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Threats to Industry Survival and Labor Productivity: World Iron-Ore Markets in the 1980's[*]

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ABSTRACT

In the early 1980's, the world steel market collapsed. Since the almost exclusive use of iron-ore is in steel production, many iron-ore mines had to be shut down. We divide the major iron-ore producing countries into groups based on the threat of closure faced by iron-ore mines in the respective country. In countries where mines faced no threat of closure, the iron-ore industry had little or no productivity gain over the decade. In countries where mines faced a large threat of closure, the industry typically had productivity gains ranging from 50 to 100 percent, gains that were unprecedented. We then argue that these productivity increases were not driven by new technology or by the closing of low productivity mines. Hence, the productivity gains were driven by continuing mines, using existing technology, increasing their productivity in order to stay in operation.

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1. Introduction

In the early 1980's, the world steel market collapsed. Between 1979 and 1982, world steel production fell twenty percent and it did not regain its 1979 level until 1993. This collapse had profound implications in world iron-ore markets since the almost exclusive use of iron-ore is in steel production. In particular, many iron-ore mines had to be closed in the 1980's.

The threat of closure faced by mines differed considerably across countries. In this paper, we divide the top-eight (noncommunist) iron-ore producing countries into groups based on the threat of closure faced by mines in the respective country in the early 1980's. We then compare the production and labor productivity records of these iron-ore producing countries over the 1980's. The results are striking. Iron-ore industries where mines faced no threat of closure had little or no productivity gain over the 1980's. Iron-ore industries where mines faced a large threat of closure typically had productivity gains ranging from 50 to 100 percent, gains that were unprecedented.

The top eight iron-ore producing countries in 1980, in order of production in 1980 (in millions of metric tons), were Brazil (114.7), Australia (90.8), the United States (70.7), Canada (49.1), India (41.9), France (28.9), Sweden (27.2) and South Africa (26.3). Below, we discuss a formal definition of threat of closure faced by mines and use it to discuss the threat faced by these national industries. Under this definition, two factors determine this threat for a mine: the location of the mine and the cost of producing iron-ore at the mine. The first factor, location, was critical because the world steel market collapse was overwhelmingly a collapse in steel production in the Atlantic Basin (steel production in the Pacific Basin barely fell at all) and because the marginal cost of transporting iron-ore is very high relative to its value at the mine. The steel collapse put Atlantic iron-ore producers at a disadvantage relative to Pacific producers. That the second factor, the cost of producing iron-ore at the mine, was important requires no explanation.

As we mentioned, the threat of closure faced by mines differed considerably across countries. This is because those industries that had the best location to deal with the steel crisis also had the lowest production costs at the mine (and, by implication, those industries with the worst location had the highest costs). In particular, and ignoring Brazil for the moment, Australia and India obviously had better locations to deal with the Atlantic steel collapse than did the Atlantic iron-ore producers in France, Sweden, South Africa, the United States and Canada (iron-ore production in the latter two countries was overwhelmingly in the eastern part of those countries) since they were closer to Asian steel producers. Also, Australia and India had much lower production costs at the mine than these five Atlantic producers. Hence, Australia and India were much "better" along both dimensions that determine the threat of closure faced by mines.

And how about the Brazilian mines? The Brazilian industry's location (which was in the eastern part of the country) was not unambiguously better than the other Atlantic producers: it was closer to the Pacific than most of the Atlantic producers, yet it was further from the Atlantic steel production centers in North America and Northern Europe. However, the Brazilian mines had the lowest costs of production in the world. Brazil's production costs were so low that it could produce and ship iron-ore to most North American and European steel centers at less cost than the iron-ore producers that were very close to these steel centers (e.g., cheaper than Sweden to Northern Europe). As a result, Brazilian mines faced little or no threat of closure. There were, then, two groups of major iron-ore producing countries in the early 1980's, one group where mines faced very little threat of closure, and comprised Australia, Brazil and India, and a second group, where mines faced significant threats of closure, and comprised the remaining five top-producers.

Turning to the labor productivity records of these major producers in the 1980's, we find that there was a close relationship between the threat of closure faced by mines in a country in the early 1980's and the subsequent productivity gains in the industry over the 1980's. In the group that faced no threat, Australia and Brazil had no productivity gains over the decade (and little in the prior decade as well). India had modest gains, about 29 percent over the decade (which was less than its 55 percent gain the preceding decade). In the group where mines were subject to a severe threat of closure, Canada, Sweden and the United States had gains approaching 100 percent over the decade, whereas each had no productivity gain over the preceding decade. South Africa had substantial gains, on the order of 50 percent over the decade. France had no productivity gains and is essentially out of the iron-ore business. (The reader can quickly view these productivity records in Figure 4).[1]

What were the sources of these productivity gains in the iron-ore industries of Canada, South Africa, Sweden and the United States? We discuss a number of possible sources of the gains, including the closing of low productivity mines, the introduction of new technology and shifts in the types of iron-ore produced toward those that required less labor per ton to produce. We argue that these sources accounted for very little of the productivity gains. The implication is that the productivity gains were primarily driven by continuing mines, using

[1] France, then, is the big exception to the finding that industries which faced a severe threat of closure had significant and unprecedented productivity gains. As we discuss below, the French industry had by far the poorest quality iron-ore among the major producers (and all producers in the world) and it is not clear that the French industry could have done anything to stave off disaster.

existing technology, and producing the same products, increasing their productivity in order to stay in operation.

These findings on the relationship between threats of closure and productivity recall the very old idea that increases in "competition" spur productivity growth. As Stigler (1957) argued

> To Adam Smith, and to his disciples for a century thereafter, competition denoted the regime of the bold, resourceful, and independent entrepreneur, whose equally endowed rivals disciplined him to diligence and stimulated him to innovation. ...The virtues of competition, in this period of the classical economics, were equally great in securing efficiency in the conduct of economic affairs and in hastening the introduction of new techniques and products. (p. 269-70).

The word "competition" has, of course, lost these connotations in the academic economics literature, though it still has such meanings in the business literature, in publications like the Economist. Whether we call the purported phenomenon that leads to productivity gains "increases in threats of closure," or "increases in competition," or something else, economists have lost interest in it because there is not a large body of evidence indicating it is true.

In our view, the reason for this small body of evidence documenting this phenomenon is not because the phenomenon is a limited one, but rather because it is difficult to find "good" experimental situations to "uncover" it. In our view, the reason we find such striking results is that we have isolated an experimental situation satisfying three important properties: (1) Mines were subjected to very different threats of closure; (2) Real output, and hence productivity, is easily measured in this industry; and (3) The world steel collapse which triggered the various threats of closure was, from the view of iron-ore producers, an “exogenous” event.

We have already discussed why the situation satis…es the …rst property: again, many of the mines that had poor locations to deal with the steel market collapse were also the highest cost producers (that is, Atlantic mines) and hence received a very large “dose” of “threat-of-closure” (while Paci…c mines received a very small dose of threat). The second property is that real output can be readily measured in this industry. While iron-ore is not a completely homogeneous product, there are only three major product-types and the type of product produced at a mine typically changes little over time, and hence real output can be measured as the weight of iron-ore produced in a year.[2] Hence, labor productivity is easily measured. Lastly, the world steel collapse was, from the view of iron-ore producers, an “exogenous” event. The collapse was driven by, among other things, the accelerated substitution of materials like plastic for steel stimulated by increases in the price of gas for cars in the middle 1970’s, while the rising share of Asia in world steel production was driven by, among other things, the extremely fast growth of many Asian countries. Iron-ore producers had little power to reverse these forces acting on steel production since the cost of the iron-ore used to produce a ton of steel amounts to only about 10 percent of the steel’s selling price.[3]

As we mentioned, the “old” view of competition summarized by Stigler has lost currency in the academic economics literature. The …ndings here, together with a few recent

[2] We can also observe if the type of iron-ore produced within a country does change over time.

[3] As we discuss below, the experimental situation satisi…es other properties that are useful for …guring out the sources of the productivity gains. For example, the technology in the iron-ore industry has changed very little over long periods of time.

research efforts showing the influence of competition on productivity in other settings, may lead to a reconsideration of this view. We discuss some of these other efforts below, including Borenstein and Farrell (1999), Nickell (1996), Prescott (1998) and Zitzewitz (1999). But first, in the next section, we present our definition of the threat of closure faced by a mine in the early 1980's. Section 3 shows that mine location was a critical factor in determining the threat of closure faced by a mine. Section 4 discusses production costs at the mine. Section 5 examines the output and labor productivity record of the eight major iron-ore industries over the 1980's. Section 6 discusses the sources of productivity gains. The last section discusses related literature, ongoing research and some implications of our findings.

2. Defining the Threat of Closure

In this section, we define the threat of closure faced by mines in the early 1980's. We first give a brief background on the world iron-ore market as of the late 70's and then discuss the world steel market collapse that began in late 1970's and early 1980's.

In this paper, we study the top-eight iron-ore producing countries. We restrict attention to the major producers because of the difficulty in obtaining data for smaller producers. While statistics on production of iron-ore are readily available for nearly all countries, statistics on labor input are more difficult to obtain. Labor input data had to be collected from statistical agencies in each country. Also, data on production costs at mines are only available, not surprisingly, for major producers.

In Table 1, we present the top eight iron-ore producers in 1980, grouped by Atlantic and Pacific Basins.[4] The first column lists the years for which we have obtained data on labor

[4] It is not necessary to go into great detail defining the area of the world we consider the Atlantic Basin (or the Pacific Basin). Since the iron-ore mines in Brazil, Canada and the United States are overwhelmingly

input for each country. The second column lists each country's production in 1980 as given in the Minerals Yearbook of the United States Geological Survey (USGS). (See Appendix A for data sources.) Total production in 1980 for these eight countries was 453.9 million metric tons (Mmt).[5] This amounts to 81 percent of total noncommunist production of 558.8 Mmt reported by the USGS in 1980.[6] The third column lists country-reported production, which we requested along with the labor input data. USGS production and country-reported production are typically very close. The last column lists the percentage of iron in the iron-ore of each country as reported by USGS.

Again, the nearly exclusive use of iron-ore is as an input to steel production. In the late 1970's, the top eight iron-ore producers shipped to one or more of the four major (non-communist) centers of steel production: an Asian center, including Japan, South Korea and Taiwan; a Northern European center, including Germany, France and the United Kingdom; and two centers in North America, the U.S. Great Lakes/Pittsburgh region and the U.S. East Coast region.

The majority of iron-ore produced in North America and Europe was shipped only very short distances, on the order of a few hundred miles. U.S. producers, who were located in the Great Lakes region, only shipped to the steel center in the U.S. Great Lakes/Pittsburgh region. French producers only shipped within France. Swedish producers overwhelmingly shipped to Northern Europe. The Canadian producers, who were again in Eastern Canada,

in the eastern parts of each country, there is little doubt about how to classify the eight producers. The same is true for classifying steel producers by basin.

[5] The next largest producers in 1980 after these eight were Liberia (17.4) and Venezuela (16.1). No other producer exceeded 10 Mmt.

[6] Since there was not much trade in iron-ore and steel between communist and noncommunist countries in the period we are studying, that is, the decade of the 1980's, we focus exclusively on noncommunist iron-ore and steel producers in this paper.

primarily shipped to both U.S. steel centers, the Great Lakes/Pittsburgh and Eastern Coast, and to Northern Europe.

The remaining four top producers shipped at much greater distances. Australian and Indian iron-ore was shipped primarily to Asia, though Australia shipped a not insignificant amount to Northern Europe. Brazil's largest market was Northern Europe, though it sent a significant share of its exports to Asia. Finally, South African shipped iron-ore to both Asia and Northern Europe.

Again, in the late 1970's, the world steel market collapsed. In Figure 1, we plot the time path of noncommunist and communist steel production from 1950 to 1996.[7] From 1950 to 1979, noncommunist steel production grew at about a four percent annual rate. After 1979, the time path of production was very different. From 1979 to 1982, steel production dropped 20 percent and it was not until 1993 that production had regained its 1979 level.

There was, of course, a significant drop in steel production beginning in 1974. However, most steel industry observers believed the 1974 drop would be short-lived and that world steel production would return to its trend growth. Based on this consensus, there was an aggressive expansion of iron-ore capacity in the late 1970's in many countries. In the United States, for example, two new mines were opened in Minnesota at Hibbing and Minorca in the late 1970's. Capacity was also added at existing Minnesota mines, like Minntac. These openings and expansions increased capacity in Minnesota (which accounted for the vast majority of U.S. iron-ore production) from roughly 41.2 million long tons in 1975 to 65.5 million long tons in 1980 (see Kakela, Kirsis and Marcus 1987, Table Z-1-34).

The behavior of iron-ore prices also shows that the crunch for iron-ore producers did

[7] Steel production figures are from the Minerals Yearbook of the USGS.

not arrive until the early 1980's. In particular, most iron-ore prices increased through the 1970's and it was not until the early 1980's, when the steel collapse became abundantly clear, that iron-ore prices began falling, many on the order of 20-33 percent over the period from 1982 to 1986.

Figure 2 presents information on iron-ore prices. Some prices are given for a particular type of iron-ore, there being three major types: lump, pellets and fines (including concentrates).[8] The upper-left panel of Figure 2 presents U.S. Bureau of Labor Statistics producer price indexes for iron-ore (all types), pellets and general producer prices. The iron-ore prices are those received by U.S. iron-ore producers at the mine and are based on both intra-company and market sales. Iron-ore prices and general producer prices moved closely together until the early 1980's. During the remainder of the 80's, iron-ore prices fell on the order of 20 percent, while general prices rose 20 percent.

The upper-right panel in Figure 2 presents the average delivered (CIF) price paid by Japanese steel producers per wet metric ton (WMT) of iron-ore from three countries: Brazil, India and Australia.[9] The average delivered prices do not vary much across these countries.[10] Average prices were a bit over $10 a ton in the late 60's, climbing to the upper $20 range by the early 80's before falling to the lower $20 range by the middle 80's.

In the bottom panel of Figure 2, we present the FOB prices of iron-ore received by the Brazilian firm CVRD for a particular type of iron-ore, fines, shipped to Europe and Japan. The prices are quoted in U.S. cents per percentage point of iron in a metric ton of iron-ore

[8] We will discuss the differences between the three types of iron-ore as their differences become relevant for the dicussion at hand.

[9] The source of the price data for the upper-right panel and bottom panel is Tex Reports.

[10] Average delivered prices may vary because, for one thing, prices vary by type of iron-ore.

(and not per ton).[11] CVRD received 30 cents per percentage point of iron for fines bound for Japan in 1982, this price dropping to about 20 cents in the late 1980's. CVRD received less for fines bound for Europe but the European and Japanese prices followed very similar patterns over time.

As the steel market collapse became abundantly clear in the early 1980's, what mines were under the greatest threat of being closed? One way to answer the question is to ask what levels of production over the course of the 1980's a "planner," one interested in minimizing the costs of supplying iron-ore to steel centers, would choose for mines across the world. To be more precise, suppose we had a list of every iron-ore mine in the world in 1980, together with the 1980 values for the marginal cost of producing a ton of iron-ore at each mine i, say c_i, the capacity of the mine, say k_i, and the marginal cost of transporting a ton of iron-ore a given distance, say t.[12] Further, let s_{jt} denote the quantity of steel produced at steel center j in year t. Then, the planning problem we consider is how to supply the steel centers with iron-ore over the course of the decade at minimum cost, taking as given the path of steel production by location over the decade, that is s_{jt}, and assuming the c_i, t, and k_i remain unchanged over the decade.

Suppose we had a solution to the planning problem. We then define the threat of

[11] In order to calculate the price received for a ton of iron-ore, we multiply the price in U.S. cents per percentage point of iron in a metric ton by the percentage of iron-ore in the ton. For example, at 30 cents per iron unit, iron-ore grading 65% iron would bear a price of 65 £ .30 = $19.50 a ton.

[12] Regarding capacity k_i, iron-ore mines have a rated annual capacity limit that is determined by factors such as the existing facilities for processing the iron-ore (that is, plant and equipment), the railroad facilities at the mine and the port facilities for moving the iron-ore to ships. There are substantial capital costs involved in starting an iron-ore mine. Moreover, as Bolis and Bekkala (1987, p. 17) argue, the costs of plant and equipment often make up only a small share of total capital costs, the costs of infrastructure, like the rail and port facilities, accounting for the greatest share. These latter costs are more likely to have a greater "sunk" component.

Regarding production costs c_i, we have implicitly assumed above that marginal costs are constant. Actually, marginal costs typically decline at a mine up until its rated capacity (more on this below), though introducing this feature would change little (since each mine's capacity is very small relative to the market).

closure faced by a mine as the percentage reduction in the mine's iron-ore production over the course of the decade in the solution to the planning problem. If the mine was slated to have a large percentage reduction in iron-ore output, then the mine would be classified as being under a large threat of closure (or having a large threat to its survival). Similarly, we can define the threat of closure faced by the iron-ore industry in a country as the percentage reduction in the country's iron-ore production over the course of the decade in the solution to the planning problem.

Under this definition, for example, if steel production fell dramatically at a particular steel center j; if all iron-ore mines had the same production costs c_i and if transport costs t were "large" relative to c_i, then those mines located near the "collapsing" steel center would be subject to a greater threat of closure than mines located near the other steel centers. If, further, the mines located near the collapsing steel center had production costs greater than those of mines near the other steel centers, the difference in the threat of closure between the two groups of mines would be even greater.

This was, of course, precisely the situation in world iron-ore markets in the early 1980's, namely, that steel production collapsed at a particular group of steel centers and that the iron-ore producers near these centers had high production costs. Because the analysis below will show very clearly that there were two groups of industries, one that faced a very significant threat of closure and another that faced little or no threat, we will not explicitly solve the above planning problem.[13]

[13] How well does such a planning problem describe the workings of the industry, namely, production levels and trade flows, prior to the crisis? Production and trade flows in the late 1970's conform pretty closely to those under this planning problem (i.e., cost minimization), though there are some anomolies. For example, Brazil shipped iron-ore to Japan at the same time that Australia shipped iron-ore to Northern Europe. What the planning problem misses, and which can account for these anomolies, are a few features of the industry,

Another way to answer the question about which mines were under greatest threat of closure would be to model the mines of the world to be engaged in a dynamic game and ask how the levels of output would evolve in a solution to such a game. Analysis of such a dynamic game would, of course, be much more difficult than the analysis of the above planning problem. But the same conclusions about which mines were under greatest threat of closure following a collapse of steel production at a steel center would very likely emerge from a model in which mines were modeled as engaging in a dynamic game.

3. Location, Location, Location

In this section, we show that the world steel collapse was primarily an Atlantic Basin collapse. We also show that the marginal costs of transporting iron-ore are very high relative to its price at port of export. Hence, everything else equal, threats of mine closure were higher in the Atlantic Basin.

The 20 percent drop in steel production between 1979 and 1982 shown in Figure 1 was nearly entirely concentrated in the Atlantic Basin. In Figure 3, the top panel, we plot noncommunist steel production in the Atlantic and Pacific Basins over 1950-1996. Steel production in the Atlantic Basin fell nearly 100 Mmt between '79 and '82, essentially the entire world drop in production. Moreover, Atlantic production had barely climbed back to its 1979 level by the middle 1990's. In contrast, Pacific production fell little between '79 and '82 and by the middle 1990's production was about one-third greater than its 1979 level.[14]

like the fact that Japan desires to keep a diversified supply and hence is willing to pay somewhat higher prices for its iron-ore and that there are different types of iron-ore.

[14] The reasons for the much stronger Pacific steel market included the strong U.S. dollar and the rapid growth of many of the developing Asian economies. But, again, from the standpoint of iron-ore producers, these regional developments in the steel market were exogenous. They had little power to alter such events.

The bottom panel of Figure 3 provides steel production for various groups of countries. Between 1979 and 1982, the sum of U. S. and Canadian steel production fell by over 40 percent; in West Germany, France and the United Kingdom it fell by over 20 percent; and in Japan, South Korea and Taiwan, production fell very little.

The marginal costs of transporting iron-ore are very high relative to its price at the mine or port of export. Data on iron-ore prices and transport costs in 1994, from Boyd and Perron (1997), are presented in Table 2. We present data for 1994 since the Boyd and Perron study o¤ers such a complete set of data on transport costs between locations. Below, in Table 3, we also present less complete data on prices and transport costs for the early 1980's. The two sets of data tell the same story regarding the size of transport costs relative to prices.

Table 2 presents the average rates paid for transport of iron-ore from mines to ports of export (that is, the rail charges), the average charges paid for transport from port of export to various markets around the world (that is, the ocean freight charges) and the prices received at port of export for two types of iron-ore, concentrates and pellets. As can be seen, transport charges are often a large share of the delivered price of iron-ore. For example, take the case of the Brazilian producer Samitri. It received $13.24 at its port in Tubarao for a ton of concentrate bound for Europe. The average ocean charge to Europe was $6.50 so that the delivered price in Europe was $19.74 ($6.50+$13.24). Now, the total transport costs for a ton of concentrate bound for Europe was the sum of the rail, $7.50, and the ocean freight, $6.50, or $14.00. Hence, the transport charges amounted to 71 percent of the delivered price ($14.00¥$19.74).

The marginal costs of transport are also signi…cant. For the Australian producers, the average charge per ton to Baltimore was $6.05 greater than the charge per ton to Japan, that is, \$11.55 as compared to \$5.50 per ton. The average charge per ton to Northern Europe was \$3.55 greater than the average charge per ton to Japan, that is, \$9.05 as compared to \$5.50 per ton. These additional costs are significant in comparison to the price received at the port of export on concentrates bound for Japan, which ranged from \$11.49 to \$15.86.

That the steel market collapse was an Atlantic collapse and the marginal costs of transporting iron-ore are very high relative to its value at the mine establishes that, everything else equal, the mines in the Atlantic were under the greatest threat of closure. Let us now turn to examine the other major factor determining threat of closure, the production costs at the mines.

4. Atlantic Mines Had Highest Production Costs

In this section, we show that the mines in the Atlantic Basin, with the important exception of Brazil, had the highest production costs in the world. Australia, Brazil and India had much lower costs than the other top producing countries, with Brazil the lowest cost producer in the world.

Calculating the production costs at mines is no small task. Luckily, there was a major effort to estimate production costs in the early 1980's by the U.S. Bureau of Mines (USBM). In Table 3 we present data from the USBM report by Bolis and Bekkala (1987). Boyd and Perron (1997) also estimated costs for a large number of mines across countries. While these costs were estimated for 1994, we also briefly discuss these estimates in Table 4.

Production or operating costs at mines, roughly the c_i above, as estimated by the USBM are given in the left-most columns of Table 3 (we discuss the other columns on transport costs in the next section).[15] Costs were estimated at a number of mines in each country (or region). The …rst column in the table gives the number of mines studied in each country (or region). The costs are broken down into the costs of mining the iron-ore and the costs of bene…ciation, which are given in the second and third columns of the table, respectively.[16] The USBM report presents the range of costs in each country (or region) — this was presumably done to avoid disclosing information about particular mines.

The top of the table presents data for Atlantic Basin producers. The producers in Canada, Europe (which includes Norway, Spain and Sweden) and the United States clearly had higher costs than Brazilian producers. Regarding the costs of mining, we see that the range of costs in Brazil ($0.70 to $2.00 per ton) was everywhere below the range in Canada ($2.00 to $2.50), Europe ($2.60 to $7.20) and the United States ($2.00 to $4.50). Regarding the costs of bene…ciating, we see that the range of costs in Brazil ($0.50 to $1.70 per ton) was everywhere below the range in Canada ($3.00 to $3.50) and the United States ($3.25 to $5.00) and nearly so in Europe ($1.50 to $4.50). Clearly, then, the Brazilian mines had a far lower sum of mining and bene…ciation costs than Canadian and U.S. mines. It also had a far lower sum than the Swedish mines since these mines were underground and there is little doubt that the highest mining costs in Europe, the $7.20 …gure above, belonged to Sweden.

What about costs in the other top Atlantic producers, South Africa and France? The

[15] The de…nition of operating costs in the study is: "total operating cost of a mining project is a combination of direct and indirect costs. Direct operating costs include operating and maintenance labor and supplies, supervision, payroll overhead, insurance, local taxation and utilities. The indirect operating costs include technical and clerical labor, administrative costs, maintenance of facilities and research" (Bolis and Bekkala 1987, p. 12). We will use the terms operating and production costs interchangeably. Note that capital costs are not included in this de…nition of operating costs.

[16] After iron-ore is mined, it nearly always undergoes some form of bene…ciation — a process of crushing and screening the iron-ore to produce uniform sized particles, improve the iron content of the product and eliminate impurities.

USBM report did not study France. It did present estimates for Africa as a group (a group consisting of …ve countries). While Brazilian mines had both lower mining and bene…ciation costs than African mines, the ranges for Brazil did not lie everywhere below the ranges for Africa. The report did examine the deposits of …nes (see Appendix B for a discussion of iron-ore types) in Brazil and Africa and estimated the total costs of producing …nes from these deposits.[17] The report shows (Figure 19, p. 33) that Brazil had huge deposits of …nes that could be mined at lower cost than the least cost deposit in Africa. Hence, this part of the report shows that South Africa had signi…cantly higher costs of producing …nes, the major South African product, than did Brazil.

The bottom of the table presents data for Paci…c Basin producers. The Paci…c producers had production costs that were much lower than the Atlantic producers with the exception of Brazil. The table indicates that Brazil was the world's lowest cost producer. While the range of costs of bene…ciation in Brazil ($0.50 to $1.70 per ton) was very similar to that in Australia ($0.30 to $1.60) and India ($0.50 to $1.50), mining costs in Brazil appeared to be somewhat lower (the range in Brazil was ($0.70 to $2.00 per ton) compared to that in Australia of ($1.60 to $2.60) and India of ($1.00 to $5.00)).

So, the Brazilian, Australian and Indian mines had the lowest costs of mining plus bene…ciation of the top eight producers. Not all bene…ciated iron-ores sold for the same price. It turns out that not only did Australia, Brazil and India have the lowest costs in producing bene…ciated iron-ore, their bene…ciated ore was worth more as well. We discuss this issue further in Appendix B.

In Table 4 we present production costs as estimated in Boyd and Perron (1997) for

[17] These costs included the costs of mining plus bene…ciation plus capital costs.

mines in 1994.[18] This study presents estimates by producer and by type of iron-ore. There are, of course, a number of reasons why cost estimates are not directly comparable across these two studies, including that somewhat di¤erent de…nitions of operating costs are employed and that the Canadian study is a decade later. Over the decade, many factors that a¤ect costs (in dollars) changed: wages, productivity, exchange rates, and much more. Still, as we show, the ranking of countries by cost is the same.

The …rst column of Table 4 presents the operating costs (mining plus bene…ciation) of mines across the world in the production of concentrate (we discuss the right-most columns in the next section). Again, the Atlantic producers Canada, South Africa and Sweden had signi…cantly higher costs than Brazil. Australia and India had lower costs than the Atlantic mines excluding Brazil, and Brazil clearly had the lowest cost mines in the world. Hence, the ranking of countries by production costs is similar in the Boyd and Perron (1997) and the Bolis and Bekkala (1987) studies.

5. Threats of Closure and Labor Productivity

In this section, we argue that there were two groups of iron-ore producing countries, one group where mines faced little threat of closure, the other where mines faced signi…cant threats of closure. We then compare the production and productivity records of the two groups of countries.

Let us for the moment ignore Brazil. Then we have shown that Australia and India had much lower production costs than the other …ve Atlantic producers. Moreover, they also

[18] Operating costs in Boyd and Perron (1997, p. 51) "include expenses in the form of materials, labour, and energy." "They do not include royalty payments, taxes, depreciation or interest costs, and fringe bene…ts or social costs."

had better locations to deal with the Atlantic steel collapse. Hence, the Australian and Indian mines faced very little threat of closure while the mines in the other …ve Atlantic producers faced signi…cant threats of closure.

Let us now reintroduce Brazil. As we show below, by referring back to Tables 3 and 4, Brazil's production costs were so low compared to the other …ve Atlantic producers that Brazil could produce and ship iron-ore to most Atlantic steel centers more cheaply than Atlantic mines that were much closer to those steel centers. Hence, Brazil's mines faced little threat of closure as well.

Let us …rst compare Brazilian and Canadian mines as competitors in Europe with the use of Table 3. First, the greatest possible production cost for a surveyed Brazilian mine was $3.70 ($2.00+$1.70). The least possible production cost for a surveyed Canadian mine was $5.00 ($2.00+$3.00). So, among the surveyed mines, the Brazilian mines had a production cost advantage of at least $1.30 over the Canadian mines.

What were the ocean transport costs of each country to Europe? The right-most columns of Table 3 present ocean freight rates from the USBM study. Rates are presented for di¤erent size ships. Rates are cheaper on larger ships (for example, see Brazil to Japan by size). Suppose we compare ocean charges of the two countries with the size of ship held roughly …xed. On the bigger ships, Brazil's ocean rate was $1.50 more than Canada's ($4.50 on a ship of size 155 10^3 DWT as compared to $3.00 on a ship of size 160 10^3 DWT). This di¤erence of $1.50 was just a bit bigger than the (minimum) Brazilian cost advantage of $1.30.

So, the (minimum) Brazilian production cost advantage nearly covers the di¤erence on ocean rates to Europe on ships of the same size. But it is very likely that, on average, the

Brazilian ore traveled on much larger ships. First, Brazil typically shipped two or three times the iron-ore to Europe than did Canada. Second, Brazil had much larger port and handling facilities, on average, than did Canada during this period (see Bolis and Bekkala 1987, Table 3, p. 6). Both these considerations suggest that Brazil's average ocean charges were much closer to the Canadian charges. (In fact, recall Table 2, which presented the average transport charges over the year and where the Brazilian and Canadian charges to Europe were similar.)

If we compare surveyed Brazilian mines to Swedish mines, the greatest possible production cost for a surveyed Brazilian mine was again \$3.70, while the least possible production cost for a surveyed Swedish mine was \$8.70 (\$7.20+\$1.50). So, among the surveyed mines, the Brazilian mines had a production cost advantage of at least \$5.00 over the Swedish mines. This cost advantage is roughly Brazil's ocean shipment costs to Europe.

Next, suppose we looked at the same issue using Boyd and Perron (1997) estimates of production and shipment costs in 1994 in Table 4. We see that in 1994 Brazil could produce and ship to Northern Europe at less cost than the Canadians and Swedes, just as Bolis and Bekkala (1987) indicated.

We now examine the production and productivity records of these two groups of countries in Figure 4. In the top part of Figure 4, we place the countries where mines faced little or no threat of closure (in alphabetical order). The bottom part of the …gure presents the countries where mines faced a signi…cant threat of closure (again, in alphabetical order). In each …gure, production equals the weight of iron-ore produced, while productivity equals production divided by hours (for the United States and Sweden) or production divided by average employment over the year (for the rest). We use the production …gures reported by the country's statistical agency if they are available and, if not, the USGS production

…gures.[19] Each series is normalized so that 1980=1.

If we …rst look at the production records of the top producers (production being the "light" line in each …gure), we see that in the early 1980's production fell very little in Australia, Brazil and India as compared to the other …ve producers in the bottom panel. Clearly, the producers who we categorized as being under the greatest threat of closure are also the producers who were initially hit hardest by the steel collapse. By the end of the decade, output had returned to or exceeded precrisis levels in Australia, Brazil and India, while among producers in the bottom panel, output in South Africa was near precrisis levels, output in France dropped through the decade, and in Canada, Sweden and the United States output equaled about 80 percent of its precrisis level.[20]

Turning to the productivity records (productivity being the "heavy" line in each …gure), we see that Australia and Brazil had no productivity gains over the 1980's (and none over the prior decade as well). India did have productivity gains of 29 percent over the decade, but this was certainly smaller than its gain the previous decade of 55 percent. Canada, Sweden and the United States all had gains that approached 100 percent over the decade of the 1980's, whereas in the previous decade each had essentially no productivity gains. For South Africa, we only have labor input data from 1980. South Africa had impressive productivity

[19] We use USGS production data for France and Sweden. The Australian data from the Australian Bureau of Statistics (ABS) are reported on a …nancial year ending June 30 basis. Production …gures were not given for two of these …nancial years, 1985 and 1986. We estimated production data for the …nancial years 1985 and 1986 from annual production data reported for 1984, 1985 and 1986 by the USGS.

[20] While output recovered to about 80 percent of its precrisis level in these last three countries, so that many operations in Canada, Sweden and the United States did ride out the crisis, the situation was touch-and-go for many that did survive. In the 1984 annual report of LKAB, Sweden's leading iron-ore producer, the company president Wiking Sjostrand stated: "Ten years ago, no one could imagine that LKAB might …nd itself involved in such a serious crisis as the one which we have just passed through .... and in fact, for a period of time, a total catastrophe was very, very close" (LKAB Annual Report, p. 3). Wayne Dalke, who was the general manager of the U.S. Steel mine in Minnesota (Minntac) during the middle 1980's, told us that U.S. Steel was threatening to close the Minntac mine during the middle 1980's.

gains of 50 percent during the decade. France had no gains over the 1980's.

Hence, there was a close connection between the threat of closure faced by mines in an industry in the early 1980's and the industry's productivity record over the 1980's. Again, the exception to the rule is France. The French case is clearly special, as can be seen in Table 1. The iron content of French iron-ore (31.4 percent) was nearly half that of the other top producers (61.7 percent).[21] The French industry was in significant decline long before the crisis in the early 1980's, its output falling by half over the 1970's. We are not sure the French industry could have done anything to stave off disaster.

6. Sources of Productivity Gains

In this section, we discuss the sources of productivity gains in the Canadian, Swedish, South African and U.S. industries. Also, we discuss the possibility that the Australian, Brazilian and Indian industries experienced no productivity gains over the 1980's because there was "no room" for productivity improvement in these industries.

A. Sources of Productivity Gains in Canada, Sweden, ...

In this subsection, we argue that the productivity gains in the industries of Canada, Sweden, South Africa and the United States were mostly driven by continuing mines, using existing technology, and producing the same products, increasing their productivity in order to stay alive. We establish this conclusion by arguing that some obvious sources of gains were not quantitatively important sources of gains.

[21] Both Germany and the United Kingdom had deposits of iron-ore that were of similar quality to the French but both these countries (essentially) left the industry in the 1960's.

Changes in the Type of Iron-Ore Produced?

Again, there are a three major types of iron-ore: lump, fines (including concentrates) and pellets. More labor is required to produce a ton of pellets than a ton of the other two iron-ores. Hence, one possible source of productivity gain in the 1980's as compared to the 1970's was that a country produced less pellets in the 1980's. In Table 5, we present data on the percentage of pellets, over the period 1970-1990, in the production (by weight) of countries for which such data is available.[22]

Over the period 1970-90, there was a shift toward pellets in Canada, Sweden and the United States. For example, in Sweden, pellets accounted for 27.7 and 24.6 percent of production in 1975 and 1980; in 1985 and 1990, they accounted for 43.1 and 50.1 percent. So, everything else equal, productivity in these countries in the 1980's should have been lower than in the 1970's. What this all suggests is that the productivity gains in producing each type of iron-ore was greater than the aggregate productivity gains in Figure 4. In this sense, then, the productivity gains in Figure 4 for these three countries are understated.[23]

Introduction of New Technology?

Until World War II, the production of iron-ore typically involved the mining of soft, high-grade iron-ore, that is, lump iron-ore, which required little further processing before it could be used in blast furnaces. The demands of WWII for steel led to a significant reduction in these high-grade deposits, particularly in the United States. What remained were deposits

[22] Data was only available at five year intervals. While data was not available for South Africa, we know it essentially had no pellet production throughout the 1970-90 period.

[23] Australia has never been a big producer of pellets given it still has vast deposits of lump ore. In fact, Australia withdrew from the production of pellets over the 1970-90 period, its production falling from 11.6 to 4.2 percent of output.

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 natural lump ore contained 50-60 percent iron). The biggest technological breakthrough in the iron-ore industry after WWII was the development of a way to process these hard rock deposits into a marketable product — pellets. 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 over the last thirty years. But no dramatic change in technology occurred, for example, in the middle 1980's that caused the productivity surges observed in Figure 4. Basically, the technology in this mature industry changes very slowly.[24]

There is a caveat to the above discussion and it concerns Sweden. In contrast to the other mines in the top-producing countries, the Swedish mines were underground mines. There have been signi…cant changes in mining methods in underground mines of all types (e.g., coal) and, in particular, in Swedish iron-ore mines (for a brief discussion, see Hellmer (1997), p. 140).

[24] In contrast to the iron-ore industry, the steel industry, which also had signi…cant productivity gains in the 1980's in the United States, underwent some fairly signi…cant technology changes in the 1980's. For example, minimills employed a new, more productive way of producing steel and minimills share of ouptut grew over this decade. There were also big changes in the way steel was produced in integrated steel plants. For example, integrated plants introduced continuous casting at a rapid rate.

Reductions in Industry Output?

Iron-ore output was lower at the end of the 1980's in each of the countries where productivity surged (except South Africa). Could this reduction in industry output have been a source of productivity gain? Reductions in industry output would lead to productivity gains if (1) output was reduced at each mine and there were decreasing returns to scale at the mine level and/or (2) output was reduced by closing low productivity mines.

Before discussing returns to scale and mine closings, notice that when output fell dramatically in United States, Canada, Sweden and South Africa in the early 1980's, industry productivity initially fell. And in earlier periods, as well, output and labor productivity typically moved together.

Regarding returns to scale, it is taken as a given by industry analysts that, at the mine level, labor productivity is increasing in mine output up until mine capacity (see, for example, Kakela, Kirsis and Marcus, 1987). In a formal econometric analysis, Ellerman, Stoker, and Berndt (1998) …nd this is true for coal mines as well.

Mine closings likely contributed only a modest amount to increased productivity during the 1980's. One reason for this conclusion is the timing of output and productivity movements in the United States, Canada, Sweden and South Africa. In the …rst three countries, output fell dramatically in the early 1980's, on the order of 40 to 50 percent. Output then recovered fairly quickly, to about 80 percent of its precrisis level, and then remained fairly constant through the remainder of the decade (in the United States, there was a strike in 1986 that led to a drop in output). Productivity gains in each country were not concentrated in the period when output fell dramatically but occurred primarily during the period when output was changing little.

Mine closings were very likely not occurring during the period when output was changing very little. The reason is that given the very large infrastructure costs of opening mines, it is likely not the case that output was produced with some mines opening and others closing. Rather, mine closings presumably occurred during the period when output initially fell dramatically. This suggests that mine closings had only a very small contribution to overall productivity gains.[25]

Summary

We have argued that shifts in the types of iron-ore produced during the 1980's understate the productivity gains in Canada, Sweden and the United States. We have also argued that the technological history of the industry indicates that no major technology breakthrough accounts for the surges in productivity in Figure 4, except that in Sweden new technology may account for substantial productivity improvements. We have also argued that the closing of low productivity mines likely contributed only a modest share to the gains. This leads to the conclusion that the productivity gains were mostly driven by continuing mines, using existing technology, increasing their productivity in order to stay alive.

But just what happened at the mines to increase productivity? Industry analysts that follow the U.S. steel and iron-ore industries attributed much of the gain in iron-ore productivity during the 1980's to changes in work rules in union contracts (see, e.g., Kakela, Kirsis and Marcus (1987), p. I-51).[26] Newspaper accounts of the surge in U.S. iron-ore productiv-

[25] Another reason that labor productivity might increase as industry output is decreased is that mines could now choose to process the "easy-to-get-at" iron-ore. However, this was not an important source of gain at these mines. As stated above, labor productivity at mines typically increased in output.

[26] Here are a few examples of changes in work practices in the U.S. iron-ore industry over the 1980's. Prior to the crisis, union contracts speci…ed many "narrowly" de…ned jobs. After the crisis, new jobs were de…ned which were combinations of many old jobs. These new, broader job classi…cations gave management more ‡exibility in scheduling and sta¢ng. Also, a whole new category of job was created, the "equipment tender."

ity during the 1980's also suggested that changes in work rules were an important factor in productivity gains (see, e.g., Taconite is Back, Minneapolis Star and Tribune, 01/08/96).[27] Similarly, Hellmer (1997, pp. 141-143) argues that changes in the work environment in the Swedish industry, in particular, improvements in labor-management relations that he refers to as a "cultural revolution," were an important factor in that industry's productivity gains.

To establish that changes in work rules in the United States and Canada, and improvements in labor-management relations in Sweden, were a major source of productivity gain in these industries, as much anecdotal evidence suggests, requires collecting and/or constructing significant amounts of additional data, on things like investment, capital stocks and union contracts. Such work is in progress (see Schmitz (1998)). We note that this work also confirms, for the United States and Canada, the conclusions of the discussion above, namely that the productivity gains in producing each type of iron-ore was greater than the aggregate productivity gains, that introduction of new technology did not play a large role in the gains of the middle 1980's and that exiting mines contributed only a small share to the productivity gains (using mine level data in Minnesota, Schmitz (1998) shows that exiting mines accounted for only about five percent of the productivity gains).

B. "No Room" for Productivity Improvement in Australia, Brazil, India?

Perhaps there was no room for improvement in productivity in the Australian, Brazilian and Indian industries? This was not the case as the experience of the 1990's demon-

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An equipment tender was a machine operator who was permitted by union contract to fix his or her machine if it malfunctioned. Prior to this new job, a maintenance and repair person would have to make all repairs.

[27] Not surprisingly, given that the Canadian industry had the same union as the U.S. industry, the United Steelworkers of America, much the same anecdotes about work practices were told about the Canadian industry.

strates. In the early 1990's, Brazil began privatizing large parts of its economy and the iron-ore industry was included in this privatization wave. During this period of privatization, Brazil's iron-ore industry experienced dramatic productivity gains (as can be seen in Figure 4). Shortly following Brazil's privatization plans, Australia's iron-ore industry showed significant productivity gains as well (again seen in Figure 4).

The newspaper accounts and reports of industry analysts regarding the productivity gains in the 1990's by Australia and Brazil closely mirror the accounts from the United States and Canada in the 1980's. That is, the gains are largely attributed to changes in union contracts and changes in work rules.

The anecdotal evidence, then, suggests that the same changes that occurred in the U.S. and Canadian industries during the 1980's were occurring in Brazil and Australia a decade later. What drove these changes and made them possible in the 1990's (where they were not possible in the early 1980's)?[28] This is subject to future work but we can give a few conjectures here. In Brazil, the changes were likely spurred by the changes in ownership. In Australia, they may have been spurred by the fact that the industry's greatest competitor (that is, Brazil) began dramatically increasing its productivity.

7. Discussion

We think our analysis makes contributions to two important points. First, the analysis suggests that there are important factors determining productivity that are not part of traditional models and thinking, which emphasize technology, physical capital and human capital. This follows from our documenting large productivity gains, sometimes 100 percent

[28] The Australian iron-ore industry did attempt to change union contracts and introduce changes in work rules in the early 1980's but were not successful.

gains, over a short period of time in a particular industry in some countries, and our arguing that the introduction of new technology and the closing of low productivity producers played only small roles, if any, in the gains, and from work in progress in Schmitz (1998) showing that investment in new plant and equipment was nearly shut o¤ in some of these industries experiencing productivity gains. Such a point is also made in the important work of Clark (1982), who documented large productivity di¤erences across countries in an industry at a point in time (we documented large productivity di¤erences within an industry over time) that also could not be explained by traditional factors like technology and capital (see, also, Prescott (1998)).

The second point is that one of these "other" factors determining productivity is, at least in this episode, the threat of closure, or perhaps we can use the term "competition," facing producers.

As we mentioned, the view that the extent of competition in‡uences productivity has lost currency in the academic economics literature. And why not. There has simply not been much evidence that such a phenomenon, of threats or competition leading to productivity gains, is important. For example, in the …eld of international trade, there have been studies of how reductions in tari¤s (which likely increase the threat of closure of some domestic producers) in‡uence industry productivity. The conclusion from some of the best work in this area, for example, Tybout, de Melo and Corbo (1991) and Tybout and Westbrook (1995), is that there is little relationship between reductions in tari¤s (or e¤ective protection) and industry labor productivity.[29]

But while the evidence that this phenomenon is important has been very thin, the

[29] But for a recent paper that …nds some relationship, see Ferreira and Rossi (1999).

situation is changing. Recently, some studies have shown that more extensive competition leads to greater productivity through "traditional" channels, like spurring adoption of technology and capital. Prescott (1998, pp. 544-546) argues that after WWII, when cheap oil became available, and the (real) price of coal began falling, the union representing the U.S. coal miners agreed to the adoption of new mining technology given that mine closures would be imminent without the technology.[30] In an interesting study, Zitzewitz (1999) argues that periods of increased competition in the tobacco industry led to increased mechanization (i.e., adoption) and productivity gains.[31]

Other evidence, like that in this paper, indicates that competition (or lack of it) may increase (decrease) productivity through channels other than technology and capital. Zitzewitz (1999) argues that "the lower intensity of competition in the UK [tobacco industry] led to a less vigorous pursuit of efficiency gains than before ...," leading to, for example, large overstaffing. Borenstein and Farrell (BF) (1999) show that when the price of gold increases, the stock-market value of gold mining companies does not increase as much when gold's price was initially high rather than low. This contradicts the predictions of standard theory and they take this as evidence that waste and "inefficiency" increase as corporate wealth grows. BF do not directly examine productivity and use the term "efficiency" in a more general sense than it is used here but their results are related nonetheless.

The studies mentioned thus far have all concerned particular episodes in specific in-

[30] Like Prescott, Ellerman, Stoker and Berndt (1998) also find that there is a negative correlation between the (real) price of coal and labor productivity (they deflate the price of coal by mining wages, whereas Prescott deflates the price of coal by a general price deflator). They argue that a rising price of coal (relative to wages) likely leads to lower productivity because during these periods marginal, harder-to-mine deposits are tapped. Prescott implicitly downplays this explanation since the movement in total output is very small relative to aggregate productivity.

[31] See also the work of Baily (1993) and Baily and Gersbach (1995).

dustries — case studies. Some advantages of these studies are that the forces leading to increased competition are clearly understood and the measurement of productivity is done with considerable confidence. But, of course, it would be helpful to have other evidence, like finding the phenomenon in large panel data sets of plants and/or firms. In an interesting paper, Nickell (1996) provides such evidence. He examines a panel of UK firms and argues that those facing greater competition had greater productivity growth. Among his measures of competition are a survey based measure (firms are asked whether they have five or greater competitors) and a measure of rents (rents equal profits less cost of capital, normalized by value-added), with lower rents taken as signaling greater competition.

Along with these recent empirical contributions, there is a recent theoretical literature that shows mechanisms through which increases in "competition," such as Aghion and Howitt (1998), and decreases in tariffs, such as Holmes and Schmitz (1998), lead to higher productivity. In both papers productivity increases because of greater research and new technology. In this sense, both are part of the traditional productivity literature emphasizing capital and technology. In contrast, Parente and Prescott (1999) present a model where groups, which have "monopoly rights" and are insulated from competition, decide to use technology at inefficient levels, a model clearly outside the traditional productivity literature.

APPENDIX A—Data Sources

Australia: Production and employment from Manufacturing Census, Australian Bureau of Statistics.

Brazil: Production and employment from Anuario Mineral Brasileiro, Departamento Nacional de Produção Mineral, Ministério de Minas e Energia.

Canada: Production and employment from Canadian Minerals Yearbook, Natural Resources Canada.

France: Production from Minerals Yearbook, United States Geological Survey. Employment from INSEE, National Accounts Department.

India: Production and employment from Indian Mineral Yearbook, Indian Bureau of Mines, Ministry of Steel and Mines. Also data from the Federation of Indian Mineral Industries.

South Africa: Production and employment from South Africa's Mineral Industry, Minerals Bureau, Department of Minerals and Energy.

Sweden: Production from Minerals Yearbook, United States Geological Survey. Employment and hours worked from Statistics Sweden (Statistika centralbyran).

United States: Production, employment and hours worked from Minerals Yearbook, United States Geological Survey.

APPENDIX B— Prices of Bene…ciated Iron-ores

In Section 4 on production costs, we claimed that not only did Australia, Brazil and India have the lowest costs in producing bene…ciated iron-ore, their bene…ciated ore was worth more as well. We now brie‡y discuss this issue.

Again, after iron-ore is mined, it nearly always undergoes some form of bene…ciation — 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 the bene…ciated ore is coarse, it can be used in this form in blast furnaces. The product is called lump iron-ore. If the bene…ciated iron-ore is less coarse, then it must undergo some form of agglomeration, since …ne particles can cause operational problems in blast furnaces. There are two major types of bene…ciated iron-ore that undergo agglomeration: …nes (or concentrates), which is agglomerated into sinter, and pellet feed, which is agglomerated into pellets. "Sintering" is typically done after the shipment of the …nes to the blast furnace. "Pelletizing" is typically done at the mine; the pellets are then shipped to blast furnaces.

Lump iron-ore typically needs relatively little bene…ciation and hence costs little to bene…ciate. And since lump iron-ore does not need to be processed further before being used in blast furnaces, it typically sells at a premium relative to the other two bene…ciated iron-ores. For example, for the three types of bene…ciated iron-ores, lump, …nes, and pellet feed, Bolis and Bekkala (1987, Table 6, p. 13) quote prices in 1984 of (in U.S. cents per iron-ore unit): lump — \$0.32; sinter …nes — \$0.28; and pellet feed — \$0.30.[32] Hence, countries that still have large deposits of lump iron-ore have low mining and bene…ciation costs and receive

[32] These prices are averages of prices received at mines around the world.

premiums for their iron-ore.[33]

Australia and India had by far the greatest percentage of lump ore in their production.[34] For 1984, for example, lump ore accounted for 3.7 percent of Canadian production, 48.5 percent of Indian production, 13.8 percent of Swedish production and 0.0 percent of U.S. production.[35] For Australia and Brazil, we know the fraction of lump ore in exports. In 1984, lump ore accounted for 41.5 percent of Australia's exports (and exports were 90.5 percent of production) and 11.3 percent of Brazil's exports (and exports were 79.0 percent of production).

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[33] When pellet feed is agglomerated into pellets, the pellets typically sell for a premium over lump ore but the operating costs of agglomeration are typically greater than the additional revenue. For example, the price quoted in Bolis and Bekkala (1987) for pellets was $0.42 an iron ore unit. A ton of lump and pellets, both grading at 65 percent iron, would then have sold for $20.80 (65£$0.32) and $27.30 (65£$0.42), respectively, or a premium of $6.50 a ton. The operating costs of pelletizing in the United States given in Bolis and Bekkala (1987) ranged from $6.00 to $10.60 a ton. In Canada, the range was from $15.00 to $22.70 a ton. There were also signi…cant capital costs associated with pelletizing.

[34] All the …gures in this paragraph are taken from United Nations (1994), except the U.S. …gure, which is from the United States Geological Survey (various years).

[35] For Canada, the …gures represent shipments (and not production).

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Table 1

Top Eight Iron-Ore Producers in 1980 and Some Characteristics
of Their Iron-Ore Production in 1980*

Countries	**Years** (for which we have labor input)	**USGS Production—1980** (million metric tons)	**Country-reported Production—1980** (million metric tons)	**USGS Metal Content—1980** (percentage iron)
Atlantic Basin				
Brazil	1972–95	114.7	113.0	65.0
Canada	1961–97	48.7	49.1	63.2
France	1970–94	28.9	28.9	31.4
South Africa	1980–97	26.3	26.3	63.9
Sweden	1965–93	27.2	27.0	64.7
U.S.A.	1965–97	70.7	70.7	63.1
Pacific Basin				
Australia	1966–97	95.5	97.0[1]	63.2
India	1965–95	41.9	41.6	62.5
Total, Top Eight Producers		453.9		61.7
Total non-communist		558.8		60.8
Total communist		332.4		52.2
Total World		891.2		57.6

* Sources explained in Appendix A.

1 For Financial Year Ending June 30.

Table 2

Freight Rates and Prices for Iron-Ore in 1994

Country	Producer	Loading Port	Freight: Rail to Port	Freight: Port to Destination: North America: Baltimore	North America: Chicago	Northern Europe	Japan and Other Asia	Price[1] (concentrates)	Price[1] (pellets)
			(US$/t)[2]			(US$/t)[2]		(US$/t)[2]	(US$/t)[2]
Australia	BHP	Port Hedland	2.25	11.55	–	9.05	5.50	15.86 (J)	na
	Hamersley	Dampier	2.50	11.55	–	9.05	5.50	15.85 (J)	na
	Robe River	Cape Lambert	1.75	11.55	–	9.05	5.50	11.49 (J)	na
Brazil	CVRD	Ponta da Madeira	4.10	8.00	nr	6.30	9.60	17.83 (E)	
	CVRD	Tubarao	3.50	8.50	24.35	6.50	10.30	16.40 (E)	28.03 (E)
	MBR	Sepetiba Bay	7.00	8.50	24.35	6.50	10.30	16.81 (E)	na
	Samitri	Tubarao	7.50	8.50	24.35	6.50	10.30	13.24 (E)	27.68 (E)
Canada	QCM	Port-Cartier	2.00	5.75	9.95	6.30	–	17.29 (E)	28.64 (E)
	IOC	Sept-Îles	2.50	5.75	9.95	6.30	…	17.22 (E)	28.86 (E)
	Wabush	Pointe-Noire	5.70	5.75	9.95	6.30	–	16.48 (E)	28.22 (NA)
India	Kudremukh	Mangalore	1.50	11.55	–	8.50	7.90	12.84 (J)	25.41 (J)
So. Africa	Sishen	Saldanha Bay	7.50	10.75	–	8.00	9.25	13.54 (E)	na
Sweden	LKAB	Narvik/Lulea	7.00	9.00	–	3.35	–	19.61 (E)	30.42 (E)
United States	Minnesota	Duluth	6.05	–	6.79	–	–	na	30.59 (NA)

Source: Boyd and Perron (1997).

[1] Price f.o.b. (port of export) for the country's largest market. E = Europe, J = Japan, NA = North America.

[2] Per tonne of product.

–Nil, or no significant trade.

…There was some trade on this route, but freight rate is not a market rate.

nr—not reported; na—not applicable.

Table 3

Operating Costs, Rail Transport Costs, and
Ocean Freight Costs for Selected Iron-Ore Mines, 1984

		Operating Costs, 1984 $/t Ore		Rail Transport Costs		Ocean Freight Costs		
Country	Number of Producers	Mine	Beneficiation	1984 $/t km	Distance, km	Destination	Ship Size 10^3 DWT	1984 $/t
Canada	3	2.00–2.50	3.00–3.50	.008–.009	410–450	Japan	130–150	…..
						Western Europe	100–160	3–4.25
Europe[1]	5	2.60–7.20	1.50–4.50					
United States	9	2.00–4.50	3.25–5.00					
Brazil	13	.70–2.00	.50–1.70	.005–.007	640–730	Japan	130–150	7–9
							220	5.25–6
						Western Europe	50–65	5.75–6.50
							80–155	4.50–6.00
Australia	5	1.60–2.60	.30–1.60	.003–.004	50–430	South Korea	100–150	5–6
						Western Europe	100–150	6.50–8.75
India	5	1.00–5.00	.50–1.50	.020(av)	60–470			

Source: Bolis and Bekkala (1987).

….. There was some trade on this route, but freight rate is not a market rate.

[1] European producers include Norway, Spain, and Sweden.

Table 4

Operating Costs for Concentrates, Rail Transport Costs,
and Ocean Freight Costs to Northern Europe for Selected Iron-Ore Mines, 1994

Country	Producer	Operating Costs, 1994 $/t Ore	Rail Transport Costs 1994 $/t Ore	Ocean Freight Costs to Northern Europe 1994 $/t Ore
Canada	QCM	9.20	2.00	6.30
	IOC	10.85	2.50	6.30
	Wabush	9.05	5.70	6.30
South Africa	Sishen	8.80	7.50	8.00
Sweden	LKAB	10.50	7.00	3.35
Brazil	CVRD—Carajas	2.15	4.10	6.30
	CVRD—Minas Gerais	3.15	3.50	6.50
	MBR	2.50	7.00	6.50
	Samitri	2.95	7.50	6.50
Australia	BHP	7.95	2.25	9.05
	Hamersley	4.15	2.50	9.05
	Robe River	3.50	1.75	9.05
India	Kudremukh	6.35	1.50	8.50

Source: Boyd and Perron (1997)

Table 5

Pellet Production as a Percentage of Total Iron-Ore Production

Year	Australia	Canada[1]	Sweden	United States
	Country			
1970	11.6	55.6	15.6	64.5
1975	9.7	54.3	27.7	80.6
1980	5.6	52.3	24.6	93.1
1985	4.0	61.4	43.1	96.4
1990	4.2	63.9	50.1	97.2

Source: United States Geological Survey (various years)
Others—United Nations (1994)

[1] Percentage of Shipments

Figure 1: World Steel Production
1950-1996

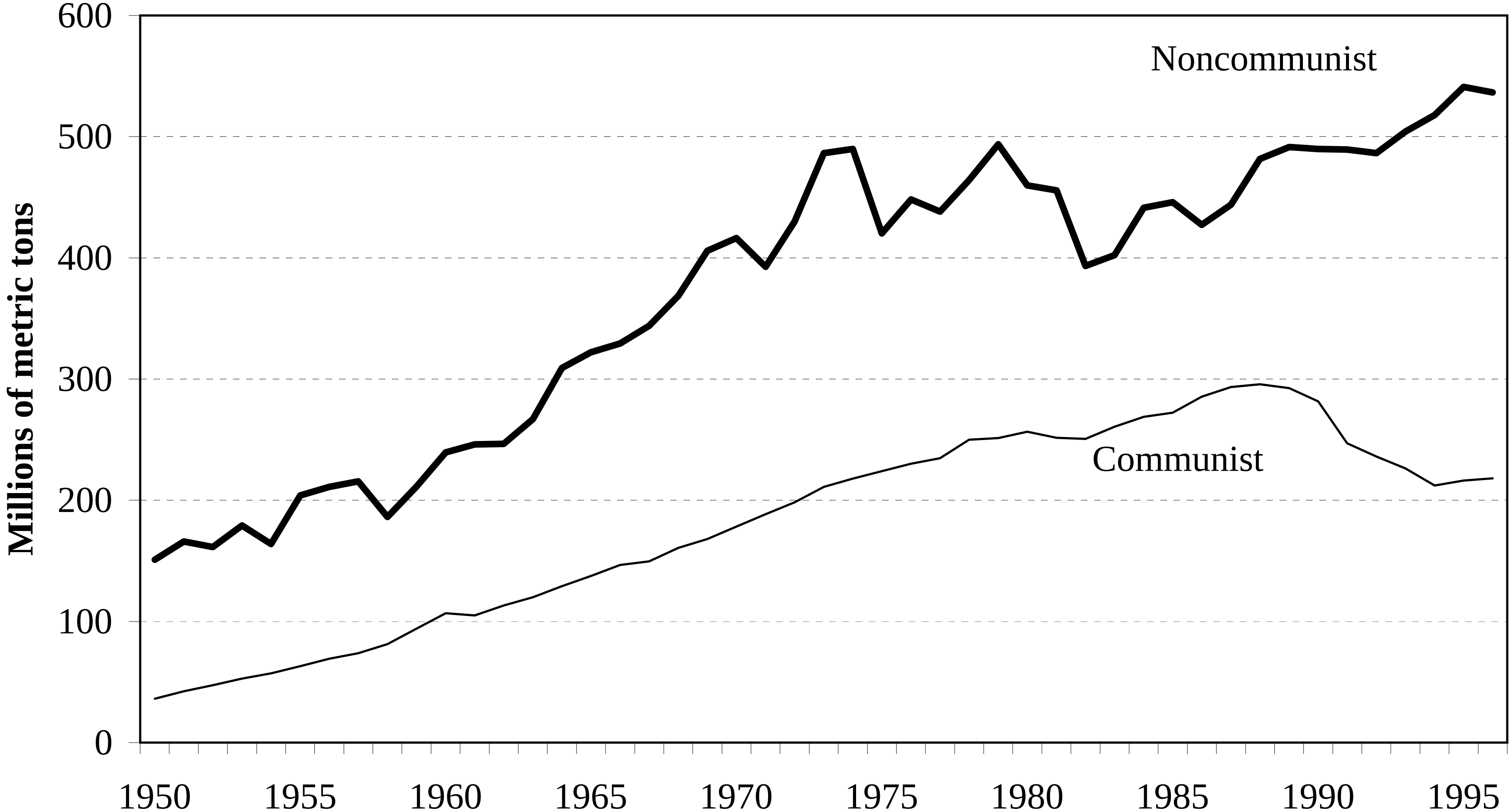
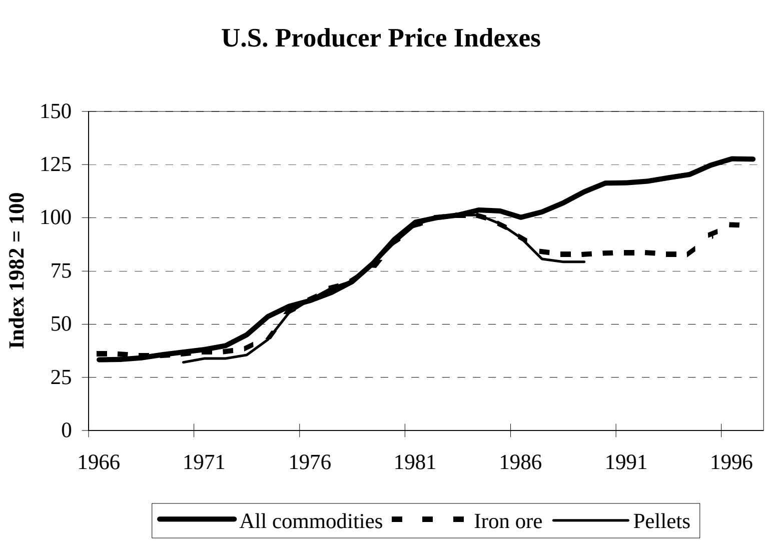
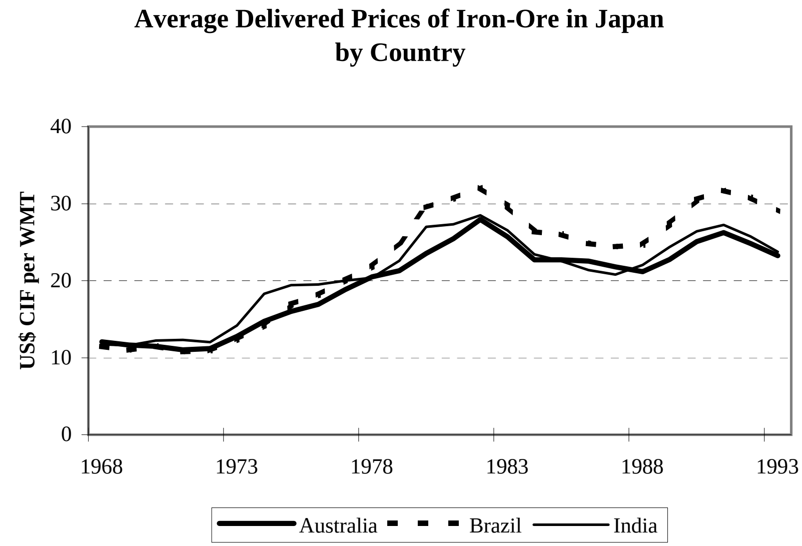


Figure 2: Iron-Ore Prices and General Prices





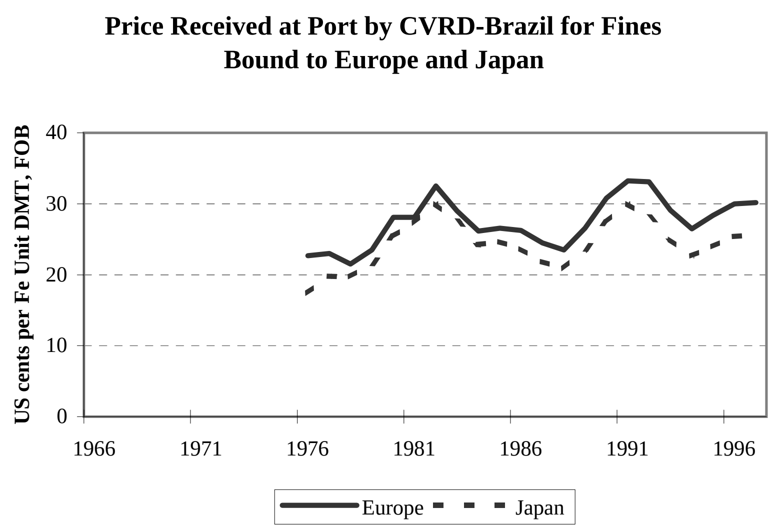
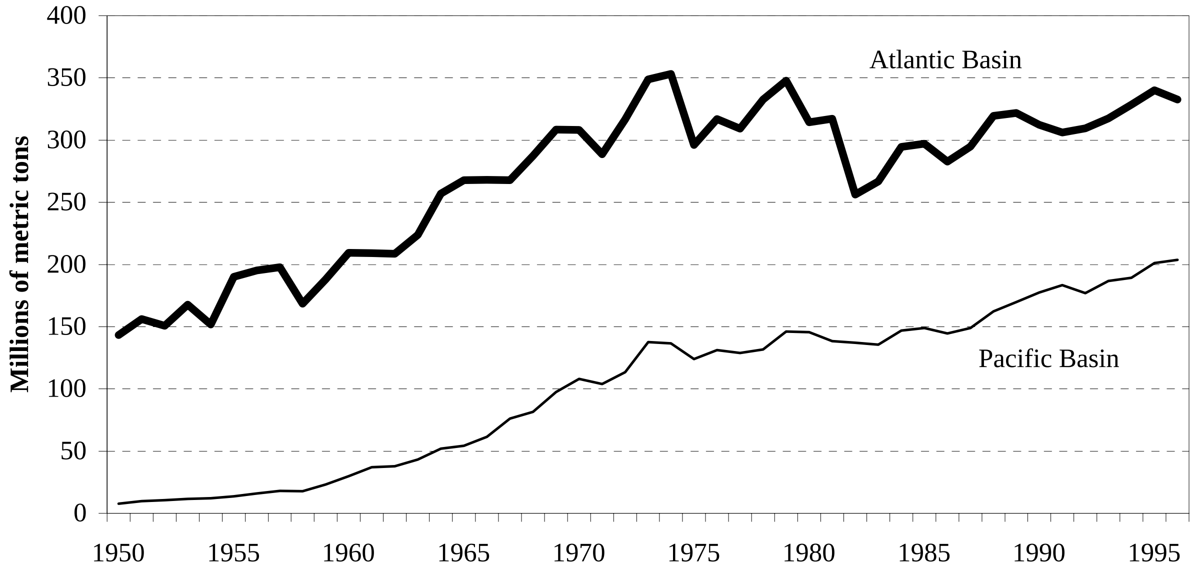


Figure 3: Steel Production by Region and by Various Groups of Countries 1950-1996



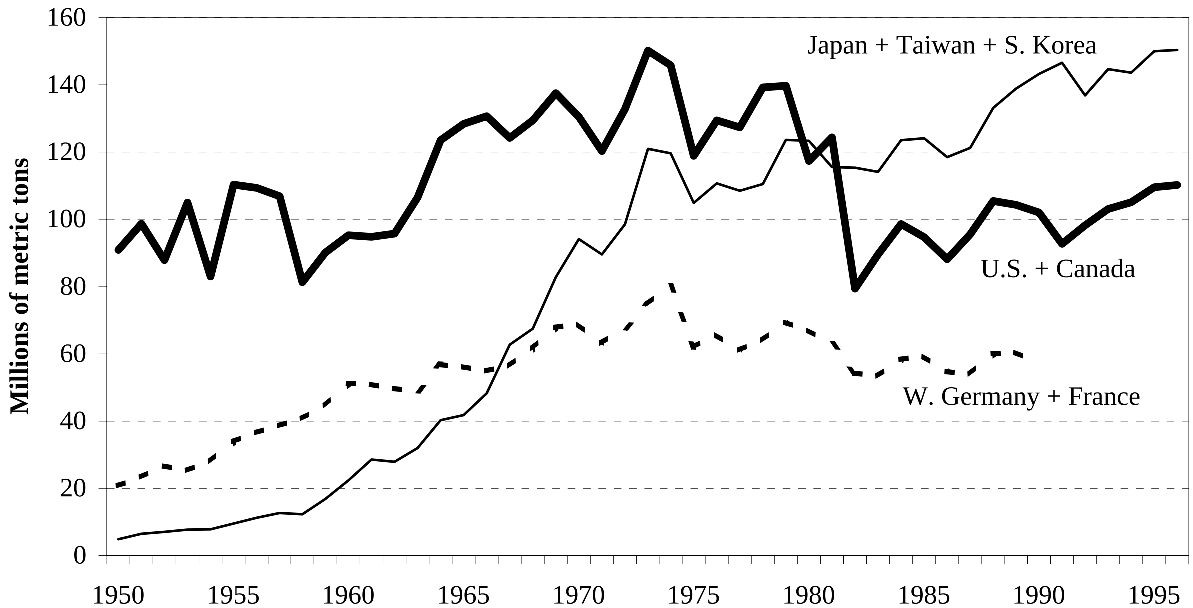


Figure 4: Iron-Ore Production and Productivity (1980 = 1)
By Threat of Closure Faced by Industry: Top Panel - No Threat, Bottom Panel - Significant Threat