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What Determines Labor Productivity?: Lessons From the Dramatic Recovery of the U.S. and Canadian Iron-Ore Industries*

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ABSTRACT

Labor productivity differences across industries and countries are largely attributed to differences in three factors: production technology (that is, the design of equipment and structures), physical capital and human capital. Perhaps this list should be expanded: I show that the U.S. and Canadian iron-ore industries doubled their labor productivity in the middle 1980s in large part through changes in work rules that (1) increased effort per hour worked and (2) reduced redundant effort. These changes were spurred by the crisis facing these industries resulting from a collapsing local steel market and from increased competition by foreign iron-ore producers for this shrinking local steel market.

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1. Introduction

Labor productivity, that is, output per hour worked, varies dramatically across countries. Even among developed countries, there are large productivity differences in a given industry, like steel or autos, across countries. These productivity differences are largely attributed to differences in three "traditional" factors: production technology (that is, the design of equipment and structures), physical capital and the skill of the workforce, that is, human capital.

Other factors have been offered as explanations for dramatic productivity differences, factors like effort per hour worked and the system of rules (either explicit or implicit) that govern workplace effort (work rules, for short).[1] Clark (1987) argued that the high levels of British and U.S. labor productivity in cotton textile production as compared to that in India in 1910, differences of factors of six, were almost entirely due to lower levels of effort per hour worked in Indian mills.[2] In the world steel and automobile industries, Japan's leap-frogging of U.S. labor productivity in the 1970s was attributed in part to new systems of work rules.[3] But this view that differences in factors other than production technology, physical capital and human capital might explain large labor productivity differences across countries and industries has been slow to influence the general productivity literature.[4]

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[1] I have used the term "production technology" to mean the design of equipment and structures. As is traditional, I think, I did not include in that term the system of work rules. In many situations, there is a close connection and overlap between the design of physical capital and the design of work rules, and if one is changed, it only makes sense to change the other. In the situation below, the production technology remained roughly the same as work rules were changed.

[2] Similarly, in contrasting the early 20th century stagnation of Indian labor productivity in cotton to its rapid growth in Japan, Wolcott and Clark (1999) indict low levels of effort per hour worked in India as the culprit. They also suggest that low effort may explain India's low *aggregate* productivity as compared to Japan.

[3] See, for example, Katz, Kochan, and Keefe (1987) for references to literature which argues that inflexible work rules and the adversarial nature of human relations in the U.S. automobile industry led to its falling behind the Japanese industry (especially footnote 2).

[4] For example, the cross-national productivity studies of Klenow and Rodriquez-Clare (1997) and Hall

In this paper, I add to the evidence that "non-traditional" factors play an important role in productivity differences. I do this in two ways. I first show that particular industries, the U.S. and Canadian iron-ore industries, doubled their labor productivity in the middle 1980s in large part through changes in work rules that (1) increased effort per hour worked and (2) reduced redundant effort. I then argue that this productivity lesson has wider applicability. I make this jump by discussing theoretical arguments as to what triggered these productivity gains. The theoretical reasoning suggests that "non-traditional" factors may play an important role in productivity differences in many industries. Let me discuss these two contributions in turn.

Iron-ore, of course, is nearly exclusively used in the production of steel. In the early 1980s, the major steel market for the U.S. and Canadian iron-ore industries, that is, the U.S. and Canadian steel industries, collapsed: its production fell by 43 percent between 1979 and 1982, and by the early 1990s production was still only about 70 percent of its 1979 level. What made matters worse for these iron-ore producers was that even this hugely depressed local steel market was up for grabs: competition from foreign iron-ore producers greatly intensified in this period. Hence, during the early 1980's, large portions of the U.S. and Canadian iron-ore industries faced a significant threat of closure. In the face of such threats, both industries doubled their productivity in a few years in the middle 1980s.[5]

In order to discuss the sources of these productivity gains, let me denote production

and Jones (1999) assume productivity depends only on production technology, physical capital and human capital. The same is true of the models in Acemoglu and Zilbotti (1999), Casselli and Coleman (2000), and Chari, Kehoe and McGrattan (1997).

[5]I have chosen to jointly study the Canadian and U.S. iron-ore industries as a way to increase the range of data that I have. For some issues the U.S. data is clearly superior to the Canadian, while for other issues the Canadian data is so. These two industries are alike in many respects and this similarity allows me, for some issues, to make rough statements about one using data from the other. But they also differ in some regards, differences that I keep in mind as I develop the story below.

of a mine by $y = f^\tau(k, \mathbf{m}, l)$, where y is the tons of iron-ore produced, τ denotes the type of iron-ore produced, f^τ is the production technology, k is the capital stock, $\mathbf{m}$ is a vector of purchased "materials" (including energy, materials and outside contract labor) and l is the mine labor input.[6] I assume that $l = g(e, \gamma, \lambda) \cdot h$, where h is hours worked, e is effort per hour worked, γ is the efficiency of effort and λ is an indicator of average human capital or skill. I show that a long list of "traditional" factors contributed little, if anything, to the gains in labor productivity, in y/h. This list is: changes in production technology, changes in the types of iron-ore produced, closing of mines, high-grading mines, increases in capital per hour worked, in k/h, and increases in materials per hour worked, in $\mathbf{m}/h$. Labor productivity gains were primarily driven, then, by increases in labor input per hour worked, in $l/h = g(e, \gamma, \lambda)$. I argue that these increases were primarily due to significant increases in e and γ brought about by changes in work rules in these industries in the 1980s.[7]

The work rules in these iron-ore industries were largely inherited from those in the U.S. steel industry. The rules involved a tremendous degree of specialization. Not only were jobs narrowly defined but there was little crossing of job boundaries: boundaries were strictly patrolled and enforced. Both the union and management supported this limited crossing of boundaries.[8]

[6]Bold letters denote vectors. Also, I discuss the properties of f^τ as they become relevant below. For example, I discuss the extent of substitution possibilities between capital and labor when I present data on increases in capital per hour worked. For now, I just assume f^τ is increasing in its arguments.

[7]Skill levels depend in large part on experience. Though I do not have data on average experience, below I make an argument for why increases in average experience, in λ, likely played only a small role in the gains in labor input per hour. But since the argument is indirect, I leave some "room" for λ in the gains, and so I say that increases in productivity were "in large part" driven by increased effort and increased efficiency of effort.

[8]Hoerr states that it was not only union rules that did not permit crossing of job boundaries, of a machine operator screwing in a light bulb, which was the in the job description of an electrician. According to Hoerr, "union rules — and company rules, for that matter — forbade the crossing of job boundaries." (Hoerr, 1988, p. 303.)

A key motivation for specialization of labor, of course, is that it leads to improvements in efficiency of effort, in γ. Specialization, at least initially, increases γ. But because of problems coordinating work, especially given strict job boundaries, specialization will lead to idle periods and hence lower effort per hour worked. I will sometimes write $g(\cdot)$ as $g(e, \gamma, \lambda) = e \cdot \gamma \cdot \lambda$. Specialization beyond some point may lead to lower $e \cdot \gamma$.

The work rules in these industries also involved a sharp and artificial distinction between production work and repair/maintenance work.[9] Machine operators, for example, were not permitted to perform even the simplest maintenance work on their machines. If a machine became inoperable then repair staff would have to be called (even if the operator was able to restart the machine). If repair staff traveled to jobs that did not require their expertise, then such effort was redundant, that is, reduced γ.

The work rule changes in these iron-ore industries in the 1980s undid some of the specialization of labor. These changes involved "job combinations," whereby the job descriptions and responsibilities of a number of different jobs were "rolled" into a single combined-job. The work rule changes also began to break down the artificial distinction between repair and production work. New contracts called for the creation of the "equipment tender" job. Equipment tenders were to be machine operators that were allowed to perform simple repair and maintenance of their equipment.

What is the evidence that these changes led to increases in labor input per hour?[10]

[9] Hoerr (1988) discusses work rules in the U.S. steel industry and states that because a "sharp division existed between production work and maintenance work," a "machine operator .. [was] not allowed under union rules to screw in a light bulb but must wait for an electrician." (p. 314) Though Hoerr discusses the steel industry, work rules in the iron-ore industry had similar sharp distinctions between production and repair work. See also Arthur and Smith (1994) for a discussion of work rules in the steel industry.

[10] Here I am talking about evidence beyond the fact that I have ruled out most other "traditional" sources for the gains.

By breaking down the distinction between repair work and production work, equipment tenders were now allowed to complete simple repair work. The repair staff did not need to travel to jobs that did not require their expertise. Redundant effort was reduced; repair-effort efficiency γ increased. The equipment tender job also clearly increased effort per hour worked e of the machine operator. If a machine became inoperable before the changes, a repair person needed to be located, travel to the machine, and then bring the machine to operable condition. Through all this the machine operator would be idle. Now, with an equipment tender, if the operator is able to restart the machine without repair staff the idle period for the operator is eliminated.

For both non-repair and repair staff, the increased responsibilities in the combined-jobs, given that there were significant idle periods before the changes, meant that e increased. The combinations also possibly led to reductions in γ. But given the very substantial idle periods prior to the changes, its hard to imagine that increased effort didn't overwhelm any reductions in γ. The overall effect of job-combinations was to increase $e \cdot \gamma$.

There is another way to look for evidence that work rule changes had significant impact on labor input per hour. The majority of the job combinations in the mid-1980s were in the repair staff at the mines. If job-combinations were to increase $e \cdot \gamma$, then, everything else equal, they should have decreased the share of repair staff in total employment.[11] Moreover, the equipment tender job, by reducing redundant effort by repair staff, was to have the

[11] The first industry person I talked to about the crisis and recovery was Joe Samargia, the president of the United Steelworkers of America (USW) local at Minntac (the USX mine in Minnesota) during the late 1970s (who now is a lobbyist for Minntac). I asked his opinion about whether changes in work rules were the major source of productivity gains. He suggested that I look at the repair shops. He basically said: "If you drive a truck, you drive a truck. Work rule changes would only have so much influence there. The real possibility for gains were in the repair staff where the work rules could influence the pace of work."

same effect. Prior to the work rule changes, the repair staffs in these industries were about 50 percent of employment. I present evidence below that there indeed were significant reductions in the repair staff at these mines: at the biggest Minnesota mine, the repair staff fell from about 50 percent of the workforce to 25 percent in a few years!

These work rule changes occurred during a period of crisis in the industries: foreign competition threatened to close the entire industry.[12] While below I discuss a few possible theoretical explanations for why these changes occurred during the crisis, let me briefly discuss one idea that can be traced back forty years to Becker (1957) and Alchian and Kessel (1962). All jobs involve a mix of pecuniary and non-pecuniary payoffs. It may be that a firm or industry with monopoly power may face restrictions in its ability to pay pecuniary returns to itself.[13] In the case of iron-ore, producers have monopoly power in their local area given that transportation costs typically loom very large in delivered charges. Given that mining is tied to the local area (because of the resources), the local political jurisdiction can extract significant portions of monetary profits (see Kolstad and Wolak (1983)). This, then, is the restriction or constraint on pecuniary payoffs: make a lot of profits and watch them be taxed. Given this constraint, the monopoly chooses to take more return in the form of non-pecuniary payoffs than would otherwise be the case. This might be in the form of leisure on the job (low effort) or even possibly redundant effort if jobs can be given to family, friends, etc.

[12] Section 2 clearly shows that these industries faced a crisis in the early 1980s. The argument that it was the crisis that spurred the changes increasing productivity is strengthened by showing that other major iron-ore producers that did not face such a crisis, like Australia and Brazil, had little or no change in their labor productivity. This is shown in another paper, Galdon-Sanchez and Schmitz (2000), who examine the productivity records of all the major iron-ore producing countries during this period. Other recent literature showing the influence of competition on productivity include Nickell (1996), Borenstein and Farrell (1999), and Zitzewitz (1999).

[13] Becker (1957) and Alchian and Kessel (1962) stress that many monopolies are government creations and for political reasons pecuniary profits cannot be excessive.

With the crisis, as the local monopoly power is reduced (as foreign producers now find it profitable to ship into the local area given their markets elsewhere have shrunk), some of these non-pecuniary payoffs must be rolled back.[14]

This theoretical argument has wide applicability. That is, wherever there are elements of monopoly, and assuming the monopoly has constraints on its payouts of pecuniary gains, we should expect the collection of rents to be conducted in more non-pecuniary ways than would otherwise be the case. Competition reduces rents and these non-pecuniary payouts are rolled back. This is how I make the jump from the situation studied here to argue that the findings have wide applicability. Below, I very briefly discuss a few other industries that support this theoretical contention.

2. Crisis and Recovery In U. S. and Canadian Iron-Ore Industries

Here I describe the early 1980s crisis that threatened the operation of much of the U. S. and Canadian iron-ore industries and then outline their dramatic recovery in the mid-1980s.[15]

In the early 1980s, the world steel market collapsed. As shown in Figure 1, the top panel, world steel production (noncommunist) fell twenty percent between 1979 and 1982 and by the end of the decade had barely regained its 1979 level. Steel production in the United States and Canada fared much worse: it fell by about 43 percent between 1979 and 1982 and by the end of the decade was still only about 70 percent of its 1979 level (Figure 1, the bottom panel). Figure 1 shows that steel production in Northern Europe also fared poorly,

[14] As shown below, the (relative) wages in these mines decreased significantly during this period when work rule changes were introduced and effort levels increased. The jobs in these mines were still highly valued even after these decreases in wages and increases in effort. Attempts were made to induce early retirements (by increasing retirement benefits to senior employees) but few workers took advantage of the program. Also, accident rates did not increase suggesting that effort was not increased to unsafe levels.

[15] In this section I present a brief outline of the crisis and recovery. More details can be found in Galdon and Schmitz (2000).

while in Japan, Taiwan and South Korea, production dropped much less and soon recovered its precrisis level.[16]

The worldwide drop in steel production was attributed to, among other things, an accelerated substitution of plastics for steel in cars following the gas price increases of the 1970s. The shift of this shrinking market away from the United States (and Europe) and toward the Pacific was attributed to, among other things, the strong U.S. dollar and the rapidly growing Asian economies. But, in any case, for iron-ore producers these developments in the steel industry were exogenous. Iron-ore producers had very little influence over how much steel was produced in the world or where it was produced.[17] The cost of the iron-ore used in steel amounts to only about ten percent of steel's selling price.

The crisis in the U.S. and Canadian iron-ore industries was much worse than suggested by the twenty percent drop in world steel production. Two reasons made the situation more dire. First, transport costs typically make up a very large share of delivered prices of iron-ore.[18] Hence, for many iron-ore producers, like those in the United States and Canada, most production was for local markets (namely, steel producers in the U.S. Great Lakes region).[19]

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[16]This steel production data is from the *United States Geological Survey's (USGS) Mineral Yearbook* (various years).

[17]Beeson and Giarratani (1998) show that regional variation in raw materials prices (including iron-ore) was not an important factor in determining the location of capacity reductions in the U.S. integrated steel industry over the period 1974-91

[18]Galdon and Schmitz (2000) present tables showing transport costs from most of the major iron-ore producing countries to most of the major steel producing countries. For example, from Table 2, the Brazilian company MBR received $9.81 at the mine in 1994 for a ton of iron-ore destined to Europe. The table also shows that railroad charges from the MBR mine to the port were $7.00 a ton. The costs of ocean shipping to Europe were $6.50 a ton. Hence, the delivered price in Europe was $23.31 a ton; the costs of shipping were $13.50 a ton. That the transport costs are so large a share of delivered cost is not unusual in the iron-ore industry. The table also shows that the ocean cost of shipping to Chicago was $24.35 a ton. The costs to Chicago are so high because the ocean transport involves the moving of ore from very large ocean vessels to smaller vessels that can manuever on the St. Lawrence Seaway.

[19]In the United States, iron-ore production has always been concentrated in the Great Lakes region (in the two states of Minnesota and Michigan). This iron-ore had traditionally been shipped to steel producers in the Great Lakes region (e.g., Chicago and Cleveland), in Pittsburgh and on the east coast. But by the late

Hence, the crisis in the early 1980s is better reflected in the 43 percent drop in local steel production, not the twenty percent drop in world steel production.

But the situation was even more dire than the 43 percent drop in local steel production because the United States and Canada were high-cost iron-ore producers.[20] Low-cost iron-ore producers that had lost markets elsewhere (most prominently Brazil, which had lost markets in Europe) were now threatening to take a share of this shrinking local market.[21] Brazil was threatening to take a larger share of the shrinking U.S. east coast market from the Canadians. In fact, in the early 1980s the Brazilians were even threatening to gain their first foothold in the U.S. Great Lakes steel market.[22]

The crisis can clearly be seen in Figure 2, in the path of iron-ore output in the two countries. Iron-ore output, measured in physical units, fell on the order of fifty percent in the United States and Canada over 1979 to 1982. The situation in the early 1980s was clearly dire.[23] Two of Minnesota's eight taconite (a type of iron-ore discussed below) mines were

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1970s, the market for the Great Lakes iron-ore had shrunk to primarily the Great Lakes and Pittsburgh steel producers. To move Great-Lakes iron-ore to the east coast required substantial transportation charges: the iron-ore either had to move over land or up the St. Lawrence Seaway (where "small" ships were involved), charges that pushed the delivered price of Great Lakes iron-ore above competitive levels. By the same token, these producers were "protected" in the Great Lakes steel market by the high tranport costs into the Great Lakes region.

In Canada, in the late 1970s, production was centered in two regions of eastern Canada: one region in Ontario, near the Great Lakes, the other in Quebec, in Labrador. Canadian Great-Lake production was shipped primarily to Great Lakes integrated steel mills. Production in Labrador was also shipped to integrated steel producers in the Great Lakes, but since it was above the St. Lawrence Seaway and iron-ore could be loaded onto the biggest ocean carriers, it was shipped as well to the U.S. east coast and to Northern Europe.

[20] See Galdon and Schmitz (2000) who show that the United States and Canada were high-cost producers (see, e.g., Tables 3 and 4).

[21] Another threat to the industries were the minimills that produced steel using scrap metal and very little virgin iron-ore. In the next version, I will document this threat.

[22] 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."

[23] Galdon and Schmitz (2000) argue that the period following the slump in U.S. steel production in 1974 was not considered a crisis period by iron-ore producers. They show that iron-ore prices continued to climb

closed during this period, and the other mines were threatened with closure.[24] In response to this crisis, the industries engineered a dramatic recovery, with output recovering to about eighty percent of its precrisis level and labor productivity, that is, output per hour, doubling.[25]

A PaineWebber study (1987) of the North American Iron-Ore industry presented a list of "some of the reasons for this dramatic improvement [in labor productivity]." The list was (p.I-51):

- computerized pit dispatching
- increased flexibility in job classification
- grouping vacations so that plants are only temporarily shut down
- changes in work assignment
- reduction or delay in plant repairs and maintenance schedules
- increased pace of work by both management and labor

The purpose of this PaineWebber report was not to examine the determinants of the increases in labor productivity in these industries. So, the only information about the sources of the gains was this list and it was presented without discussion.

While no ranking of these six sources of productivity gain was given, it seems clear that some of the sources, like grouping vacations, were only of minor importance. Computerized pit dispatching, clearly an improvement in production technology, presumably led to more

in the 1970s. In the early 1980s, (nominal) iron-ore prices fell by about a third (see Figure 2, Galdon and Schmitz (2000)).

[24] For example, U.S. Steel's iron-ore mine, Minntac, was threatened with closure (Wayne Dalke, the general manager of Minntac mine during the crisis, indicated that U.S. Steel was considering closing the mine).

[25] The production (in metirc tons) and hours series in Figure 2 for the United States are from the *United States Geological Survey*. For Canada, *Natural Resources Canada* publishes a production (in metric tons) series, an hours series for production workers, and a total employment series. In Figure 2, I use the total employment series to calculate productivity. The average hours worked by production workers changes very little over time.

efficient deployment of trucks and to fewer hours of trucker's time (for a given amount of material moved). But its impact on overall productivity was likely very small.[26] Reductions or delays in repair likely had significant impact on productivity, but repair schedules had to be resumed and this source of gain could not persist more than a few years.

This leaves three sources of gain that might have had a large impact on productivity over a long period of time. One is increased pace of work or increased effort. The last two, changes in work assignment and increased flexibility in job classification, can be roughly grouped into changes in work rules. Changes in work rules can lead to changes in effort per hour worked and in efficiency of effort. So, the three potential major sources of gain are really two: increased effort and increased efficiency of effort.[27]

This, then, is the rough outline of the crisis and recovery in the U.S. and Canadian iron-ore industries, as well as the views of industry experts who were on the "ground" at the time of the recovery as to the sources of the productivity gains. In the remainder of the paper I present evidence that increases in effort and efficiency of effort were indeed the major sources of the productivity gain. I first show that a long "list" of traditional factors contributed little, if anything, to productivity gains. I then present direct evidence that increases in effort and in efficiency of effort made significant contributions to the gains.

[26] I say this because employment in the actual mine or "pit" where trucks operated accounted for only a small share of employment in most mining operations in the United States and Canada prior to the crisis. Below I give a brief discussion of the layout of mines but here let me say that at the Minntac mine in Minnesota before the crisis, employment in the pit accounted for 20 percent of employment, plants (where iron-ore is processed) accounted for 25 percent and the repair shops 55 percent. I discuss other mines below. Moreover, employment in the pit inlcuded not only truckers, but those that worked loading and those that worked with explosives.

[27] Effort may increase because of a change in work rules or simply because workers were scared. But presumably the lasting influences on effort are the work rule changes.

3. New Technology and New Products?

Here I argue that changes in production technology and in the types of iron-ore produced contributed very little, if at all, to the productivity gains in the middle 1980s.

There are three major products of iron-ore mines: lump, fines (or concentrates) and pellets. After iron-ore is mined, it must usually undergo beneficiation. This is a process of crushing and screening the iron-ore to produce uniform sized particles, improve the iron content of the product and eliminate impurities. If this process can be done in a way that yields a relatively coarse product, then the product, *lump* iron-ore, is shipped for direct use in blast furnaces.[28] If the product is not coarse enough, then the iron-ore must undergo agglomeration before being used in blast furnaces (since fine particles can cause operational problems in blast furnaces). Some of this fine beneficiated iron-ore is called *fines* (or *concentrates*). This product is typically shipped to blast furnaces before it undergoes agglomeration (it is agglomerated into sinter). Some of the fine beneficiated iron-ore is agglomerated into pellets. This is typically done at the mine and the *pellets* are then shipped to blast furnaces.

The major technological breakthrough of the 20th century in the world iron-ore industry was the development of this last product, pellets. Strong economic growth in the United States, together with the large demands of WWII for iron-ore, led to a depletion of the U.S. lump iron-ore deposits over the first half of the 20th century. With the expected depletion of these high-grade (i.e., high iron content), easy-to-mine and easy-to-beneficiate deposits, the future of the U.S. and Canadian iron-ore industries was in doubt after WWII. New products had to be developed to replace the vanishing lump deposits (which were still available in some parts of the world and had not been mined). What remained in the United States, once the

[28] Blast furnaces are where iron-ore is processed into pig iron for use in making steel.

lump ore deposits were depleted, were deposits of very hard rock, like the taconite deposits in the U.S. Great Lakes region, that contained very small amounts of iron (about 20 percent iron, whereas lump ore contained 50-60 percent iron). The technological breakthrough was to develop a way to turn these deposits into a product, pellets, that could compete with lump iron-ore and other iron-ores. This process was developed in the United States and Canada and most of the technology was developed by the late 1950's.

Besides the development of pellets, there have been no dramatic changes in the technology for producing iron-ores over the last forty years. There have been gradual improvements in technology, of course, and these gradual improvements have led to much better iron-ore products and higher productivity. Examples of such improvements include the gradual increase in size of equipment and the gradual integration of computers into the production process, like the use of computers in pit dispatching mentioned above. But these improvements have been gradual and no dramatic change in technology occurred in the middle 1980's that caused the productivity surges observed in Figure 2. The technology in this mature industry changes very slowly.[29]

Changes in the types of iron-ore produced in these countries also cannot account for any of the productivity gains. In fact, during the 1980s there were shifts to products that required more labor per ton to produce. First, more pellets were produced in each country in the 1980's than in earlier years and, given the hardness and low grade of the rock deposits

[29] In contrast to the iron-ore industry, the steel industry, which also had significant labor productivity gains in the 1980's in the United States, underwent some major technology changes in the 1980's. 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 big changes in the way steel was produced. For example, integrated plants introduced continuous casting at a rapid rate.

that are processed into pellets, more labor is required to produce a ton of pellets than a ton of the other two iron-ores.[30] What this move to pellets suggests, then, is that the productivity gains in producing *each* type of iron-ore was greater than the aggregate productivity gains in Figure 2. In this sense, the productivity gains in Figure 2 are understated. In the next section, we show that productivity in producing a particular product in Minnesota, pellets, did increase at a faster rate than the U.S. national total. Second, there was an improvement in the pellets produced in Minnesota over the period. In particular, limestone began to be added to the pellets (the pellets are called flux pellets) and this added to the labor required per ton of pellets.

4. Closing Low Productivity Mines and High-Grading Mines?

Here I study mine level data from Minnesota to examine whether productivity gains were due to low productivity mines being closed. I also discuss the issue of high-grading mines, that is, the possibility that the productivity gains were driven by mines switching to the "easiest-to-mine" deposits.

In 1980, there were eight Minnesota taconite pellet mines. These mines accounted for 95 percent of Minnesota production (there was a bit of concentrate produced in Minnesota) and 62 percent of U.S. iron-ore production. The output and labor productivity of the Minnesota taconite industry (that is, the industry composed of these eight mines) is given in Figure 3.[31] The output and productivity of this industry closely mirrors, not surprisingly,

[30] In the United States, pellets accounted for 64.5, 80.6 and 93.1 percent of production in 1970, 1975 and 1980; in 1985 and 1990, they accounted for 96.4 and 97.2 percent. In Canada, pellets accounted for 55.6, 54.3 and 52.3 percent of production in 1970, 1975 and 1980; in 1985 and 1990, they accounted for 61.4 and 63.9 percent.

[31] Production data (in tons) by mine is obtained from the Minnesota Department of Revenue. Hours data by mine is obtained from the mine inspectors in each Minnesota county where mines are located (primarily St. Loius county). Productivity is hence in tons per hour (in Figure 3 and Figure 4).

that of the U.S. national industry. As mentioned above, the productivity gains in the 1980s in this industry were greater than in the national industry.

The output and labor productivity in each Minnesota taconite mine is presented in Figure 4. 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, a period of industry expansion (Hibbing and Minorca). As a result of the crisis in the early 1980s, two mines were closed during the middle 1980's, even though both had showed productivity gains (Butler and Reserve). Butler was closed in 1986 and remains closed. Reserve was closed in 1987 and reopened in 1990 as a nonunion mine and at higher productivity levels.[32]

The output and labor productivity pattern at each mine mirrors, fairly closely, the industry pattern, though the increase in productivity differs across mines. The productivity gains between 1980 and 1987 (the peak productivity year) at the six continuing mines ranged from 50 to 150 percent: Erie/LTV (76 percent), Eveleth (51), National (140), Hibbing (85), Minorca (119) and Minntac (149). So, Figure 4 suggests that industry productivity growth was driven in large part by continuing mines.

A formal labor productivity decomposition shows this. Let y_{it} and h_{it} denote output and hours at mine i at date t, respectively. Denote mine labor productivity by $\pi_{it} = y_{it}/h_{it}$. Define industry productivity Π_t to be a weighted average of the π_{it}

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

where s_{it} is the share of mine i in a particular industry variable. I consider both $s_{it} = y_{it}/Y_t$

[32] While only two mines closed, other mines shut down production lines during the crisis as they weighed the full closure decision.

and $s_{it} = h_{it}/H_t$, where $Y_t = \sum_{i \in M} y_{it}$ and $H_t = \sum_{i \in M} h_{it}$ denote industry output and hours and M_t denotes the set of mines in operation at date 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:

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

where $C_{t,t'}$ is the set of mines that operated in t and t' (continuing mines), $E_{t,t'}$ is the set of mines that operated in t' and not t (entering mines), and $X_{t,t'}$ is the set of mines that operated in t and not t' (exiting mines). There are five terms in the decomposition. Let $term_j$ refer to the jth 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 due to the continuing mines increasing their productivity (often called the within mine term). The second term is the increase in productivity resulting from the above-average continuing mines expanding their industry share relative to the below-average productivity mines (often called 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 in productivity due to entrants (which is zero in this case since there are no entrants).

Table 1 gives information on the decomposition between the base year $t = 1980$ and years $t' \in \{1981, ..., 1995\}$. In part A, I use a mine's share in industry hours in the decomposition; in part B, I use a mine's share of industry output. 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 four present the share of the percentage productivity gains (or share of the loss) due to the corresponding term, that is, $\frac{term_j}{\Delta\Pi} \times 100$, $j = 2, 3, 4$.

Both parts of Table 1 show that productivity gains due to closing mines were very small and that the overwhelming source of industry productivity gains were from within mine gains. The last column shows that closing mines never contributed more than 7 percent of the gains between any two years and most often nothing.[33] The share of industry productivity gains due to continuing mines after 1984 was never less than 73 percent when hours are used as the weights and 80 percent when output shares are used. Typically the share due to continuing mines was much larger.

Perhaps these mines were able to increase productivity by switching to "easier-to-mine" iron-ore deposits when the crisis hit (the mines may have been "high-graded"). Let the total material moved at a mine be denoted w. Total material moved includes overburden (waste that is cleared in preparing to mine the ore) and the iron-ore that is delivered to the plants to be beneficiated. The iron-ore that enters the beneficiation process is typically called *crude iron-ore*, which I denote by x. The product that is sold and shipped from the mine, sometimes called *usable iron-ore*, was denoted y above.[34] Data is available on the ratio x/y for both the United States and Canada at the industry level. This ratio increased through the 1980s in both countries. This was primarily a result of the increase in pellets as a share of output (pellets require much more beneficiation than the other ores). At individual pellet

[33] 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.

[34] Obviously the tons of material moved exceeds the tons of crude ore delivered to the plants which exceeds the tons of the product shipped from the plants.

mines in Minnesota, as far as I know, there is not much room to change this ratio x/y (that is, the deposits of crude ore do not vary much in the iron content of the ore).

There is no publicly available information on material moved. But if mines simply stop removing overburden from fields, this would lead to drops in the ratio w/y. But productivity gains that result from failure to clear overburden can only last so long. Figure 4 shows that for most Minnesota taconite mines that remained open, production in the middle to late 1980s returned to previous levels, so that clearing of overburden returned to precrisis levels.

5. Shifts in Structure of Employment

The next possible source of productivity gain that I consider is increases in capital per hour at the mines, in k/h. For this discussion, it is important that I introduce a significant change that occurred in these industries in the 1980s, namely, a large shift in the structure of employment at the mines. In order to describe this change, let me first introduce a more detailed production structure at the mines.

There are three major "locations" at a typical iron-ore mining facility. First, there is the mine (or pit) where waste material is cleared, where crude iron-ore is mined and which delivers crude ore x to the plants for processing. Second, there are the plants where crude iron-ore from the mine is beneficiated and agglomerated into usable iron-ore y. Finally, there is the maintenance and repair shops which provide repair services, which I denote z, to both the mine and plant. For the points I want to make, I will aggregate the mine and plant together and refer to them as location one, with the repair shops location 2.

I express the usable iron-ore y produced at the plants as

$$y = f_1(k_1, \mathbf{m}_1, l_1, z)$$

where the subscript "1" denotes the mines and plants, $(k_1, \mathbf{m}_1, l_1)$ is the capital, materials and labor input used at the mines and plants and z is the repair services provided by the repair shops to the mines and plants (where I drop τ).[35] I assume that $l_1 = g(e_1, \gamma_1, \lambda_1) \cdot h_1$ and similarly for l_2 below.

The repair services z provided by the repair shops is given by

$$z = f_2(\mathbf{m}_2, l_2)$$

where m_2 and l_2 are the material and labor inputs at the shops devoted to producing repair services for the mines and plants. I assume that the only inputs at the shops are labor and material inputs. Maintenance and repair staff clearly have some capital, such as their tools, but the capital in the shops is extremely small compared to the capital in the plants and mines. So, the specification above is an approximation meant to capture that very little capital, as a fraction of the total, is employed in the shops.

The production function $y = f(k, \mathbf{m}, \mathbf{l})$ introduced above is then just

$$y = f(k, \mathbf{m}, \mathbf{l}) = f_1(k_1, \mathbf{m}_1, l_1, f_2(\mathbf{m}_2, l_2))$$

where $k = k_1$, $\mathbf{m} = (\mathbf{m}_1, \mathbf{m}_2)$ and $\mathbf{l} = (l_1, l_2)$.

Prior to the crisis in the early 1980s, the repair staff accounted for a very large share of employment at most iron-ore mines. In the Minnesota taconite mines, repair staffs were on the order of 50 percent of employment. For example, in the Minntac mine prior to the crisis,

[35] The capital in the mines includes drilling and blasting equipment, trucks and trains to transport crude ore, and equipment to load ore onto the transport equipment. The material used at the mines include electricity, gas, steel wear parts, and explosive materials. The capital at the plants is composed of the equipment that is used to crush, beneficiate and agglomerate the crude ore, as well as the structures that hold that equipment. The material used in the plants include electricity, gas, steel wear parts, and binding materials used in agglomeration.

the repair staff accounted for 50-55 percent of total hours (depending on the year), while plant hours varied between 25-30 percent and mine hours between 15-20 percent. Learmont (1982) presents employment distributions for the Minorca and Eveleth mines. For Minorca, in 1983, the distribution was: repair (52.5 percent); plants (29.5); and mines (18.4). For Eveleth, where the exact year in the early 1980s is not presented in the report, the distribution was: repair (46.5 percent); plants (21.2); and mines (32.3). So, before the crisis, repair hours made up roughly 50 percent of total hours in all three mines.[36]

During the crisis, there was a large shift in the hours worked by location at these iron-ore mines. The best information I have on this shift comes from the Minntac taconite mine in Minnesota. In Figure 5, I plot the share of hours by location at the Minntac pellet plant. Again, before the crisis, maintenance and repair hours were approximately 50-55 percent of total hours, while plant hours varied between 25-30 percent and mine hours between 15-20 percent. After the crisis, maintenance and repair hours were approximately 28 percent of total hours, while plant hours were about 44 percent and mine hours 28 percent.[37]

For Canada, I have information on repair spending in the iron-ore industry. I argue in the Appendix that this Canadian data also indicates a drop in repair staffs as a fraction of total employment. I return to discuss these changes in the distribution of employment at the mines when I discuss changes in work rules. But for now, I continue to discuss "traditional" sources of productivity gain.

[36] Minntac's repair staff may have been a bit bigger than the average because (1) Minntac still had some very small non-pellet operations and the repair staff at the pellet mine provided services to this operation and (2) Minntac had an apprentice program for repair staff.

[37] 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 5.

6. Increases in the Capital-Labor Ratio?

Here I discuss the extent to which increases in the capital-labor ratio raised industry labor productivity. I plot the real capital stock in the Canadian iron-ore industry, which I denote K_t, in Figure 6. It fell by about one-third over the decade.[38] But the capital stock did not fall as fast as industry employment, so industry capital per worker, K_t/H_t, doubled over the decade.[39] While this is a significant increase in capital per hour, I argue here that this increase was likely not an important source of industry productivity gain. I give three reasons (discussed in the three subsections below). First, the increase in capital intensity was primarily driven by changes in the share of employment by location at the mines — capital per hour at the plants and mines (where capital is employed) went up much less than suggested by Figure 6.[40] Second, to the extent that capital per hour increased at the plants and mines, there were few substitution possibilities between capital and labor. Third, since as I argue below, effort per hour increased in the industry, then capital per effective hour (hours multiplied by effort) at the mines and plants increased even less than capital per hour.

A. Compositional Changes Increased the Industry Capital-Labor Ratio

As shown in the previous section, the greatest reductions in staff were of workers that employed little capital in their jobs, that is, the repair staff. So, capital per hour at the

[38] In United States, the Census of Mineral Industries provides a capital stock estimate and an investment number every five years for the U.S. iron-ore industry. However, both the capital stock and invesmtent figure are in current dollars so that it is not possible to obtain any real capital stock estimates (even if only at five year intervals).

[39] As I mentioned above, for Canada I only have an hours series for production workers. Hence, I use total employment in Figure 6. As I also mentioned, average hours for production workers changed very little over the period. Rather than introduce new notation for employment, in the remainder of this section I continue to use the hours notation.

[40] If, for example, a mine consisted of one truck, two drivers, and two repair staff before the crisis, then if a repair person was let go, capital per hour at the mining operation would increase but not the capital per hour of those using capital.

mines and plants, where capital is employed, increased at a much slower rate than the overall increase depicted in Figure 6.[41]

In order to see this, suppose for simplicity that there was a single mine in the industry. Let h_1 and h_2 denote the hours at each location (plants and mines, and repair shops, respectively), where $h = h_1 + h_2$. Recall that $k_1 = k$ and $k_2 = 0$. Consider the (gross) growth rate in capital per hour at the industry level and at the location level between two periods. I denote "next" period's variables with a "prime" (that is, k' is next period's capital), while unprimed variables are the current period variables. These two growth rates are, respectively,

$$\frac{k'}{k}(\frac{h'}{h})^{-1} \qquad \text{and} \qquad \frac{k'}{k}(\frac{h_1'}{h_1})^{-1}.$$

A typical mine lost about half its hours over the crisis period. So, normalizing total hours to one, I assume that $h = 1$ and $h' = 1/2$. Let me take the changes in the distribution of hours at Minntac to be representative of the industry. From Figure 5, repair hours before the crisis were roughly half of total hours, hence $h_1 = 1/2$ and $h_2 = 1/2$. After the crisis, repair hours were roughly 25 percent of hours, hence $h_1' = 3/8$ and $h_2' = 1/8$. I can rewrite the growth rates in capital per hour at the industry level and at the plants and mines as

$$2 \cdot \frac{k'}{k} \qquad \text{and} \qquad \frac{4}{3} \cdot \frac{k'}{k}.$$

At the industry level, growth in capital per hour is double the growth in industry capital, while in the mines and plants, it is only four-thirds times as big as the growth in industry

[41] As an example of a production function, suppose I write $y = f(k, l_1, l_2)$ as

$$y = f(k, l_1, l_2) = f(\widetilde{f}(k, l_1), l_2)$$

where f is homogeneous of degree one (hod-1) in $\widetilde{f}$ and l_2, and $\widetilde{f}$ is hod-1 in k and l_1. I can then write

$$y = f(\widetilde{f}(k, l_1), l_2) = f(h_1 \widetilde{f}(k/h_1, g_1), l_2)$$

which emphasizes that labor productivity y/h depends on capital intensity at the mines and plants.

capital. If there was no change in industry capital, then industry capital per hour would double, while capital per hour at the mines and plants would increase by one-third.

There were also small shifts in the type of iron-ore produced in Canada during the 1980s that increased industry capital per hour. In particular, the share of pellets in production increased from about 50 percent to 60 percent over the decade. The capital per hour worked at pellet plants is significantly higher than at other iron-ore mines.[42] Capital per hour may be as much as four times higher in pellet mines as compared to lump mines.[43]

Hence, for these two reasons, the reduction in repair staff as a fraction of total staff and the small increase in pellets as a fraction of output, the growth in industry capital per hour exceeded, and likely by a large amount, the growth in capital per hour at the plants and mines of a given facility. I, unfortunately, do not have the data to make a more precise statement. But just as important as these compositional changes is the fact that there was not a lot of substitution possibilities between capital at a location and labor.

B. Limited Substitution Possibilities

What were the substitution possibilities between capital and labor at the various locations at these mines? In the mine or pit, there are clear substitution possibilities between, for example, truck size and labor input. Larger trucks mean fewer truck drivers for a given

[42]Each type of mine has capital in the pit or mine itself (e.g., trucks and loaders). But the capital involved in the processing plants at pellet mines is massive, involving crushing and agglomerating equipment, as well as the massive structures that house this equipment. The capital per hour worked in these pellet plants is much larger that the capital per hour in other processing plants. It is also much larger than the capital per hour in the pits.

[43]Kakela (1978, pp. 1152-53) briefly discusses the capital costs of building pellet and lump capacity. He argues that the capital costs per annual ton of capacity for pellets was about five times that for lump. This gives an estimate of relative capital-output ratios, that is, $(k^p/y^p)/(k^l/y^l)$, p for pellets, l for lump. He also argues that (physical) output per hour in pellets was about three-fourths of that in lump ore. This provides an estimate of relative labor productivites $(y^p/h^p)/(y^l/h^l)$. The product of these two ratios (of five and three-fourths), gives a very rough estimate of the relative capital per hour.

quantity of ore x to be delivered to the plants. In making investment choices, these substitution possibilities are clearly an important ingredient in the analysis. Over very short periods of time, or during periods when new investment is not planned, however, there are limited substitution possibilities between trucks and labor input. This is true of the other capital at the mines. So, substitution possibilities depend on the planning horizon and the extent that investment is planned.

Given that the capital stock fell in Canada over the 1980s, this suggests that investment in new and bigger trucks, for example, was not robust. It is conceivable that the industry purchased significant amounts of new equipment in the 1980s and that the capital stock fell because the industry retired tremendous amounts of old equipment. While this might be theoretically possible, the information I have on investment in the industry indicates this was not true.

I have two sources for investment data. From Natural Resources Canada, I have a time series on investment but its only available on a continuous basis from the late 1970s.[44] For earlier periods, only a few observations are available. From Statistics Canada, I have a time series on investment less discards (in constant dollars). Discards is that capital which is retired before it is fully depreciated.[45] The extent of discards is determined from a formula based on previous levels of gross investment (see bibliography reference to *Statistics Canada* for a description of discards). I plot both these series in Figure 7.

Looking first at the period since the late 1970s, investment was running between 200

[44]The investment series is taken from the *Canadian Minerals Yearbook (CMY)*. The *CMY* series is in current dollars; I deflate that series by the investment price deflator for the iron-ore industry from Statistics Canada.

[45]For disclosure reasons, Statistics Canada provided me with the series "investment less discards" but not with the series "investment."

and 400 million dollars in the late 1970s and fell to around 150 million for much of the 1980s. Clearly, investment in the 1980s was much weaker than in the late 1970s.

Comparing investment in the 1980s to that in the period before the late 1970s is not as straightforward. On the basis of the limited investment data, in the late 1960s, investment was running at about 200 million, stronger than the 1980s. In the middle 1970s, investment was very strong as compared to the 1980s.[46] Looking at the investment less discards series, it is lower in the middle 1980s than in any other period. All this suggests that investment was weak in the middle 1980s. Hence, given that new equipment purchases were not significant by historical standards, there were likely few gains to labor productivity from the increases in capital per hour that were brought about by reducing the hours at the mines.[47]

C. Increases in Effort

The first subsection argued that the increase in capital per hour at the mines and plants, k/h_1, was much smaller than at the industry level. If, as I argue below, effort per hour increased in the industry, then capital per effective hour (hours multiplied by effort) at the mines and plants increased even less still.[48]

7. Substitution of energy, materials, outside labor for mine labor?

Here I discuss the extent to which increases in purchased inputs per hour worked, including energy, materials and contract labor, increased labor productivity. The evidence

[46] In both the U.S. and Canadian industry, there was considerable new investment in the late 1970s because the U.S. steel market was expected to return to significant growth. That never happened.

[47] Continuing with the above example, the claim that there was little substitution between capital and labor in the middle 1980s is a claim about the properties of the $\widetilde{f}(k,l_1)$ function.

[48] Continuing with the above example, I can write

$$y = f(\widetilde{f}(k,l_1),l_2) = f(e_1 h_1 \widetilde{f}(k/e_1 h_1, \gamma_1 \lambda_1), l_2)$$

to emphasize that labor productivity depends on capital per effective hour at the mines and plants.

suggests that such substitution was not an important source of gains.

Let me first discuss the hiring of outside contract labor. There are two ways that contract labor can substitute for employee labor. First, outside contract labor can be utilized at the mines to perform tasks that employees previously accomplished. Second, the company can purchase goods from outside contractors that were previously made by mine employees. Traditionally in these industries the Basic Labor Agreement (BLA) between management and labor gave strong protection against work being contracted out, either by outside contract labor being utilized at the mine or through purchases of goods. For example, in the BLA between Minntac and the United Steel Workers of America, the part that deals with contracting out begins with the section "Basic Prohibition," which states that (p. 11)

> In determining whether work should be contracted out or accomplished by the bargaining unit, the guiding principle is that work capable of being performed by bargaining unit employees shall be performed by such employees. Accordingly, the Company will not contract out any work for performance inside or outside the plant unless it demonstrates the such work meets one of the following exceptions.

The word "capable" is, of course, a pretty strong word in this context. It meant that many of the goods used at the mines in the production process were constructed at the mine.

During the early 1980s, at the height of the crisis, management attempted and sometimes succeeded in getting work contracted out through purchases of goods. But this led to strong union opposition and in the middle 1980s, new BLAs set up detailed guidelines about the type of work contracted out (the "exceptions" above). One item that could be contracted out were so called "shelf items." This is described in the Minntac/USW BLA:

> the Union recognizes that as part of the Company's normal business, it may purchase standard components and parts or supply items, 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 detailed manufacturing instructions supplied by the Company or at its behest or it is otherwise made according to detailed Company specifications. (p.13)

While some exceptions to the basic prohibition against contracting out were permitted, like shelf items, the evidence suggests that these were not important in the productivity gains. Suppose prior to the crisis that the workforce spent significant effort making shelf items. If after the crisis significant quantities of shelf items were purchased, there would have been a reduction in the workforce on this account. But there does not seem to be much evidence for this. Shelf items would either be recorded as purchases of materials or investment. There doesn't seem to have been a dramatic increases in investment, as shown in Figure 7. If the shelf items were recorded as materials, then, as I now show, real-value added per hour would not have increased to the same extent as gross output per hour. But it did.

Suppose I specify the vector of material purchases as $\mathbf{m}_i = (elec_i, \widetilde{h}_i)$, where $elec_i$ denotes electricity and $\widetilde{h}_i$ hours of contract labor at location i. I write production as $y = f(k, \mathbf{m}, \mathbf{l})$ as

$$y = f(k, \mathbf{m}, \mathbf{l}) = f(k, elec_1, elec_2, g_1 \cdot h_1 + \widetilde{h}_1, g_2 \cdot h_2 + \widetilde{h}_2)$$

where I have assumed that one hour of contract labor provides one unit of labor input l. Value added is (assuming the output price is one) $f(k, \mathbf{m}, \mathbf{l}) - (\mathbf{p}_e \mathbf{elec} + \mathbf{p}_w \widetilde{\mathbf{h}}) = f - c$.

Consider the (gross) growth rate in gross output per hour and in real-value added per hour between two periods. I denote next period's variables with a "prime" (that is, h' is next period's mine hours), while unprimed variables are the current period variables. The growth rates are

$$A = \frac{f'}{f}\left(\frac{h'}{h}\right)^{-1} \qquad \text{and} \qquad B = \frac{f' - c'}{f - c}\left(\frac{h'}{h}\right)^{-1}$$

where again $h = h_1 + h_2$ and $c' = \mathbf{p}_e(\mathbf{elec})' + \mathbf{p}_w(\widetilde{\mathbf{h}})'$. Note that the prices are base year prices (and not "primed") since I am calculating real-value added. The growth rate in gross output per hour exceeds that of real-value added per hour, that is, the ratio A/B exceeds one, if

$$\frac{c'}{c} > \frac{f'}{f}.$$

Hence, gross output per hour increases faster than real-value added per hour if the growth in real purchases exceeds the growth of gross output.

The output of most mines after the crisis was about the same as before the crisis. For simplicity, let me assume that $f' \approx f$, which allows me to write

$$\frac{A}{B} \approx \frac{f/c - 1}{f/c - c'/c}.$$

Hence, the ratio is increasing in c'/c. That is, as the extent of contracting out increases, or more generally, the extent to which real purchases increases, the divergence in the growth rates increases, that is, A/B increases.

If contracting out increased dramatically, or if energy substituted for mine labor, then gross output per hour would have grown faster than real value-added per hour. But Figure 8 shows that real value-added per worker increased at about the same rate as gross output per worker in Canada during the 1980s, suggesting that such substitution was not an important source of the productivity gains.

8. Sources of Gain: Increased Effort and Efficiency of Effort

I have shown that a long list of traditional factors contributed little, if anything, to the productivity gains in these industries in the mid-1980s. By a process of elimination, I have shown that the productivity gains were overwhelmingly driven by gains in labor input per hour worked, that is, in $l/h = g(e, \gamma, \lambda)$. In this section, I provide direct evidence that changes in work rules led to significant gains in effort per hour worked and to some gains in efficiency.[49] I then argue that increases in average skill were probably not an important a source of productivity gains.

A. Background: Work Rules Prior to the 1980s

The work design in U.S. and Canadian iron-ore mines prior to the early 1980s was borrowed in large part from work design in the U. S. steel industry. The development of this work design began in the 1920s and culminated in agreements reached by U.S. steel companies and the United Steel Workers of America (USW) in 1947 (see, e.g., Steiber, 1959).

Some of the key principles of this work design were based on the ideas of Frederick Taylor and other industrial engineers of the period. One key principle was the emphasis of specialization. As argued by Piore (p. 52, 1995),

[49] As mentioned, inflexible work rules have been cited as a key reason why the U.S. automobile industry (and the U.S. steel industry) fell behind the Japanese. Also, the recovery of the U.S. steel and automobile industries in the 1980s was attributed, in part, to increases in teh flexibility of work rules. But early studies of work rule changes in the U.S. automobile and steel industries had difficulty showing that work rule changes were indeed important for productivity gains (see, e.g., Katz, Kochan, and Keefe (1987) and Keefe and Katz (1990)). But such analyses are faced with significant obstacles since so many of the other factors that influence productivity were also changing in theses industries in the mid-1980s, like the types of products produced and the production technology. In a careful study, Ichniowski, Shaw and Prennushi (1997) show that the introduciton of "innovative work practices" in steel finishing industries led to productivity gains. If I read them correctly, they argue that the gains were due to increases in the efficiency of effort (γ in the above notation). Nickell and Nicolitsas (1997) study a broad set of manufacturing industries and argue that "falls in market power .... lead to both lower pay rises and a high probability of a reduction in restrictive [work] practices." They also show that reductions in restrictive work practices increased productivity.

> Taylor, and the industrial engineering profession more broadly, emphasized the dimension of specialization, the division of the production process into neat and well-defined pieces with clearly new tasks that could be unambiguously assigned to particular workers or work groups.

The U.S. steel industry, and by association the U.S. and Canadian iron-ore industries, clearly fit this description, of many jobs with narrowly defined tasks, of extensive specialization. There was also strict patrolling of job boundaries. Both the union and management preferred little crossing of jobs boundaries.

Another feature of the work design was a sharp distinction between production work and repair/maintenance work.

B. Work Rule Changes in the 1980s

The crisis in these iron-ore industries during the early 1980s led to significant changes in work design that began in 1983 and continued throughout the 1980s.[50] To give some idea of the seriousness to which both the union and management accorded work design changes, consider the following section of the February 1, 1987 Basic Labor Agreement (BLA) between Minntac and the USW (from Appendix W, "Employee Protection/Job Realignment Agreement", p. 266):

> 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 re-alignments and a definition of new jobs and seniority units necessary to achieve

[50] I focus my discussion of work design changes on those made at Minntac, the Minnesota taconite mine owned by U.S. Steel. Similar changes were made at the other North American mines.

the objectives and commitments of this Agreement.[51]

This language certainly indicates that both management and the union were willing to undergo significant changes in work design in order that the mine continue operating.

Two major changes in work design were implemented in the 1980s: (1) job combinations and (2) creation of the job of equipment tender. In the March 1, 1983 BLA, union and management agreed to job combinations, whereby the job descriptions and responsibilities of a number of different jobs were "rolled" into a single combined-job. For example, the March 1, 1983 BLA created the combined-job of "ironworker," whose duties were to include the existing crafts of boilermaker, rigger, and welder. Other combined-jobs included "millwright" (whose duties were to include the existing crafts of plumbers, pipefitters, welders, and mechanics) and "system repairman" (whose duties were to include the existing crafts of electronic repairman and instrument repairman).

Union and management also agreed to create the job of "equipment tender." Equipment tenders were to be machine operators that were allowed to perform simple repair and maintenance of their equipment. Prior to this type of job, there was a sharp distinction between those involved in repair work and those in production work.

C. Changes in Work Rules Increased Labor Input per Hour

Most of the argument was sketched in the introduction. Here I review the argument and present some evidence.

[51] The objectives of the Agreement, that is, the "Employee Protection/Job Realignment Agreement," were set out at the beginning of Appendix W: "During the course of 1986-87 collective bargaining negotiations, the Union stressed the need to provide inducements for more senior employees to elect retirement and to provide job opportunties for those more junior employees who are laid off or whose opportunities for steady employment are uncertain. The Company stressed the need to attain manning procedures to preserve the Company's competitive base and its ability to be a sustaining employer." (p. 258)

By breaking down the distinction between repair work and production work, equipment tenders were now allowed to complete simple repair work. The repair staff did not need to travel to jobs that did not require their expertise. Redundant effort was reduced; repair-effort efficiency γ increased. The equipment tender job also clearly increased effort per hour worked e of the machine operator. If a machine became inoperable before the changes, a repair person needed to be located, travel to the machine, and then bring the machine to operable condition. Through all this the machine operator would be idle. Now, with an equipment tender, if the operator is able to restart the machine without repair staff the idle period for the operator is eliminated.

For both non-repair and repair staff, the increased responsibilities in the combined-jobs, given that there were significant idle periods before the changes, meant that e increased. The combinations also possibly led to reductions in γ. But given the very substantial idle periods prior to the changes, its hard to imagine that increased effort didn't overwhelm any reductions in γ. The overall effect of job-combinations was to increase $e \cdot \gamma$.

There is another way to look for evidence that work rule changes had significant impact on labor input per hour. The majority of the job combinations in the mid-1980s were in the repair staff at the mines. If job-combinations were to increase $e \cdot \gamma$, then, everything else equal, they should have decreased the share of repair staff in total employment. Moreover, the equipment tender job, by reducing redundant effort by repair staff, was to have the same effect.

Management believed the new job would have this effect. Before proposing and implementing job changes in accordance with Appendix W of the 1987 BLA, the company did a study that suggested the potential benefits associated with certain changes. The company estimated that by implementing 49 equipment tender jobs in 1987, there would be a savings (net reduction) of 19 repair staff jobs.

Prior to the changes, the repair staffs in these industries were about 50 percent of employment. As I showed in Figure 5 above, and in the Appendix below, there was a dramatic reduction in repair staff: at Minntac, repair staff fell from about 50 percent of the workforce to 25 percent in a few years.

D. Wages and Accidents

I next discuss wages and accidents in the industry. I show that relative wages declined over the period of the increases in effort. The increase in effort was not part of a package that increased compensation. I also show that there were no increases in accidents. The pace of work did not increase, presumably, to a level that was not safe (see Shea (1992) for references to literature on the relationship between accidents and effort).

Turning first to wages, if the relative wage paid to miners increased during the crisis, this might suggest that higher wages were part of a new bargain that included greater effort. In Figure 9, I plot the hourly wage of a Minnesota taconite worker, both an entry level employee (class 1&2), and a more skilled class (class 20). I plot each wage relative to the national private-average hourly wage and the manufacturing-average hourly wage. All four series show roughly the same movements over time. The skilled taconite worker earned nearly 40 percent more per hour than the average-private worker throughout the late 1960s and early 1970s. From the late 1970s to early 1980s, this premium increased by nearly 30 percent (from 1.4 to nearly 1.8). The late 1970s was a period of optimism in the United States iron-ore industry, and the industry was aggressively expanding taconite capacity. During the crisis in the middle 1980s, the premium paid to the skilled class fell back from 1.8 to 1.4. Relative wages fell during the crisis. A similar pattern was followed by the entry level wages.

Next, I consider accident rates. In Figure 10, I plot the days lost due to injury in St. Louis County iron-ore mines as tracked by county mine inspectors. The vast majority of the hours worked in the Minnesota taconite industry are within this county. There was no increase in the days lost due to accidents in middle 1980s.

E. Increases in Human Capital?

Skill levels depend in large part on experience. Though I do not have data on average experience, an indirect argument suggests that increases in average experience, in λ, likely played only a small role in the gains in labor input per hour.

Changes in average experience are likely highly correlated with changes in hours worked, since seniority is a key variable determining order of layoffs at mines. During the period when hours were reduced the most, that is, in the first one or two years of the crisis, and hence the period when average experience likely increased the most, there was little or no change in productivity.

After the bottom was reached in terms of hours, hours stayed roughly flat in some mines, and increased a bit in others. Productivity gains commenced in this period when hours were flat or were beginning to increase in the mines. This argument suggests a limited role for increases in λ. But since the argument is indirect, I leave some room for λ, and say that increases in productivity were "in large part" driven by increased effort and increased efficiency of effort.

9. Understanding Productivity Differences in Iron-Ore and Elsewhere

What triggered the increases in effort per hour worked and reductions in redundant effort? These work rule changes occurred during a period of crisis in the industries: foreign competition threatened to close the entire industry. In the introduction I sketched a theoretical explanation for why these changes occurred during the crisis that can be traced back forty years to Becker (1957) and Alchian and Kessel (1962). All jobs involve a mix of pecuniary and non-pecuniary payoffs. It may be that a firm or industry with monopoly power may face restrictions in its ability to pay pecuniary returns to itself. Given this constraint, the monopoly chooses to take more return in the form of non-pecuniary payoffs than would otherwise be the case. This might be in the form of leisure on the job (low effort) or even possibly redundant effort if jobs can be given to family, friends, etc. If monopoly power is reduced, some of these non-pecuniary payoffs must be rolled back.

Here I fill in a few more details of the argument, in particular, why these iron-ore industries had some monopoly power and why they faced constraints on pecuniary payouts.

In the case of these iron-ore producers, monopoly power stemmed from a few factors. The low effort levels and high (relative) wages in these mines obviously led to "high" prices of U.S. iron-ore at U.S. steel plants. How was it that these iron-ore industries did not disappear? First, iron-ore costs make up only a small portion of total steel production costs. Hence, high iron-ore prices did not lead to much greater steel prices which might have led to substitution away from steel to, for example, plastics. But why didn't high iron-ore prices lead to entry of new producers, either foreign or domestic? Producers were "protected" in the Great Lakes region from foreign producers because of the much greater transport costs of foreign producers into the Great Lakes area (where many of the U.S. steel mills were located). Regarding domestic entry, the iron-ore workforce has historically been organized by a single union and new entrants could expect to be unionized as well. It was the above circumstances then that implied "high" mine-prices didn't spell disaster for these industries (until the crisis of the early 1980s).

Given that mining is tied to the local area (because of the resources), the local political jurisdiction can extract significant portions of monetary profits (see Kolstad and Wolak (1983)). The firms that invested in the Minnesota taconite industry were certainly wary of the ability of Minnesota legislators to capture monopoly rents. Davis (19xx) describes how he and colleagues had solved the engineering problems associated with processing hard taconite rock into a usable iron-ore product only to be told by potential investors that they would not invest in the very expensive (and only-useful-in-Minnesota) equipment needed to produce taconite pellets. The impasse was averted when the state constitution was amended to limit the ability of the legislature to tax the industry at exorbitant rates.[52] This, then, is the restriction or constraint on pecuniary payoffs: make a lot of profits and watch them be taxed.[53]

Other arguments for the type of work rules in these industries have been offered. In discussing why the USW supported the work rules in the steel industry, Hoerr argues that they limited the discretion of management in assigning jobs to workers and were also thought to lead to higher levels of employment. According to Hoerr, "Labor's interest in categorizing jobs as narrowly as possible has two motivations. One is to prevent bosses from exercising

[52] The Minnesota legislature, of course, found ways to circumvent this amendment over time.

[53] Another contraint on pecuniary payout might be a desire to "hide" the degree of monopoly rents from shareholders (or management in far-away places (like Pittsburgh)).

their biases in assigning duties to people, like putting blacks on the meanest job. .... [the other] is to maintain the level of the workforce..." (p. 315)

This argument can be subsumed in the original idea with one twist. Having narrow job categories to limit biases in job assignment is, of course, a non-pecuniary benefit. But Hoerr's discussion suggests (and is no surprise) that there is disagreement and conflict between groups at the mines (e.g., managers vs. employees). The original argument only had conflict between the mines and the legislature. So, the added twist is that within-mine conflict may also be important in determining how non-pecuniary benefits are collected. In this regard, narrow job classifications might be seen as an attempt by some groups to "construct" an O-ring technology (a la Kremer (199x)) to provide leverage in bargaining over rents.[54] [55]

As I said, I think this theoretical argument has wide applicability. That is, wherever there are elements of monopoly, and assuming the monopoly has constraints on its payouts of pecuniary gains, we should expect the collection of rents to be conducted in more non-pecuniary ways than would otherwise be the case. Competition reduces rents and these non-pecuniary payouts are rolled back. Let me briefly discuss three other industries that

[54] A different argument is that the work design system was a big mistake and the crisis enabled the industry to correct it. Let me sketch the outline of such an argument, though I do not know if it can ultimately be tied together in a coherent story. When the work rule system in these industries was designed, there was a great deal of uncertainty among both management and the union regarding the effects on effort and the efficiency of effort. As Scheiber (1959, p. xvii) argues, the steel companies were the party that initially proposed and implemented the system of extensive job descriptions and job classification (the system was formulated in the "CWS" manual). The union was at first a reluctant participant. But the tables turned: management wound up opposing the system, while the union became a supporter. According to Scheiber, the steel companies that developed the system decided not to use it in other industries in which they were engaged and where they did not deal with the USW. The USW, on the other hand, have attempted to apply the manual on a wide scale among companies with which it bargains outside the steel industry. So, suppose the mix of (and total) pecuniary and non-pecunairy gains given to some groups was much different than other groups had forecasted. There then may have been gains from trade between the groups (brought about by changes in work rules and in pecuniary compenstaion). But perhaps the groups were deadlocked in their bargaining (because of private information, etc.) The crisis may have led the groups to reach previously unattainable bargains.

[55] Other models of effort choice include Leamer (199x) and Bils and (199x).

support this claim, of substantial productivity increases through increases in effort per hour worked and reductions in redundant effort, triggered by increases in competition.

The first example is another mining industry, copper. As Aydin and Tilton (2000) show, labor productivity in the U.S. copper mining industry more than tripled over the period 1975-1995. The purpose of their paper was to show that the gains were not due to shifts in output from low- to high-productivity mines. Three–quarters of the gain were due to productivity gains at individual mines. They do not discuss in detail the sources of the gains at the individual mines. They do suggest that new technology may have played a role. In this industry you can point to a new technology, the "SX-EW" technology, that was introduced over the period.

But my very strong suspicion is that the gains were primarily driven by the same factors that drove the gains in the iron-ore industry. First, the vast majority of the productivity gains occurred in a few year period, from about 1982-85. This was, in fact, a period of crisis in the industry: the real price of copper fell by half over the period.[56] Second, the productivity gains occurred in both underground and open pit mines, and at the very same time. Presumably the technologies in these two subindustries differed. They did share the same union and work practices.[57]

The introduction of railroads in the United States in the nineteenth century has been extensively studied. However, the literature has mostly missed that the railroads dramatically

[56] http://minerals.usgs.gov/minerals/pubs/metal_prices/

[57] Other arguments suggest new technology was not key. It would seem unlikely that every mine would adopt at the same time and during a period of crisis (see Boone (2000)). But more importantly, the fraction of output produced using SX-EW was fairly small: the U.S. output produced with SX-EW rose from 6% to only 27% over the period 1980-95. When Aydin and Tilton present a list of factors that might have increased productivity, in addition to new technology, they do mention more flexible work rules but its not given any special significance. I bet it was the crucial factor.

reduced the monopoly power that was inherent in the water transportation industry where cargo had to move through ports like New Orleans and where groups like longshoremen wielded significant monopoly power. Holmes and Schmitz (2001) show that the increased competition from railroads led longshoremen to increase their effort per hour worked (work rules that limited the amount of cargo moved were changed to permit more cargo moved per day) and to reduce redundant effort (restrictions on the use of equipment were lifted somewhat).

The third industry is sugar refining in the United States. The sugar industry in the United States is highly protected.[58] I have studied the impact on cane-sugar refining of increases in competition from alternatives to sugar, such as corn sweeteners. The cane-sugar industry had dramatic increases in labor productivity during this period when corn sweeteners were introduced. While my work is still preliminary, it appears that the gains were driven in large part by some of the same changes occurring in the iron-ore industry.[59]

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[58] There are quotas that limit imports of sugar. There are also quotas on domestic production that limit domestic entry. The U.S. price of sugar is very high relative to the world price, typically twice as high (Krueger, 1988).

[59] Union workers in cane-sugar processing plants certainly had significant non-pecuniary benefits. For example, these workers received periodic sabbaticals. This is a non-pecuniary benefit to which I am not entitled at the Federal Reserve Bank of Minneapolis.

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Appendix: Canadian Repair Spending

I have information on repair spending in the iron-ore industry in Canada. This information is gathered as part of Canada's investment and capital stock measurement program (see McGrattan and Schmitz (1999) for a discussion). Repair spending is the sum of: (1) wages paid to repair employees, (2) the materials and parts used by the employees and (3) the value of repair contract work by outside firms. Unfortunately, I do not have a breakdown by these three categories.

I plot repair spending (in current dollars) and repair spending as a fraction of total wages in Figure 11. Repair spending fell significantly during the crisis period. I use the series "repair spending as a fraction of total wages" to make some comparisons of the Canadian spending data with the Minnesota employment data. As discussed above, there was very little contracting out in these industries both prior to and after the crisis. Hence, as an approximation, I assume contracting out (the third category) is zero. Dividing repair spending by total wages yields

$$\frac{repair\ spending}{total\ wages} = \frac{(wage\ rate) \times (repair\ emp.)}{(wage\ rate) \times (total\ emp.)} + \frac{(price\ of\ parts) \times (repair\ parts)}{(wage\ rate) \times (total\ emp.)}.$$

The first term, then, is the ratio of repair employees to total employees. The second term is the product of two ratios, the first the ratio of the price of parts to the wage rate, the second the ratio of repair parts to total employment.

Let me initially focus on the second term. As an approximation, repair parts is likely proportional to production.[60] Hence, the ratio of parts to employment behaves roughly like labor productivity. The ratio therefore likely increased significantly over the 1980s, a

[60] Fixing the type of iron-ore produced.

conservative estimate being 75 percent. I do not have a price for parts but it likely behaves similarly to the price of investment.[61] I plot the price of investment divided by the average wage in the industry in Figure 12. While this ratio has fallen significantly over the entire period, from 1980 to 1987 it fell very little, and from 1980 to 1990 the drop was less than 25 percent. Hence, the second term likely increased significantly over the 1980s, on the order of 30 percent.[62]

The ratio of repair spending to total wages did not change significantly over the 1980s. That the second term above increased over the 1980s then implies that the first term, the ratio of repair employees to total employes, fell. This is consistent with the experience in Minnesota. I can provide a very rough estimate of the extent to which the first term fell. From the Minnesota mines, prior to the crisis, the share of repair hours was about 0.50. The ratio in Canada was likely smaller, lets say 0.35.[63] With the ratio of repair spending to total wages equal to about 0.80 prior to the crisis, this puts the second term at 0.45. During the 1980s, if the second term increased about 30 percent, it would then equal about 0.60. If I approximate the ratio of repair spending to total wages after the crisis by 0.80, this implies the first term was about 0.20. This estimate is, of course, a very rough one.

[61] One reason that the price of parts likely behaves like the price of investment is as follows. If a machine or structure is being repaired and a large component needs to replaced, this expenditure can often be classified as repair. Firms, of course, have an incentive to label it as repair (and not investment) for tax purposes since such expenditures can be fully deducted from revenue in calculating taxes (see McGrattan and Schmitz (1999) for a discussion).

[62] If the first ratio decreased by about 30 percent and the second ratio increased by about 75 percent, then the product increased by about 30 percent. This seems to me a conservative estimate.

[63] Repair work is much greater in pellet production. During the 1980s, pellet production in Canada varied between 50 and 60 percent of production.

Table 1

Minnesota Taconite Industry
Decomposition of Industry Productivity Growth
(All figures in percent)

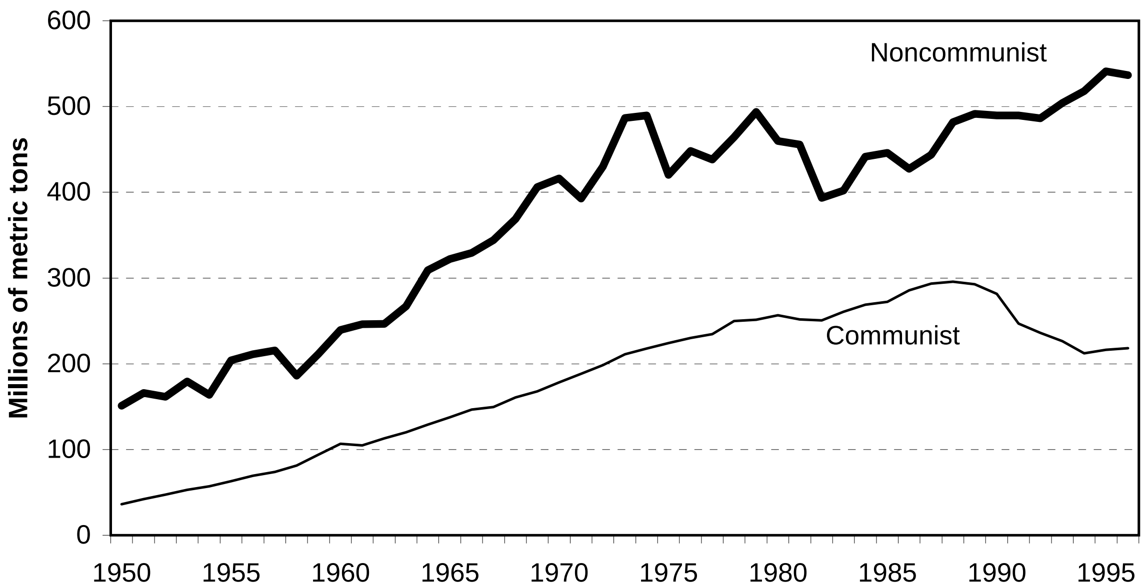
A. Weights are mine's share of industry hours

		Share of Industry Growth Due to:			
Growth Between 1980 and	Overall Industry Growth	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

B. Weights are mine's share of industry output

		Share of Industry Growth Due to:			
Growth Between 1980 and	Overall Industry Growth	Within Mines	Between Mines	Cross Mines	Closing Mines
1981	7.80	109	–43	33	0
1982	5.90	–145	122	124	0
1983	24.10	56	18	27	0
1984	53.00	90	2	8	0
1985	63.40	97	–1	3	0
1986	79.20	85	5	10	0
1987	118.50	81	3	12	4
1988	104.10	81	2	12	5
1989	95.00	80	2	13	5
1990	94.40	93	3	4	0
1991	84.70	90	4	6	0
1992	89.20	89	5	6	0
1993	99.70	98	0	2	0
1994	107.80	99	1	–1	0
1995	116.10	94	2	4	0

Figure 1: World Steel Production and Steel Production By Various Groups of Countries 1950-1996



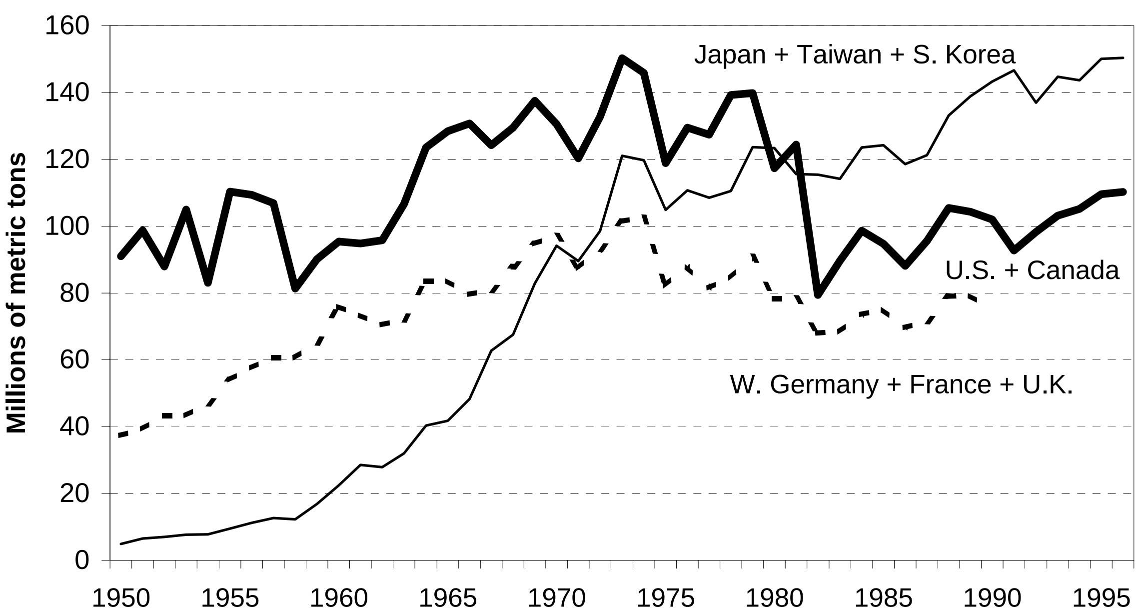
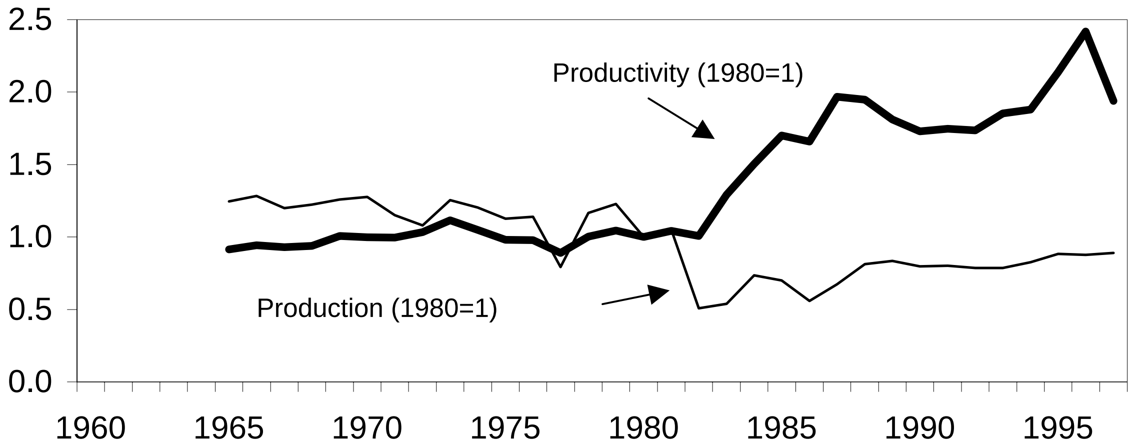


Figure 2: Production (Tons) and Productivity (Tons per Hour (US)/Tons per Worker (Canada))

in United States Iron-Ore Industry



in Canadian Iron-Ore Industry

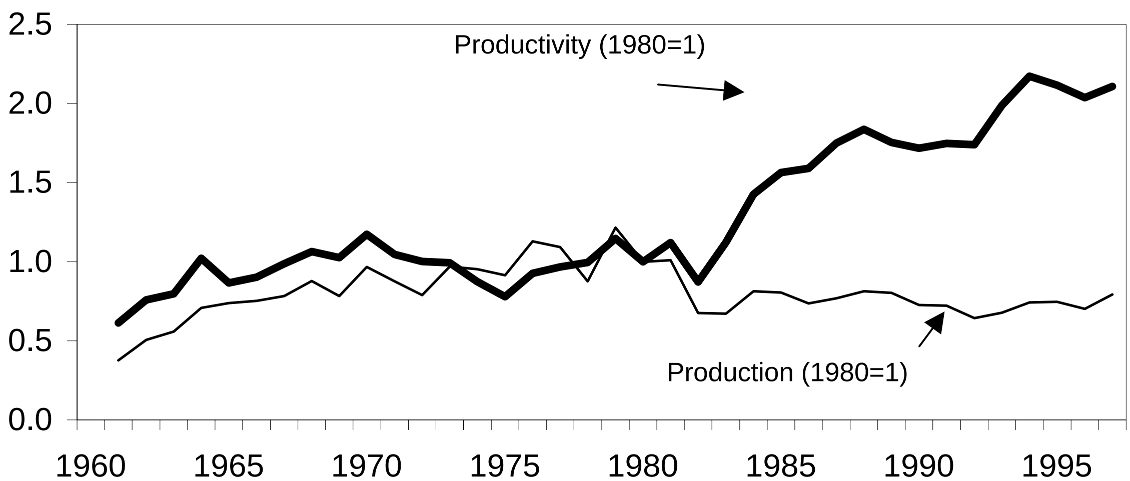


Figure 3:
Minnesota Taconite Production and Productivity

Figure 4:
Taconite Production and Productivity in Minnesota by Mine

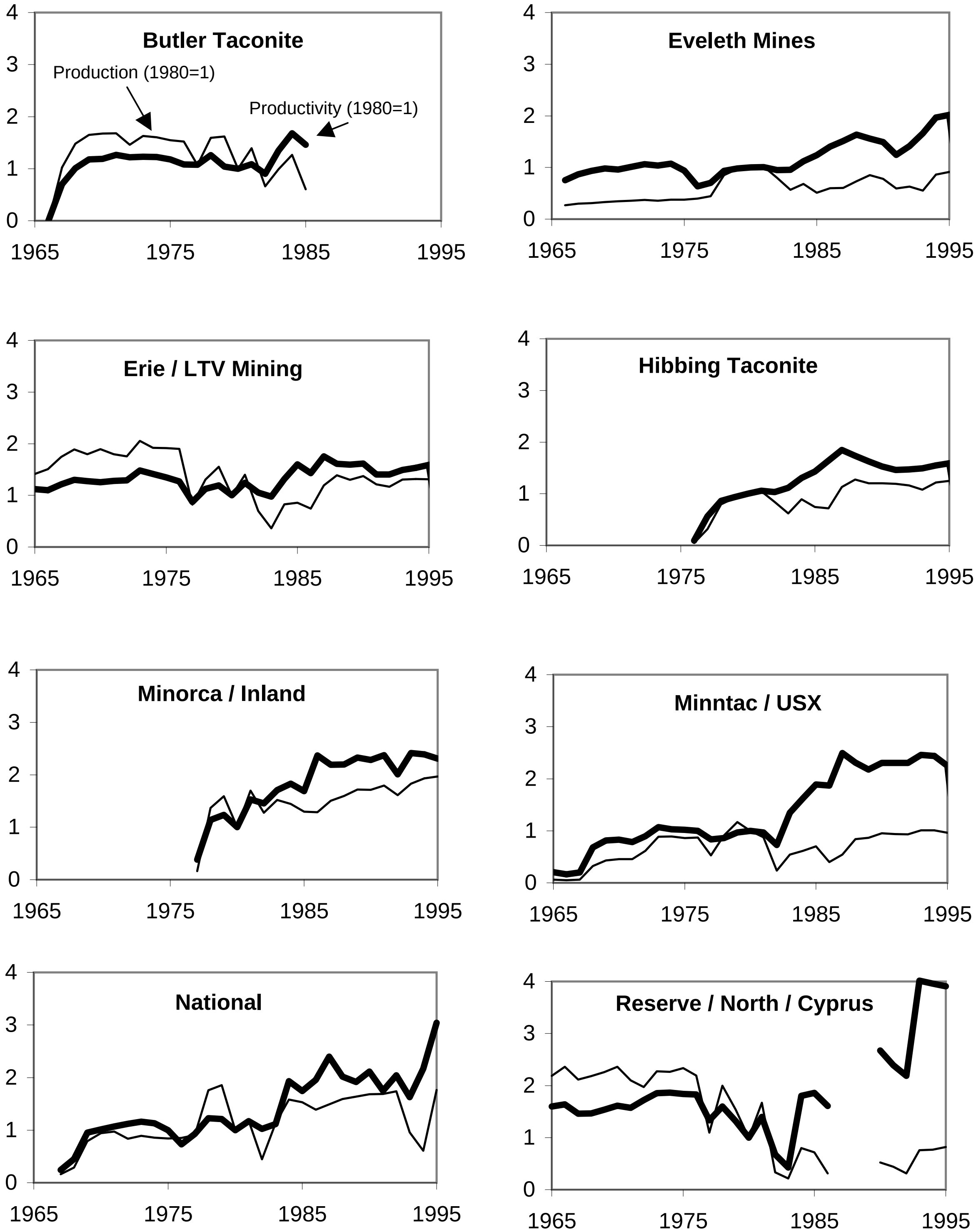


Figure 5:
Hours Worked in Mine, Plant and Maintenance as Percentage of Total Hours at Minntac (USX Taconite Mine)

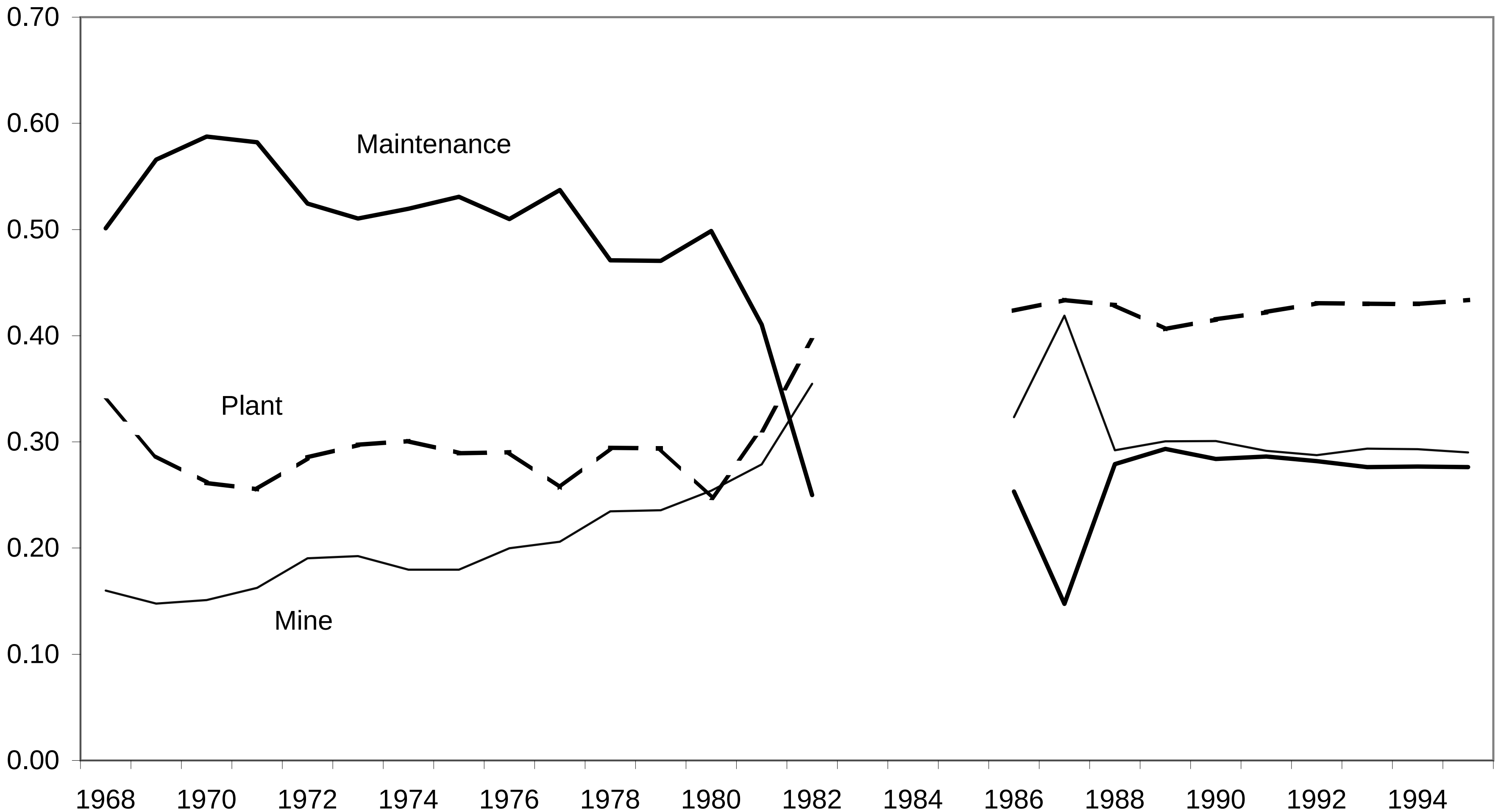


Figure 6:
Capital Stock and Capital Stock per Worker (Constant Dollars)
Canadian Iron Ore Industry

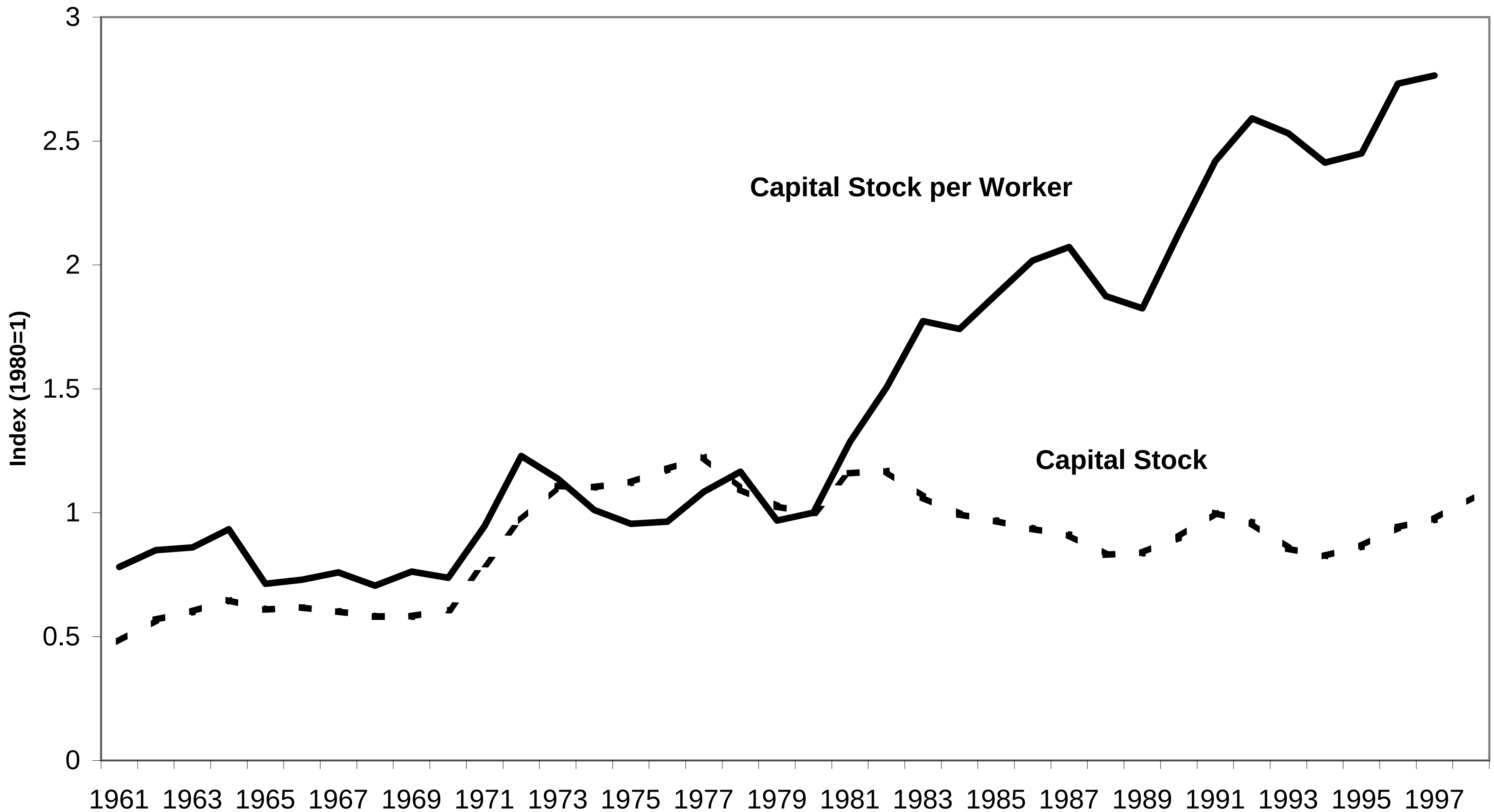


Figure 7:
Total Investment and Total Investment minus Discards (Constant Dollars)
Canadian Iron Ore Industry

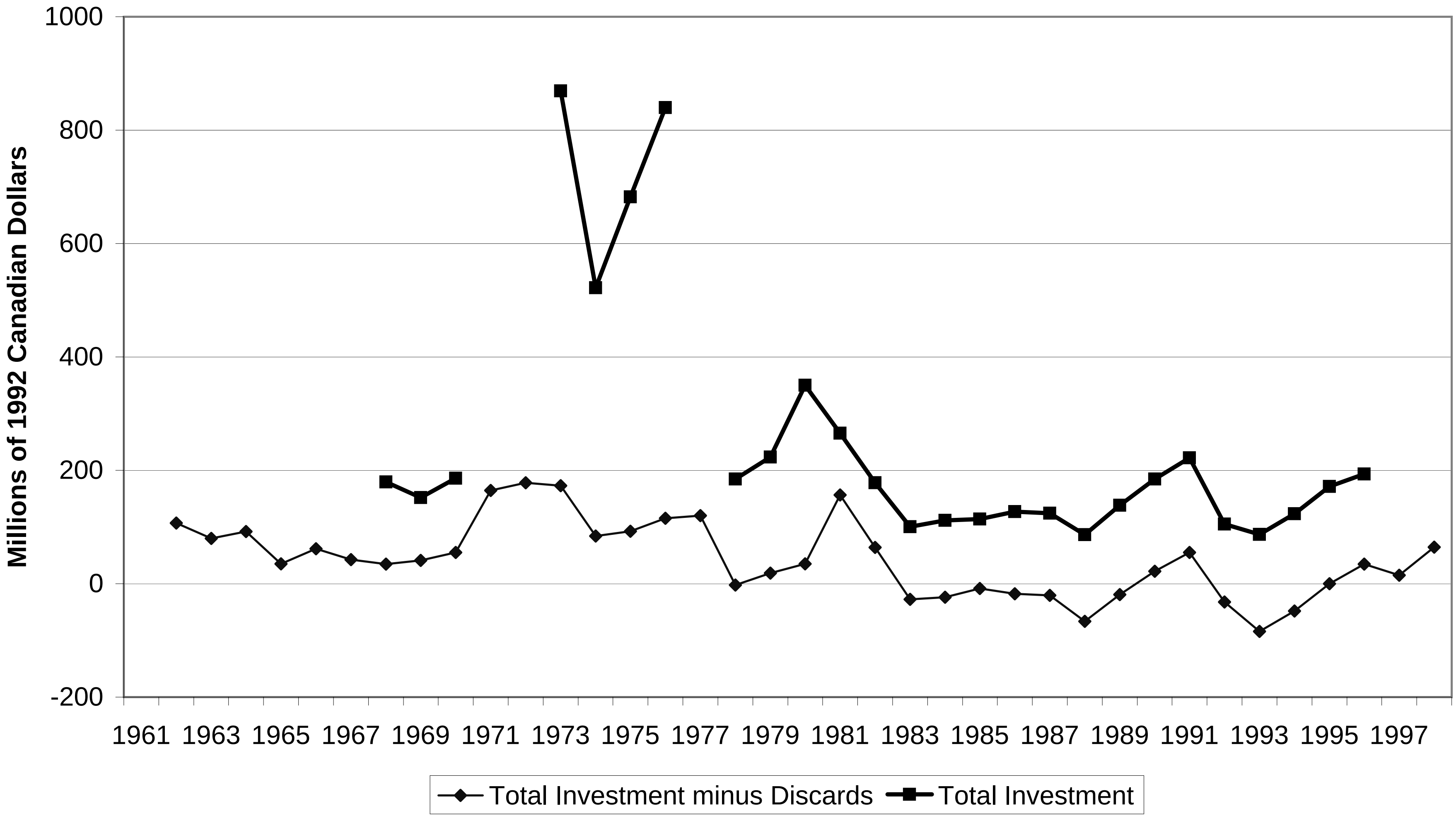
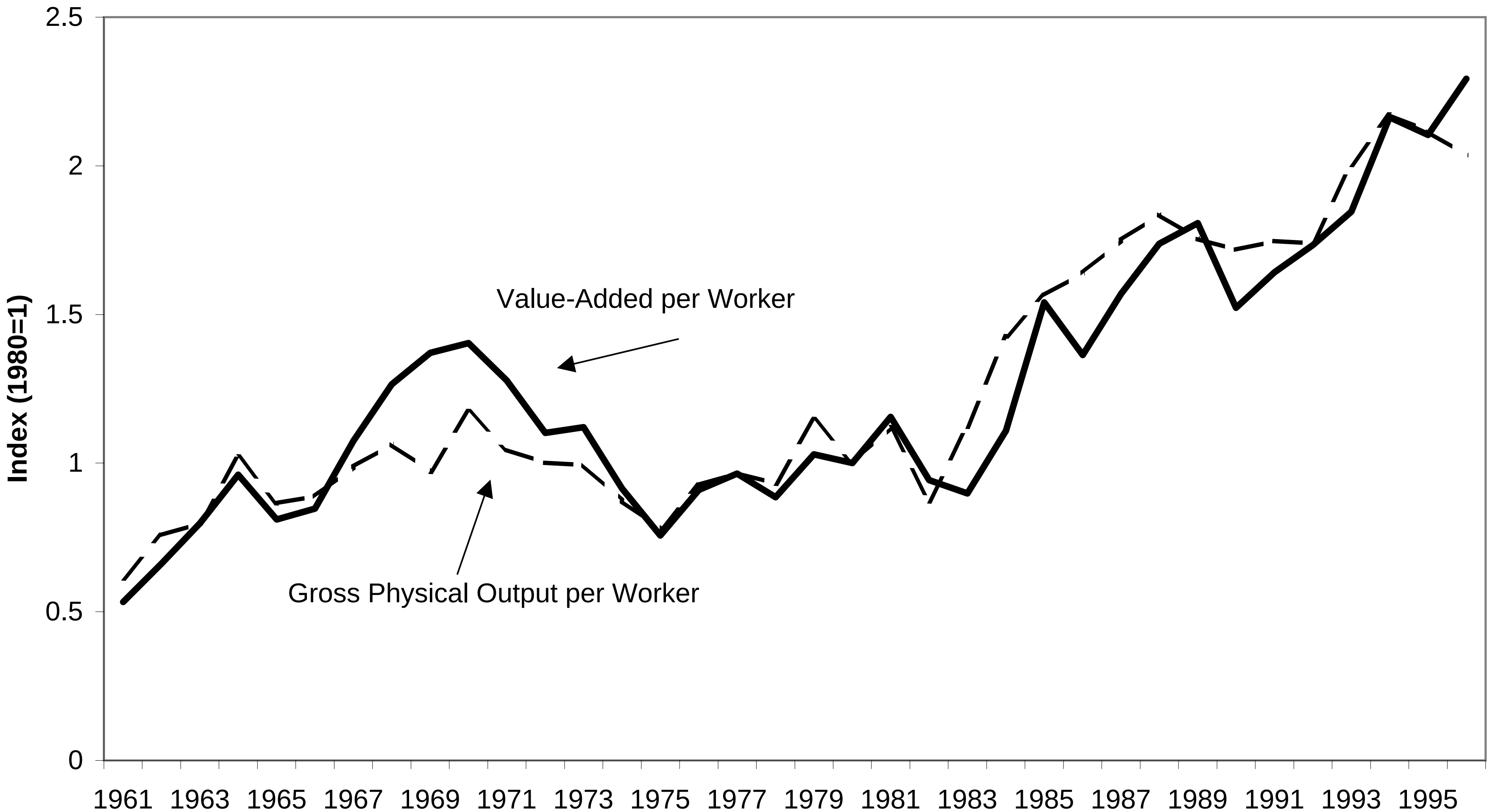


Figure 8:
Value-Added per Worker and Gross Physical Output per Worker
Canadian Iron Ore Industry



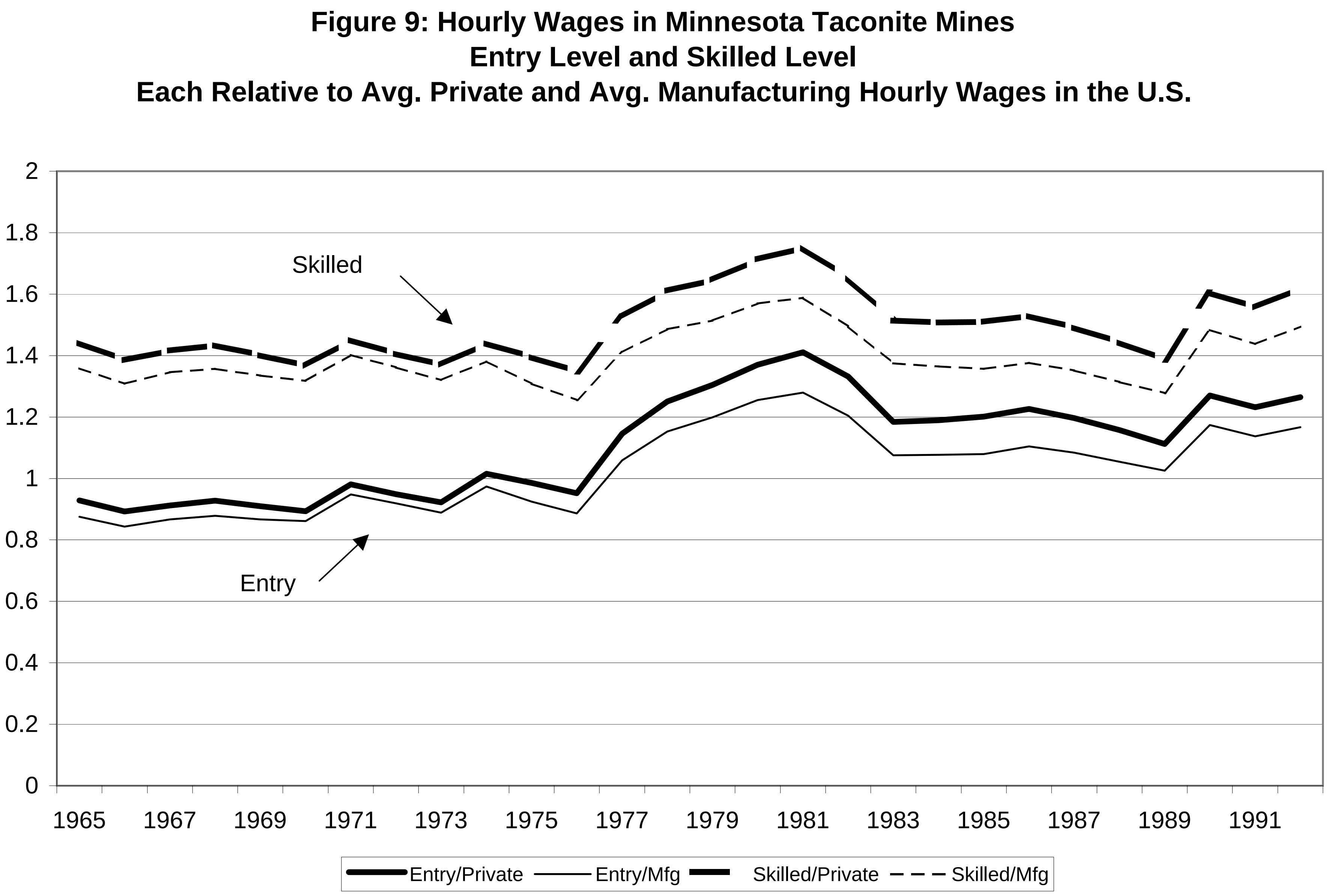


Figure 9: Hourly Wages in Minnesota Taconite Mines
Entry Level and Skilled Level
Each Relative to Avg. Private and Avg. Manufacturing Hourly Wages in the U.S.
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Skilled
Entry
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
Entry/Private
Entry/Mfg
Skilled/Private
Skilled/Mfg

Figure 10:
Days Lost Due to Injuries per Million Hours
St. Louis County Iron Ore Mines

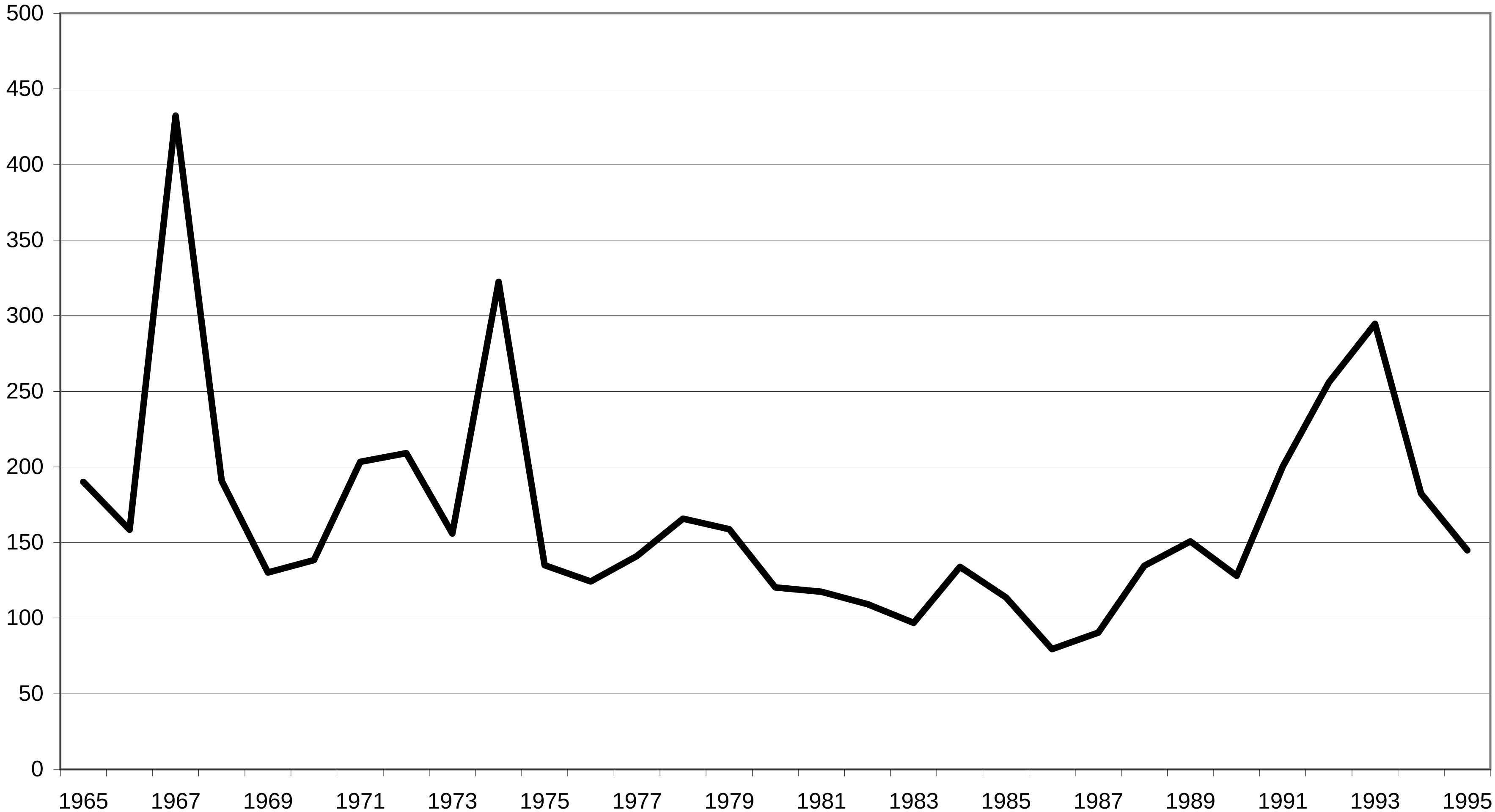


Figure 11:
Repair Spending and Repair Spending as Fraction of Total Wages
Canadian Iron Ore Industry

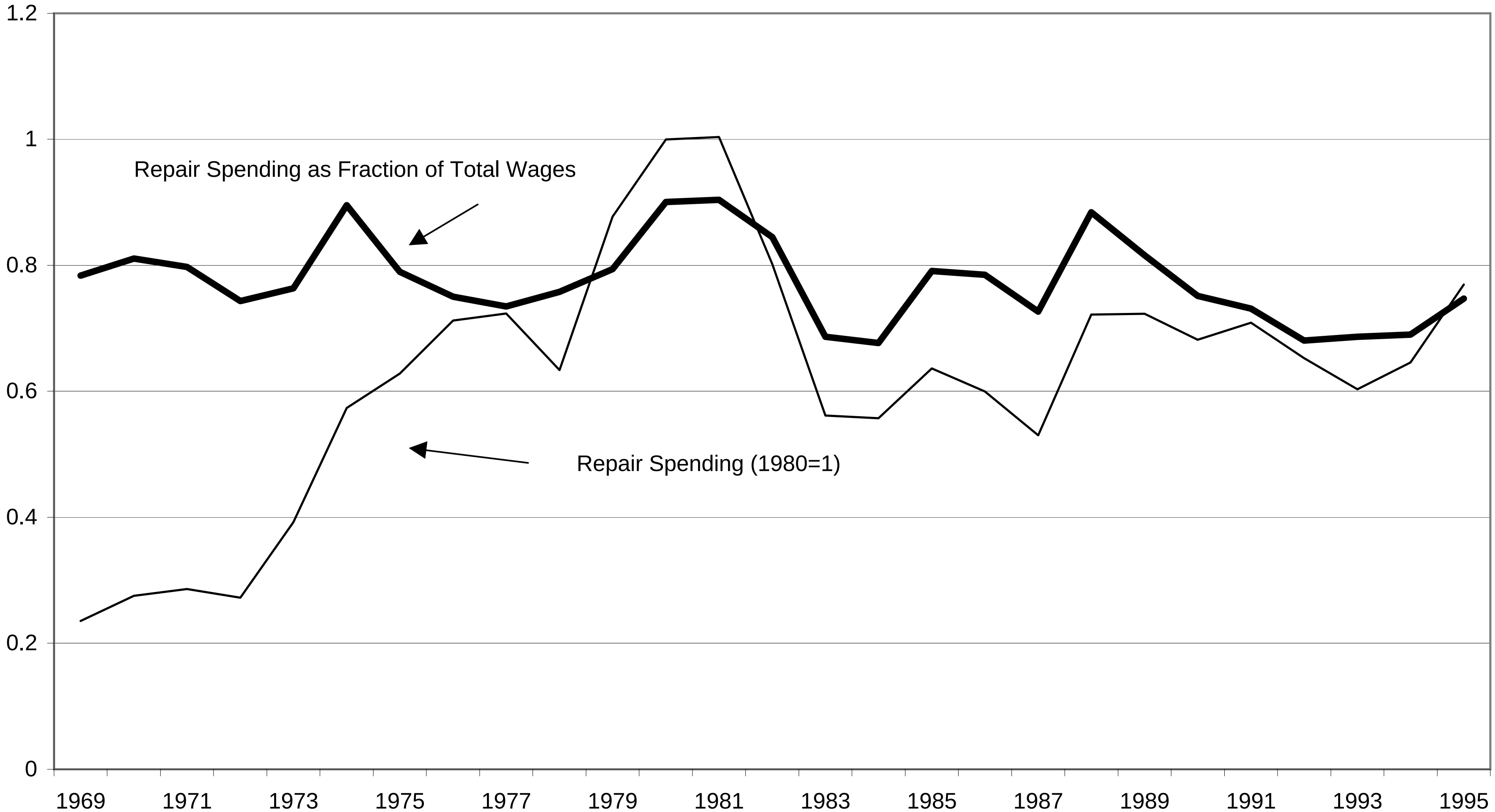


Figure 12:
Price of Investment Relative to Average Wage
Canadian Iron Ore Industry