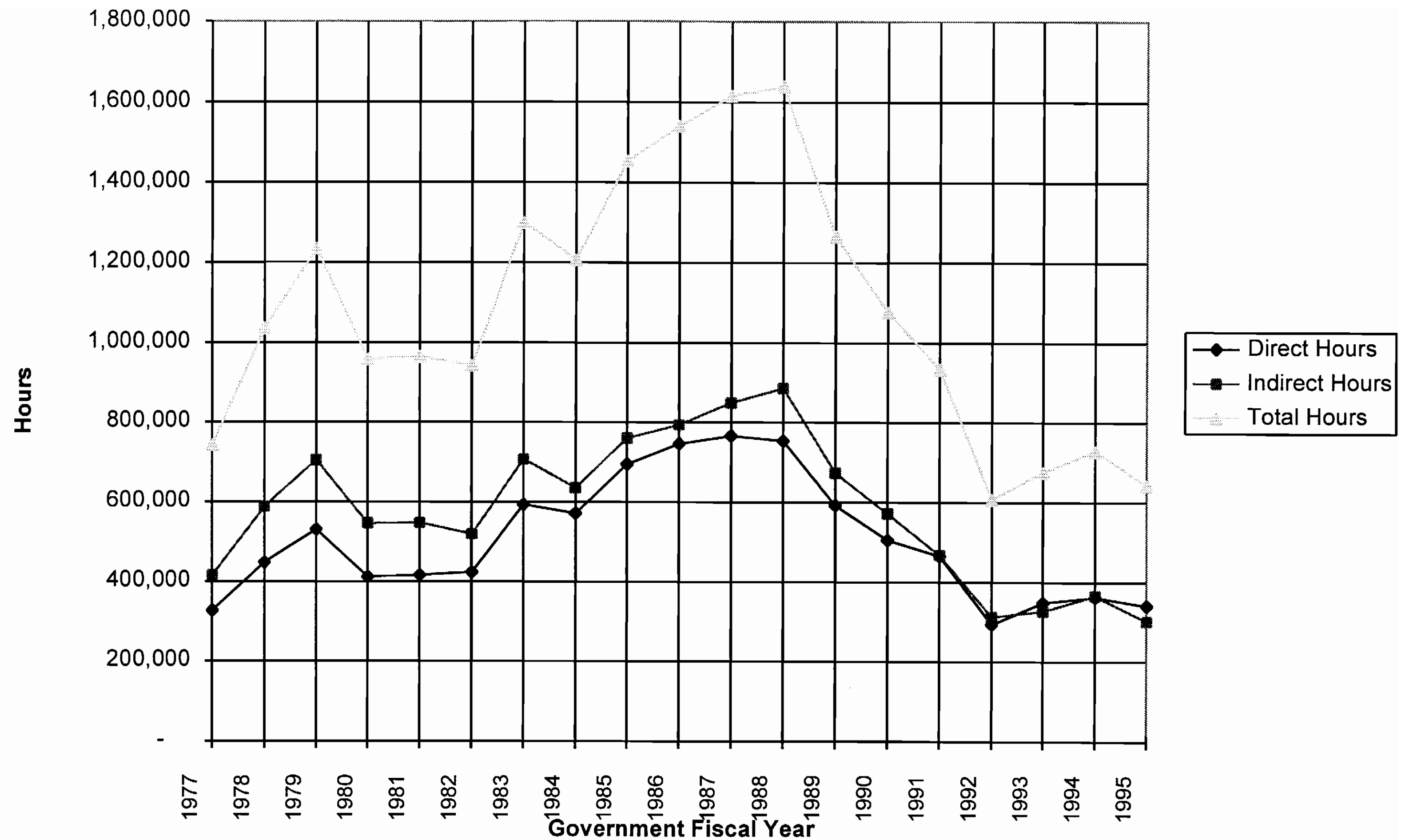

Figure 7 Trends in Total Manufacturing Hours

5. Interpretation of Findings

This paper has attempted to define the growth rate in labor productivity for a Government owned and operated manufacturing facility for the period 1977-95. The purpose of this investigation was to apply the current BLS labor productivity methodology to the firm's data set in order to derive an output and input index series. Combining the ratio of output in the current year to input in the current year yields the measure of output per hour. The important analytical concepts utilized and discussed in this paper have included the definition of labor productivity, the measurement techniques of labor productivity, the reporting techniques of labor productivity metrics, and the interpretation of labor productivity findings. This analysis was developed from a data set constructed from historical cost accounting records collected from the firm. Normalization or adjustment for inflation to bring all costs up to a constant 1996 dollar basis was conducted using DOD inflation indexes. The application of the BLS labor productivity techniques was reviewed by a senior economist at the BLS for accuracy and consistency.

The concept of measuring the amount of labor input required to produce a product or group of products is a straightforward process. Regardless of whether the firm produces a single uniform product or a group of heterogeneous products, the employee hours index is calculated as the employee hours expended in the current year divided by the hours expended in the base year. The input index does not utilize any weighting schemes. The index value in the current period equals the employee hours in the current period divided by the employee hours in the base period. Conversely, the output index relies on complicated weighting schemes to account for the possibility that relative product prices and the mix of products being produced may change from the base period to the current period. The so-called Tornqvist index yields a ratio of the output in a given period to that in the previous year. These ratios are then chained together to form a series. The series reflects output as an aggregate measure. As in this instance, the firm produced multiple products, similar in function and design, yet distinct enough to warrant different model names. The final output index aggregates the growth rates of the various products between two periods, with weights based on the products' shares in the firm's total manufacturing cost of production. The weight for each product is its average value share in the two periods.

Between 1977 and 1990 labor productivity exceeded or equaled the 1977 base year value three out of fourteen years. Eleven of those years saw productivity drop, in one instance by greater than 20% in 1985. In 1978, employee hours rose 39% from the previous year but the growth in output was 48% leading to a 6% jump in productivity. Between 1978 and 1981, growth in employee hours outpaced the growth in output leading to three consecutive years of productivity declines. Despite the fact that 1980 has the lowest level of output during the 1980 decade, five years following it demonstrated dramatic growth in annual output. The lowest production level in the 1980's was 1980 where approximately 1,100 units were produced. Conversely, the peak annual output achieved in 1988 was for approximately 3,200 units. Relative to the base year, every year during the 1980's decade had growth in employee hours. Unfortunately, the magnitude of this growth was not always equaled in the weighted output index series.

The year 1985 is a particularly interesting year in which productivity spiked downward noticeably. The reason is because the employee hour index yielded a value of 1.96 versus an output index of 1.40. Further research into these events leads me to draw the following conclusions. The year 1985 marked the initial production year for a major new product for this firm. The hours reported for the work orders in this year probably include a substantial portion of nonrecurring costs in addition to the recurring production costs reported. Thus, the labor hours which I derived for both direct and indirect labor personnel are more than likely biased and include more than the recurring production effort. This would tend to inflate the employee hours in this year and thereby reduce the productivity in that year. We see this to be the case in the labor productivity trend illustrations.

The primary conclusions to be drawn from this research are that the firm did not capture immediate productivity gains as a result of the multi-million dollar capital investment program implemented between 1978 and 1986. Perturbations in annual demand coupled with the rising direct and indirect costs and the treatment of labor as a quasi-fixed factor of production all combined to produce negative productivity growth between 1978 and 1988. Beginning in 1989, we see productivity jump ahead of the base period value and generate an upward spiral with only two downward spikes. These productivity declines occurring in 1990 and 1993 could very well be the result of an inclusion of nonrecurring hours into the reported recurring labor hour database. Further insight into the causes of changes in productivity at this firm will require additional analysis along the lines of multifactor productivity in which the capital stock is explicitly accounted as a contributed to productivity change. One thing is certain about understanding productivity at this firm—the measures derived through mathematical means relate output to hours expended in production. They do not measure the specific contribution of labor, capital, or any other factor of production. They in fact reflect the joint effects of many factors, including technological change, changes in output, capacity utilization, factor input prices, business costs and the composition of the workforce.

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Vita

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