



Productivity Trends in the Natural Resource Industries

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- PRODUCTIVITY CHANGES IN U.S. COAL MINING, by Joel Darmstadter with the Assistance of Brian Kropp (RFF Discussion Paper 97-40);
- PRODUCTIVITY GROWTH AND THE SURVIVAL OF THE U.S. COPPER INDUSTRY, by John E. Tilton and Hans H. Landsberg, RFF Discussion Paper 97-41 (forthcoming);
- THE FOREST SECTOR: IMPORTANT INNOVATIONS, by Roger A. Sedjo, RFF Discussion Paper 97-42 (forthcoming);
- CHANGING PRODUCTIVITY IN U.S. PETROLEUM EXPLORATION AND DEVELOPMENT, by Douglas R. Bohi, a book from Resources for the Future (forthcoming);
- PRODUCTIVITY TRENDS IN THE NATURAL RESOURCE INDUSTRIES, by Ian W. H. Parry, RFF Discussion Paper 97-39;

and

- UNDERSTANDING PRODUCTIVITY CHANGE IN NATURAL RESOURCE INDUSTRIES, edited by R. David Simpson, a book from Resources for the Future (forthcoming).

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Ian W.H. Parry

Abstract

This paper examines multi-factor productivity trends in the U.S. petroleum, coal, copper and logging industries since 1970. Measures of multi-factor productivity growth are negative for all four industries during the 1970's. At the time this led to fears that stocks of natural resources were being exhausted, and this might hinder future economic growth. However in retrospect the 1970's look like an exceptional period, rather than marking a change in long run productivity trends. The decline in measured multi-factor productivity in that decade appear to be explained by a number of special factors that generally have a transitory rather than a permanent effect on productivity growth. For example, the rise in natural resource prices encouraged the entry of relatively inefficient producers. New environmental and health & safety regulations were phased in during the period that also reduce measured multi-factor productivity.

Over the last 15 years however, productivity measures have improved significantly in all the industries. For example, we estimate that the level of productivity in 1992 was around 75% higher in the petroleum industry than at the trough of the productivity slowdown, and around 60% higher in coal and copper. To some extent these improvements represent restructuring and consolidation in response to falling output prices. However, technological developments have also played an important role in all four industries.

Key Words: productivity, natural resources, technological innovation, depletion effect

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1. INTRODUCTION

People have long been concerned about the exhaustible nature of natural resources and the effect of resource scarcity on limiting the possibilities for economic growth. In the early 19th century Thomas Malthus predicted that finite quantities of land and other types of capital would constrain population growth and improvements in living standards. David Ricardo argued that the costs of producing output would rise over time as the higher quality deposits of natural resources were used up.

Contrary to these gloomy predictions, most natural resources remained abundant throughout the 19th century and the first half of the 20th century. Countries such as the United States and Britain experienced rapid population growth and economic development. Thus economists paid little attention to the problems of resource scarcity. During the 1940's, however, the prices of agricultural and other natural resource products rose, leading to concerns about future supplies in these industries. This led to the founding of Resources for the Future, and the seminal study on resource scarcity by Barnett and Morse (1963). They found that average production costs and prices had been falling in the natural resource industries in the United States during the period 1870 to 1957. Indeed the price increases of the 1940's were at least partially reversed in the 1950's. Barnett and Morse concluded that the effective resource base had been increasing over time. That is, new discoveries of deposits and the ability to make use of lower grade ores because of technological advances, had more than compensated for the depletion of resource stocks.

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The post World War II economic boom came to an abrupt end in the 1970's. The level of productivity for the US economy as a whole actually fell.¹ At the same time the prices of agricultural land and most natural resources increased markedly. This led to studies claiming that the world was running out of resources, and that the limits to economic growth were being reached.² However the most prominent studies were based on a flawed analysis and their predictions turned out to be well wide of the mark.³ Indeed since the 1980's economic growth and productivity growth for the whole economy have recovered, although not quite to the rates experienced between 1945 and 1970.

This study attempts to update the work of Barnett and Morse by looking at economic performance in a number of natural resource industries since 1970. We focus on productivity rather than average production costs. This is because the latter measure is directly affected by changes in input prices (for example energy prices) and these are typically caused by developments in other markets. We present a “top down” statistical analysis of productivity trends in four representative natural resource industries: coal, petroleum, copper and logging. Complementary studies by Bohi (1997), Darmstadter (1997), Tilton (1997) and Sedjo (1997) present “bottom up” analyses of these four industries. That is, these other studies discuss in detail changes in the state of technology, industry structure, the regulatory environment, and so on that have affected productivity levels during the period.⁴

Our objective in these studies is to focus as much as possible on the *extraction* of natural resources – rather than the *processing* of natural resources into products – since the former is more important for resource availability. Previous work in this area has tended to

¹ For a discussion of possible reasons for the productivity slowdown see the symposium in the Fall 1988 edition of the Journal of Economic Perspectives.

² The most well known study was by Meadows et al. (1972), which was prepared for the Club of Rome.

³ For lucid critiques of these studies see Nordhaus (1992) and Simon (1997).

⁴ In this series of studies we will not be concerned with economic efficiency per se. Thus we do not attempt to quantify possible market imperfections caused by environmental externalities, imperfect property rights, government subsidies, and so on (for a technical discussion of these issues see Stiglitz (1979)).

use broader industry definitions that incorporate downstream activities.⁵ We use a multi-factor definition of productivity, which is more reliable than simple labor productivity. The analysis follows the growth accounting method, which decomposes changes in industry output into changes in the quantity of inputs and a residual reflecting changes in productivity.

Productivity performance in the four industries was much more erratic over the last 25 years, compared with the steadily increasing productivity common to each industry prior to 1970. All four industries, and particularly petroleum, experienced significant negative growth in measured multi-factor productivity during the 1970's. However in retrospect the 1970's look like an exceptional period, rather than marking a change in long run productivity trends. The productivity declines of that decade appear to be explained by a number of special factors that generally have a transitory rather than a permanent effect on productivity growth. For example, the rise in natural resource prices encouraged the entry of relatively inefficient producers. New environmental and health & safety regulations phased in during the period also reduced productivity measures.

Since the early 1980's productivity growth has resumed in all the industries, although by markedly different amounts. For example, we estimate that the level of productivity in 1992 was around 75% higher in the petroleum industry than at the trough of the productivity slowdown, and around 60% higher in coal and copper. To some extent the productivity improvements represent restructuring and consolidation in response to falling output prices. However, technological developments have also played an important role in all four industries.

Thus the productivity performance of the industries analyzed below, and by implication resource scarcity in the United States, appears to be much less of a worry today than in the 1970's. There are some caveats to this comforting conclusion. First, the rate of productivity improvements in recent years may not necessarily continue in the future. Indeed to the extent

⁵ For example, practically all previous studies of productivity in forestry focus on processing rather than harvesting (see Stier and Bengston (1992)). In addition, our purpose is to look for common patterns across industries, while most other studies have focussed purely on one industry.

that the recent improvements represent a once and for all restructuring in response to a more competitive global environment, we might expect productivity growth to slow down somewhat in the future. Second, not all natural resource industries are represented in our study. In particular, we do not consider the fishing industry where excessive depletion can occur because of the open-access nature of many fisheries.⁶ Nonetheless it is far from obvious that resource scarcity will be a major obstacle to economic growth in the United States over the next several decades.⁷

The next section describes the theoretical framework for deriving a formula for multi-factor productivity. Section 3 discusses how measures of output and input quantities in the four industries are obtained. Section 4 presents our estimates of productivity trends in each industry, along with other measures of industry performance. Section 5 summarizes.

2. Theoretical Framework

The theoretical analysis below is based on the growth accounting framework developed primarily by Denison, Kendrick, Jorgenson and Griliches.⁸ We begin by specifying the following production function:

$$Q_t = A_t F(L_t, K_t, M_t) \tag{2.1}$$

⁶ See for example Anderson (1977) for a detailed discussion.

⁷ The potential drag on economic growth from resource scarcity is smaller, the smaller the share of natural resource industries in net national product, and the greater the availability of products that can be substituted for those produced with natural resources. Nordhaus (1992) presents some, albeit crude, calculations suggesting that resource constraints will reduce economic growth per capita in developed countries by around one third of one percent per annum, over the next 50 years. This compares with average annual per capita income growth rates in industrial countries of around 1.5% since 1870 (see *Historical Statistics*).

⁸ See for example Denison (1962, 1967, 1974), Kendrick (1961, 1973), Jorgenson and Griliches (1967) and Griliches (1960). This approach has been more common than econometric analyses in time series studies of productivity. The reason is that input and output quantities are closely correlated over time, making the individual regression coefficients difficult to decompose.

Q_t is physical output in an industry (tons of copper, etc.) at time t . L_t is labor input. This is the total number of hours worked, which in turn are the average hours per employee, multiplied by the total number of employees. K_t is the flow of services from the physical capital stock, broadly defined to include buildings and structures, land, equipment, and inventories. The measurement of K_t is discussed below. M_t is intermediate goods input. This consists of raw materials, purchased services and energy.⁹

A_t is a residual scalar, representing all unobserved factors that may cause the production function to shift over time. There are three potentially important determinants of changes in A_t . First, improvements in the state of technology. These include more efficient techniques for combining inputs in production (disembodied technological change) and improvements in the quality of the capital stock such as better machines (embodied technological change). Second, changes in economies of scale. These can arise from the entry and exit of firms into the industry, if these firms differ in efficiency from incumbent firms. Decreasing returns to scale can also occur at the firm level because extraction costs tend to rise as a deposit is depleted. Third, regulations can affect the level of productivity by diverting inputs away from producing output to other activities, such as improving health and safety conditions in the workplace or the surrounding environment. Thus, our productivity measures may reflect a good deal more than technological innovation.¹⁰

Firms are assumed to maximize profits taking the price of output (p_t), labor (w_t), capital (r_t) and intermediate goods (v_t) at time t as given. This price-taking assumption seems a reasonable approximation, given the large number of firms in each of the four industries, and

⁹ Purchased services are activities performed by outside contractors rather than within the firm. Examples may include exploration and drilling activities in petroleum, and road building in logging.

¹⁰ Improvements in the quality of the labor force—such as increases in the average level of education, skill and health of employees—affect the level of productivity. However, these appear to have been less important during the period than the other factors.

that no one firm produces a substantial share of industry output.¹¹ Therefore we can use the familiar first order conditions, equating value marginal products with factor prices:

$$p_t \frac{\partial F}{\partial L_t} = w_t; \quad p_t \frac{\partial F}{\partial K_t} = r_t; \quad p_t \frac{\partial F}{\partial M_t} = v_t \quad (2.2)$$

Differentiating (2.1) with respect to time gives:

$$\dot{Q}_t = \frac{\partial F}{\partial L_t} \dot{L}_t + \frac{\partial F}{\partial K_t} \dot{K}_t + \frac{\partial F}{\partial M_t} \dot{M}_t + \dot{A}_t F \quad (2.3)$$

where $\dot{L} = dL / dt$, and so on. Substituting (2.2) in (2.3) and dividing by Q gives:

$$q_t - \{p_t^L l_t + p_t^K k_t + p_t^M m_t\} = a_t \quad (2.4)$$

where lower case letters denote growth rates ($l_t = \dot{L}_t / L_t$, and so on), and

$$p_t^L = (w_t L_t) / p_t Q_t; \quad p_t^K = (r_t K_t) / p_t Q_t; \quad p_t^M = (v_t M_t) / p_t Q_t \quad (2.5)$$

p_t^L , p_t^K and p_t^M are the shares of payments on labor, capital and intermediate inputs in value product.¹²

In equation (2.4) a_t is the growth rate of multi-factor (or total factor) productivity at a point in time. This is equal to the growth rate in output less a weighted combination of the growth rate in the quantity of labor, capital and intermediate inputs. Many other studies focus

¹¹ Competition can be consistent with decreasing returns to scale at the firm level. Rents accrue to the scarce input—the resource stock. Part of the rent is retained by firms. The rest goes to the government when it sells exploration and development rights, or imposes royalty fees.

¹² If we had not assumed competition, and therefore been unable to use (2.2), the p 's would be the elasticities of output with respect to each factor input. However, data on these elasticities are not available, whereas the factor shares can be measured.

on labor productivity rather than a multi-factor measure of productivity. However in the industries analyzed here, capital and intermediate goods are important inputs in production. Using a simple labor productivity measure may give a misleading impression of overall productivity (in quantitative, though not necessarily qualitative, terms): labor productivity growth overstates multi-factor productivity growth when the quantity of capital and intermediate inputs are increasing relative to labor input over time.¹³

Some studies (for example those by Denison, and Jorgenson and Griliches) use a productivity measure that is net of increases in input quality, while others (for example Kendrick) use the gross productivity measure adopted here. This is really a matter of accounting preference, rather than a substantive difference.¹⁴ One advantage of the gross measure is that it gives a better indication of changes in the well-being of society over time, in terms of how much can be produced from a day's work. In addition, because of data limitations at our level of industry disaggregation, measures of input quality are necessarily very crude.¹⁵

Finally, since data is not available on a continuous time basis, we replace the continuous growth rate variables in (2.4) by the analogous discrete time growth rates:

$$l = (L_{t+1} - L_t) / L_t, \quad (2.7)$$

and so on.

¹³ Similarly, because of data limitations, Barnett and Morse (1963) used production costs per unit of labor when analyzing the forestry, fishing and individual mineral industries. This overstates the fall in average production costs over time when capital and intermediate goods are increasing relative to labor.

¹⁴ However it is obviously important to take into account these different procedures when comparing productivity statistics across different studies.

¹⁵ We did estimate productivity growth for each industry using quality-adjusted inputs, where quality was proxied by the real input price. However this adjustment had very little impact on reducing the productivity residuals.

3. THE MEASUREMENT OF INDUSTRY OUTPUT AND FACTOR INPUTS

This section discusses various issues in the measurement of output and input series for each of the industries.¹⁶ The data sources are then described.¹⁷

A. Industry Output

(i) *Stage of production.* Output for each industry is defined at the extraction level, from production on both public and private lands. For petroleum (oil and natural gas) this industry definition captures drilling activities from on- and off-shore wells, but not refining into gasoline, etc. Similarly, coal and copper output is volume produced from the mines. For logging, output is after the trees have been harvested and cut into logs.¹⁸ In each case, measured inputs do not include those used to transport the commodity to processing facilities. The SIC codes are 1311 (petroleum), 122 (coal), 1021 (copper) and 2411 (logging).

(ii) *Changes in the quality of output.* Ideally, to compare output at different points in time, allowance should be made for changes in the quality of output over time. However for the industries studied here changes in output quality have been negligible over the period, because they essentially produce unprocessed raw materials. For example the quality of a barrel of oil or natural gas, measured by BTU content, is more or less the same now as it was 25 years ago. Therefore we make no adjustments for changes in quality.¹⁹

(iii) *Changes in the composition of output.* The composition of industry output may change over time, for example the ratio of natural gas to total oil output increased by 20% between

¹⁶ For more detailed discussions of these methodological issues see for example Denison (1974), Jorgenson and Griliches (1967).

¹⁷ All the raw data used is available from the author upon request.

¹⁸ This includes wood harvested for both lumber and pulp and paper production.

¹⁹ Indeed measuring quality changes for the output of non-resource industries is problematic. Usually quality is proxied by the real price of output. However the price of output can also change due to other factors, such as shifts in demand.

1970 and 1994. However in terms of pure energy use, a BTU of oil is identical to a BTU of natural gas. Therefore petroleum output is measured by the sum of oil and natural gas, measured in terms of BTU's.²⁰ The average BTU content of a ton of coal has declined by 10.5% over the last 25 years, due to the substitution in favor of low sulfur content coal. To incorporate this effect, coal output is measured by the volume of coal output multiplied by the average BTU content. In the copper industry, the quality of a ton of copper ore is generally uniform across mines and over time, so production is measured by total tonnage. Finally, logging output is roundwood, which comprises the sum in cubic meters of hardwood, softwood and (less important) scrap wood. We do not make an adjustment for changes in the composition of forestry output, since these have only been very slight over the last 25 years.

(iv) Gross output or value added? Industry output could be defined gross (as above) or net of intermediate goods purchased from other industries that are used in combination with labor and capital as inputs in production. We use the more general gross output definition, since this enables us to include an assessment of the contribution of intermediate inputs relative to labor and capital in industry output growth. In addition, only value added can be measured and this is an imperfect measure of output added, since it is affected by changes in the product price.

(v) Output gross or net of depreciation? In addition, output can be defined gross or net of depreciation of the industry's capital stock. The latter definition gives a more accurate indication of the welfare to society from industrial output. This is because welfare depends on what is available for current consumption and net additions to the capital stock, and not the amount of resources used up in maintaining existing capital goods. However, in this paper we are attempting to infer the state of technology in the industries – that is the ability to transform

²⁰ It is not possible to derive productivity measures for oil and gas individually because the inputs into these industries cannot be separated out.

inputs into outputs. Since technological changes affect output *gross* of depreciation, this is the appropriate measure to use (Hulten (1992)).

(vi) *Non-market impacts.* There are three types of non-market impacts from the extraction of natural resources. First, environmental impacts such as the loss of natural habitat from logging and damage caused by oil spills. Second, possible adverse health effects for workers within the industry, for example black lung disease caused by coal mine dust. Third, changes in the stocks of natural resources. These changes could be positive or negative, depending on whether depletion is more than offset by new discoveries and technical improvements enabling the use of lower grade ores. Again, accounting for these types of non-market effects would be important if we were examining productivity from a broader social welfare perspective.²¹ However, we ignore them because our study is attempting to infer changes in the state of technology in each industry for transforming inputs into output.

(vii) *Gross or net of inventories?* Finally, output is measured by production rather than sales; that is, it includes additions to inventory stocks.²²

B. Labor Input

It is straightforward to obtain an aggregate measure of the quantity of labor because data is readily available on hours worked in the four industries. These are actual rather than potential hours; that is they do not include time lost because of strikes, sick days, and vacations.²³

²¹ For a discussion of how to adjust conventional productivity measures to take into account environmental impacts see Repetto et al. (1996).

²² Again this just a matter of accounting preference. However this does affect the appropriate measure of capital input: if output is gross (net) of inventories, capital inputs should include (exclude) inventory stocks.

²³ For non-production workers (accountants, payroll personnel, and so on) only the total number of employees is available. We assume that each of these employees works 35 hours per week for 49 weeks per year. The ratio of non-production workers to production workers is typically less than 0.1.

C. Capital Input

Capital inputs are decomposed into four broad categories in the data: equipment; buildings and structures (henceforth structures); land and inventories. We first discuss how we obtain measures of the stock of each of these types of capital, and then how these are aggregated into a single measure of capital input.

Beginning with the easiest first, data are available on the physical stock of inventories in each period for each industry. Data are not directly available on the physical quantity of land used in the industries. However the Bureau of Labor Statistics provides estimates of the (constant dollar) value of land holdings in the industries. These are based on the same perpetual inventory method described below, where the depreciation of land is taken to be zero.

The stocks of productive equipment and structures in each period are not directly observed. Information is available on the *book value* of assets – the historical cost of an asset adjusted by some assumption about depreciation – but this can be a misleading indicator of the value of capital.²⁴ Instead, we adopt the commonly used perpetual inventory method to derive a proxy for these capital stocks. This requires information on gross investment in each period in current dollars, an initial quantity for the particular asset, and an assumption about economic depreciation of each asset over time.

First we divide the current dollar amount of gross investment in structures and equipment by the respective producer price indexes for structures and equipment in that industry.²⁵ This gives the constant dollar quantity of investment for each asset. We assume that fraction d_i of a particular capital stock depreciates each period; thus

$$K_{it} = (1 - d_i)K_{i,t-1} + I_{it} \quad (3.1)$$

²⁴ In particular, the current value of an asset may differ substantially from its original purchase price because of inflation (which was substantial during the 1970's). Furthermore, the formulas for depreciation used by accountants to calculate book value (such as straight-line depreciation) may bear little resemblance to true economic depreciation.

²⁵ These price indexes (which are from the Bureau of Labor statistics) are for slightly broader industry definitions. For logging we used producer price indexes for manufacturing as a whole.

This equation says that K_{it} , the stock of asset i in period t , equals $(1 - d_i)$ times the stock in the previous period plus the current amount of gross investment, I_{it} . By recursive substitution:

$$K_{it} = (1 - d_i)^t K_{i0} + \sum_{j=0}^{t-1} (1 - d_i)^j I_{it-j} \quad (3.2)$$

that is, the current capital stock is a weighted average of past investment and the capital stock in the initial period. We obtained estimates of d_i for equipment and for structures from the Bureau of Labor Statistics.²⁶ K_{i0} can only be measured by book value divided by asset price. To substantially reduce the influence of this on our capital stock series we set K_{i0} equal to the capital stock in 1945 for petroleum and coal, 25 years before the start of our period of interest.²⁷

We now need to attach weights to the individual asset stocks in order to aggregate them into a single measure of capital input. The usual procedure is to weight an individual capital asset by its share of earnings in the total earnings for capital (for each period). Data are not available on capital earnings; hence this has to be estimated. We do this by assuming an earned rate of return on capital. The (ex ante) rental rate (r_{it}) on a capital asset is given by:

$$r_{it} = s_t + d_{it} - \frac{\dot{p}_{it}}{p_{it}} \quad (3.3)$$

This consists of three components. First the market rate of interest (s_t), that is the opportunity cost of using capital rather than lending it out to other users.²⁸ Second the cost of

²⁶ These are estimated rates of depreciation averaged over 1970-1994. For coal these are 0.17 (equipment) and 0.08 (structures); for petroleum 0.15 and 0.115; and for copper 0.15 and 0.08. Estimates of capital depreciation rates in logging are not available. We assumed values of 0.15 and 0.08. I thank Larry Rosenblum for supplying these data. The capital stock series are not particularly sensitive to alternative plausible values for depreciation rates.

²⁷ Given our values for depreciation, this implies that only around 2% and 25% of the 1945 book value of equipment and structures respectively, is left by 1970. For copper and logging, because of data limitations, we had to use a more recent value of K_{i0} .

²⁸ We use the six month Treasury bill rate (see the *Economic Report of the President*). To convert the Treasury bill rate into a real interest rate we subtract the rate of consumer price inflation. The capital stock series we obtain are not sensitive to using alternative interest rate series (including those adjusted for taxes).

depreciation of that unit. Third, subtracted from these costs is the rate of (real) price appreciation from holding the asset. The overall productivity statistics are not very sensitive to different assumptions about the values of these components.

To add up different types of capital in an industry at time t , we follow the usual procedure of weighting each asset by its share in the total cost of assets. That is,

$$K_t = \sum_i l_{it} K_{it}; \quad l_{it} = \frac{r_{it} K_{it}}{\sum_i r_{it} K_{it}}; \quad (3.4)$$

where K is the aggregate capital stock and l_{it} is the share of asset i in the total value of capital assets at time t .

Unfortunately, only data on labor input are available for the copper industry, and not expenditures on investment or intermediate goods. However, copper is a substantial share -- around 40% during 1970-1994 -- of the metal mining industry as a whole, for which these data are available. We assumed that the ratio of investment in individual capital assets to non-labor costs was the same for copper as in metal mining as a whole. Therefore, a proxy for investment expenditures on individual copper assets was obtained by multiplying the relevant series for metal mining by the share of non labor costs in copper (that is, the value of output less labor earnings) in total metal mining non-labor costs.

D. Intermediate Goods Inputs

Data are available for expenditures on energy, purchased services and raw materials, and these need to be converted into constant dollars to obtain an input quantity series. There are separate producer price indexes for energy for each industry, and another one for purchased services and raw materials combined.²⁹ We divide the expenditure series for energy by the price index for energy, and the expenditure series for purchased services and raw

²⁹ Again the exception is logging, and for this industry we used price indexes for manufacturing as a whole.

materials combined by the other price index, to obtain constant dollar series. These two series are then aggregated using weights, equal to the share of the variable in total intermediate goods expenditures.

Again, copper expenditures on purchased services, energy and raw materials are proxied by those for metal mining as a whole, multiplied by the share of non-labor costs of copper in metal mining non-labor costs. Finally, in logging we exclude payments for stumpage from intermediate goods. This is because these payments fluctuate substantially, and this mainly reflects changes in rents rather than changes in input quantities.

E. Aggregating Labor, Capital and Intermediate Goods

So far we have explained the methodology for obtaining the series for Q , L , K and M . These are easily converted to q , l , k and m in equation (2.4), by using the rate of growth formula. In order to derive the productivity series, the last step is to obtain the weights attached to each of these three input series, or p_i 's. These weights are the share of earnings of that input in total value product. Labor earnings and expenditures on intermediate inputs (the sum of expenditures on energy, purchased services and raw materials) – and hence the weights for these inputs – are easily obtained for each industry. In other industry studies total capital earnings is often estimated as a residual by subtracting payments to labor and on intermediate goods from the value of output. This is valid in industries that are characterized by constant returns to scale, since the sum of the factors shares in equation (2.4) would be unity (by Euler's theorem). However in natural resource industries part of the earnings are rents to the resource stock (thus the sum of the shares is less than unity): using this procedure would count these rents as earnings to capital and overweight the capital share.³⁰ Therefore instead we

³⁰ However the overall productivity trends for the industries turn out to be similar under this approach to those presented below.

obtain capital earnings in period t by multiplying the quantity of each capital asset K_{it} by the rental cost of capital (r_{it}) and then aggregating over all assets.³¹

Finally, the value of output is equal to price multiplied by production. The coal and copper prices used are the average price per ton at the mine-head. Petroleum prices are a weighted average of the BTU price for oil and natural gas, where the weights are the respective shares in the total value of BTU petroleum output. The total value of production from logging is obtained from published data.

F. Data Sources

(i) *Coal*. All the data we used are from the Department of Energy's *Annual Energy Review*, except investment and expenditure on intermediate goods, which are from the *Census of Minerals Industries*. Intermediate goods are available every four or five years. To interpolate the intervening years, we assume that the share of intermediate goods expenditures in value product changes linearly between the observation points. That is, if the first and fifth year shares are 0.450 and 0.454, then the second year is taken to be 0.451, the third 0.452, and so on.

(ii) *Petroleum*. Production and value product are obtained from the *Annual Energy Review*. Hours worked are from the *Basic Petroleum Data Book*. Investment and expenditure on intermediate goods are from the *Census of Minerals Industries* and again the missing years from intermediate goods are interpolated by the same procedure used for coal.

³¹ Changes in output prices imply substantial changes in the sum of the input weights over time. This would result in our estimated productivity series being distorted by output price effects. To avoid this problem, we scale the input weights such that they sum to the same value in all periods. This value is the average sum of the weights over the 25 year period. However the *relative* input weights are variable over time. The weight attached to labor is slightly biased downwards because fringe benefits and social security taxes paid by employers are not included in labor costs. The capital weight is also slightly understated because estimated capital costs do not include corporate tax payments. These payments are not as large as they may appear because interest payments, depreciation and (at times) investment expenditures are tax deductible.

(iii) *Copper*. Output and value product are obtained from the *Minerals Yearbook*. Labor hours and earnings are from *Employment and Earnings*, published by the Bureau of Labor Statistics. Investment and expenditures on intermediate goods from metal mining (which are scaled down to proxy for copper) are from the *Census of Minerals Industries*, with the same interpolations for intermediate goods.

(iv) *Logging*. Output is from the *FAO Yearbook* and all other statistics are from the *Census of Manufacturers*.³²

4. ECONOMIC INDICATORS OF INDUSTRY PERFORMANCE

We now present and discuss statistics on economic performance in the four industries. Sections A and B describe trends in output, price and share of industry output in total manufacturing output since 1945. Section C discusses labor productivity trends, and compares these with trends in broader sectors of the economy. Sections D and E describe, and offer some explanations for, our estimates of multi-factor productivity trends over the last 25 years. The final section presents some summary statistics.

A. Output and Price Trends

Figures 1 and 2 show output and real price – that is, output price relative to the consumer price index – trends for each industry over the last 50 years.³³

(i) 1945-1970

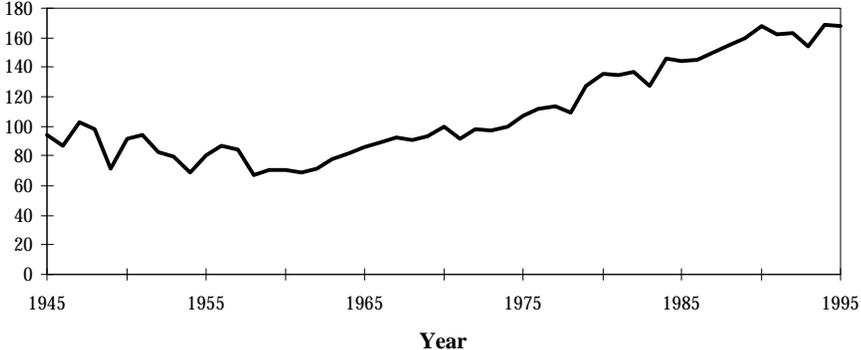
Output in the petroleum and copper industries was on an upward trend from 1945-1970, mirroring the steady expansion in the U.S. economy as a whole. During this period

³² Data for purchased services are only available for 2 of the 25 years. However, in these years it is only around 5% of intermediate goods expenditures, and therefore we ignore purchased services for this industry.

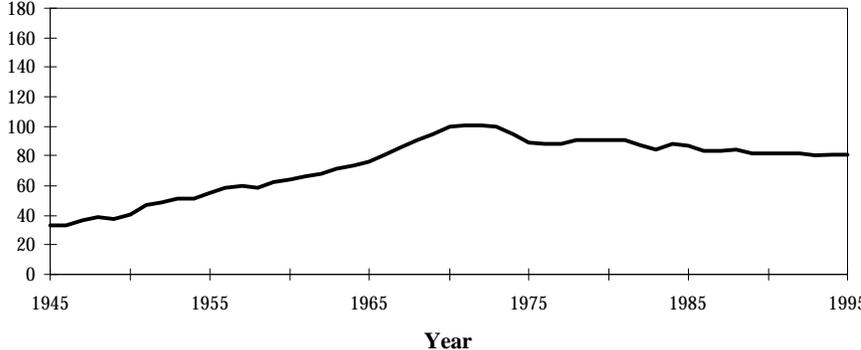
³³ Data for logging is only available from 1958. For earlier periods, only broader measures of forestry output are available.

Fig. 1. Real Output Trends
(1970=100)

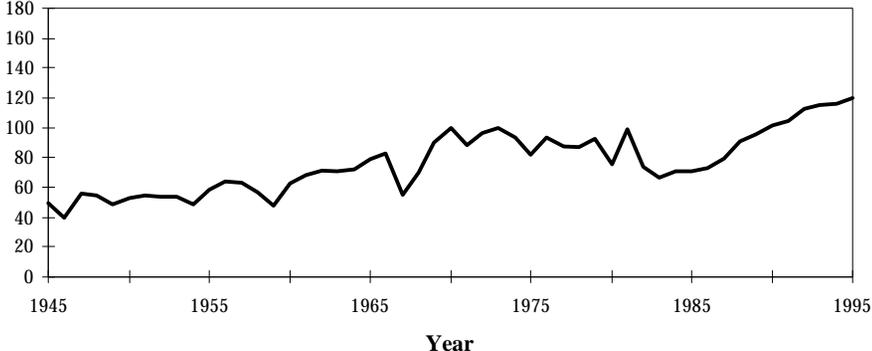
(a) Coal



(b) Petroleum



(c) Copper



(d) Logging

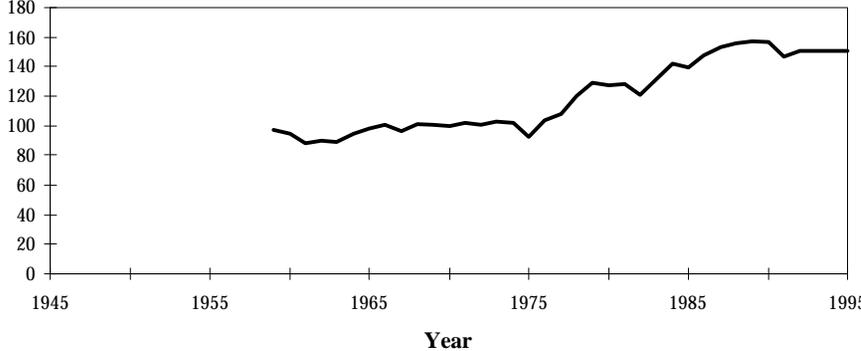
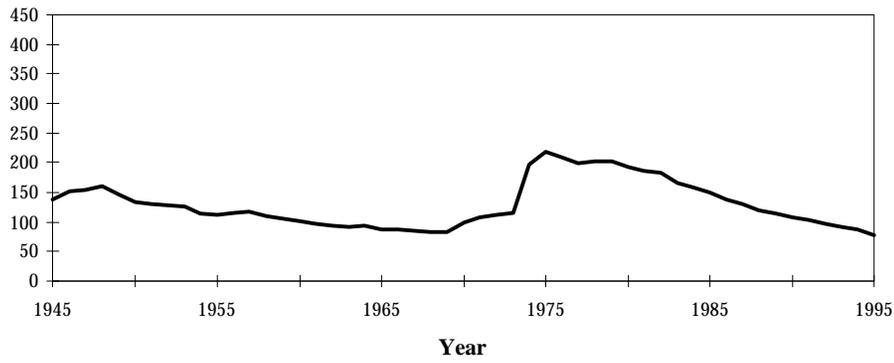
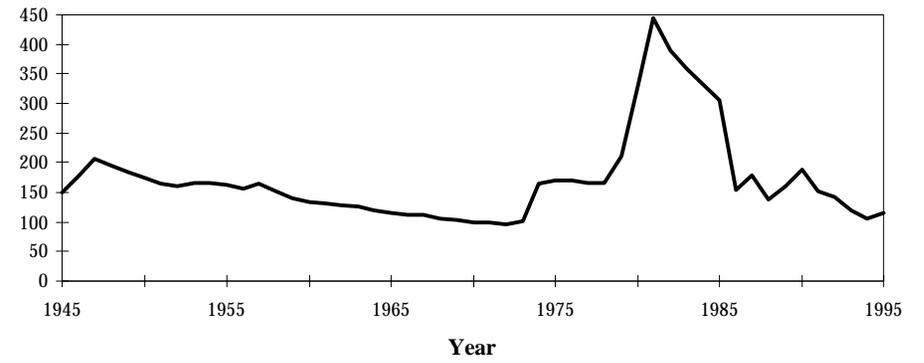


Fig. 2. Real Price Trends
(1970=100)

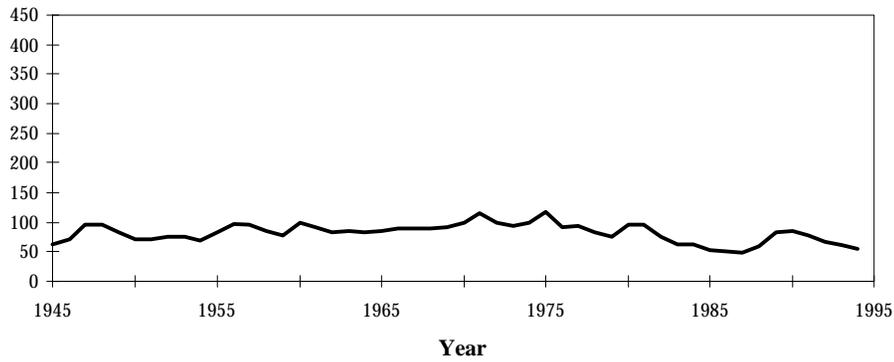
(a) Coal



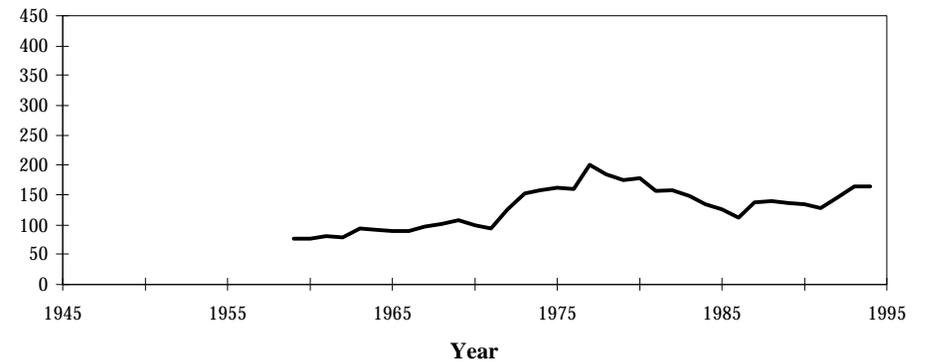
(b) Petroleum



(c) Copper



(d) Logging



output more than doubled in both industries. Coal output declined in the 1950's, in response to falling demand. In particular, diesel trains replaced steam trains and electricity produced with oil and gas began to compete with coal-fired power plants. During the 1960's, however, the continuing expansion in demand for energy enabled coal output to recover. Logging output was only increasing slowly from the late 1950's to 1970, partly because of increasing competition from Canadian imports.

Coal and petroleum prices were declining steadily during 1945-1970. This suggests that any increase in demand in these industries was being more than offset by increases in supply. The main sources of supply increases were the opening up of new reserves, and increases in extraction rates because of technological progress. Real copper and logging prices were on an upward trend during the 1950's and 1960's, however the increase in prices was very slight.³⁴

Output trends in coal and copper mining have traditionally been somewhat erratic. One reason for this is that they have been relatively labor intensive industries and prone to short run disruptions in output from strike activity. Since the early 1980's however, these industries have become much more capital intensive and the remaining labor is less unionized. As a consequence, there has been a dramatic fall in strike activity.

(ii) 1970-1995

The experience in these industries during the 25 years after 1970 was very different from that in the 25 years before 1970. During the early 1970's output growth in all four industries stagnated, but thereafter followed widely divergent paths. Coal and logging output expanded rapidly ending the period 70% and 50% higher respectively, than in 1970. There has been a slight contraction in logging since the mid 1980's, because new environmental regulations have limited access to forestlands. The copper industry declined after 1970 and by 1982 output had

³⁴ A price index for logging was obtained by dividing the value of output by the total volume of wood harvested.

fallen by over 30%. However, the industry then made a strong recovery and output almost doubled over the next 13 years. Unlike the other industries, petroleum output has fallen monotonically over the last 25 years and is now around 20% below peak output in 1970.

Prices increased in all the industries during the 1970's, but then fell back in the 1980's. However the extent of these price movements differed substantially between the industries. The most dramatic was petroleum, where the relative price increased by 350% from 1970-1981, then collapsed and by 1994 was back down to 1970 levels. Coal prices also rose initially – by over 100% – but then decreased steadily from the mid 1970's onwards, and were around 20% below 1970 levels by 1994. Copper prices followed a number of cycles, though they were on a downward trend ending the period 45% lower. Logging prices doubled between 1970 and 1977, then fell back sharply, only to increase again after 1986. By the end of the period logging prices were around 60% higher than 1970 levels.

As is well known, the U.S. petroleum price trends during this period are mainly explained by developments in the world oil market. World oil prices rose dramatically in 1974, and again in 1979, following reductions in supply from members of the Organization of Petroleum Exporting Countries. Prices then fell back as these countries began to exceed their agreed quotas, and oil importers substituted for other fuels and developed more energy efficient technologies. What is surprising is that these changes had very little impact on U.S. petroleum production.³⁵ As discussed in Bohi (1997), there was a marked increase in exploration activity up to the early 1980's, but this was offset because the average rate of discovery for new oil wells fell significantly. In addition, previously known but unprofitable wells were developed, but this was offset by declining production as some existing wells were exhausted. After the early 1980's exploration activity decreased and some higher cost wells were shut down. However the reduction in production was partially offset by increases in

³⁵ However, to some extent these figures mask an increasing share of natural gas relative to oil in total petroleum production.

efficiency due to technological developments such as horizontal drilling and deepwater production platforms (Bohi (1997)).

The increase in oil price led to an increase in demand for other fuels, especially coal, in the 1970's. Hence coal production, and particularly prices, rose rapidly. The continued expansion in coal output over the last 15 years is surprising at first glance. This is because the demand curve for coal was "shifting in" as the price of oil fell, and environmental regulations were imposed on (downstream) coal-fired power plants. However this effect was more than offset by a downward shift in the supply curve, caused by rapid productivity growth (see below).

Logging prices follow the same pattern of rising and falling over the period. The same is true for most natural resource prices, including land. A possible explanation for this is that the general climate of high inflation in the 1970's led to a shift out of financial assets and into real assets such as land, which bid up the prices of natural resources on the land. The reverse happened in the 1980's as inflation was brought under control.³⁶ The slowdown in output growth and increase in logging prices since the mid 1980's seem to be caused by new environmental regulations restricting logging, particularly in areas of natural habitat on public lands (Sedjo (1997)).

Copper prices follow the same downward trend in the 1980's, but unlike other natural resources, copper prices did not rise substantially during the 1970's. This may have been due to unique developments in the world copper market. In particular, the Chilean copper industry became more competitive in the 1970's following privatization, and overtook the United States as the world's largest exporter. The fall in copper prices induced a substantial restructuring of the U.S. industry away from small-scale mines, towards larger scale, more efficient mines. Productivity growth in this much leaner industry account for the expanding output since the early 1980's (Tilton (1997)).

³⁶ Consistent with this explanation, real stock prices fell in the 1970's and rose sharply in the 1980's.

B. Shares in Value of Manufacturing Output

To put some perspective on these trends, Table 1 illustrates how the shares of these industries in the total value of manufacturing output have changed over time. The petroleum share fell sharply from 16.9% to 7.9% between 1955 and 1965, mainly because of the fall in price of petroleum relative to other manufacturing goods. Despite rebounding during the high prices of the 1980's, the petroleum share has now fallen to 3.4% reflecting the absolute decline in output below 1970 levels. During the period of high coal prices, the share of coal output in the value of manufacturing output rose to 4.1% in 1975. This has since halved – in spite of much higher output – because of the decline in relative coal prices. In contrast the share of logging and copper output in the value of manufacturing output have been increasing over the last decade. However in the case of copper, the share is still below its level prior to the restructuring of the industry in the early 1980's.

Table 1. Share of Industry Output in Value of Manufacturing

Industry	1955	1965	1975	1985	1994
Coal	3.1	1.2	4.1	3.3	2.0
Petroleum	16.9	7.9	7.9	11.6	3.4
Copper	0.6	0.5	0.5	0.2	0.4
Logging	1.1	0.7	1.2	1.3	1.7

C. Labor Productivity

(i) In the Four Industries

We begin our examination of productivity trends by looking at how labor productivity, Q_t/L_t , has changed over time in the four industries. This typically overstates multi-factor productivity growth, because capital and intermediate goods tend to grow faster than labor. However, since single- and multi-factor measures of productivity generally move in the same direction, it gives an indication of qualitative trends in productivity. Moreover, it makes for

consistent comparisons with simple labor productivity measures for the rest of the economy, and for earlier periods within the four industries.³⁷

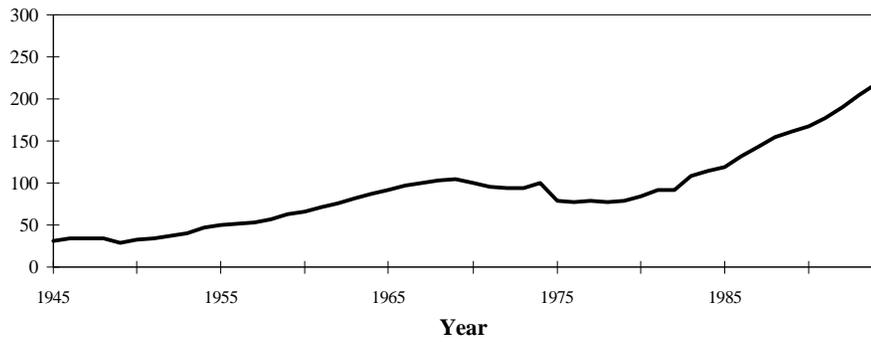
Figure 3 shows labor productivity in all four industries for the period 1945-1995. Beginning with the latter 25 years, labor productivity is generally stagnant or declining until the mid-1970's, and thereafter follows markedly different patterns. In the coal industry labor productivity more than doubled between 1970 and 1994, and grew at an annual average rate of 2.4%. This is even more remarkable, given that labor productivity fell significantly during the 1970's, and was still 25% lower in 1978 than in 1970. Indeed over the last 15 years, output increased by 24% while labor input fell by 52%! Labor productivity growth was even stronger in the copper industry, finishing the period 170% higher than in 1970. The average annual growth in labor productivity was 3.7%. In the petroleum industry labor productivity fell substantially, to only 40% of its 1970 level by 1982. Since then it has recovered somewhat, but was still 35% below the 1970 level in 1994. In logging, labor productivity recovered strongly in the 1980's and was 60% above the 1970 level by 1986. However, it has since fallen back slightly and leveled off. The average annual growth in labor productivity over the whole period was approximately -2.4% in petroleum and 1.4% in forestry.

In the 25 years prior to 1970, labor productivity increased steadily in all four industries, with comparatively minor fluctuations about this trend (the exception to this is logging where labor productivity growth was more sluggish). Thus the productivity slowdown in the 1970's, and the widely differing trends thereafter, are in marked contrast to the experience in the first half of the post-1945 period.

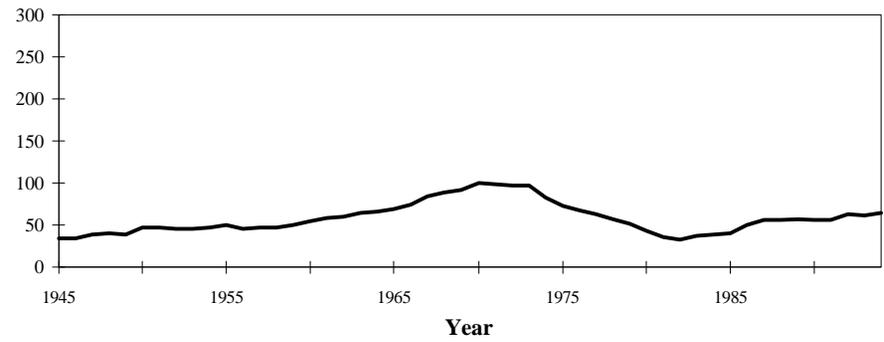
³⁷ Estimates of multi-factor productivity for the four industries in earlier periods are more difficult to obtain because of data limitations.

Fig. 3. Labor Productivity Trends
(1970=100)

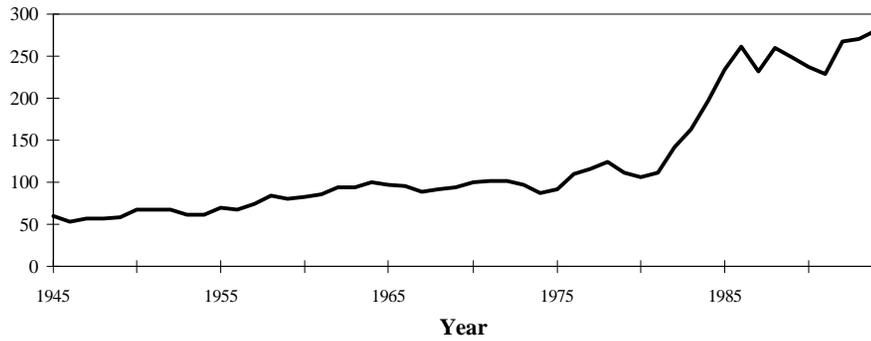
(a) Coal



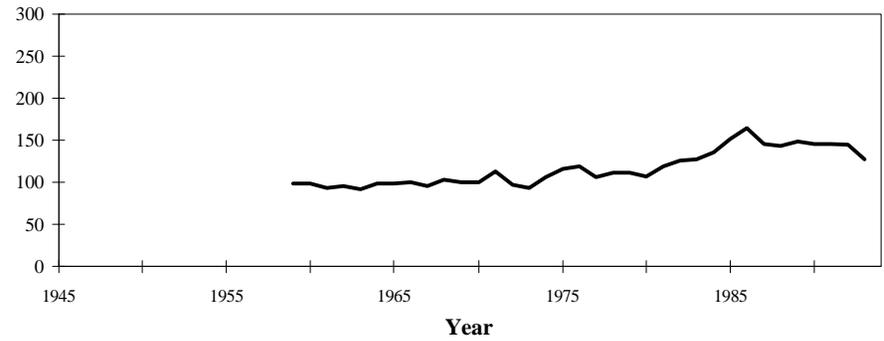
(b) Petroleum



(c) Copper



(d) Logging



(ii) In Broader Sectors of the Economy

Figure 4 indicates labor productivity trends in broader sectors of the economy, GDP and manufacturing, over the same period. Again in both these sectors, labor productivity growth increased steadily for the first 25 years, stopped in the 1970's, but then recovered to end up roughly 20% higher than 1970 levels by 1994. However, the productivity growth rate achieved in the last 15 years (determined by the slope of the curves in Figure 4) has not been as high as that from 1945-1970. These trends are qualitatively very similar to those in the industries studied here, although the recovery in coal, copper and logging was relatively stronger, and relatively weaker in petroleum.

D. Multi-Factor Productivity

Figure 5 shows multi-factor productivity trends in the four industries, that is output divided by total factor input at time t , or $Q_t / (p_t^L L_t + p_t^K K_t + p_t^M M_t)$, where the 1970 value is normalized to 100. For petroleum, the multi-factor productivity trend is very similar to the labor productivity trend. That is, productivity declines steadily to only 33% of the 1970 level by the early 1980's! However, productivity is now 75% higher than in the trough of the productivity fall. The productivity recovery in the coal industry during the 1980's is drastically lower than implied by the labor productivity measure. By the end of the period, multi-factor productivity is slightly below the 1970 level, compared with the 120% increase in labor productivity. However, compared with the late 1970's productivity has increased by around 64%.³⁸ For copper, the multi-factor measure still indicates a significant rise in productivity over the last 15 years, although not as dramatic as implied by the single factor measure. By 1992 productivity was 23% higher than at the start of the period, and 60% higher than at the trough of the productivity slowdown in 1979. The productivity performance in logging is worse when the multi-factor measure is used. There was a noticeable recovery in productivity

³⁸ These trends are consistent with a recent study of multi-factor productivity in the coal industry by Ellerman and Berndt (1997).

Fig. 4. Economy-Wide Trends in Labor Productivity

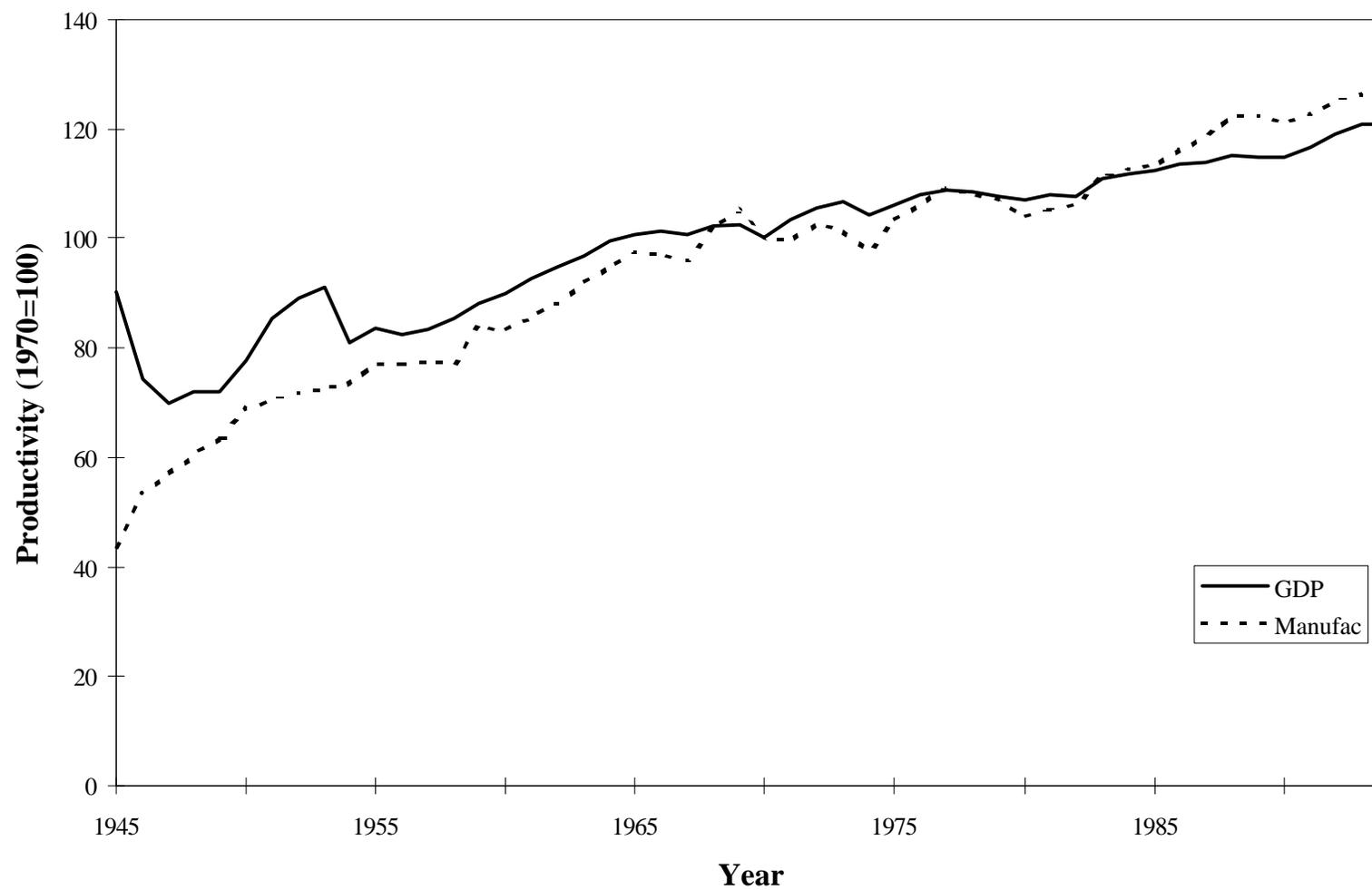
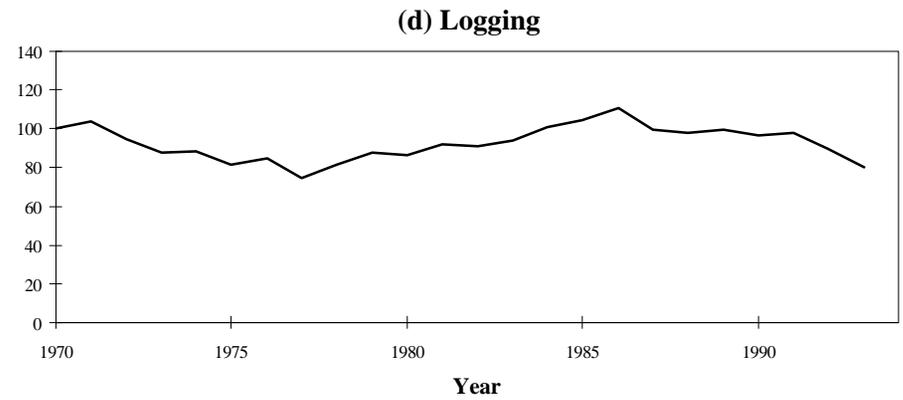
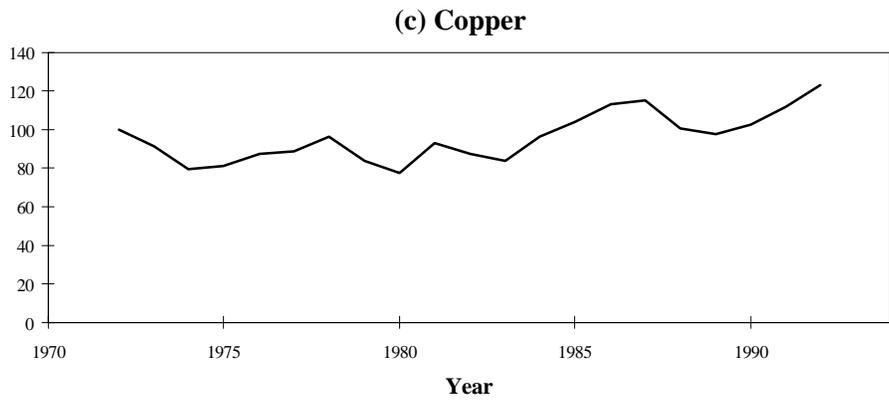
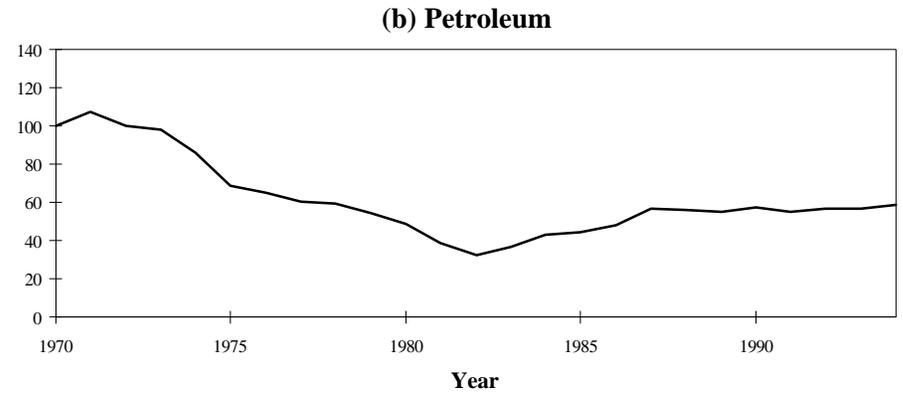
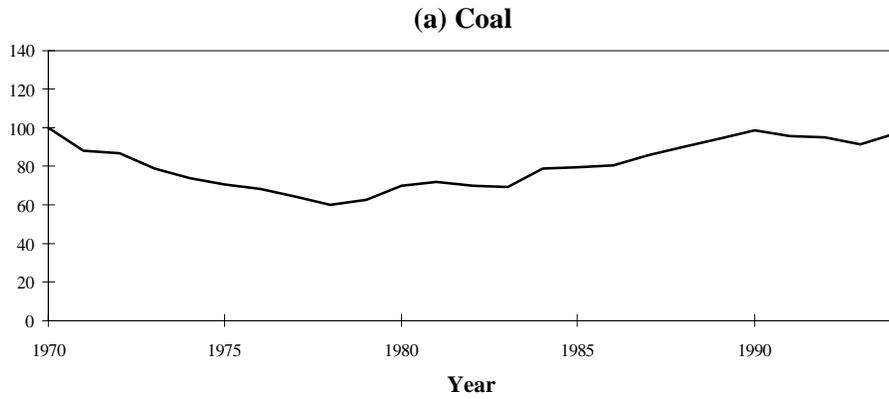


Fig. 5. Multifactor Productivity Trends
(1970=100)



during the 1980's, however this has been reversed somewhat in recent years. Productivity is now 20% higher than in the trough year, 1977.

Multi-factor productivity in manufacturing as a whole followed a similar qualitative pattern during the period. However the decline during the 1970's was much more severe in the natural resource industries, suggesting that there were special factors at work (see below). Since the early 1980's multi-factor productivity in manufacturing has increased by around 20% and is around 28% higher than in 1970.³⁹

E. Contribution of Inputs to Output Growth

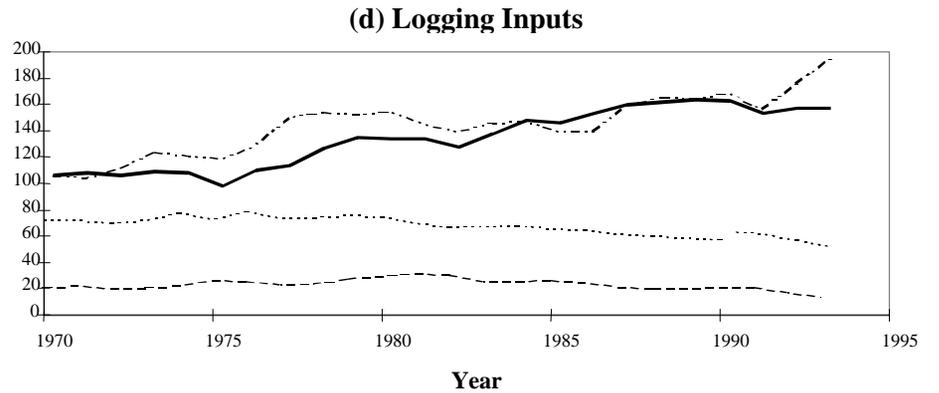
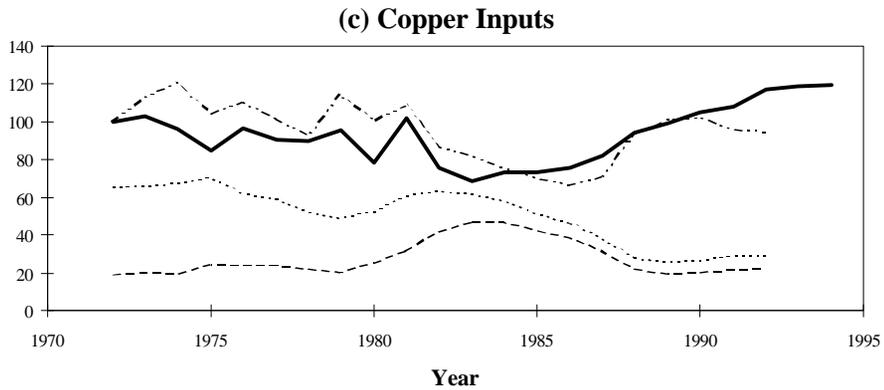
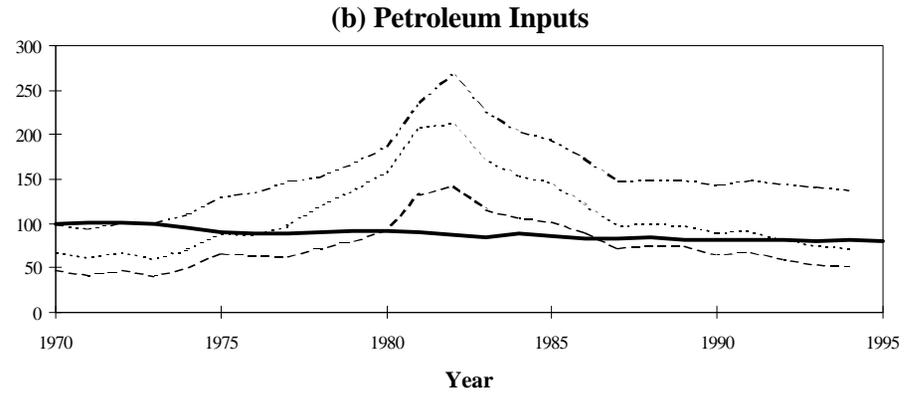
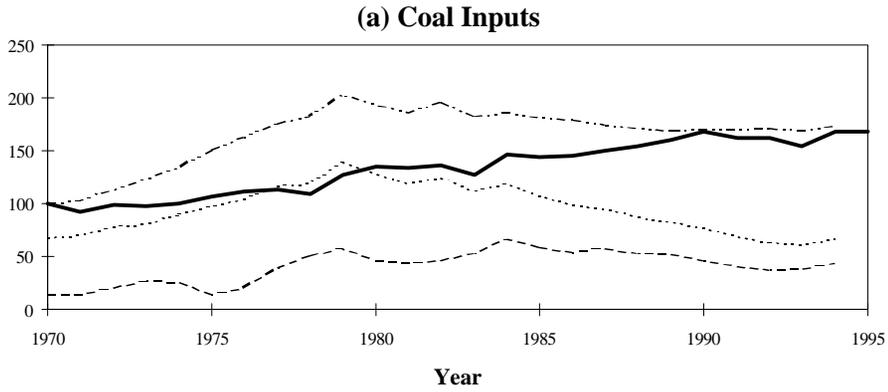
Figure 6 shows the contribution of input quantities over time in "explaining" output trends. The dashed curves are, from bottom to top, the weighted capital input, weighted capital plus labor input, and weighted capital plus labor plus intermediate inputs, where the weights are the shares in value product, or p_i 's. Thus the difference between these dashed curves indicates approximately (since the relative weights vary somewhat over time) how input quantities change. The gap between output (the solid curve) and the top dashed curve is an absolute measure of productivity change between a particular year and 1970. When this dashed curve lies below (above) the solid curve, productivity is greater (less) than in 1970.⁴⁰

In the coal industry inputs were increasing faster than output in the 1970's, hence productivity was declining. As discussed in Darmstadter (1997), these trends can be broadly attributed to three factors. First, the entry into the industry of small, relatively inefficient mines, in response to the jump in coal prices. This increased output and reduced the average level of productivity. Second, a variety of health and safety standards and environmental regulations were introduced during this period. For example, in underground mines standards were established for roof building, ventilation, and allowable concentrations of coal dust and methane. Other regulations restricted mining in areas in close proximity to national parks,

³⁹ These data are from the Bureau of Labor Statistics website.

⁴⁰ The curves in Figure 5 are equivalent to the ratio of the solid curve in Figure 6, divided by the highest dashed curves.

Fig. 6. Decomposing Output Trends
(1970=100)



..... Capital
..... Capital+Labor

..... Capital+labor+Int. Good
————— Output

Note: Input Quantities are weighted
by the share in value product

and required that exhausted surface mines (on federal lands) be transformed back into the pre-existing vegetative state. Loosely speaking, such regulations have a once-and-for-all effect on increasing input requirements per unit of coal output, and therefore have a permanent effect on the *level* of productivity but only a transitory effect on the rate of productivity *growth*. Third, this was a period of industrial confrontation, which culminated in the highly disruptive strikes of 1971 and 1977. Strikes have a once-and-for-all effect on reducing output and productivity below their potential. This climate of high prices and industrial strife during the 1970's most likely slowed down the adoption of new technologies.

In the 1980's, these factors were largely reversed. Falling coal prices drove many of the small-scale, less efficient mines out of the industry, thereby boosting the average level of productivity. In addition, falling prices forced the industry to become more competitive. Productivity was increased by the adoption of labor saving technologies, such as long-wall mining in underground mines, and cutting by draglines in surface mines (see Darmstadter (1997)).

Similarly in the petroleum industry inputs increased sharply in the late 1970's and early 1980's. This had no noticeable effect on output, hence productivity fell markedly. As mentioned above, the increase in petroleum price led to a big increase in exploration activity (the "extensive margin"), and the development of known wells that were previously too costly to be profitable.⁴¹ The fall in average productivity was compounded by the depletion of the "intensive margin", that is, the exhaustion of reserves in lower cost wells.⁴² In the 1980's, the fall in petroleum price led to the closure of many high cost wells (that is, depletion of the extensive margin); thus the quantity of capital was reduced and productivity rose. Technological breakthroughs further increased productivity and mitigated the fall in output (see Bohi (1997)). These included the development of floating platforms for petroleum

⁴¹ This effect was stronger because petroleum price controls in the US were lifted during the 1970's. These had artificially inflated the level of productivity by keeping marginal, relatively less efficient producers out of the industry.

⁴² In contrast, the depletion effect has not been significant in coal because reserves are very plentiful (see Darmstadter (1997)).

extraction in deepwater areas, and techniques to drill horizontally into petroleum deposits. However in the 1980's there was also an important trend towards contracting out activities, such as site surveying and well drilling, rather than providing them internally in the firm. These activities have become much more high-tech, but this is not reflected in a productivity improvement in Figure 6, because they are now intermediate inputs in production.

In the copper industry the quantity of inputs and output produced were (roughly) on a constant trend during the 1970's. Then, in the early 1980's the quantity of labor and capital were reduced sharply, and thereafter productivity rose steadily. As discussed in Tilton (1997), the story of the copper industry over the last 25 years is one of remarkable recovery from being on the brink of collapse. By the end of the 1970's the industry had become highly uncompetitive. For whatever reasons – opposition from unions or timid management – falling product prices had not led to the closure of loss-making mines or reductions in wages.⁴³ Then in the early 1980's everything changed and the whole industry was restructured. Many jobs were lost, for example hours worked in 1986 were only one third of those in 1981, and average real wages fell by 25% over these five years. This led to a dramatic “shake out” of small scale, less efficient mines, and consolidation into a fewer number of larger, more efficient mines. In addition, there has been significant technological innovation over the last 15 years, for example the development of new chemical processes for extracting copper from copper ore (see Tilton (1997)), and processes for copper recycling.

The most noticeable feature of the panel for logging in Figure 6 is the increasing importance of intermediate goods over the last 25 years. This reflects an increase in the costs of road building services as logging has shifted towards less accessible areas. In part this is because of a depletion effect as first growth and second growth forests are logged. But environmental regulations restricting areas that can be logged have also played a role, particularly since the mid 1980's. This depletion effect has limited overall productivity growth,

⁴³ In addition, the government turned down petitions in 1978 and 1984 for protecting the industry against foreign imports.

in spite of some technological improvements in logging such as the replacement of the chain saw by mechanical tree fellers in certain regions.

In fact the forestry industry more broadly is in the middle of a transition away from logging in virgin forests, towards a sustainable “agricultural” industry based on tree planting, growing and harvesting. As discussed in Sedjo (1997), this trend is partly a response to increasing environmental regulations limiting access to traditional forest areas. In addition the attractiveness of tree farming has been increasing because of improvements in productivity. These have included the selection of superior species for planting, and more recently the development of genetically engineered trees. However these important improvements in the forestry sector more broadly do not show up in Figure 6, because this focuses purely on harvesting and not tree growing.

F. Summary Statistics

Table 2 summarizes the average annual rate of growth in multi-factor productivity in the industries for 1970-1980 and for 1980-1992. During the 1970’s decade, this ranged from -1.5% in logging to -7.0% in petroleum. For manufacturing as a whole multi-factor productivity growth averaged 0.8% per annum. This was well below historical levels, but significantly better than the performance in the natural resource industries. During 1980-1992, productivity growth in the natural resource industries ranged from 0.3% in logging to 3.9% in copper. For manufacturing, productivity growth was 1.4% per annum over this period. Broadly speaking, the performance of the natural resource industries since 1980 has been more in tune with – if not better than – that for manufacturing as a whole.

Table 2. Summary Statistics on Productivity

Average annual growth in multi-factor productivity	Coal	Petroleum	Copper	Logging	Manufacturing
1970-1980	-3.5	-7.0	-2.5	-1.5	0.8
1980-1992	2.6	1.3	3.9	0.3	1.4

There have been many suggested explanations for the decline in manufacturing productivity growth during the 1970's.⁴⁴ These include: the increase in price of energy following the oil price shock; a reduction in the rate of savings and investment; a slowdown in the accumulation of knowledge from R&D activity; the effect of new regulations such as the Clean Air and Water Acts; the crowding out of private industry by the increasing share of public spending in GDP. Since the productivity decline in the natural resource industries was initially much more severe, this suggests that additional factors were at work in the natural resource industries. One such factor was the cushioning of the natural resource industries in the 1970's, due to the unusually high product prices. This allowed relatively inefficient producers to enter these industries. In addition, the lack of competitive pressure reduced the incentive for technological innovation and to avoid disruptive labor disputes.

5. SUMMARY

This paper estimates multi-factor productivity trends in four natural resource industries – petroleum, coal, copper and logging – over the last 25 years. During the 1970's productivity declined in all four industries. This contrasted sharply with the historical experience of gradually declining average production costs in natural resource industries identified by Barnett and Morse (1963). At the time this led to concern that natural resource endowments were being exhausted and this would limit future opportunities for economic growth.

In hindsight the 1970's appear to be an exceptional period rather than marking a sea change in long run productivity trends. For example, unusually high natural resource prices encouraged the entry of relatively inefficient producers and the phasing in of new environmental and health & safety regulations had a once-and-for-all impact on depressing productivity levels. Since the early 1980's productivity has been increasing in all four industries. Part of this appears to be due to restructuring and downsizing in response to lower output prices. However technological improvements have also played an important role in all the industries.

⁴⁴ See the reference in footnote 1.

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