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What Determines Labor Productivity? Lessons From the Dramatic Recovery of the U.S. and Canadian Iron-Ore Industries Since Their Early 1980s Crisis*

James A. Schmitz, Jr.

Federal Reserve Bank of Minneapolis

ABSTRACT

In the early 1980s, as a result of unprecedented developments in the world steel market, iron-ore was entering the Great Lakes from as far away as South America. The Great Lakes regional producers, that is, the U.S. and Canadian iron-ore industries, faced a major crisis that cast doubt on their future. In response to the crisis, these iron-ore industries dramatically changed how they produced iron-ore, in the process doubling their labor productivity and pushing foreign competition out of the Great Lakes. I show that most of the productivity gains were due to changes in institutional rules, and most importantly in work rules, that governed how production took place.

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1. Introduction

For nearly a century following the discovery of iron-ore in Minnesota in the 1890s, iron-ore mines in the Great Lakes region were essentially the sole suppliers of iron-ore to the Lower Great Lakes steel producers (that is, the vast steel market lying along the lower rims of Lake Michigan and Lake Erie). This century-long dominance was primarily attributable to one fact: these mines had significantly lower transport charges to these steel producers than mines outside the region. Large transport costs had kept non-Great-Lakes iron-ore out of the Great Lakes region for nearly a century as the 1970s closed, and there was every reason to believe this situation would persist for many more years.

But it didn't. In the early 1980s, as a result of unprecedented developments in the world steel market, iron-ore was entering the Great Lakes region from as far away as South America. The Great Lake regional producers, that is, the U.S. and Canadian iron-ore industries, faced a major crisis that cast doubt on their future.[1]

In response to the crisis, these iron-ore industries dramatically changed how they produced iron-ore, in the process doubling their labor productivity and pushing foreign competition out of the Great Lakes region. I show that most of the productivity gains were due to changes in institutional rules, and most importantly in work rules, that governed how production took place. In answer to my question "What determines labor productivity?" then, the experience of these industries clearly shows that first, competition does, and second, that institutional arrangements do. Here, an increase in competition spurred work rule changes that led to productivity increases.

[1] Great-Lake mines (those within a very short distance of a Great Lake) made up a large majority of the combined production of the U.S. and Canadian iron-ore industries (see more on this below).

Galdon-Sanchez and Schmitz (2002) have shown that as a result of developments in world steel production in the 1980s, some national iron-ore industries, like the U.S. and Canadian industries, came under tremendous competitive pressure, while others, like the Australian and Brazilian, came under little or none. They showed that in the former group productivity soared, while in the latter group it changed little. In this paper, I provide greater detail regarding the increase in competition faced by the U.S. and Canadian iron-ore industries (in Section 2). But primarily I study in detail the sources of the productivity gains in these industries (something not done in Galdon-Sanchez and Schmitz).

Since they are the centerpiece of the story, I begin my analysis of productivity in Section 3 by describing the work rules that prevailed before the crisis. These placed restrictions on the tasks individuals could perform at mines, particularly repair work. First, machine operators were not permitted to perform even the simplest repair work on their machines. Second, repair staff had restrictions on their work. In particular, there were a very large number of repair job classifications, close to thirty. A person with a given classification was permitted to complete repair jobs assigned to this classification but not others. In response to the crisis, work rules were changed to allow machine operators to conduct simple repairs and which reduced the number of repair job classes. In Section 3 I argue that, qualitatively, these changes should have led to labor productivity growth, and that a growth accounting exercise would show this growth (from changes in work rules) was "accounted" for by increases in TFP, and in the capital-labor and materials-labor ratios.

I present the labor productivity records of these industries in Section 4, showing that it doubled in the United States and increased a little less so in Canada over a few years in the 1980s. I also present a growth accounting exercise for the Canadian iron-ore industry, showing that labor productivity growth was "accounted" for by increases in TFP, the capital-labor ratio and the materials-labor ratio.

By a process of elimination of other candidates, Section 5 argues that institutional changes accounted for the vast majority of the labor productivity gains (or, stated differently, for the gains in TFP, the capital-labor ratio and the materials-labor ratio). First, I show that a number of important determinants of labor productivity were changing little over the period, including the industry's product, the technology used to produce it, and the skill of the workforce. I also show that closing low productivity mines, or shifting of production to high productivity mines, were not major sources of gain. I also show that mine-labor had not become very expensive relative to capital and materials like energy (which might have led to substitution towards these inputs and an increase in labor productivity).

I turn to direct evidence on institutional changes in Section 6. As a result of the crisis, there were a host of institutional changes introduced at the mines, including labor-management cooperation teams, profit sharing, contracting out changes and work rule changes. I show that contracting out changes were not a significant source of productivity gain. Then I provide evidence that the work rule changes accounted for the majority of the gains. I first argue that, on a priori grounds, these work rule changes that improved the efficiency of repair work could have significant productivity consequences. Repair staffs accounted for 50-55 percent of employment at many mines. And mines did studies which estimated that for every five machine operators that were permitted to engage in simple repair, two repair positions could be eliminated. I then show that those mines that changed work rules most aggressively had the largest productivity gains. In the largest U.S. mine, for example, repair staff fell from 50 to 25 percent of the workforce over the 1980s (as total mine employment fell by 60 percent and output returned to its precrisis level!).

I conclude by addressing wide-ranging questions in Section 7: Why was it necessary to have a dramatic increase in competition to change these work rules? Does monopoly (or market power) lead to inefficiency? How far do the lessons learned here extend?

2. A Dramatic Increase in Competition

In this section, I introduce the market. I discuss the logic as to why producers might possess significant market power in it. I document that they did. Finally, I show that increased foreign competition dramatically cut into this power.

The market, again, is the market for iron-ore at the Lower Great Lakes (LGL) steel plants. As mentioned, for nearly a century essentially the only iron-ore sold in this market was mined in the Great Lakes region.[2] In fact, before the 1980s, the determination of iron-ore prices in the Great Lakes region and the prices outside it were roughly a separate affair. Brazil was the overwhelming leader in exports in the Atlantic Basin region, and negotiations between these iron-ore producers and European steel producers set iron-ore prices in Europe (see Helmer 1997). When I say prices $p_{B,E}$ (Brazilian iron-ore in Europe) and $p_{M,C}$ (Minnesota iron-ore in Chicago) were determined independently, I mean the Brazilians would have made losses shifting iron-ore from Europe to Chicago, that is, prices and transportation charges

[2] U.S. iron-ore production was 70.7 million metric tons (mmt) in 1980. Nearly all U.S. iron-ore was produced in Minnesota and Michigan, within at most 100 miles of a Great Lake. This iron-ore was shipped to the LGL market (and a short distance inland into Ohio and Pennsylvania). Total Canadian production was 48.7 mmt in 1980. In Canada, some mines were in Ontario, again very close to a Great Lake, and these accounted for roughly 20 percent of output. This iron-ore was also shipped only within the Great Lakes. Nearly all remaining Canadian production was located further north and east of the Great Lakes, near Labrador City (on the Quebec and Newfoundland border, which for the discussion above I have classified as being in the Great Lakes region). The Labrador mines sent iron ore to Europe, the U.S. East and South coasts, and into the Great Lakes. These Labrador mines faced at least as great an increase in competition as did the U.S. and Canadian mines that were buried deeper in the Great Lakes region. Finally, the combined U.S. and Canadian production amounted to 21.4 percent of non-communist world iron-ore output in 1980. Employment at U.S. and Canadian mines in 1980 was 18.2 and 13.8 thousand, respectively.

satisfied

$$(1) \qquad p_{B,E} - t_{B,E} >> p_{M,C} - t_{B,C}$$

where the LHS is what the Brazilians earned in Europe (net of transportation $t_{B,E}$) and the RHS is what they would have earned in Chicago (net of $t_{B,C}$) at the price $p_{M,C}$.[3]

As for the determination of the price $p_{M,C}$, some groups had a monopoly on providing inputs to the iron-ore industry. Here I discuss two such groups, the townships in which the mines were located (and "supplied" the land) and the United Steelworkers of America (USW), the union that represented hourly and salary workers at the mines in both countries. Not only did some input suppliers have a monopoly, but conditions were such that they could likely exploit this position. First, the demand for iron-ore by LGL steel producers was relatively inelastic. The cost of iron-ore made up a fairly small share of these steel producers' total costs (between 5 and 10 percent). Second, there was little fear of competition from foreign (that is, non-Great-Lakes) iron-ore producers in the market before the 1980s.[4] Again, the fundamental reason was that foreign iron-ore faced very high transport costs into this market.[5]

[3] PaineWebber (1987) estimated that during the late 1970s, the price of Brazilian iron-ore in Chicago (say if it was diverted from Europe to Chicago), $p_{B,E} - t_{B,E} + t_{B,C}$, was about 20 percent higher than the prevailing Chicago price $p_{M,C}$. They estimate that this price fell below the Chicago price at the start of the crisis (by roughly 20 percent). Regarding the sources of prices, Brazilian dock prices for European bound iron-ore, $p_{B,E} - t_{B,E}$, are available from the U.S. Geological Society. The price of iron-ore at Chicago, $p_{M,C}$, is a bit difficult to estimate since much of the iron-ore in the Great Lakes region prior to the 1980s was sold on a transfer price basis.

[4] This logic for why input suppliers with a monopoly might exploit their position was not lost on investors in Minnesota when the taconite industry was developed in the late 1950s (see discussion on this industry below). Investors realized that towns could tax the hell out of them once mines were built. So, before mines were built, investors demanded and received changes to the Minnesota constitution (see Davis (1964)).

[5] Great-Lake region mines shipped iron-ore short distances, and then mostly over water, to this market. Non-Great-Lake region mines shipping iron-ore over the Atlantic Ocean (from say Brazil) had three alternatives on the last leg of the trip, all involving great expense: over land from the U.S. East Coast or over water in small vessels, either up the Mississippi River from the south or down the Saint Lawrence Seaway. To get some idea of the magnitude of the transportation charges into the Great Lakes, a study by Natural Resources

And market power clearly was exercised. Mining-towns in Minnesota charged a tax on each ton of iron-ore produced (amounting to about 10 percent of mine value). Whereas towns typically offer subsidies to attract industry, here towns exercised significant market power over the mines. The USW was able to offer its workers at the mines very attractive job packages (I provide evidence shortly).

The market power of these two groups was dramatically reduced in the early 1980s. This was precipitated by huge drops in world steel production. LGL steel production fell, a blow to local iron-ore producers. However, it was not a death knell. But steel production fell as well in Europe, and on the U.S. East and South Coasts. The path of combined U.S. and Canadian pig iron production, and of the big European producers, is given in Figure 1.[6] Prices of iron-ore at markets outside the Great Lakes region began dropping significantly. For example, Brazilian dock prices for European bound pellets (a type of iron-ore), that is, $p_{B,E} - t_{B,E}$, fell 25 percent from 1982-84 (where they remained for the next three years).[7] Brazil now found it profitable to ship into the Great-Lakes region: inequality [1] reversed.[8]

As evidence of reduced market power, towns significantly cut their production tax.

Canada estimated that for 1994, $t_{B,E} = \$6.50$ and $t_{B,C} = \$24.35$, so that transport costs to Chicago were nearly four times as large (port prices in Brazil were as low as $p_{B,E} - t_{B,E} = \$20.00$). For detailed evidence on transport costs see Galdon-Sanchez and Schmitz (2002).

[6] The data sources for all figures, as well as discussion of data issues, are presented in Appendix B. Regarding Figure 1, integrated-steel producers turn iron-ore into pig iron in the steel making process so pig iron is a better indicator of demand for iron-ore than steel production (which includes minimill production). The huge drops in U.S. and European integrated-steel production from 1979-82, and its anemic growth afterwards, were driven by a large number of factors, including a major recession, the movement of steel production toward Asia, the growth of minimills which primarily use scrap and not virgin iron-ore, and the accelerated substitution of plastics for steel due to energy price increases. All these factors are obviously beyond the control of these iron-ore producers. The path of pig-iron production is exogenous to them.

[7] The Census of Mineral Industries reports that revenue per ton (at the mine) in the U.S. industry fell 35 percent between 1982 and '87.

[8] As one observer noted, during this period "Brazilian iron-ore arrived at the docks near Chicago — the heart of the domestic market." Engineering and Mining Journal, September, 2002.

The USW and its workers lost significant compensation and benefits. Wages were cut.[9] Work rules were changed which gave management more discretion over work, something opposed by the union before the crisis. Most of the attrition in the mines was from young, less senior employees, indicating jobs were still in demand and how good the jobs were before the crisis. But the most striking piece of evidence is that when a mine in Minnesota (Reserve/Northshore) reopened in 1990 after closing in 1986, it opened non-union. I think most industry participants in the late 1970s would have found it nearly impossible to imagine a mine in Minnesota would be non-union a decade later.[10]

3. Major Changes in Work Rules

In this section, I discuss the changes in work rules spurred by the crisis, and the qualitative impacts they were expected to have on labor productivity.

As I mentioned, the crisis in these iron-ore industries led to a liberalization of restrictions on repair work. First, machine operators were now permitted under contract to do some repairs (such operators were often called "equipment tenders"). To give some idea of the tasks now permitted, let me briefly quote from the Basic Labor Agreement (BLA) between the USW and the National Steel Pellet mine, dated July 1, 1994, that states now "Mobile equipment operators, small equipment operators, drillers, blasters, and shovel operators, will do minor repairs including but not limited to; tighten nuts and bolts on mirrors, door handles, door panels; replace fuses, replace wiper blades; ... jump start vehicles, change

[9] See the Federal Reserve Bank of Minneapolis staff report 263, Schmitz (2001), for evidence on wages.

[10] As is well known, it is very difficult to find good measures of increased competition. But here the increase in competitive pressure is very clear and large. For other recent studies looking at the relationship between competition and productivity, see Aydin and Tilton (2000), Borenstein and Farrell (1999), Nickell (1996), Sivadasan (2003), Symeonidis (2002), and Zitzewitz (1999). Most of these papers look at changes in competition and its influence on productivity. Syverson (2003) has examined differences in competition in a cross section of geographically isolated concrete industries and its impact on productivity.

tires, and fluids, change bulbs, batteries, etc. .... Provide help to maintenance as needed in repair of equipment and general housekeeping. Perform non-craft painting on equipment and facilities as needed. ... pick up small supplies and parts incidental to the job" (pp. 158-60). This is quite a wide range of tasks, and is only a sample of them.

Second, repair workers were now permitted to do a wider range of repairs. New jobs were created that "rolled" the responsibilities of a large number of previous repair jobs into a single new combined-job. An "ironworker" was to perform the duties that were previously done by boilermakers, riggers, and welders. A "millwright's" duties were to include those previously assigned to plumbers, pipefitters, welders, and mechanics. In some mines, the number of repair job categories fell from the upper twenties to the low single digits.[11]

To begin analyzing these changes in work rules, let me introduce a mine production function. Let production of iron-ore at a mine i be given by

$$(2) \qquad y_{it} = A_{it} f(m_{it}, k_{it}, n_{it})$$

where y_{it} is tons produced, A_{it} is a TFP-parameter, m_{it} is purchased energy and materials, k_{it} is units of capital, n_{it} is hours of labor and $f(\cdot)$ is a production function that I assume is homogeneous of degree one (so labor productivity (y_{it}/n_{it}) depends on TFP (A_{it}), materials-labor ratio (m_{it}/n_{it}) and capital-labor ratio (k_{it}/n_{it})). Work rules can be thought of as restrictions on input choices.[12]

[11] Just as some jobs had been assigned to a certain type of repair worker, tools were only to be used by certain workers. For example, in the July 1, 1994 contract between the USW and the National Steel Pellet mine, it states that "in order to facilitate maintenance and operations productivity improvements, the following are examples of tools that will clearly not be considered as craft/operator specific: [where I list only a few] chain saw, hammer drills, hoses, screwdriver, hammer, air tools, magnetic drills, and paint and painting supplies and equipment" (p. 169).

[12] That is, work rules may specify that inputs be chosen from some set Λ that is a strict subset of $\{(m, k, n) : (m, k, n) \geq 0\}$. Some work rules might require that machines have a set number of workers, that is, $k_{it}/n_{it} \leq \gamma$.

What impacts should these work rule changes have had on labor productivity?[13] And what would "account" for this change in a growth accounting sense? Consider these issues first for a familiar and simpler work rule change in the railroad industry. When diesel locomotives replaced steam, train crew (i.e. firemen) were no longer needed to shovel coal into steam engines. But firemen remained on diesels for years. After many years, work rule changes eliminated (some) firemen. Consider the impact of this change in the simplest setting: sending a train between two points, with the same load, first with a fireman and then without. On the second "run," as compared to the first, output does not change, employment falls, and labor productivity increases. Capital and materials do not change; hence, the capital-labor and the material-labor ratios increase. Growth accounting would show that the labor productivity gain was accounted for by increases in these ratios and TFP.[14] Note that the capital-output and the materials-output ratios do not change.

Back to iron-ore. Permitting machine operators to perform simple repairs means there is no longer the requirement to wait for repair staff to be located and travel to the site for such repairs.[15] Since machines can be brought back to operation sooner, they run more

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Suppose there are different types of workers so that n_{it} is a vector, say, $n_{it} = (n_{1it}, n_{2it}, n_{3it})$. Another work rule might require that there be a certain fraction of each type of worker, or in particular that $n_{1it} = n_{2it} = n_{3it}$ (see the paper by Eberts and Stone (1991)).

[13] There has been some study of work rules in the U.S. auto industry (see, e.g., Katz, Kochan, and Keefe (1987) and Keefe and Katz (1990)) and the U.S. steel industry (see, e.g., Arthur and Konzelmann (1994)). Nickell and Nicolitsas (1997) study work rule changes in a broad set of manufacturing industries.

[14] Let me present this example in the notation above. Suppose that the tons moved between the two points were given by $y = Af(m, k, n_e)$, where n_e is the number of train engineers. Suppose the work rule requires that the number of firemen n_f be a fraction of the engineers, say $n_f = \gamma n_e$ (note that firemen are assumed not to influence y). Then labor productivity can be expressed as $y/n = Af(m/n, k/n, n_e/n)$, where $n = (1+\gamma)n_e$. A reduction in γ (with m and k fixed), increases m/n, k/n, and n_e/n.

[15] In the case where machine operators are not permitted to do any repair, the work rule has the effect of requiring for each machine that there be a certain number of (or fraction of) repair workers to do simple maintenance. Eliminating the work rule removes this restriction on input choice; now machine operators can be used. Note there is a difference between this case and the firemen case. In the machine operator case, operators are expending more effort when the work rule is removed (as when he is fixing his machine instead of waiting for repair staff). So, changes in work rules lead to more effort. For analyses of effort choice see

continuously, leading to an increase in output.[16] There is also less need for repair staff, leading to reduced employment. Since output increases, and employment falls, labor productivity increases. Capital does not change.[17] Materials used for repairs do not change (the operator uses the same materials as the repair staff). Hence, the capital-labor and materials-labor ratios increase. Growth accounting shows that increases in these ratios, and TFP, account for the labor productivity gain. Here the capital-output and the materials-output ratios fall.[18]

Permitting the repair staff to engage in a broader range of repair jobs allows greater flexibility in assigning repair staff to jobs. Before the crisis if a welder were repairing a machine and needed to perform a task in a pipefitter's job description, a pipefitter would need to be called. Now, the welder is permitted under union contract to perform the task. With more flexibility in assigning repair staff, machines can again be brought back to operation sooner, leading to increased output as above. Also, because of greater flexibility in assignment, repair staffs can be reduced. The consequences of this work rule change, then, look like those of permitting machine operators to perform simple repairs.[19]

Bils and Chang (2003) and Leamer (1999).

[16] Having machines run more continuously was an important goal of work rule changes as this excerpt from the National Pellet Mine's BLA attests: "The parties recognize that most mining equipment is in a non-production mode for a significant amount of time each day. Minimizing this lost time is essential to improve productivity and help to insure our viability in the highly competitive iron ore market" (p. 170).

[17] Capital utilization would increase, but measured capital would not increase.

[18] Let me give a simple example to help think about the materials-output ratio. Consider two pieces of equipment, a truck and shovel. Let me divide a morning into two periods, $t = 1, 2$. If both pieces of equipment run in a period, then say they produce $y_t = y$ units of output and use $e_t = e$ units of energy. Suppose the truck goes down at the start of $t = 1$ and requires real materials of m to repair it. Consider first the case of no work rules. Suppose then that the truck can be brought back to operation right away so output is produced in $t = 1$, namely $y_1 = y$, $e_1 = e$, $m_1 = m$. Since the truck was run in period $t = 1$, let me assume there is a probability λ that the truck goes down again at the start of $t = 2$ and needs repair. Then $y_2 = y$, $e_2 = e$, and $m_2 = \lambda m$. In the case where there are work rules, suppose it takes the entire period $t = 1$ to bring the machine up. No output is produced in $t = 1$, but some energy, say μe, is used since machines are not turned off as others are fixed, $y_1 = 0$, $e_1 = \mu e$, $m_1 = m$. In period $t = 2$ the machines are run and $y_2 = y$, $e_2 = e$, and $m_2 = 0$. The materials-output ratios in the two cases are $[m + \lambda m + 2e]/2y$ and $[m + \mu e + e]/y$. Note that in equation [2], m was used to denote both repair parts and energy, so the notation is a little different here.

[19] There is no change in capital when the repair staff is reduced. In the example above, the welder that

4. Huge Gains in Productivity

In this section I show the labor productivity gains in these industries and discuss the sources of these gains, in a growth accounting sense.

A. Gains in labor productivity

I plot the path of industry output Y_t and productivity Y_t/N_t in Figures 2 and 3 for the U.S. and Canadian iron-ore industries (where $Y_t = \sum y_{it}$ and $N_t = \sum n_{it}$ using the notation in equation [2]). Output is in physical units for both countries. Labor input is hours for the United States. For Canada I present productivity using labor input from Natural Resources Canada (employment) and from Statistics Canada (hours).

Iron-ore output fell on the order of fifty percent in the United States and Canada over 1979 to 1982. But as foreign iron-ore producers entered the LGL steel market to replace markets they lost elsewhere, the fear was that local production would fall even more. Productivity in both countries showed no trend over the 1970s. It did vary somewhat with output, tending to be procyclical. The path of productivity in the 1980s was dramatically different than the 1970s. It trended strongly upward in both countries through 1987. At its peak in 1987, U.S. productivity was twice its 1980 level; in Canada it was 83 percent above its 1980 level (using NRC data) and 67 percent (using StatsCan data).[20] This dramatic increase in labor productivity was a major reason the industry was able to stave off disaster.[21]

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now performs repairs in the pipefitters description uses the same equipment as the pipefitter.

[20] While the two Canadian productivity series move closely until the middle 1980s, they do move apart somewhat afterwards. I discuss these issues in Appendix B. Another path for Canadian labor productivity is given in Figure 4, and this shows stronger growth than both these time-series in Figure 3 (see below).

[21] For example, as a PaineWebber report (1991, p. 13) stated: "The industry's new competitiveness can be typified by the retreat of foreign ore, which had threatened to penetrate the lower lake markets in the early 1980s, but is no longer feared. The domestic industry had pushed the breakeven point for the delivered price of foreign versus domestic ore from Chicago, where it was in 1982, out the St. Lawrence Seaway and down the east coast to Baltimore by late 1989."

B. Gains Due to Increases in TFP and Capital-Labor and Materials-Labor Ratios

Let me assume that industry production can be modeled by

$$Y_t = A_t F(M_t, K_t, N_t)$$

where Y_t is tons produced, A_t is a TFP-parameter, M_t is purchased energy and materials, K_t is units of capital, and N_t is hours of labor. If I assume that $F(\cdot)$ is Cobb-Douglas, a common assumption, then labor productivity can be written as

$$(3) \qquad \frac{Y_t}{N_t} = A_t(\frac{M_t}{N_t})^{\theta_M}(\frac{K_t}{N_t})^{\theta_K}$$

where θ_M and θ_K are the elasticities of output with respect to materials and capital, respectively. It is often assumed that these elasticities are equal to the input's share in industry revenue, say s_M and s_K. Growth in TFP, A_{t+1}/A_t, can then be calculated from equation [3] by dividing Y_{t+1}/N_{t+1} by Y_t/N_t (where I let $s_{M,t}$ and $s_{K,t}$ vary over time).

While I have data for Y_t and N_t for both the United States and Canada, I only have data for K_t and M_t for Canada. In the United States, the lowest level of aggregation for which capital and materials are available is "metal mines." This grouping includes the copper, gold, and iron-ore industries (and a bit more). Hence, I can make growth accounting calculations only for Canada, and then only from 1981 onwards (I have M_t from 1981 only). One way to assess the contribution of increases in TFP and the materials-labor and capital-labor ratios to labor productivity growth is to examine how the three multiplicative terms in equation [3] move over time. In Figure 4 (and Table 1), I present the variables Y_t/N_t, A_t, $(M_t/N_t)^{s_{M,t}}$, and $(K_t/N_t)^{s_{K,t}}$ (where I have normalized all variables to equal one in 1981).[22] All three

[22] Note that labor productivity in Figure 4 is calculated using a real output measure (not tons) from Statistics Canada and hours from Statistics Canada (the same used in Figure 3). At its peak, productivity is

terms were contributors to the labor productivity gains, TFP more so than the others. What remains is to show that work rule changes were responsible for the lion's share of increases in TFP and the capital-labor and materials-labor ratios.

5. Gains Not Driven by the Usual Candidates

I now show a host of usual candidates were not important sources of productivity gain.

A. Change in Types of Products Produced?

As suggested above, iron-ore is not a homogenous product. But there are only a few types, and these can easily be tracked. As I argue now, changes in the type of iron-ore produced did not lead to any of the productivity increases observed in Figures 2 and 3.

Iron-ores are typically grouped into three types: lump, concentrates and pellets. A major difference between these iron-ores is how difficult it is to mine and process them. Production of a ton of pellets typically requires more labor per ton than the other ores. Hence, the labor productivity of an industry (measured in tons per hour) will increase if pellets are decreased as a share of output (and vice versa). Hence, it is important to consider whether, and how, the mix of products changed over time.[23]

80 percent above its 1981 level. In Figure 3, peak productivity for the NRC measure was 83 percent above its 1980 level. If one looks at Figure 3, one sees that 1981 is a relatively high productivity year, so productivity growth using real output provides the strongest estimate of productivity growth (see Appendix B).

[23] All iron-ore mines consist of a pit, where "crude" ore is mined, and a mill, where the crude ore is processed into "usable" ore for sale. Lump iron-ore deposits typically contain high concentrations of iron (50 percent and more) and do not require lots of processing in a mill. Pellets are made from deposits of very hard rock with low concentrations of iron (20 percent). Given the low iron content of the deposits, and the great hardness of the rock, the crude ore must undergo much greater processing in the mill than typical ores. Pellet mines typically have much greater capital-labor and material-labor ratios than other mines. Even so, the tons produced per worker is typically smaller. Pellets were first developed in Minnesota since the deposits of other iron-ore were being depleted, leaving the hard taconite deposits (research at the University of Minnesota demonstrated that these taconite deposits could be turned into an iron-ore product, namely (taconite) pellets [see Davis, 1964]). It was economical to undergo the vast processing expenses because of the large transport costs into the Great Lakes. Pellets typically sell at a premium relative to other iron-ores, though the premium is not as great as the extra processing and capital costs of pellets.

The share of pellets in U.S. and Canadian production are presented in Figure 5. Pellets increased slightly as a share of U.S. production in the 1980s, a bit more in Canada. So, the change in product mix was toward a product requiring more labor input per ton than the average and hence was not a source of productivity gain. But were the productivity gains in the 1980s relative to the 1970s due in part to faster introduction of pellets in the 1970s than the 1980s? For Canada, this is clearly not the case. There was little change in the share of pellets in the 1970s, while there was some increase in the 1980s. The productivity gains in the 1970s are, if anything, overstated relative to the gains in the 1980s. For the United States, pellets were introduced at a faster rate in the 1970s than the 1980s. Fortunately, I can look at productivity within a U.S. product class. I have data for the Minnesota (taconite) pellet industry which in 1980 accounted for 95 and 62 percent of Minnesota and U.S. iron-ore production (by weight), respectively. The output and labor productivity of the Minnesota taconite industry is given in Figure 6. As the figure shows, within a major U.S. product class, the gains of the 1980s are as dramatic relative to the 1970s as in the overall industry.[24]

B. New Technology?

There were no major changes in the technology for producing iron-ore in the 1980s. There were some minor improvements, of course, just as in the 1970s. One improvement in the 1980s was that computers began to be integrated into the production process. Here, computerized pit dispatching is mentioned as having led to productivity improvements. By reducing logjams of trucks dropping crude ore from the pit at the mill, improved pit dispatch-

[24] In fact, the 1980-pellets required more labor per ton to produce than the 1970-pellets. In particular, limestone began to be added to the pellets in the 1980s (the pellets are called flux pellets) and this added to the labor required per ton of pellets.

ing has the potential for reducing the number of truck operators (for a given flow of crude ore to the mill). But the potential for increasing productivity was limited by the fact that in pellet mines employment in the pit before the crisis was only about 25 percent of total, and this includes drillers, blasters and shovel operators, in addition to truck operators.[25] Moreover, computers were being integrated into production in other countries, like Australia, yet there was little change in Australian iron-ore productivity over the 1980s.[26]

C. Increases in Skill?

If there was a large increase in the average skill of the workforce, industry labor productivity would have increased. As part of their productivity program, Statistics Canada has developed measures of quality-adjusted labor input. In classifying workers by type, they use seven age and four education groupings (and a couple of others). While the quality-adjusted labor input for the iron-ore industry falls less in the 1980s than does total hours worked, the differences are very small. From 1981-90, for example, hours worked fell 46 percent, and quality-adjusted labor input fell 43 percent. So, on the basis of this information, there does not seem to be a significant increase in the average quality or skill of worker.[27]

[25] As discussed in greater detail below, the Minntac mine in Minnesota reported its total hours worked by three groups: repair workers, production workers in the mill and production workers in the pit. Prior to the crisis, production worker hours in the pit, as a fraction of total hours, varied between 18 and 25 percent.

[26] See Galdon-Sanchez and Schmitz, 2002. The fact that technology was not dramatically changing in the iron-ore industry during the 1980s was one of the major reasons for examining the industry as a way to assess the potential for institutional changes to increase productivity. The institutional changes taking place in the iron-ore industry were also occurring to some degree in the steel and auto industries. But the steel production technology underwent some major changes in the 1980s. For example, as the decade advanced, minimills made up a larger share of industry output, and minimills employed a new, more productive technology for making steel. Even within the integrated steel plant portion of the industry, there were huge changes in the way steel was produced. For example, integrated plants introduced continuous casting at a rapid rate during the 1980s.

[27] It is also important to keep in mind that seniority provisions in union contracts had a large influence on who lost jobs at mines. Management could not freely choose who left and who stayed.

D. Closing Low Productivity Mines?

If low productivity mines were closed, or production shifted towards high productivity mines, then industry labor productivity would increase. This was not a major source of productivity gain for the Minnesota taconite industry. There were eight Minnesota taconite mines in operation in 1980, and their output and labor productivity records are given in Figure 7.[28] The labor productivity pattern at each mine mirrors, fairly closely, the industry pattern seen in Figure 6.

In order to present the labor productivity decomposition, denote mine and industry labor productivity by $\pi_{it} = y_{it}/n_{it}$ and $\Pi_t = Y_t/N_t$, respectively. Industry productivity Π_t can be expressed as a weighted average of the π_{it}

$$\Pi_t \equiv \sum_{i \in I_t} s_{it}\pi_{it}$$

where $s_{it} = n_{it}/N_t$. The change in industry productivity between date t and t', where "Δ" is the difference operator (that is, $\Delta\Pi_{t,t'} = \Pi_{t'} - \Pi_t$), can be expressed as

$$\begin{aligned}(4) \qquad \Delta\Pi_{t,t'} = & \sum_{i \in C_{t,t'}} s_{i,t}\Delta\pi_{it,t'} + \sum_{i \in C_{t,t'}} (\pi_{it} - \Pi_t)\Delta s_{it,t'} + \sum_{i \in C_{t,t'}} \Delta\pi_{it,t'}\Delta s_{it,t'} \\ & - \sum_{i \in X_{t,t'}} s_{i,t}(\pi_{it} - \Pi_t) + \sum_{i \in E_{t,t'}} s_{i,t'}(\pi_{it'} - \Pi_t)\end{aligned}$$

where $C_{t,t'}$ is the set of mines that operated in t and t' (continuing mines), $E_{t,t'}$ is the set that operated in t' and not t (entering mines), and $X_{t,t'}$ is the set that operated in t and not t' (exiting mines). There are five terms in the decomposition. Let $term_j$ refer to the jth

[28] Six pellet mines were in operation by the middle 1960s (Butler, Erie/LTV, Eveleth, Reserve/Northshore, National, and Minntac). Two mines began operations at the end of the 1970s (Hibbing and Minorca). As a result of the crisis in the early 1980s, two mines were closed, even though both had shown productivity gains. Butler was closed in 1986. Reserve was closed in 1987 and reopened in 1990.

term (where I let $term_4 = -\sum_{i \in X_{t,t'}} s_{i,t}(\pi_{it} - \Pi_t)$). The first term is the increase in industry productivity from continuing mines increasing their productivity at initial hours (the within-mine term). The second term is the increase in productivity resulting from continuing mines with above-average productivity expanding their share of hours relative to below-average productivity mines (the between-mine term). The third term is the cross-mine term. The fourth term is the increase in productivity due to exits. The fifth term is the increase due to entrants (which is zero in this case since there are no entrants).

Table 2 gives information on the decomposition between the base year $t = 1980$ and years $t' \in \{1981, ..., 1995\}$. The first column reports the percentage industry productivity gain between t and t', that is, $\frac{\Delta \Pi}{\Pi} \times 100$, while columns two through five present the share of the percentage productivity gains due to terms $j = 1, 2, 3, 4$, respectively, that is, $\frac{term_j}{\Delta \Pi} \times 100$. Table 2 shows that productivity gains due to closing mines were very small, never contributing more than 7 percent of the gains and most often nothing.[29] The major source of industry productivity gains was within-mine gains, this term never accounting for less than 73 percent of the gains. While the cross-mine and between-mine terms accounted for some gains, from 1990 onwards the within mine gains accounted for over 90 percent of the gains.

E. Gains from reducing scale at continuing mines?

In the last subsection I asked whether closing down portions of the industry (that is, mines) was a source of productivity gain. Here I ask whether closing portions of individual mines (that is, shrinking the production of a mine) was a source of productivity gain. There

[29] Note that the first mine to close, Butler, closed in 1986 and in that year closing mines contributed nothing to growth. That is because Butler's labor productivity was very close to the industry average in the base year 1980 and because it was a small mine as well. Reserve closed in 1987 and reopened in 1990, when the contribution again returned to zero.

are two issues here: first, would reducing output at a mine lead to productivity increases? Second, was output in fact reduced at mines? On the first issue, I am not talking about gains from scaling back production in anticipation that it might cease altogether in a few years but rather the possibility of increasing productivity by reducing output to a new, "permanent" level.[30] It would be surprising, I think, to expect reductions in mine output to raise productivity since closing mines (in Minnesota) did not lead to productivity gains and since one expects differences in mineral endowments and other factors to be greater across mines than within mines. And the general wisdom in the industry certainly was that mine productivity increased up to the mine's capacity (see, e.g., PaineWebber, 1987). On the second issue, for most Minnesota mines that remained open, output in the late 1980s was in fact not less than 1980 levels. (Figure 7 shows it was less only at Reserve and Eveleth.)

F. Changes in relative prices of inputs?

If mine-labor had become expensive relative to other inputs, this may have led to substitution towards these inputs, increasing the capital-labor and materials-labor ratios, thereby increasing labor productivity. But mine-labor had not become relatively expensive.

Consider first the price of labor relative to the price of new capital, p_N/p_K, which I plot in Figure 8 together with the capital-labor ratio, K/N. From 1972-80, the price of labor increased about a third relative to the price of capital. During the 1980s, the price of labor increased much less slowly relative to the price of capital. It seems that the very large increase in the capital-labor ratio during the 1980s cannot be explained by a dramatic

[30] For example, as the crisis began, mines cut back on long-term, preventative maintenance. They also reduced their stripping and clearing operations in the pit. There was little need to prepare new fields for mining of crude ore. Both these changes would lead to increases in productivity but only for a few years. Clearly, repair and stripping would have to resume if the mine survived.

increase in the price of labor relative to capital.[31]

Consider materials next. I have data on the price and usage of electricity in Canada and the United States. In Figure 9, I plot the price of labor relative to the price of electricity, p_N/p_E, and the electricity-labor ratio, E/N, for Canada. There is no trend in the relative price p_N/p_E over 1972-90. Again, it seems that the very large increase in the electricity-labor ratio during the 1980s cannot be explained by a dramatic increase in the price of labor relative to electricity.[32] Figure 10 provides the same information for the United States. I do not have the prices of other materials. But if materials, or capital, were being substituted for labor in a significant way, then the materials-output and capital-output ratios should have increased. In Figure 11, where I plot the materials-output and capital-output ratios in Canada, there is no evidence that these ratios significantly increased over the 1980s.

6. Gains Driven by Institutional Changes

There were a host of institutional changes introduced at the mines in response to the crisis, including the work rule changes discussed in Section 3, contracting out changes, and "other" institutional changes, such as labor-management cooperation teams and profit-sharing. The analysis of Section 5 has used one method, a process of elimination of other candidates, to argue that institutional changes accounted for the majority of the productivity gains. I now turn to more direct evidence. First, I show that contracting out changes were

[31] Two items are important to discuss. First, the price p_K is the price of new capital and not a measure of the cost of capital which I would prefer (but is not available). Second, let me discuss the "spikes" in both time-series in 1978. There was a strike that year that led to low hours worked, and hence a high K/N. The price of labor used in Figure 8 is compensation per hour (which includes wages and fringes). It increased 40% between 1977-78, then fell 13% between 1978-79. Over the same years, wages per hour for production workers increased 9% and 12%. Clearly, something unusual happened to fringe payments in 1978.

[32] There is again the issue of the "spikes" in both time-series in 1978. Again, the spike in the relative price is due to something unusual happening with fringe payments in 1978. I honestly am not sure about the spike in E/N.

not a significant source of productivity gain; then I show work rule changes were.

A. Changes in Contracting Out: Productivity Contribution Small

The transfer of work from mine-employees to outside-employees can occur in many ways: outside-employees might replace mine-employees on site; machines requiring major repair could be shipped to outside repair shops, sometimes referred to as "item-exchange"; or supplies and parts that were previously manufactured in-house could be purchased outside, sometimes referred to as the "shelf-item" procedure.[33] All these methods would lead to increases in materials purchases, namely to increases in contracting out payments in the case of item-exchange, and to increases in purchases of parts in the case of buying shelf-items. If work was transferred from mine-employees to outside-employees in the 1980s, then materials usage (relative to output) at the mines would have increased. Recall that materials usage relative to output did not increase in Canada (see Figure 11), and hence there is no evidence work was transferred from mine to outside employees in a significant way.

Let me next discuss the United States, beginning with a little history. Historically, there was very little contracting out at these mines. But at the beginning of the crisis, management made clear that industry survival was dependent on improvements in maintenance and repair efficiency and began contracting out some work. Negotiations over proposals to roll back contracting out became tied, not surprisingly, to those over changing work rules regarding repair work. In the middle 1980s, contracting out was rolled back but typically on

[33] This shelf-item procedure was introduced in the 1980s. It literally was a new provision in contracts whereby if a part could be found for sale on a shelf, it could – by contract – be purchased. As an example of the contract language, here is an excerpt from the Inland/Minorca mine's BLA (Aug. 1, 1986, p. 117): "the Company may purchase standard components or parts or supply items, mass produced for sale generally ('shelf items'). No item shall be deemed a standard component or part or supply item if its fabrication requires the use of prints, sketches or manufacturing instructions supplied by the company or at its behest or it is otherwise made according to Company specifications."

condition that work rules be changed.[34] Again, while there is no time-series of real materials purchases for the U.S. iron-ore industry, the Census of Mineral Industries (CMI) publishes materials purchases (in current dollars) at five year intervals which I can use to show that contracting out did not significantly contribute to the productivity gains.

The CMI divides materials purchases into various components, including parts and contracting out charges. Let me first consider contracting out. Of the six CMI published from 1972-97 (one every five years), contracting out payments were reported only in 1972, '82 and '87 (in other years the amount was not disclosed). Payments to contractors, as in the case of item-exchange transactions, include the wages of outside-employees but also the materials used by the outside-employees, payments to capital owned by contractors, transportation, etc. Contracting out charges were 5.1, 4.5, and 12 percent of mine-employee compensation in 1972, '82 and '87, respectively.[35]

Let me place these numbers in context. Let Y_t, N_t, and L_t denote tons, mine-employment, and outside-employment at dates $t = 1, 2$. Suppose that mine employment falls between the two periods, namely $N_2 = \alpha N_1$, where $\alpha < 1$. Total mine-jobs lost equal $(1 - \alpha)N_1$. Some of the mine-jobs were lost because work was transferred to outside-employees. Let the fraction of the jobs lost for this reason be denoted β; in total, the jobs lost to outside-employees is $\beta(1 - \alpha)N_1$. Suppose it requires a fraction ψ of outside-employees to complete the task of a single mine-employee. Then outside-employment in

[34] Before the crisis, there were very few differences in contracts across the iron-mines. The mine-locals bargained as a group. It was after the crisis, in the middle 1980s, that mine contracts began to diverge. Initially, some mines changed work rules to a much greater extent than others. But continued pressure on the industry led the mines that initially lagged to introduce further changes in the later 1980s and early 1990s.

[35] Given my brief historical sketch of contracting out above, my guess is that the ratio of contracting out to employee compensation peaked in 1984-85 and that it was decreasing in 1986 and 1987 and in subsequent years. That is because contracts were signed in 1986 and 1987 to roll back contracting out.

period 2 is $L_2 = \psi\beta(1-\alpha)N_1 + L_1$. Let me denote industry productivity gains when only mine-employment is counted by z_1 and the gains when both mine and outside-employment are counted by z_2. Then

$$(5) \qquad z_1 = \frac{Y_2/N_2}{Y_1/N_1} = \frac{Y_2}{Y_1}\frac{1}{\alpha} \qquad \text{and} \qquad z_2 = \frac{Y_2/[N_2+L_2]}{Y_1/[N_1+L_1]} = \frac{Y_2}{Y_1}\frac{1+L_1/N_1}{[\alpha+(1-\alpha)\psi\beta+L_1/N_1]},$$

where $z_1 > z_2$ if $L_2/N_2 > L_1/N_1$ (which is implied by my assumptions). In Appendix A, I use the CMI to make "back of the envelope" calculations that show L_1/N_1 and $\psi\beta$ were very small, roughly 0.025 and 0.01, respectively, meaning the "overstatement" z_1/z_2 is very small.

What does a small $\psi\beta$ mean? One possibility is that many jobs were lost to outside-employees (β large) but outside-productivity was much greater (that is, ψ was small).[36] Contracting out would have significantly reduced mine-employment, but the productivity calculations would not be overstated much. But what was closer to the truth, as I argue next, is that $\psi\beta$ was small because β was small, that is, the labor productivity gains were driven by the remaining institutional changes.

I discussed changes in two major work rules, let me call them "repair" work rules, in Section 3. As I mentioned, there were "other" institutional changes. The extent to which repair work rule changes and "other" institutional changes influenced *industry* productivity depends on (i) how much they influenced *mine* productivity where they were introduced and (ii) how many mines introduced them. Let me initially discuss evidence regarding (i).

[36] I have not analyzed shelf items. In this case, outside-employees are likely to have far greater productivity than mine-employees. First, items produced for sale generally are likely to be produced in factories under conditions that are far more ideal to manufacture than at a mine. In a factory mass production techniques can be employed. Second, they are likely to be produced at a factory with few if any of the work rules that guide repair staff at these mines. Third, they are likely to be produced by workers with fewer skills than the repair staff at mines.

B. "Other" Institutional Changes: Limited Evidence

"Other" institutional changes included labor-management cooperation teams and profit-sharing plans. They also included changes in what I'll call work "practices," such as (1) where job breaks would be taken (e.g., near machinery instead of elsewhere); (2) taking wash-up time after work; and (3) giving management more control over when workers took vacation. These "other" institutional changes clearly had an impact on mine productivity. Ichniowski, Shaw, Prennushi (1997) and others have shown that labor-management cooperation teams and profit-sharing plans can have impacts on productivity. The changes in work practices must have led to more effort at the mines.[37] But there is not much information to ascertain how large an impact these "other" institutional changes had on mine productivity. For example, most mines introduced these other institutional changes at the same time (middle 1980s). In contrast, there is good evidence to indicate that changes in repair work rules had major impacts on mine productivity. Let me turn to this evidence.

C. Repair Work Rule Changes: Productivity Contribution Large

Here I argue that repair work rules changes had the potential to significantly increase productivity (the first three subsections), and in fact did so (the last two subsections).

Repair Staffs Large. As I discussed in Section 3, work rule changes were expected, everything else equal, to increase output and (primarily) reduce repair staff. Repair staffs in this industry were large so, a priori, work rule changes could have been important. Repair staffs accounted for roughly 50 percent of employment at most pellet mines prior to the crisis. In Minnesota, repair staffs accounted for 50-55 percent of total hours at Minntac, 52.5 percent

[37] Moreover, the fear of job loss, which inspired all the institutional changes I have discussed, must also have had an independent effect on effort.

at Inland/Minorca, and 46.5 percent at Eveleth.[38]

Repair Work Rule Changes Better than Contracting Out Changes. As a logical point, liberalization of work rules had greater potential to increase labor productivity than liberalization of contracting out rules. For example, while you might ship off a machine for major repairs to avoid work rules, contracting out cannot overcome the issue of machine operators not permitted to conduct simple repairs. Liberalization of work rules can address both issues. But how important was changing the rules regarding machine operators? Fortunately, some mines asked this very question.

Mine Studies. In the middle 1980s, as part of the process of bargaining over work rule changes, some mines completed studies to estimate the impact of changing repair work rules. In particular, Minntac estimated that for every 5 machine operators that were made equipment tenders, the repair staff could be reduced by 2. This is quite a large expected impact on repair employment per equipment tender position. Taking a minute to recall the partial list from Section 3 of what machine operators were now allowed to perform, including helping repair staff, the estimated impact might not seem so large.[39]

In the next two subsections, I turn to variations in work rule changes across-mines and within-mines to demonstrate that work rule changes had dramatic impacts on productivity.[40]

[38] Below I present the evolution of repair hours relative to the total for Minntac (see Figure 13). The evidence on the Inland/Minorca and Eveleth mines is from Learmont (1983). The data for Minorca is from 1983; Learmont doesn't specify the year for Eveleth, other than it is in the early 1980s. Minntac's repair hours (as a fraction of the total) fell sharply in the early 1980s, so these figures for Minorca and Eveleth may understate the repair staffs prior to the crisis.

[39] It is interesting to note that equipment tenders were discussed as possible sources of large productivity gains in other industries, like the auto industry, that were undergoing work rule changes in the 1980s. For example, Luria (1986) noted that while studies had not been done to assess the effect of work rule changes in the auto industry, "the most sizable cost reductions will probably come from the broadening of job descriptions to enable production workers to set up and maintain their own equipment" (p. 24).

[40] I have studied the contracts at the various mines to learn about how the contracting out, repair work rule, and other institutional rule regimes evolved over time. Regarding these regimes, the mines in the middle

Across-mine variation in work rules and productivity. Let me start by comparing across mines. Let me consider three groups of mines, the first being LTV, Eveleth and National; the second, Minntac; and the third, Reserve/Northshore.[41] Minntac's work rule changes during the 1980s were far more sweeping than the changes in the first group of mines, while its contracting out changes were similar to the groups. The Feb. 1, 1987 BLA between Minntac and the USW contained an "Employee Protection/Job Realignment Agreement" section that stated in part: "the Company shall have a one-time opportunity to reman each affected facility, to be completed by June 30, 1987, including crew composition changes, job realignments and a definition of new jobs and seniority units necessary to achieve the objectives and commitments of this Agreement." No other mine contract in the 1980s had this type of language on work rule changes.[42] Minntac introduced the two major work rule changes I talked about above, the equipment tender and the reductions in job classifications.[43]

Minntac's labor productivity is contrasted with that of the first group in Figure 12. Minntac's productivity relative to that of each mine was greater after the crisis than it was prior to the crisis.[44] Notice the large "spike" in Minntac's productivity in 1976 relative to

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1980s differed most significantly in the repair work rule regimes. The other regimes were similar across mines. The sections on work rule changes and contracting out can run to many pages, so it's not possible to make fine distinctions between contracts. Rather, I consider cases where there are clear and substantial differences.

[41] In comparing productivity across mines before and after the crisis I have left out Hibbing and Inland since both were just opening in the late 1970s and don't have much of a track record before the crisis.

[42] An interesting question is why differences in contracts emerged across mines in the 1980s (where they were very similar prior to 1980). It may have been that the differences were based on differences in competitive pressure faced by individual mines. In this regard, it is interesting to note that differences in contract changes in the auto industry across plants were attributed to different threats. According to Luria (1986), "The pressures for change are clearly uneven. Restrictive work rules and narrow classifications have lasted longer in those sectors of the industry that can best withstand foreign competition and outsourcing competition – for example, in plants that assemble large cars and trucks ..." (p. 24).

[43] Actually, Minntac introduced only a limited number of equipment tenders (fifty of them) in this contract. However, the contract allowed machine operators to do repairs and other maintenance work on their "turns," as they were coming on and off their shifts.

[44] Minntac's productivity relative to Erie's varied between about 0.8 and 1.0 before the crisis, whereas during the 1980s it varied between about 1.4 and 1.6; relative to Eveleth's it was about 0.8 before the crisis,

Eveleth and Northshore. This was due to unusually low productivity at these latter mines due in part to major expansion programs that year. Notice also the large "fall" in Minntac's productivity in 1993 again relative to Eveleth and Northshore. This was due to surges in Eveleth's and Northshore's productivity from work rule changes (discussed below).

Since work rule changes were to primarily influence the repair staff, it would be nice to compare how the repair staffs evolved at each mine. Unfortunately, I can only examine the share of hours by the maintenance and repair staff at Minntac (see Figure 13). The share was approximately 50-55 percent before the crisis; after the crisis, it was approximately 28 percent.[45] So, repair hours fell almost in half when total hours were falling by 60 percent.

Let me now compare Reserve to the first two groups. As I mentioned, the Reserve/Northshore mine reopened in 1990 as a non-union mine. Hence, it was not bound by contracting out provisions or work rules of union contracts. Reserve was going through court battles on environmental issues in the late 1970s which severely reduced its productivity. Hence, I will compare Reserve's productivity to the other mines in 1970-75, and then again in 1990-95. Over 1970-75, Reserve's productivity was roughly 0.8 that of each mine in group one, and was roughly equal to Minntac's (see Figure 14). Regarding the 1990-95 period, an important fact to note is that when mines first open, or reopen after an extended closing, their productivity is initially low for a couple of years, as was Reserve's. But a few years after its reopening, its productivity was above all those mines in the first group, and its productivity had approached Minntac's level. Note again the surge in National's and

whereas during the 1980s it was about 1.2; and relative to National's it varied between about 0.6 and 0.8 before the crisis, whereas during the 1980s it varied between about 0.8 and 1.0.

[45] Minntac stopped reporting hours by location to the mine inspectors for a few years during the crisis (though total hours were still reported). That is why there is a "gap" in Figure 13.

Eveleth's productivity (discussed shortly). Minntac's performance relative to Reserve shows that if work rules are dramatically changed, a union mine could match a non-union mine.

Within-mine variation in work rules and productivity. It is very difficult to use within-mine regime changes in the 1980s to learn how work rule changes influenced labor productivity. For example, recall Figure 13 on Minntac's repair hours. In the early 1980s, repair hours (as a share of the total) crashed at Minntac (and elsewhere) since long-term maintenance was stopped, broken machines didn't have to be repaired if there were idle ones available, contracting out was expanded and stripping operations were scaled back, leading to less repair work. In the middle 1980s, each of these trends was reversed (that is, long-term repair was restarted, contracting out rolled back, etc.) just as Minntac introduced major work rule changes. But some mines that initially lagged in work rule changes introduced further changes in the later 1980s and the early 1990s (and, in fact, typically introduced more sweeping changes than the "leaders" did in the middle 1980s), a period when contracting out rules, etc., were not changing much. For these mines, within-mine variations provide good evidence on the impact of work rule changes. Two mines introduced major changes in work rules in 1993: Eveleth and National.[46] As I mentioned above, both mines experienced major productivity gains as a result of these work rule changes.

[46] While these industries faced a dramatic increase in competitive pressure in the early 1980s, they have continued to face the prospect that mines would close (and some have closed since 2000). This has led to further rounds of work rule changes in the late 1980s and 1990s. In the early 1990s, National Steel Pellet mine was purchased by a Japanese firm which demanded work rule changes to keep it operating (it had actually closed for a number of months and it was not clear it would reopen; see the drop in production in Figure 7).

D. Work Rule Changes and "Other" Institutional Changes: Assessment

It's hard to make precise statements about how important the "other" institutional changes were relative to repair work rule changes in influencing industry productivity. At some level, it's not important to make such an assessment. Together they accounted for the majority of industry productivity gains. Still, I think there is good reason to give top-billing (as I have done) to changes in repair work rules, since there is strong evidence that they had significant impacts on mine productivity and by the late 1980s/early 1990s most mines had introduced them.

7. Summary and Discussion

I have argued that changes in institutions accounted for the majority of the dramatic productivity gains in the U.S. and Canadian iron-ore industries in the 1980s. Through a process of elimination, Section 5 showed that the usual candidates contributed little to the gains. Section 6 provided direct evidence that it was not changes in contracting out but in repair work rule changes and other institutional changes that led to the productivity gains.

Let me finish with some wide-ranging discussion, starting with the question: Why was it necessary to have a dramatic increase in competition to change these work rules?[47] Let me present one explanation that goes like this: While there were obvious large productivity gains to changing work rules, there were significant obstacles to changing them. Let me discuss two

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[47] These repair work rules were initially developed in the U.S. steel industry during the early twentieth century and then transferred to the iron-ore industry. As discussed in Stone (1974), during this period management decided to train mechanics for only a very narrow range of tasks, thus limiting their outside opportunities and hence their bargaining power. Hoerr (1988) suggests work rules that did not permit production workers to maintain their machines came from management's lack of trust in workers to make good decisions. How did the industry get to this point where work rules could be changed and productivity increased? Was there some exogenous trend that led to this possibility? One change over the 20th century was that general and technical education expanded and was primarily done (for free) in schools. Repair staffs, then, were receiving additional training outside the mines.

obstacles. First, there may be disagreements on how to divide up the gains from changes. Second, even if there is agreement on how to divide gains, achieving them may require some workers to leave (as in the iron-ore case), and there may be difficulties "buying-out" workers.[48]

Management and workers can disagree on how to divide up gains from changes, and workers may disagree among themselves. A good example of this latter point is the airline industry, where negotiations to change work rules have often broken down in disagreements among groups of workers about what each should surrender.[49] Even if agreement is reached, achieving gains may require reductions in employment. The present value of what is owed departing workers may be huge compared to current profits. Can current workers and management commit to paying departing workers in the future (if funds cannot be raised today)? Departing workers can be promised greater pensions, as some were in these industries in the 1980s, but can companies commit to not canceling pensions (as some are doing).[50] They can be given equity, but its value depends on the future compensation of those that stay.

Supposing this "obstacles" explanation has some merit, let me turn to an old question: Does monopoly or market power lead to inefficiency? If work rules were not changed because there was difficulty committing to future payouts to departing workers, then from the perspective of industry participants it's hard to say there was an inefficiency. Nobody has

[48] A different type of explanation goes like this: the USW and its workers enjoyed significant market power in the iron-mines, meaning workers earned significant wages. With high wages, they "purchased" non-pecuniary benefits at work. Hoerr describes a number of such benefits, which were thought to include increased manning levels (which were often jobs for kids) and less power by management to discriminate against workers.

[49] In the airline industry, separate unions represent pilots, mechanics, stewards and others. Each of these unions has contract provisions and work rules that limit productivity. For example, contracts with pilots often forbid planes under a certain size and contracts with mechanics give them the right to pull back planes, a job that could be done by less skilled workers. These different unions disagree about how much they should give up in work rule changes relative to other unions.

[50] Another difficulty in making payouts is a "political" one. Becker (1957) and Alchian and Kessel (1962) have argued that groups with market power in an industry may take returns in non-pecuniary ways to avoid "detection." Under this story, if workers were given large bonuses to leave, this may have influenced, for example, the taxing decisions of towns.

access to a perfect commitment technology. But consider matters from society's perspective. Suppose laws are passed that restrict entry into an industry (or raise tariffs on foreign competitors) which have the effect of increasing market power of groups in the industry. Changes will occur in the industry, some of which may imply less staff is needed. Then we arrive at a situation like that in the iron-ore industry. Because of lack of commitment, there are obstacles to reducing employment. From society's perspective, erecting entry restrictions and tariffs leads to valuable labor resources not being utilized in the future. In this sense, laws restricting entry lead to inefficiency.

Do the lessons learned here apply to many industries?[51] One unusual characteristic of the iron-ore industries is their concentration in a few rural areas. But changes in work rules have led to large productivity gains in the longshore industry, one clearly not in rural areas but one concentrated in a few places (like NYC and LA). But work rules like that above persist today in the U.S. railroad industry, one not concentrated in any spot. What these industries share is (to some extent) a lack of competition and that changes in work rules required (or would require) significant downsizing of the workforce (that is, large price reductions following from productivity gains were not expected to significantly increase output).[52] Both these features are common to many industries (especially protected ones), and I see the lessons here as fairly broad.[53]

[51] An important predecessor to this paper is Clark (1987) who argued that British and U.S. labor productivity in cotton textile production was six times that in India in 1910 almost solely because of lower levels of effort per hour worked in Indian mills.

[52] For some theoretical discussions in this direction, see Holmes and Schmitz (1995), Parente and Prescott (1999), Kocherlakota (2001) and Herrendorf and Teixeira (2003).

[53] A key question in economics is why there are large differences in aggregate productivity across regions and countries (see Acemoglu and Zilbotti (1999), Caselli and Coleman (2000), Chari, Kehoe, and McGrattan (1997), Hall and Jones (1999), Klenow and Rodriguez-Clare (1997), and Prescott (1998)). One idea is that industries in different countries are subject to differing degrees of competition because government policy (on tariffs, entry restrictions, etc.) varies across countries. Here I have studied an episode akin to a natural

Appendix A: Calculations from the Census of Mineral Industries

Let me first calculate L_t/N_t. I denote the compensation of mine-employees by $W_t = p_{Nt}N_t$, where p_{Nt} is compensation per mine-employee. I denote the amount of contracting out by C_t. Again, payments to contractors include the wages of outside-employees but also the materials used by the outside-employees, payments to capital owned by contractors, transportation, etc. Suppose a fraction δ_t of contracting out payments are made to labor, that is, $\delta_t C_t = p_{Lt}L_t$, where p_{Lt} is compensation per outside-employee. Then L_t/N_t can be expressed as

$$\frac{L_t}{N_t} = \delta_t \frac{p_{Nt}}{p_{Lt}} \frac{C_t}{W_t}.$$

As I reported above, the ratio C_t/W_t was 0.051 and 0.045 in 1972 and '82, respectively. I will assume the ratio p_{Nt}/p_{Lt} equals 3/2 and does not change over time. Typically, the share of labor costs in total costs is about 1/4 at most establishments and there is no reason to think this is not a reasonable approximation for outside repair shops. If some outside-employees worked on site using materials of the mines, then a larger share δ_t should be used. But outside-employees on site were not common.[54] So, a value of $\delta_t = 1/3$ seems reasonable, leading to estimates of L_t/N_t of .025 and .022 for 1972 and '82, respectively.

I next calculate $\psi\beta$. I denote the compensation of mine-employees who lost their jobs between periods by $\widehat{W} = p_{N2}(1-\alpha)N_1$, where I value the lost jobs at p_{N2}. Contracting out

experiment to further explore this idea.

[54] In fact, as part of the rolling-back of contracting out in the 1986 contracts, a provision was added to most contracts that stated mine craft employees were guaranteed pay for 40 hours of work if they were on layoff and there were craft employees of contractors working in the mine. For the contract language, see, for example, the Inland/Minorca mine's BLA, pp. 174-76.

payments to outside-employees at $t = 2$ equal $\delta_2 C_2 = p_{L2} L_2 = p_{L2}[\psi\beta(1-\alpha)N_1 + L_1]$. Then

$$\frac{\widehat{W}}{\delta_2 C_2} = \frac{p_{N2}(1-\alpha)N_1}{p_{L2}[\psi\beta(1-\alpha)N_1 + L_1]},$$

and after rearranging terms, $\psi\beta$ can be expressed as

$$\psi\beta = \delta_2 \frac{p_{N2}}{p_{L2}} \frac{C_2}{\widehat{W}} - \frac{1}{(1-\alpha)} \frac{L_1}{N_1}.$$

Again, I assume that the ratios p_N/p_L and δ are as before, namely 3/2 and 1/3.

I choose the second date as 1987. Contracting out payments in 1987 were $C_2 = \$35.2M$ (million). I next need an estimate of the compensation of employees that lost jobs, $\widehat{W} = p_{N2}(1-\alpha)N_1$. This compensation can be expressed as $\widehat{W} = [(1-\alpha)/\alpha]W_2$, since again $W_2 = p_{N2}\alpha N_1$. In 1987, employee compensation was $W_2 = \$293M$. So, I next need an estimate of α. Suppose date $t = 1$ is 1982. According to the CMI, there were 11.7 thousand workers in 1982 and 7.1 thousand in 1987, hence $\alpha = .61$. Then $\widehat{W} = [(1-\alpha)/\alpha]W_2 = \$187M$ and $C_2/\widehat{W} = 0.19$. Then using $L_1/N_1 = 0.022$, I have $\psi\beta = (1/2)(0.19) - (2.56)(0.022) = .095 - .056 = .039$.

Since the crisis started before 1982, I would prefer the first date $t = 1$ to be, say, 1980. But I do not have CMI data to estimate L_1/N_1 for that date. Presumably, it would not differ much from the 1972 and 1982 figures (which were close). But the value of α would be smaller, certainly less than 1/2. This would mean a smaller value for $\psi\beta$. Let me calculate $\psi\beta$ under the assumption that $L_1/N_1 = 0.025$ and $\alpha = 0.5$. Then $\widehat{W} = W_2$ and $C_2/\widehat{W} = 0.12$. Hence, $\psi\beta = (1/2)(0.12) - (2.0)(0.025) = .06 - .05 = .01$. If I return to equation [5] above, and using $\alpha = 0.5$, $L_1/N_1 = 0.025$, and $\psi\beta = 0.01$, and for simplicity using $Y_1 = Y_2$, then $z_1 = 2$ and $z_2 = 1.93$. So, according to these calculations, the productivity estimates using only mine employment are not much greater than those incorporating outside-employment.

Appendix B: Data Sources and Discussion

Figure 1. Source: Minerals Yearbook of the United States (various issues), United States Geological Survey (USGS).

Figure 2. Source: Production (in tons) and hours worked from the Minerals Yearbook of the United States (USGS). The Bureau of Labor Statistics (BLS) publishes a productivity series, where output is revenue divided by a price deflator. BLS productivity looks very much like USGS's series.

Figure 3. Source: Production (in tons) is from Natural Resources Canada (NRC). Two measures of labor input are used to construct productivity. Employment is from NRC and hours worked from Statistics Canada. Hours worked is typically a better measure to use, but the employment series for NRC differs from StatsCan's employment series. The reason for differences in the measures of Canada's productivity are primarily due to differences in employment across agencies, and not variations in average hours worked. I thought it best to present both measures.

Figures 4 and 11/Table 1. Source: Real (gross) output Y, capital services K, real materials purchases M and hours worked N are from Statistics Canada. I am indebted to Wulong Gu for providing me with this data. Real output is revenue divided by a price index. From 1981 onwards (when this data starts), this measure of real output falls less than tons produced (for the reason why, see the discussion on types of iron-ore). Hence, labor productivity growth with this real output series is greater than with tons.

Figure 5. Total tons and tons of pellets (agglomerates) are from the Minerals Yearbook (for the United States) and the Canadian Minerals Yearbook.

Figures 6, 7, 12, 13, and 14/Table 2. Production data (in tons) by mine is obtained from the Minnesota Department of Revenue. Hours data for a mine is obtained from the mine inspectors in each Minnesota county where mines are located (primarily St. Louis County). Some mines have operations in two counties (the pit and the mill can be in separate counties) so for these mines hours figures must be combined.

Figure 8. Price of new capital, price of labor (that is, compensation per hour), hours worked and capital stock are from Statistics Canada. Note that I have capital services from 1981 onward, and I use this series in Figure 4 and 11. I have capital stock in years prior to 1981. From 1981 onwards, the capital stock falls slightly more than capital services.

Figure 9. Usage of electricity and price of electricity are from NRC. Price of labor (that is, compensation per hour) and hours worked are from Statistics Canada.

Figure 10. Price of electricity, price of labor (that is, compensation per hour), hours worked and electricity usage are from CMI.

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Table 1

Labor Productivity and Contributions From TFP,

Materials Per Hour and Capital Per Hour

Canadian Iron-Ore Industry

Year	Labor Productivity	Contribution from:		
		A_t	$(M_t / N_t)^{S_{M_t}}$	$(K_t / N_t)^{S_{K_t}}$
1981	1.00	1.00	1.00	1.00
1982	0.94	0.91	0.98	1.06
1983	0.97	0.86	1.06	1.07
1984	1.09	0.91	1.14	1.05
1985	1.19	1.00	1.08	1.10
1986	1.61	1.33	1.09	1.11
1987	1.64	1.34	1.05	1.16
1988	1.78	1.46	1.10	1.11
1989	1.79	1.48	1.08	1.12
1990	1.57	1.36	1.04	1.11
1991	1.64	1.40	1.06	1.11
1992	1.58	1.41	1.01	1.11
1993	1.59	1.50	1.00	1.06
1994	1.75	1.54	1.05	1.07
1995	1.64	1.51	1.02	1.06

Table 2

Minnesota Taconite Industry

Decomposition of Industry Productivity Growth

(All figures in percent)

Weights are mine's share of industry hours

Growth Between 1980 and	Overall Industry Growth	Share of Industry Growth Due to:			
		Within Mines	Between Mines	Cross Mines	Closing Mines
1981	10.20	105	-16	11	0
1982	-1.40	764	-314	-346	0
1983	13.60	79	16	5	0
1984	55.10	93	6	1	0
1985	67.90	97	3	0	0
1986	77.50	87	7	6	0
1987	121.50	77	3	14	6
1988	108.80	76	3	15	7
1989	101.80	73	3	16	7
1990	100.90	95	7	-2	0
1991	87.20	96	9	-5	0
1992	91.70	92	9	-1	0
1993	104.40	108	6	-13	0
1994	113.70	106	6	-12	0
1995	119.90	101	6	-7	0

Figure 1: Pig-Iron Production By Various Groups of Countries 1950-1996

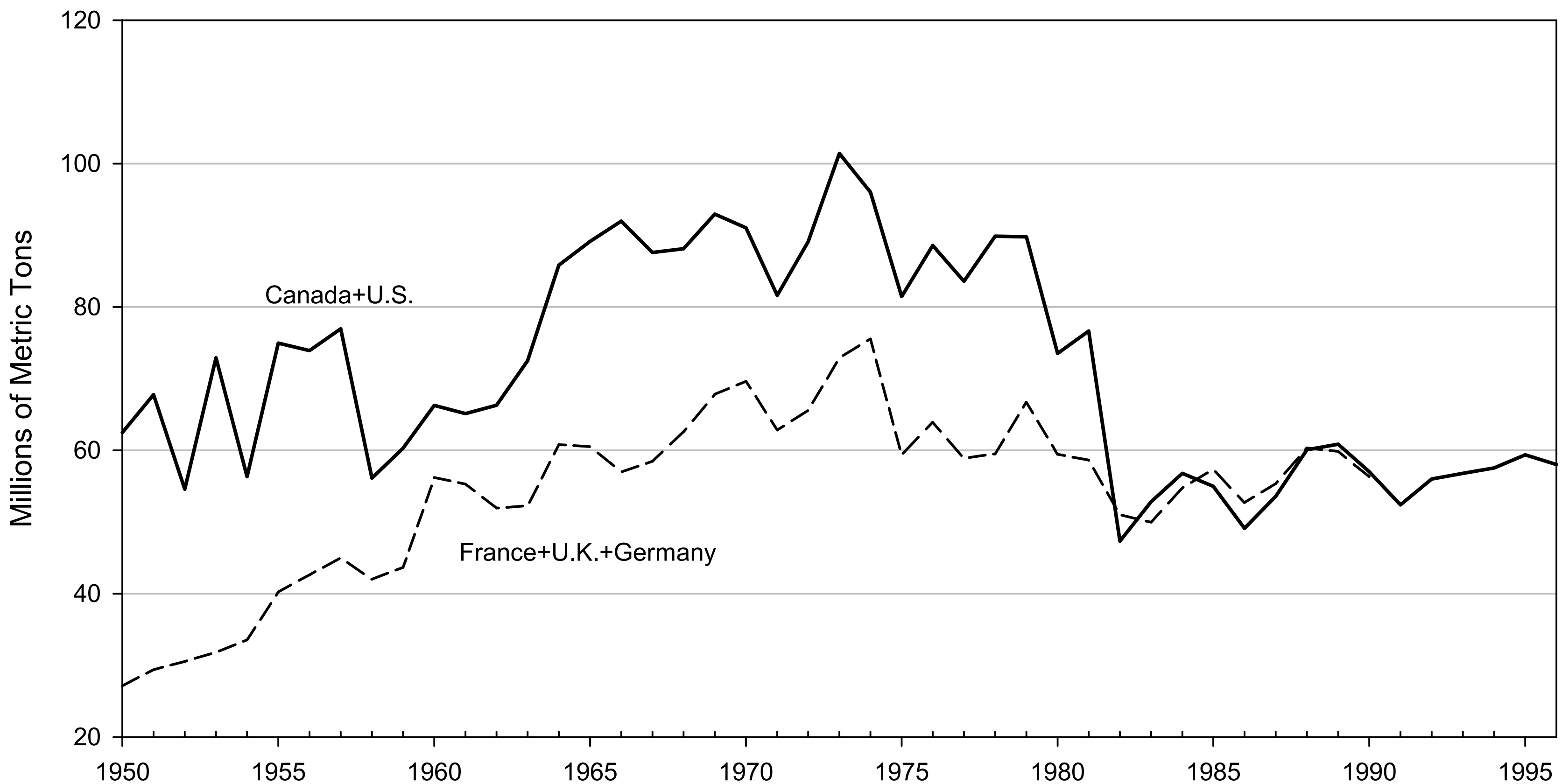

Figure 2: Production and Labor Productivity in U.S. Iron-Ore Industry

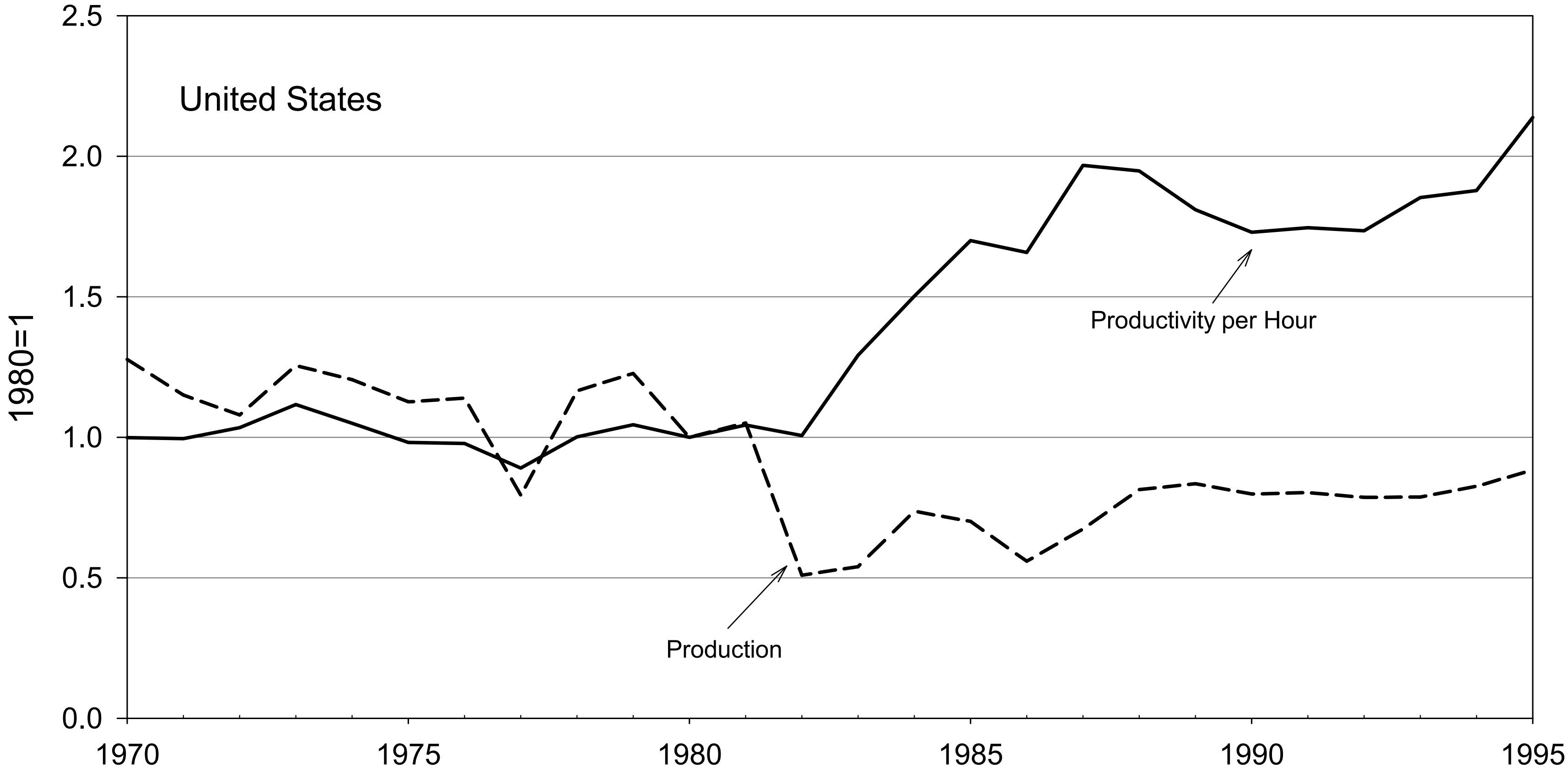

Figure 3: Production and Labor Productivity in Canadian Iron-Ore Industry

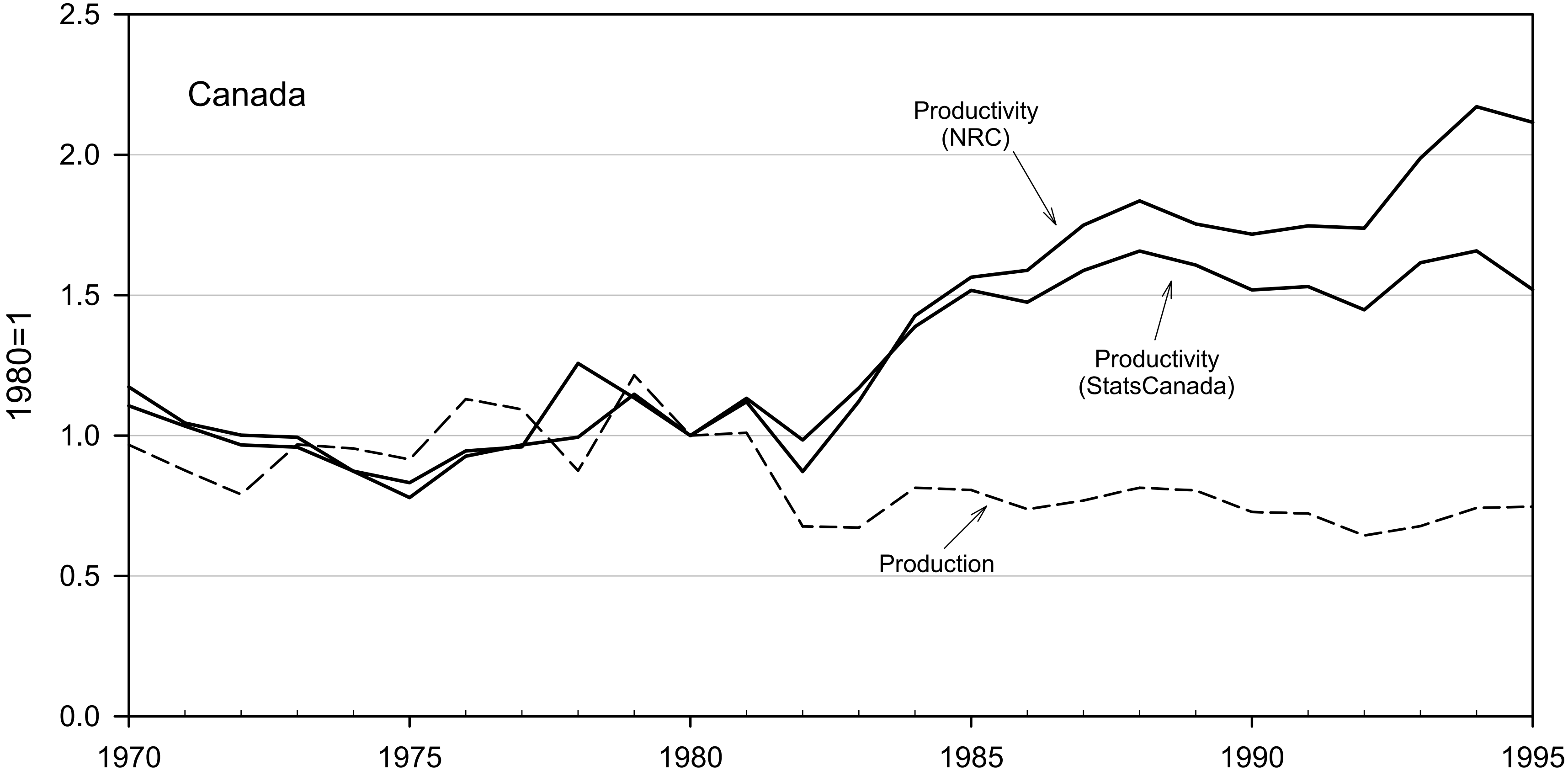

Figure 4: Labor Productivity and Contributions of TFP, Materials Per Hour and Capital per Hour
Canadian Iron-Ore Industry

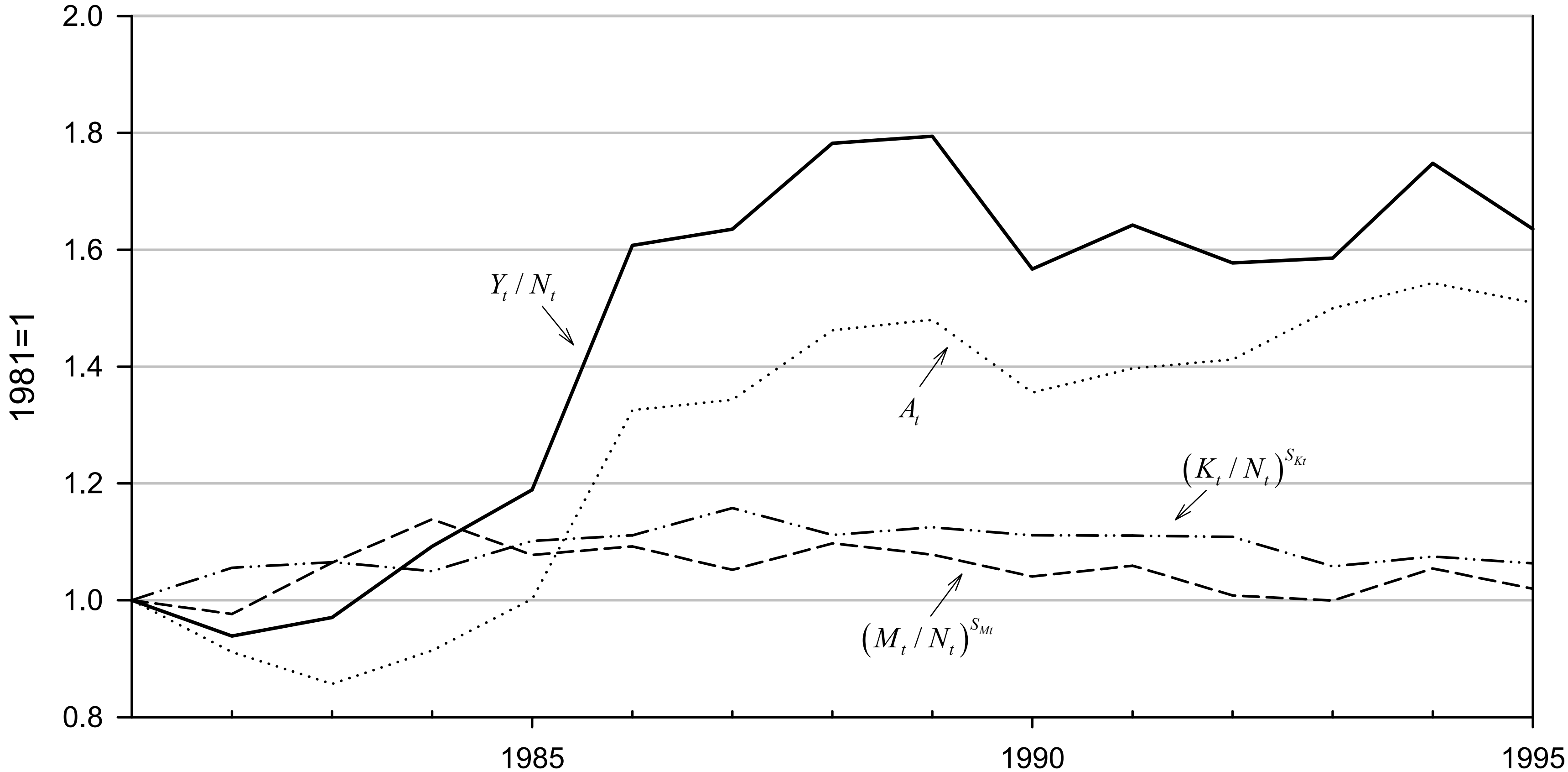

Figure 5: Pellets as a Share of Total Production
U.S. and Canadian Iron-Ore Industries

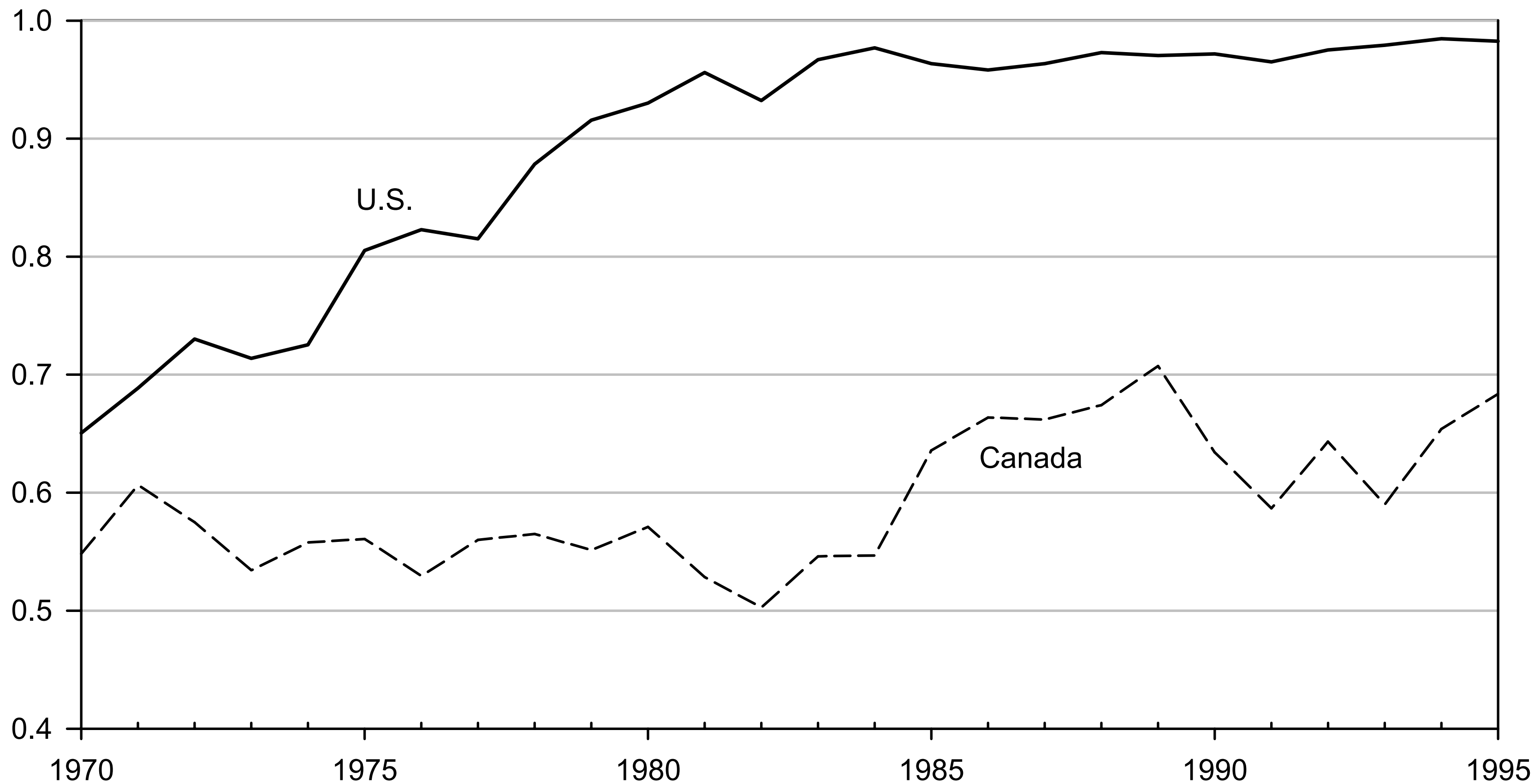

Figure 6:
Minnesota Taconite Pellet Production and Productivity

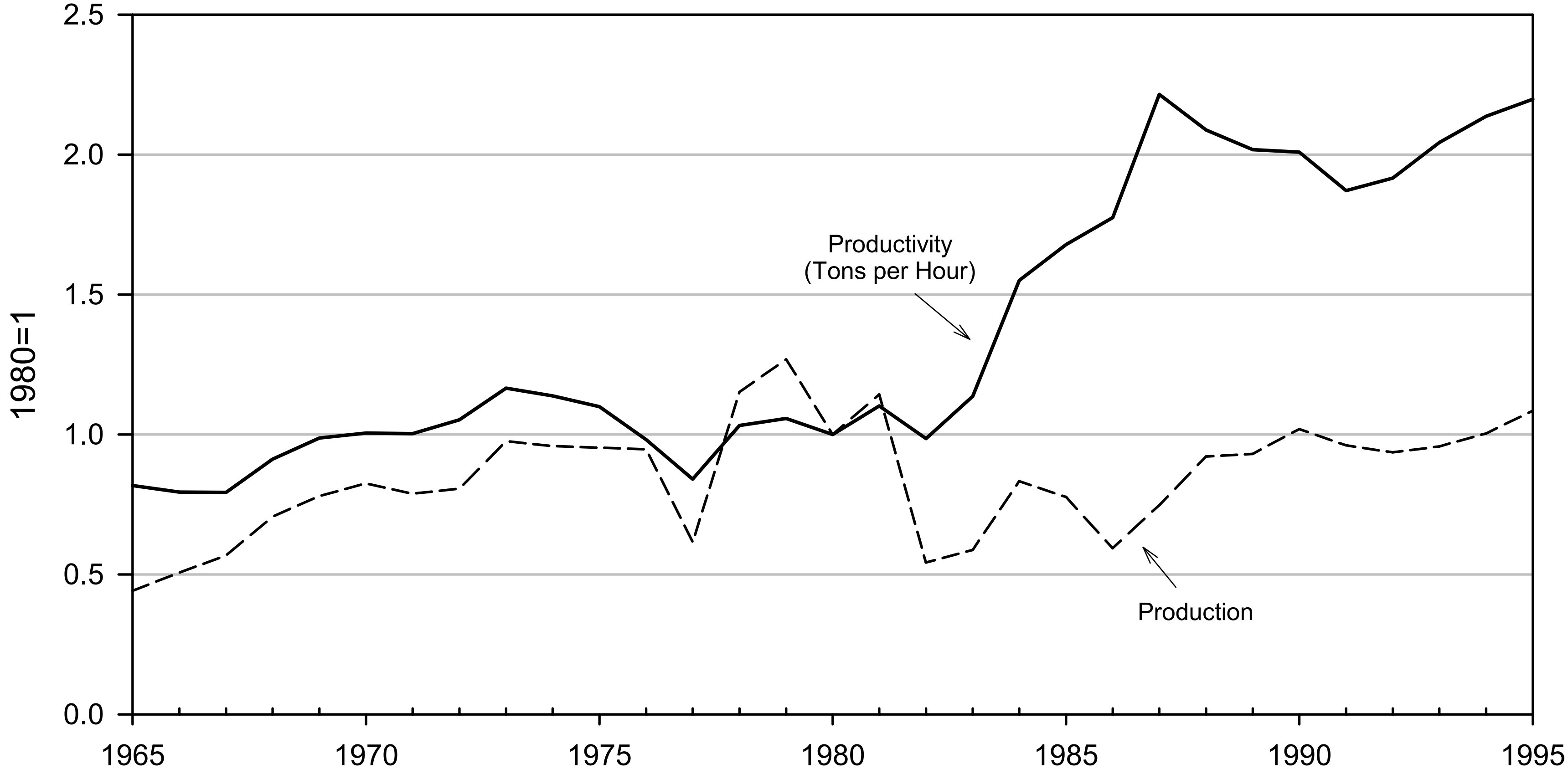

Figure 7: Taconite Production and Productivity in Minnesota by Mine

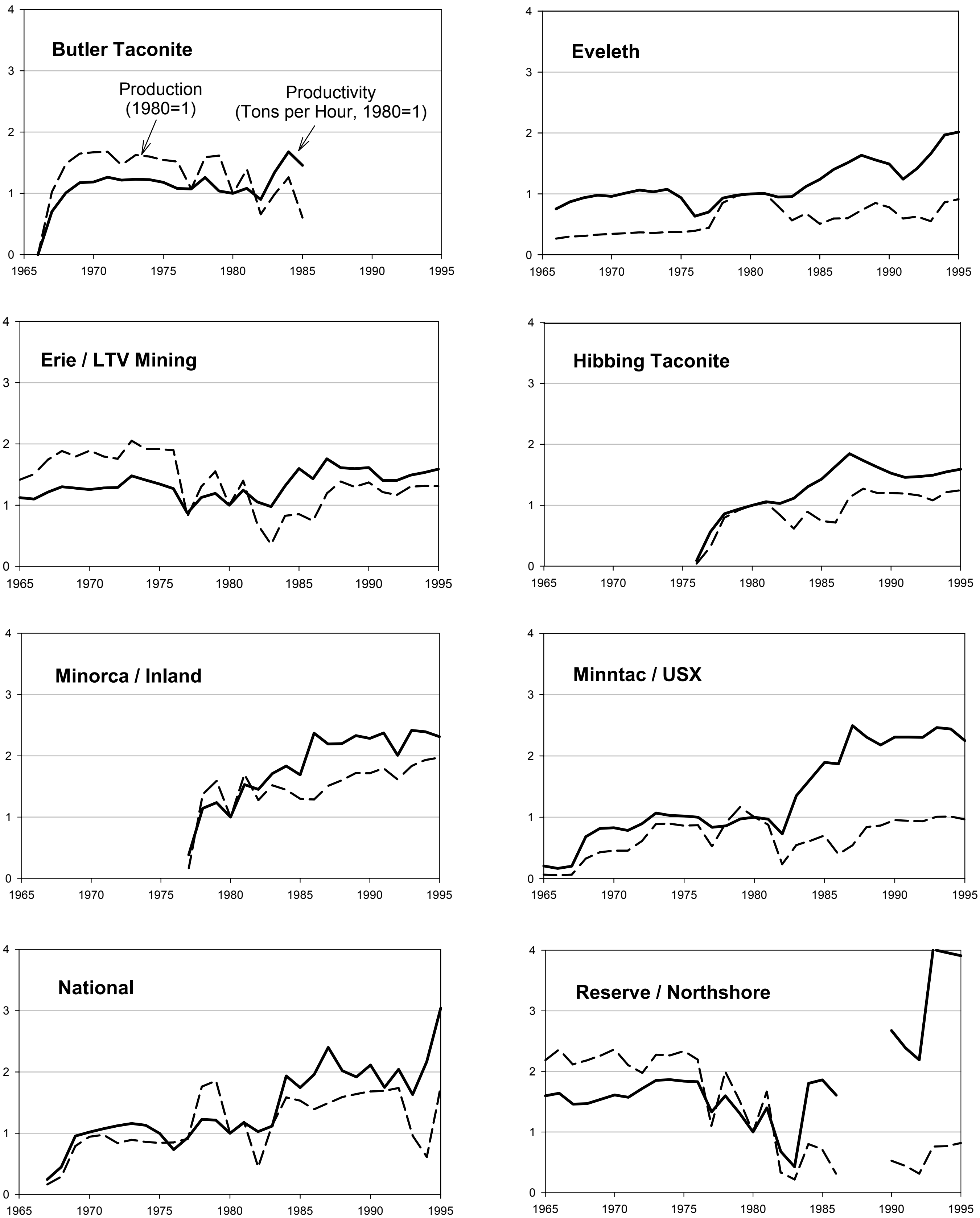

Figure 8: Price of Labor Relative to Price of New Capital
and Capital Usage Relative to Labor Usage
Canadian Iron-Ore Industry

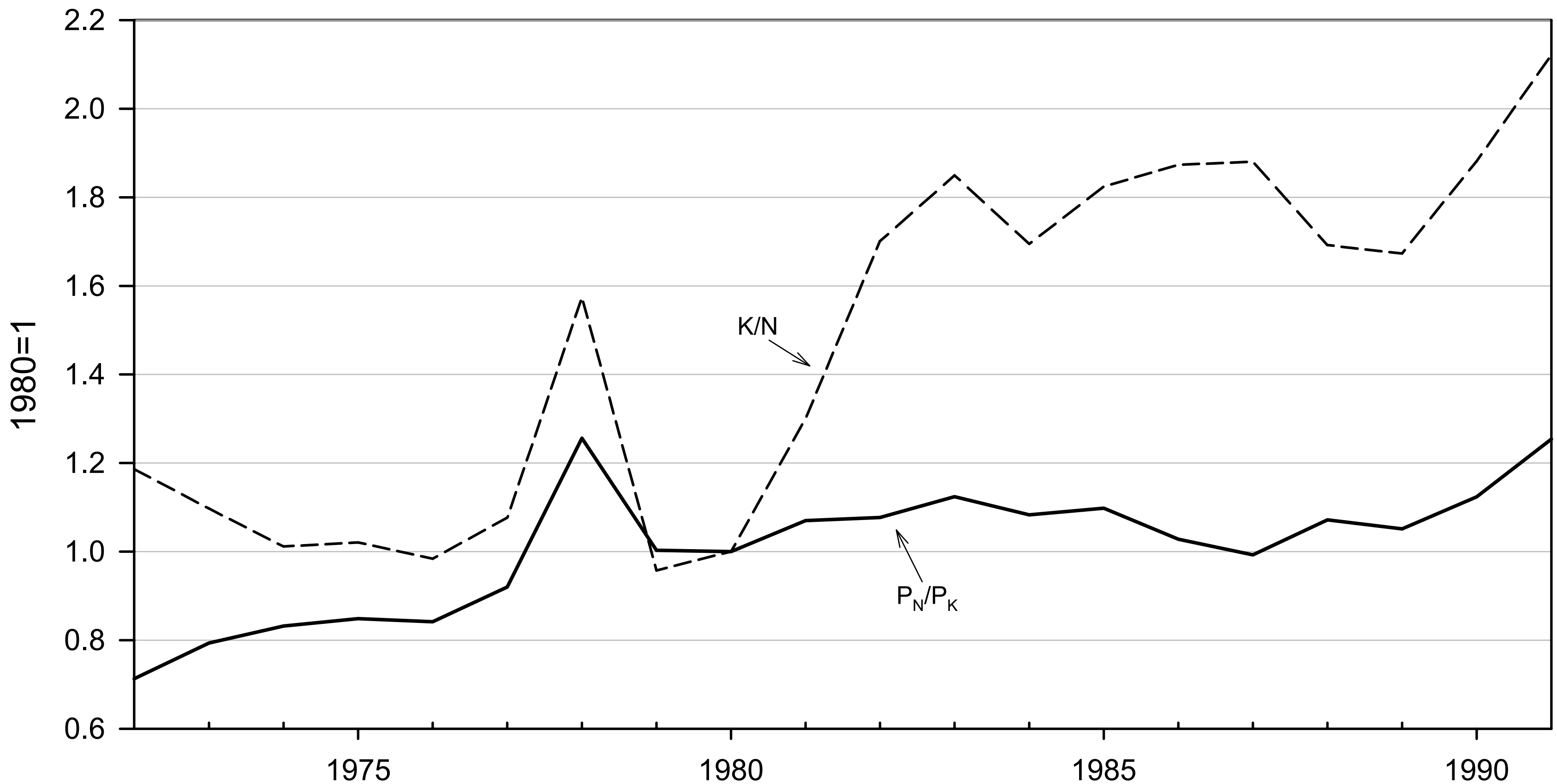

Figure 9: Price of Labor Relative to Price of Electricity vs.
Electricity Usage Relative to Labor Usage
Canadian Iron-Ore Industry

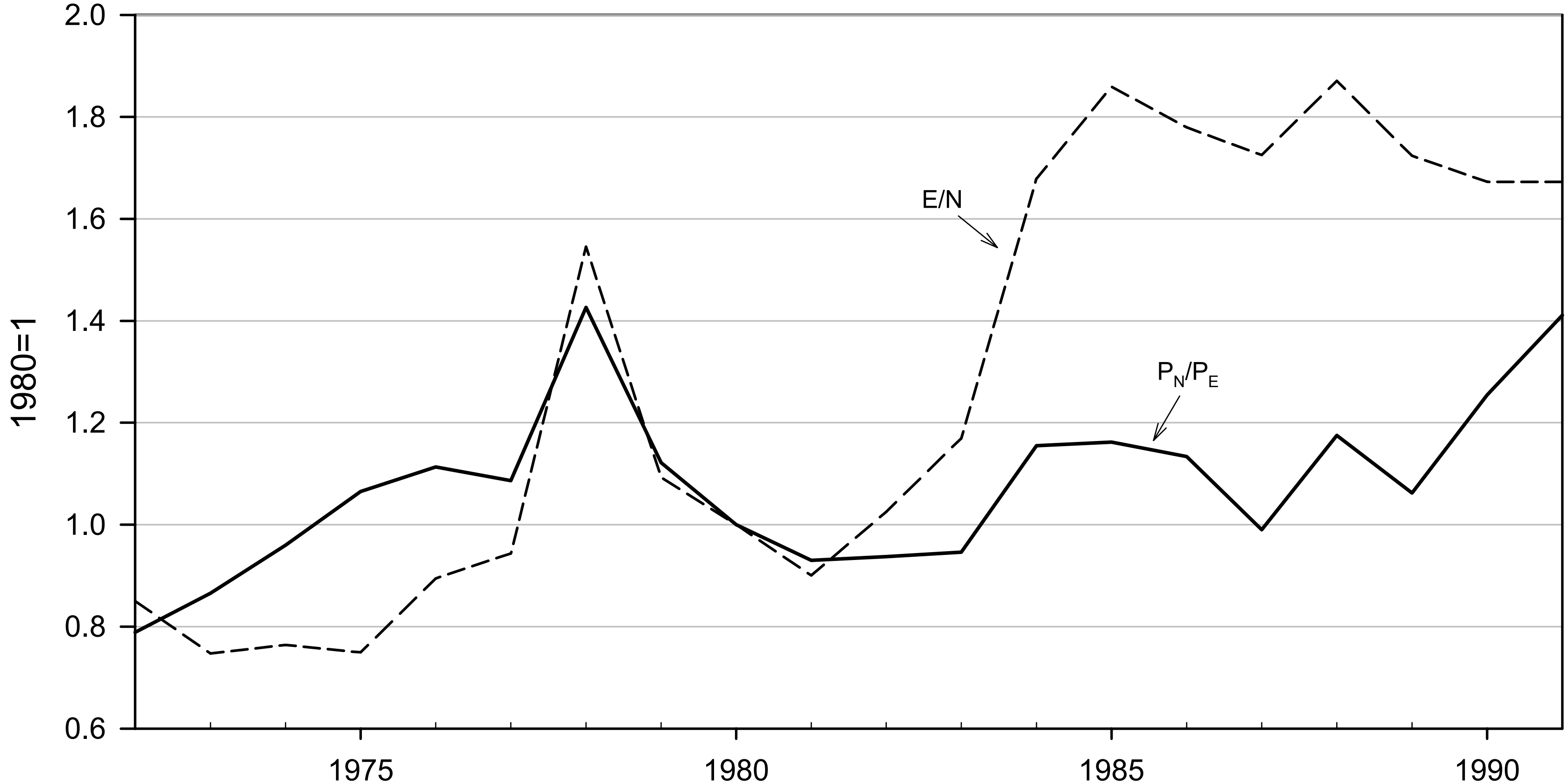

Figure 10: Price of Labor Relative to Price of Electricity vs. Electricity Usage Relative to Labor Usage
United States Iron-Ore Industry

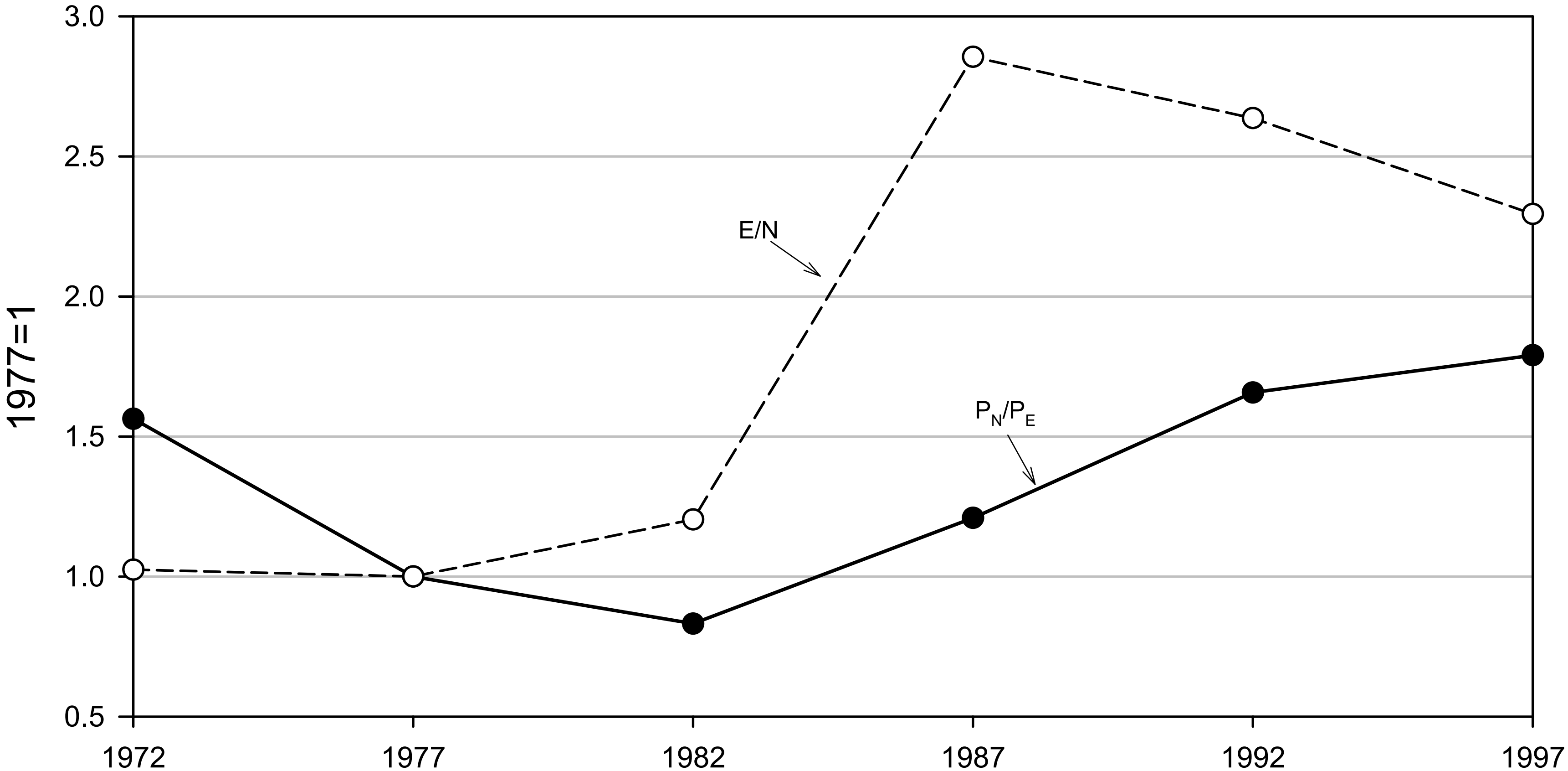

Figure 11: Materials-Output and Capital-Output Ratios
Canadian Iron-Ore Industry

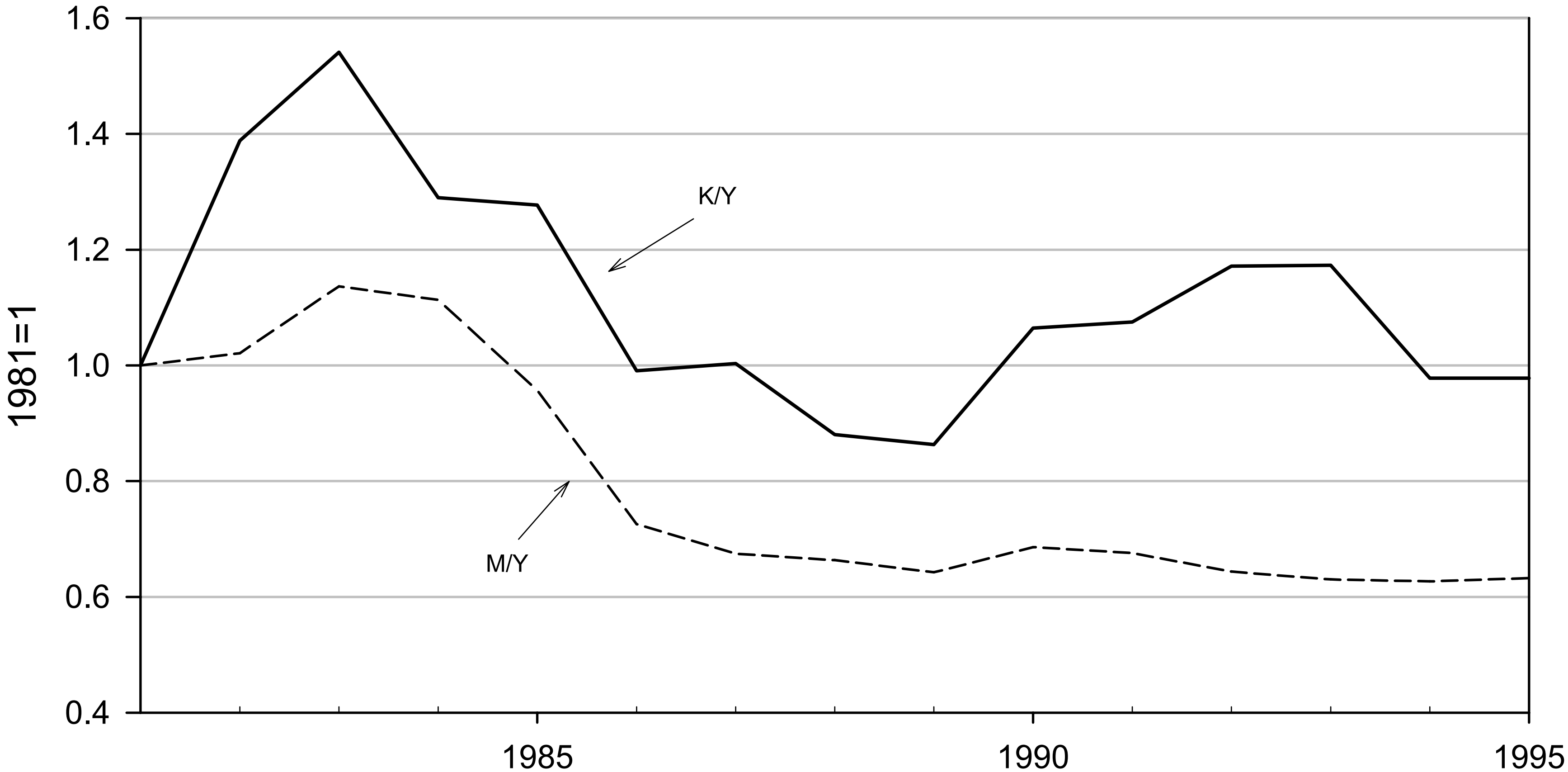

Figure 12: Labor Productivity of Minntac
Relative to Erie, Eveleth and National

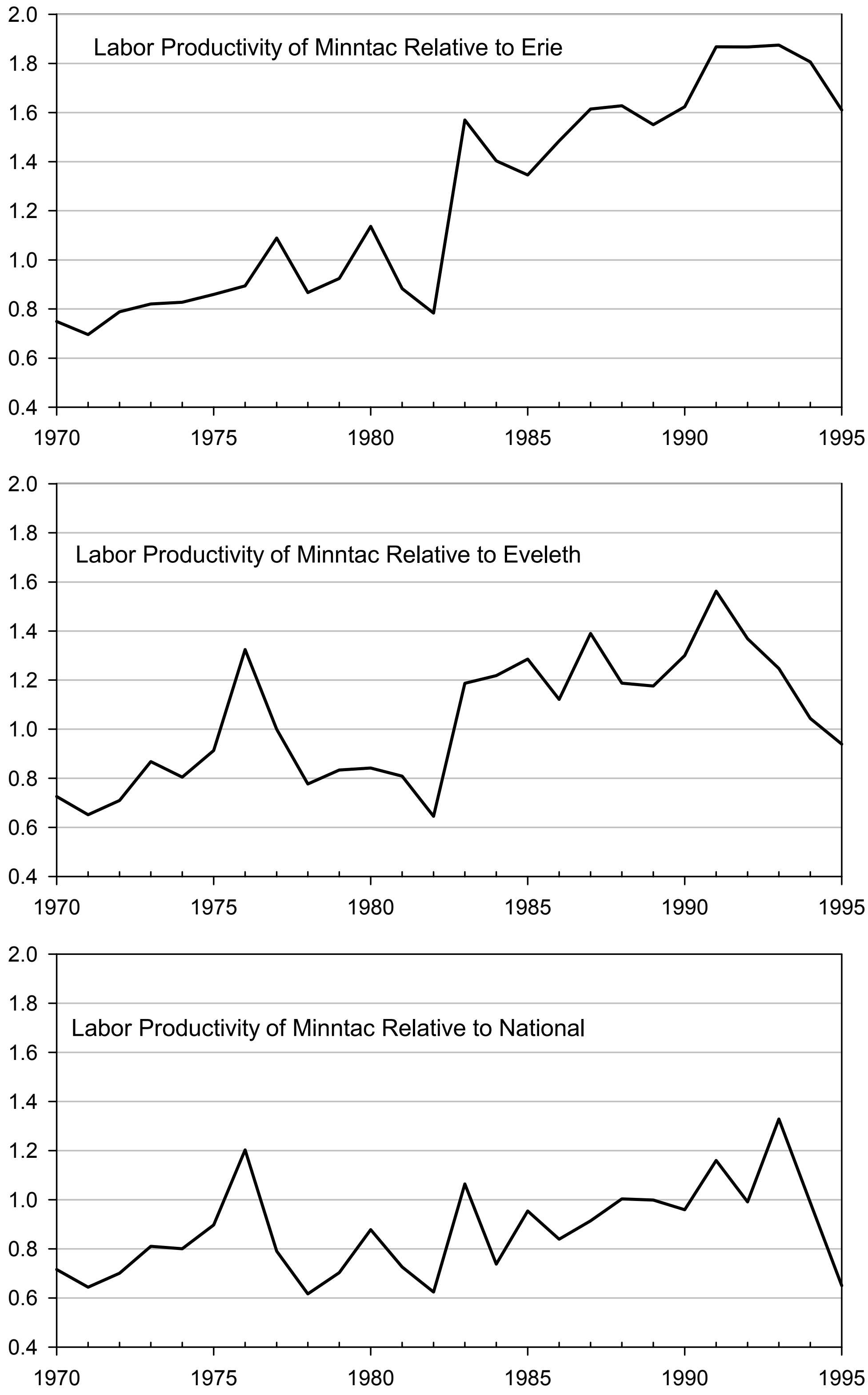

Figure 13:
Total Hours Worked at Minntac and Repair Hours as Percentage of Total

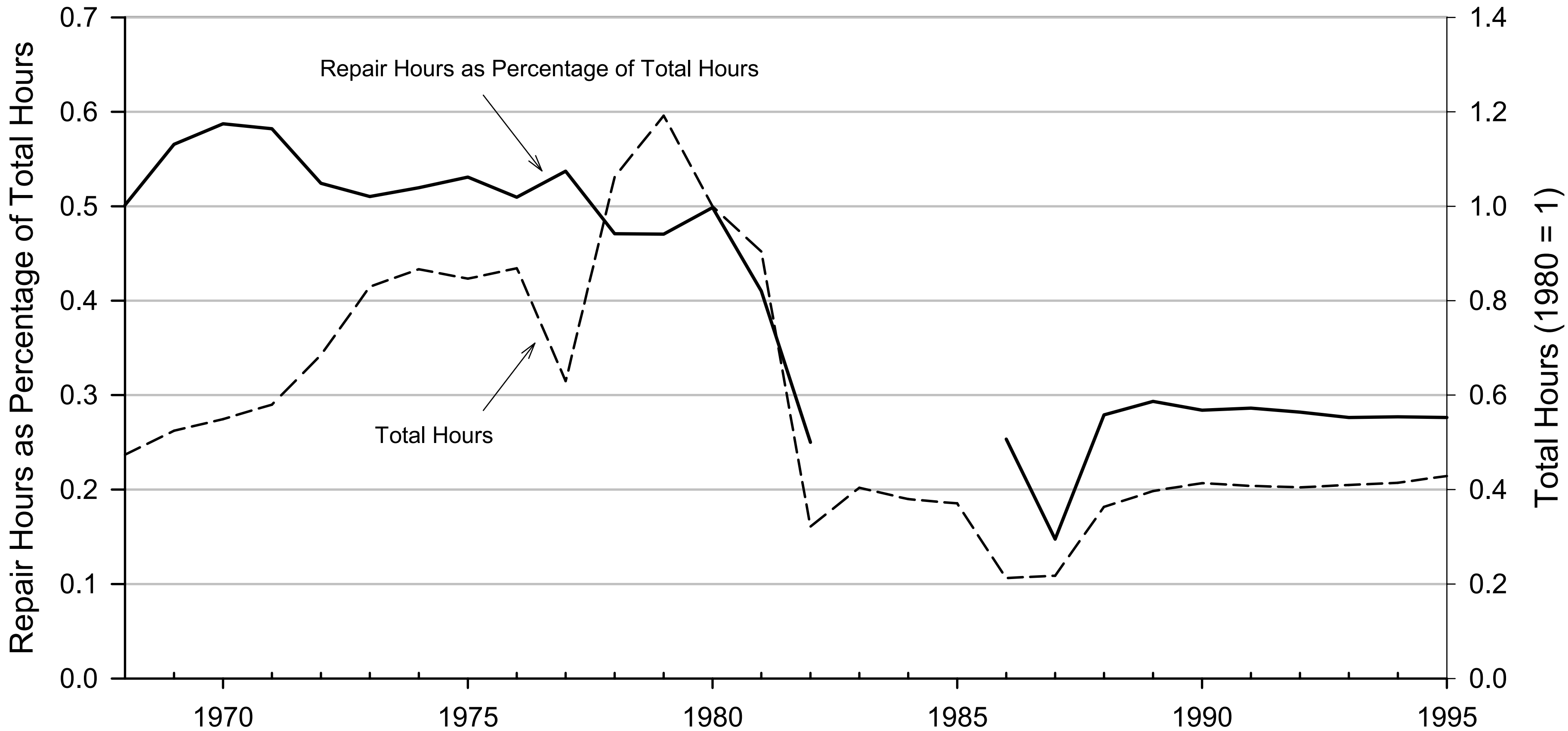

Figure 14: Labor Productivity of Reserve Relative to Erie, Eveleth, Minntac, and National