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RATIONAL ATROPHY: THE US STEEL INDUSTRY

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The ideas presented in this paper are derived from my involvement in steel privatization in Mexico, visits to steel plants and conversations with several people involved in the steel industry. I have visited the steel plants of Ahmsa, Hylsa, Sibalsa and Sicartsa in Mexico. I have talked with the following people: Sir Ian Mcgregor, chairman of British Steel during its privatization years and of British Coal; Felipe Cortes, former chairman of Hylsa, a Mexican integrated steel producer; Robert Garvey, former chairman of North Star Steel, one of the biggest minimills in the US; Bradley Jones, former chairman of Republic Steel, one of the biggest integrated steel producers in the US; Gabriel Magallon, former chairman of Sicartsa steel works in Mexico; Lakshmi Mittal, chairman of Ispat Steel, an Indian multinational steel producer; Lynn Williams, president of the United Steel Workers union during the 1980s; Ian Mathieson of McLellan Consultants and Don Barnett, who are consultants to several steel companies; Edward Mangan, the World Bank expert on steel; Carlis Kirsis, vice president of World Steel Dynamics at Paine Webber and a leading steel analyst. None of the aforementioned bear any responsibility for the views contained in this paper. I thank for helpful discussions V. V. Chari, Pat Kehoe, Philip Lane, Erzo Luttmer, Paul O'Connell, and participants at seminars at the NBER and the Federal Reserve Bank of Minneapolis. Alice Lee, Michael Tan, and Jaejoon Woo provided excellent research assistance. This paper is funded by the Alfred P. Sloan Foundation via the NBER Project on Industrial Technology and Productivity. This paper is part of NBER's research program in Productivity. Any opinions expressed are those of the author and not those of the National Bureau of Economic Research.

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ABSTRACT

During the seventies and eighties the US steel industry received trade protection. However, these rents were not used to improve competitiveness. Instead, they were reflected in higher wages and a greater share of profits invested in sectors not related to steel. Moreover, the steel industry failed to adopt technological innovations on a timely basis and was displaced by the minimills. We rationalize these puzzling outcomes using a dynamic game between workers and firms.

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1. Introduction

Integrated steel production is one of the few industries in the US that successfully obtained trade protection between 1970 and 1989. However, several observers agree that the profits generated by protection were not reinvested in the industry to increase competitiveness. Instead, higher revenues were squandered in the form of higher wages and investments outside of the steel industry. As a result, trade protection had the unintended effect of inducing the entry of new small steel producers (the minimills) that in recent years have managed to capture a large share of the US steel market. Five facts characterize the US steel protection experience:

Fact 1 As trade protection increased, the integrated steel industry declined. During the period of protection from 1970 to 1989, the domestic real price of steel in the US *increased* by 15%, while the production of integrated steel firms in the US *fell* by 45%, and employment fell from 545,000 workers in 1970 to 210,000 in 1989 (see Figures 1, 7 and 8).

Fact 2 Higher steel prices were associated with higher wages, despite the fact that productivity in steel did not increase relative to the manufacturing sector. The wage premium of steel over manufacturing *increased* from 24% in 1970 to 57% in 1982, despite the fact that the ratio of labor productivity in steel to that in manufacturing *fell* from 0.7 to 0.6 during this period. By 1989 the wage premium in the steel industry had fallen to 36%, while the ratio of productivity in steel to that in manufacturing had increased to 0.8 (see Figure 2).

Fact 3 Higher steel prices were associated with lower rates of investment in steel. During the 1970s and 1980s there was a fall in the share of profits that management of big integrated steel producers, such as US Steel, invested in steel. Profits were increasingly invested in sectors other than steel (out of unions' reach) or distributed as dividends. As a result, the ratio of steel-related assets to total assets in US Steel fell from 56% in 1976 to 19% in 1990 (see Figure 3).

Fact 4 The decline in the production of integrated steel firms cannot be blamed on a reduction in US demand or on foreign competition. An important share of the market was captured by new entrants. Between 1970 and 1989, US demand for steel declined 22%, yet minimills increased their share of US steel production from 15% in 1970 to 37% in 1989. Trade protection prevented imports from increasing (in fact, imports declined slightly during that period, from 18 to 17 million tons). However, trade protection induced the entry of minimills (see Figures 4 and 5).

Fact 5 There was rational atrophy in the integrated steel industry. The industry failed to adopt on a timely basis new technologies that were available and had been proven to increase productivity. This failure was not limited to the minimill technology. Starting in the early 1960s, US steel producers were slow, relative to the Japanese and the Europeans, to adopt the new technologies that were available and that had proven to increase productivity. The main examples are the basic oxygen furnace and continuous casting. In 1975, 9% of US and 31% of Japanese steel production used continuous casting. In 1989, these shares were 65% and 94% respectively (see Figure 6).

These facts are puzzling. Why did integrated steel producers squander their revenues during the protection period by investing outside the steel sector and by granting wage increases above what would be justified by productivity improvements? Why did they fail to adopt new technologies and thus allow small entrants to capture a significant share of the US market? What is the rationale behind this self-inflicted atrophy?

One explanation that has been given for this puzzle is that unions and management were engaged in an "end-game." Since investment in steel became decreasingly profitable from the early 1950s on, unions and management were extracting the declining rents available (this point of view is exposed by Lawrence and Lawrence (1985)). With hindsight, this explanation is not satisfactory because the seventies were years of very high expectations within the industry. Even new green fields were planned in the late seventies. Moreover, the important wage concessions of 1973 occurred when the world steel market was booming and this short term upswing was considered a trend (Barnett and Crandall (1986) expose this view). An additional piece of evidence against the end-game hypothesis is provided by the rapid expansion of minimills in the US.

In this paper, we present a maximizing model not based on this end-game hypothesis that rationalizes the facts listed above. In the model the growth rate of the industry falls as protection increases. This is due to a voracity effect that induces: (a) wages to increase with prices even if labor productivity does not change (fact 2); and (b) the reinvestment rate chosen by managers to fall with prices (fact 3). The model also rationalizes why integrated steel producers failed to adopt new technologies and allowed minimills to capture a very big share of the market (facts 4 and 5).

Our point of departure is the observation that in US integrated steel firms, control is divided between managers/owners and unions, who both behave uncooperatively. Unions have the power to determine the wage bill, while managers decide what to do with the remainder (i.e., with profits). They can reinvest in steel, they can invest in sectors other than steel, outside of the unions' reach, or they can distribute dividends. If the unions' strategy was to set the wage bill at its highest possible level, then the owners would have no incentive to reinvest. As a result, the future capital stock would be depleted and high wages would not be sustainable in the future. Similarly, if owners set the reinvestment rate at zero, unions would find it profitable to set the wage bill at its maximum possible level and extract as much rent as possible in the short run. In an interior equilibrium, unions moderate their demands, insuring a sufficiently high rate of return to owners, and owners reinvest part of profits. We show in this paper that a property of this equilibrium is that an increase in the price of steel induces a more than proportional increase in the wages demanded by unions and a more than proportional reduction in the reinvestment rate in steel on the part of management. Thus, the effect of an increase in the price of steel is a reduction in the growth rate of the capital stock destined to produce steel. This is the voracity effect.

In our model, the equilibrium wage policy of unions is such that in every period, the rate of return received by owners/managers in the steel sector is equal to the riskless interest rate. That is, any profitability gains are captured by the unions through higher wages. This result has two implications. First, even if there is an infinitesimal sunk cost of adopting a new cost-reducing technology, owners/managers will have no incentive to adopt it. By not adopting it, they earn the same rate of return while saving the sunk cost. The second implication is that owners/managers are indifferent to how their wealth is allocated (steel vs. non-steel). That is, they do not lose if minimills capture a greater share of the market. Of course, as a group, unions and owners/managers lose by not adopting new technologies and losing market share. However, they cannot precommit to not engaging in future voracious wage and divestment behavior in the future. Therefore, protection policies that increase the profitability of the industry induce the entry of firms with unitary control (minimills), where the decisionmaker can reap the benefits of adopting new technologies.

There are four actors in our model: a government that sells protection, the owners of fixed factors in the steel sector that buy protection, the owners/managers, and the unions. In each period, the owners of fixed factors lobby the government for trade protection, which increases the firms' revenues. The owners then receive a fixed share of the firm's revenues. The remainder is split between the union and the manager. We model the interaction between the owners of fixed factors and the government as in Grossman and Helpman (1995), and we model the interaction between the manager and the union as an infinite horizon dynamic game.

The structure of the paper is as follows. In section 2 we present the stylized facts that characterize the steel industry throughout the period 1950-1995, as well as material from my interviews with industry participants. In section 3 we present the model. In section 4 we present our conclusions and the reactions of industry participants to these conclusions.

2. Stylized Facts

In this section we expand on each of the stylized facts summarized in the introduction. We present material from our interviews with industry participants and relevant statistical information.

2.1. Wage Settlements

Wages in the integrated steel sector of the US have not been set competitively. Rather, they have been determined through negotiations between the United Steel Workers union and the major steel producers. Until 1985, wages were negotiated in a centralized fashion for the entire industry. According to some observers, centralized wage setting served the interest of the big producers because it was a mechanism to enforce an oligopoly. It insured that no other producers enjoyed lower labor costs.

The power of the union is reflected in a premium of the wage in steel relative to the manufacturing average. As can be seen in Figure 2, this premium has not been constant through time. It increased from around 20% in early 1950s to a peak of almost 60% in the early 1980s. In the 1990s, it declined to around 40%. What is puzzling is that the increasing wage premium was not accompanied by an increase in labor productivity in steel relative to the average in manufacturing.

The opposite is true: the ratio of steel to manufacturing productivity fell from 0.8 in 1950 to 0.6 in the early 1980s.

In Tables 1-3 we investigate econometrically the relation between the steel wage premium, the ratio of steel productivity to the average in manufacturing, and the ratio of the US steel price to the WPI. The main result is that throughout the period 1950-94, the steel wage premium has been positively related to the real price of steel. However, there is no relation between the steel wage premium and steel productivity. These facts suggest that the wages negotiated by unions reflected the behavior of steel prices more than changes in labor productivity in the steel sector.

Table 1 shows that the three series have unit roots. Since in all cases the statistics obtained under the null hypothesis of a unit root are always smaller than the critical values, we cannot reject the null hypothesis of a unit root in any of the three series.

In a neoclassical world with perfectly competitive factor markets we would expect steel wages and labor productivity to be cointegrated. That is, a relationship between wages and productivity should exist in the long run. On the other hand, since steel is internationally traded, we would not expect steel prices to be cointegrated with steel wages or steel productivity. The Johansen cointegration tests in Table 2 show that over the period 1950-94 the opposite was true: wages and prices were cointegrated, while wages and productivity were not. In the case of wages and prices the likelihood ratios are greater that the critical values. Thus, we reject the hypothesis of the absence of a cointegration relation, as well as the hypothesis of at most one cointegration relation. In the test for wages and productivity, we reject both hypotheses. Part (b) of Table 2 shows the existence of a positive long run relation between wages and prices. The estimate of the coefficient relating prices and wages is 0.48 (with a standard error of 0.08).

Table 3 presents the estimation results from an error correction model, which is a vector autoregression on the first differences of wages and prices plus a term including the deviation of wages and prices from their long-run relation. Here we present an abbreviation of the estimated equation for wage changes (standard errors in parentheses):

$$\begin{aligned} \Delta w_t = \; & \underset{(0.09)^{**}}{-0.30[w_{t-1} - 0.48 price_{t-1}]} \; \underset{(0.15)^{**}}{+0.36\Delta w_{t-1}} \; \underset{(0.12)}{-0.07\Delta price_{t-1}} \; +\epsilon \\ R^2 = \; & 0.47 \qquad Sample: 1954-94 \end{aligned} \tag{2.1}$$

According to this representation current wage adjustments have two components.

First, an error correction component that induces wage adjustments to close the gap with respect to the long run relation between wages and prices. Second, an autoregressive component that might generate short run deviations from the long-run relation between wages and prices. This relation is given by the cointegrating coefficient in Table 2. The coefficient on the error component is -0.30,and it is significantly different from zero at the 1% significance level. The coefficient on lagged wage changes is also significant, although the coefficient on past price changes is not.

Since wages and productivity are integrated series of order one, but are not cointegrated, the following OLS regression is appropriate:

$$\begin{array}{lllll} \Delta w_t = & 0.002+ & 0.03\Delta prod_{t-1}- & 0.05\Delta prod_{t-2}+ & 0.03\Delta prod_{t-3} \quad +\epsilon \\ & (0.006) & (0.11) & (0.13) & (0.03) \end{array}$$

$$R^2 = 0.18 \qquad Sample : 1954 - 94$$

This regression includes a correction for autocorrelation. Note that none of the estimated coefficients on current and lagged productivity changes are significantly different from zero.

These results make it clear that wage increases in the steel industry were not related to productivity changes, but rather to price changes.

There are several explanations for the behavior of steel wages. During the 1950s, when there was no threat from imports and demand exhibited strong growth, wages and prices in the steel sector increased at a faster pace than the average wages and prices in manufacturing. These wage and price increases were coined "the annual rites of spring." They were considered excessive, and on various occasions generated tensions between steel producers and the President of the United States. After the long strike of 1959, steel imports into the US increased significantly, reducing the price-setting power of US steel producers. This fact, combined with a weak demand for steel during the 1960s, led to a slight decline in the real price of steel in the United States. During this decade the steel wage premium declined.

During the 1970s and early 1980s, US prices and wages in steel increased significantly. Several observers give an institutionalist explanation for this positive correlation. They argue that the steel market improved during the early 1970s because the dollar was devalued, and because the US government negotiated voluntary restraint agreements for steel products with Japan and Europe for the period 1969-1974. In order to reap the benefits of the boom in demand, management tried to buy labor peace by reaching an agreement with the union in 1973, one year before labor contracts were up for renegotiation. Thus, the integrated steel producers signed with the union the Experimental Negotiating Agreement (ENA), which insured a 3% annual wage increase over the following three years, plus a reimbursement of up to $\frac{3}{4}$ of realized inflation in exchange for a commitment from the union not to strike. Despite having been so onerous for the industry, the ENA was renewed in the next round of contract renegotiations in 1977. Observers argue that this was because the USW was scheduled to elect a new president in 1977. A radical insurgent (Sadlowski) was challenging the groomed McBride, who was considered to be a moderate. Management feared that an attempt to negotiate ENA away might result in McBride not being elected, and the union becoming more anti-management. This 1977 concession turned out be very expensive. As before, to contain imports, the steel industry as a whole pressured Washington for a renewal of protection.

The recession of the early 1980s hit the industry hard, and firms asked the union for wage concessions in 1982. However, the union rejected the proposal. As a result, several plants were closed and massive layoffs took place. Employment in the steel industry fell by 30% in one year, from 286,000 employees in 1981 to 198,000 in 1982. Bitter relations between workers and management of integrated steel firms continued through the 1980s (see Hoerr (1988)). Centralized wage negotiations were cancelled in 1985. In 1986, LTV, the second largest US steel producer, filed for bankruptcy protection under Chapter 11. Also in 1986, a blockout/strike of 184 days erupted in US Steel, the biggest US steel producer. Despite the formidable employment reductions and plant closures of the 1980s, management-union relations have not improved in the 1990s.

Institutionalist explanations for the positive correlation between wages and prices are not satisfactory. An explanation based on rational behavior is the so-called end-game hypothesis (Lawrence and Lawrence (1985)). According to this hypothesis, investment in steel was considered to be unprofitable for the infinite future. As a result, unions tried to capture as many rents as they could, given that they expected none to be reinvested anyway. This explanation does not fit well with the fact that the biggest wage increases took place in 1973 and 1974, when steel demand was very high and the future looked as bright as it had at any point during the last two decades.

Like the end-game hypothesis, the explanation we give in this paper is based on the fact that unions had the power to determine wages, and that management had the power to determine the reinvestment rate. However, we do not impose the restriction that investment in steel will never be profitable. We consider an infinite horizon and allow investment and wage decisions to depend on one another. We show that in a Markov perfect equilibrium, as steel prices increase, unions and managers try unilaterally to capture a greater share of revenues by increasing wages and the divestment rate. As a result, the capacity growth rate in the steel sector falls in response to a price increase.

2.2. Divestment of US Steel

Management can allocate profits in three different ways. It can reinvest them in steel production facilities; it can invest them in sectors other than steel, out of the union's reach; or it can distribute dividends. The steel firms' reaction to the excessive wage increases the unions pushed for was to reduce the share of profits they reinvested in steel. The reduction of investment in steel during the 1970s and 1980s is clearly illustrated by the case of US Steel, the biggest steel producer in the US. Figure 3 plots the ratio for US Steel of dividends and non-steel investments to investment in steel. This ratio increased from 0.7 in 1976 to a peak of 27 in 1985, levelling off to 5 in the 1990s. It is interesting to compare the similarity of this ratio's behavior to that of the steel wage premium depicted in Figure 2. It seems that throughout the late 1970s and early 1980s, both unions and managers were trying to milk the firms.

The falling ratio of the quantity, dividends plus non-steel investment, to steel investment reflects more than a simple diversification to reduce risk. This trend reflects a program designed to shift investment away from steel in favor of oil and gas and, ultimately, to close down steel plants. In 1982, US Steel purchased Marathon Oil for $6 billion (interestingly, 1982 was the year that steel firms' request for wage concessions was rejected by the union). At the time, US Steel argued that it invested in oil because it could not obtain financing to invest in steel. This explanation is not fully convincing because US Steel used $1.4 billion of its own cash to buy Marathon Oil. In principle, it instead could have used this cash to invest in, for example, continuous casting. In 1984, US Steel acquired Husky Oil for $500 million, and in 1985 it merged with Texas Oil and Gas.

The net result of this divestiture program was a reduction in the share of total assets corresponding to steel-related activities, from 55% in the late 1970s to only 19% in 1990. Moreover, this shift was reflected in the change of the company's name from US Steel to USX, and later on to the split of USX into USX Steel, and USX gas and oil.

2.3. Trade Protection[1]

During the 1950s US steel producers were the leaders in the world market for steel and did not feel the threat of imports. During the 1960s imports increased significantly and the steel industry pressured the government for trade protection. As a result the US government negotiated voluntary restraint agreements (VRAs) with Japan and the European Community for the period 1969-1974. In exchange, the US steel industry agreed not to pursue active protection.

The US steel industry was hit hard by the 1974-75 recession. In 1977 the first closures of steel plants took place. Alan Wood Steel went bankrupt, while Youngstown Sheet and Bethlehem Steel closed down three plants. In response, the Congressional Steel Caucus was formed to press for a renewal of steel industry protection. The Carter administration gave in, and the Trigger Price Mechanism was instituted in 1977. This mechanism established a minimum import price based on Japanese costs plus an 8% profit margin. This program was more protectionist than the prior VRA since it applied to *all* imports. Thus, it blocked the admittance of imports previously diverted through other countries. This mechanism reduced imports from 19 million tons in 1978 to 17 million tons in 1981 (see Figure 4), and it allowed the premium of US domestic steel prices over the world price to increase (see Figure 1).

The US steel industry was again hit by recession in 1981-82. Pressures for more protection took the form of 61 countervailing duty and 33 antidumping duty petitions filed in January 1982 against the European Community. The International Trade Commission ruled favorably on 20 of the former and 18 of the latter petitions. Since these duties do not have time limits, and since they cannot be eliminated by executive order, the Reagan administration was faced with the imposition of prohibitive tariffs on European imports and with the loss of discretionary control over trade policy in steel at a time when relations with Europe with regard to the USSR were delicate. To avoid this loss of control, the administration opted for a new VRA for the period 1982-86.

However, steel imports did not decline, because the US dollar appreciated and because other countries filled the gap left by the EC. In 1984 the US steel industry reacted by taking three actions. First, it filed new countervailing duty and antidumping duty petitions against non-EC countries. Second, it filed an escape clause petition that could result in protection for the entire industry if

[1] A detailed analysis of protectionist programs for the steel industry can be found in Moore (1994).

the ITC issued an affirmative decision and the President accepted it. Third, it induced the Congressional Steel Caucus to propose legislation imposing an across-the-board 15% quota on steel imports ("The Fair Trade in Steel Act of 1984"). The ITC recommendation was favorable for some sectors of the industry, and the President had to accept the granting of protection by September 1984, because if he rejected it, he would have been forced to veto the quota legislation just before elections. The outcome was a formal rejection of the ITC recommendation. However, the Reagan administration compromised by agreeing to negotiate VRAs with all major exporters of steel to the US to cover all segments of the industry for the period 1984-1989. This has been the most favorable protectionist program that the US steel industry has enjoyed.

In 1989, President Bush extended the VRA program, but only for two-and-a-half years. This renewal round was disappointing for the industry because many of the quotas included in it were not binding. In 1992, the steel industry filed close to 70 anti-dumping and countervailing duty petitions to pressure the Bush administration to renew the VRA program. However, this time the President refused. The ITC ruled favorably on only half of the petitions. This allowed producers to increase steel prices, as can be seen in Figure 1.

No new protectionist program for steel has been implemented since 1992. According to some observers, this reflects the diminished political clout of the integrated steel producers.

2.4. Adoption of New Technologies

Steel is produced in integrated mills through the following process. First, coal is transformed into coke, and iron ore is pelletized. Then, the iron pellets and coke are melted together with limestone in a blast furnace. This results in pig iron. To eliminate the impurities in the pig iron and obtain liquid steel, the pig iron is poured into an open hearth furnace or a basic oxygen furnace. The molten steel is then poured into ingots. These in turn are reheated and transformed into slabs (used to produce flat products) or billets (for long products). These intermediate products are passed through rolling mills to produce the final products.

There have been three major technological breakthroughs that the big integrated steel producers failed to adopt in a timely fashion: the basic oxygen furnace, continuous casting and the minimill technology. We will consider each in turn.

2.4.1. The Basic Oxygen Furnace

After World War I, the open hearth (OH) process replaced the Bessemer process as the dominant technology used to convert pig iron into molten steel. After World War II, the basic oxygen furnace (BOF) made the open hearth obsolete. As can be seen in Figure 6, the US was much slower than Japan and the European Community in installing BOFs. In 1970, while the share of steel produced using OH was 4% in Japan and 26% in the EC, it was 36% in the US. By 1982, all steel production was done using BOFs in Japan and the EC, while OHs were still used for 8% of US production. Furthermore, Oster (1992) has shown that within the US, large firms were slower to install BOFs than small producers.

The most common explanation for this delay is that Japan and several European countries built their steel industries from scratch after World War II, while the US did not. As a result, large sunk costs prevented US firms from investing in BOFs until their OHs were totally depreciated.

2.4.2. Continuous Casting

Another major technological breakthrough in steel production was continuous casting. In traditional steel production, molten steel was poured into ingots. These ingots then had to be reheated and sent to primary mills to be converted into semi-finished goods (billets, blooms and slabs), which were then fed into the rolling mills that generate final products. By contrast, in continuous casting molten steel is poured directly into semi-finished shapes. This process bypasses the reheating and rolling steps, generating significant labor and heating savings. Again, as Figure 6 shows, the US was much slower than Japan and Europe in adopting this clearly superior technology. In 1975, 31% of Japanese and 16% of European crude steel production was done using a continuous caster, while in the US, this percentage was only 9%. By 1989, this percentage was 93%, 88% and 65% for Japan, the EC, and the US respectively. As was the case with BOFs, large firms in the US were slower to adopt continuous casting than small producers (Oster (1992)).

Some observers argue that continuous casters were not quickly adopted by big US steel producers because they would not significantly reduce costs if they were combined with old open hearth furnaces or old rolling mills. Thus, to fully exploit the advantages of continuous casting, the upstream and downstream parts of plants would have to be revamped. This is precisely what the Japanese and the Europeans did. Why did the US steel producers not take this action? The point we make in this paper is the following. Such revamping entailed significant investments. Management in the US industry was hesitant to make these large investments not because of a lack of funds, but because the expected excess return was zero since the unions would appropriate the rents, ex-post.

2.4.3. The Minimill Technology

Minimill technology consists of pouring scrap into an electric furnace to produce molten steel. This process bypasses the processes of coking, pelletizing and melting pig iron that are used in integrated plants. Since this process does not use blast furnaces or BOFs (which need a minimum plant size of 3 million tons per year), it realizes economies of scale at much lower production levels (less than one million tons per year). This reduces capital costs significantly. The other advantage of minimills is that because they are small, they can be located closer to each of their markets, thus reducing transport costs. However, using current technology, minimills cannot produce the high grade steels integrated plants produce.

Originally, electric furnaces were used in integrated plants to refine sophisticated products such as stainless steel. In the 1960s, the first independent minimills used electric furnaces to produce the least sophisticated long products, such as concrete reinforcing bars. Minimills constituted a fringe of independent steel producers. In the early 1960s, they produced less than 10% of the total steel produced in the US (see Figure 5). During the 1970s, independent minimills diversified into more sophisticated long products (such as wire rods and structural shapes) and produced 28% of US steel output by 1980. By 1994, minimills' share of US production had reached 39%. Today, minimills have displaced integrated producers from the long products market and are making inroads into the flat products segment of the market.

In 1990, Nucor completed the first thin-slab minimill that produces flat products by melting scrap in an electric furnace. Nucor's Crawfordsville plant has a capacity of one million tons (much less than the capacity of integrated plants), a capital cost of $275 million, and labor productivity more than 4 times that of the most efficient integrated plants. This thin-slab caster was invented in 1983 by SMS Schloemann-Siemag in Germany. It is considered to be among the most important technological breakthroughs in steel-making of this century. Nucor signed the purchase agreement in 1987. After a difficult start, Nucor successfully opened its Crawfordsville plant in 1990 and started the construction of a second plant. Several other minimills have followed. Today in the US, the electric furnace thin-slab capacity is around 6 million tons, and it is expected to reach 19 million tons by the year 2000 (Marcus and Kirsis (1995), p. 111).

It is puzzling that although this technology has been available to integrated steel firms, not one of them has adopted it yet. According to Barnett and Crandall: "They [the integrated producers] cannot walk away from these plants and build a new set of smaller, efficient electric furnace plants for a major share of their output. Their workers, bankers, and political allies simply would not allow it." (Barnett and Crandall (1986) pp. 55).

It is interesting to note that in the early 1980s Nucor was not an important player in the steel market. Its name stands for Nuclear Corporation of America. It was founded by Ransom Eli Olds (the inventor of Oldsmobile) in 1904 under the name of Reo Motor Car Co. Having experienced minimal success in producing cars, it became a nuclear company in the 1950s. Then, after almost going bankrupt in the 1960s, it shifted to steel. Today, Nucor is one of the top steel producers in the US.

It is often argued that the decline of the integrated steel producers was caused by the rapid increase in imports and the decline in steel consumption. As Figure 4 shows, this is not an accurate explanation. The rise of the minimills played a significant role in the decline. Production of integrated firms fell by 50 million tons, from 111 million tons in 1970 to 61 million tons in 1994. During this period, domestic consumption fell by 17 million tons, net imports increased by 15 million tons, and minimills production increased by 18 million tons.

The reasons that are commonly given for the rapid expansion of minimills at the expense of integrated steel firms are the following. First, the price of scrap and electricity have been low relative to the price of iron and coal during the last two decades. Second, since the efficient size of minimill plants is much smaller than that of integrated plants, minimills face lower capital costs and can enjoy geographic specialization. Last, but most important, minimills are not dominated by strong labor unions. Thus, they have been able to achieve lower unit labor costs and to implement new labor-saving technologies.

A common explanation of why integrated steel producers have not adopted the minimill technology is that the price of scrap and electricity has been expected to increase significantly. If this price increase were to occur, molten steel production in electric furnaces would be more costly than production in BOFs in integrated plants. This explanation is not very convincing. First, ex-post, minimills already produce 39% of US steel. Second, during the 1970s and 1980s the projected availability of scrap was quite high. The price of scrap has only started to increase in recent years. Third, it is not likely that scrap prices will skyrocket because electric furnaces can also be supplied with scrap substitutes such as iron carbide and directly reduced iron, produced in countries like Venezuela, where natural gas is abundant.

Our interpretation of what happened is the following. The trade protection that was granted during the 1970s and 1980s increased the profitability of producing steel in the US. This induced the entry of new small firms into the industry. These new entrants were continuously implementing new technological advances, while big steel producers stayed put. One possible explanation for this seemingly irrational behavior is that in minimills, control is concentrated at the owner-manager level, while in the big steel companies, control is divided between managers and unions. This division of control made it unprofitable for managers to adopt any technological innovation because the unions would capture the resulting rents. In the model we present below, the union designs its wage policy so that in equilibrium, the rate of return received by the owner-manager is always equal to the riskless interest rate. As a result, in equilibrium, the owner-manager will not lose by not adopting a new technology, even if this means losing market share. Thus, investment of funds outside the firm yields the riskless interest rate, while investing and not losing market share also earns the riskless interest rate minus a possible sunk cost.

One reason why unions have not been able to overtake the minimill sector is that the fixed assets of firms in this sector are not concentrated in a single location. Thus, if there is an attempt by a union to take control, it is cheap (relative to the cost for integrated steel producers) for the firm to transfer production to other locations. In other words, capital is not as "fixed" as in the integrated plants.

3. Model

The poor performance of the integrated steel industry has been rationalized in the existing literature by invoking the end-game assumption and the existence of divided control between managers and other stakeholders. The argument is that the steel industry in the 1970s and 1980s was doomed, so powerholders simply tried to extract as much as possible from the steel firms. But the end-game assumption is difficult to defend empirically. During the 1970s expectations were high, and ex-post demand did not collapse and foreigners did not conquer the US market. Moreover, as the experience of the minimills has shown, the US is capable of being a competitive steel producer.

In contrast to the existing literature, my argument is not based on the end-game assumption. I assume divided control among powerholders with infinite horizons. In this setup powerholders do not try extract as much as possible from the firms in every period, and, as observed in reality, there might be some investment to improve the plants. However, price increases do not lead to increased investment, but rather to higher wages and more divestment, as observed during the 1970s and 1980s. Another property of our model is that it delivers rational atrophy. Since, ex-post, unions and other powerholders appropriate excess returns, managers have no incentive to adopt new technologies. This makes way for new entrants (minimills) to adopt the new technologies and thereby capture a big share of the market.

The model we present rationalizes the following facts. First, during the period in which the integrated steel industry enjoyed trade protection, some investment to improve plants took place. However, the growth rate of capacity declined and even became negative. This decline was associated with the fact that increases in steel prices, which (i) lead to increases in steel wages relative to the manufacturing sector (despite the lack of productivity growth), and (ii) lead to a reduction in the share of profits reinvested in steel activities. Second, there was rational atrophy. That is, integrated steel producers did not adopt technological innovations on a timely basis and thus allowed small entrants (the minimills) to capture a significant share of the market.

To explain rational atrophy we could have simply used a two-period model instead of an infinite horizon model. In a two-period model the manager/owner will not invest in the first period if the other stakeholders can appropriate the rents in the second period. However, since a two-period model represents the special case of an end-game, agents extract resources from the firm at the highest possible rate. Therefore, such a model could not rationalize the first stylized fact, for two reasons. First, it would not be able to explain the fact that some investment was taking place. Second, since extraction in an end-game is always done at the highest possible rate, the two-period model cannot explain the more than proportional response of wages to price changes, nor the decline in the reinvestment rate. In an infinite horizon model, by contrast, managers and workers do not extract resources at the highest possible rate, so such a model can rationalize both stylized facts.

The model we present consists of two parts. The first part considers the determination of trade protection. The second part analyzes the accumulation game between members of the protected industry. The main argument is in the second part. The determination of trade protection in the first part may be skipped, and the reader may begin at section 3.2, taking the import tariff function as given.

In order to analyze trade protection, the model considers an economy that consists of two sectors, F and M, producing food and manufactures, respectively. Sector M is politically organized and obtains trade protection, while sector F is competitive and not politically organized. The measure of the "voting population" in the F sector is one, while that of the M sector is zero. Agents in both sectors differ in their sources of income, and their access to capital markets. Agents cannot move from one sector to the other.

We start by describing the F sector. Agents in this sector consume both food and manufactures. They live for only one period, and their instantaneous utility function is

$$V_f = c_f^f(t) + c_f^m(t) - \beta c_f^m(t)^2 \tag{3.1}$$

where the subscript f denotes agents in the $F-$sector, and the superscripts f and m stand for food and manufactures respectively. The separable quadratic utility function will allow us to obtain a linear import tariff function, which will be useful in obtaining a closed form solution for the accumulation game in the protected industry.

Each agent in the F sector is endowed with one unit of labor, which he supplies inelastically to produce one unit of food. Also, in every period each agent receives a government transfer $T(t)$. Letting food be the numeraire, we have that the budget constraint of the representative agent in the F sector is

$$c_f^f(t) + p(t)c_f^m(t) \leq 1 + T(t) \tag{3.2}$$

During each period the representative agent in the F sector maximizes utility function (3.1) subject to budget constraint (3.2), taking as given the transfer $T(t)$ it receives from the government. The solution to this problem is

$$\hat{c}_f^m(p(t)) = \frac{1 - p(t)}{2\beta}, \qquad \hat{c}_f^f(p(t)) = 1 + T(p(t)) - p(t)\hat{c}_f^m(p(t)) \tag{3.3}$$

Substituting (3.3) in (3.1), we have that the indirect utility function of the representative agent in the F-sector is

$$\hat{V}_f(p(t)) = 1 + T(p(t)) + \frac{[1 - p(t)]^2}{4\beta} \tag{3.4}$$

Now we turn to the M-sector. In order to simplify and obtain a closed-form solution we will separate the lobbying and the accumulation decisions. We do so by assuming that there are $n+1$ agents in this sector: n power-holders and one lobbyist. Control rights are split among the n power-holders such that each of them has the power to appropriate a certain share of revenues. The lobbyist has no control rights and possesses the sole role of "buying" protection from the government. One can think of the lobbyists as proxies for the political networks that exist in company towns. They have an interest in lobbying for protection for the firms in their localities since they derive rents from them, although they do not exert any direct influence over the firm. In the real world managers and unions are also involved in inducing protection. However, for modeling purposes we will keep their roles separate from that of the lobbyists. This dichotomization is useful because it allows us to solve for the import tariff independently of the accumulation game in the protected industry. The power-holders are the managers, the labor unions, and other stakeholders[2]. Even if the workers are the only stakeholders, we should assume $n > 2$ because wage determination is seldom made in a centralized fashion. Even within a union, young and old workers with different objectives may be represented by different sections of the union.

As mentioned above, modeling accumulation decisions requires consideration of a dynamic set up. A static model cannot capture the intertemporal trade-offs involved in wage setting and investment decisions: an increase in the wage bill leads to lower investment, which in turn reduces future revenues and the possibility of increasing future wages.

The objective function of each power-holder in the $M-$sector is

$$V_{ph} = \int_0^\infty \frac{\sigma}{\sigma - 1} c_i^f(t)^{\frac{\sigma}{\sigma-1}} e^{-\delta t} dt, \qquad \sigma > 0 \tag{3.5}$$

Manufactures are produced using a linear technology, with capital as the only input: $q(t) = \gamma k(t)$. Letting the world price of manufactures be p^*, and denoting the import tariff as $\tau(t)$, we have that the domestic price of manufactures in terms of food is $p(t) = p^*[1 + \tau(t)]$. It will turn out that under the restrictions on parameters (3.18) and (3.19) consumption of manufactures will be greater than production along the equilibrium path. Therefore we can express revenues in the M-sector as

$$\pi(t) = \gamma p(t) k(t) \tag{3.6}$$

During each instant the lobbyist receives a fixed share $s \in (0, 1)$ of revenues $s\pi(t)$. It follows that the revenues available to the $n-1$ power-holders equal $[1 - s]\pi(t)$.

[2]We will not distinguish the managers from the owners, though we recognize that managers often do not maximize shareholder value.

Therefore, the accumulation equation for the capital stock in the M-sector is given by

$$\dot{k}(t) = [1 - s]\pi(t) - \sum_{i=1}^{n} w_i(t) \tag{3.7}$$

where $[1 - s]\pi(t)$ denotes revenues minus lobbying expenses, and $w_i(t)$ denotes the appropriation of group i. To interpret this equation, let $n = 2$, and suppose that one agent is a centralized union and the other is the firm manager. The union has the power to set the wage bill $w_1(t)$, while the manager has the power to choose how to allocate profits $[1 - s]\pi(t) - w_1(t)$: they can be reinvested in the M sector, invested in an alternative technology out of the union's reach, or distributed as dividends. The sum of the last two options corresponds to $w_2(t)$. Letting n be greater than two allows for the possibility that wage negotiations are not centralized under an all-powerful union leader, or for the possible existence of other power-holders.

The amount appropriated by each group $w_i(t)$ can be consumed or invested in an internationally traded bond, which is out of the reach of the other $n - 1$ groups. This bond yields a fixed rate of return r in terms of food. Since agents in the M-sector consume only food, it follows that the other accumulation equation faced by each power-holder i is

$$\dot{b}_i(t) = rb_i(t) + w_i(t) - c_i^f(t), \qquad i = 1, ..., n \tag{3.8}$$

Equation (3.8) captures the idea that managers can protect future revenues from the voracity of unions by investing them in other sectors out of the reach of the unions. When applied to workers, (3.8) can be interpreted as saying that workers do not need to consume their entire wage bill, and can accumulate savings.

We consider that the characterization of a protected industry given by equations (3.5)-(3.8) is a better description of the US steel industry than a description of the industry wherein managers have all control rights and workers are hired in a competitive labor market.

3.1. The Political Market

In this subsection we will derive a tariff function which is increasing in the capital stock of the M-sector. We will use a simplified version of the Grossman and Helpman (1994) model of Protection for Sale. Such a tariff function can be derived using other solution concepts, such as the Nash-bargaining solution (see footnote (5)) The reader not interested in the determination of trade protection can skip this subsection and proceed to subsection 3.2.

There are two players in the political market: the policymaker who sells protection and the M-sector lobbyist who buys it. Both players have a one-period horizon. During each period the lobbyist offers the policymaker a political contribution, which is a function of the imposed import tariff $B(p(\tau(t)))$, and the policymaker sets the import tariff $\tau(t)$.

We assume that the lobbyist consumes only food and has an objective function[3]

$$V_l = s\pi(k(t), p(t)) - B(p(t)) \tag{3.9}$$

The policymaker's objective is a function of the political contribution she receives from the lobbyist and of the utility attained by agents in the $F-$sector, who constitute 100% of the voting population,

$$V_g = B + aV_F \tag{3.10}$$

where a measures the marginal rate of substitution between political contributions and welfare in the F-sector. This objective function is consistent with the idea that the policymaker's probability of being reelected depends on the political contributions received and on the well being of the voters. Substituting (3.4) into (3.10), it follows that the policymaker's objective function can be rewritten as

$$V_g(p) = B(p) + a\left[1 + T(p) + \frac{(1-p)^2}{4\beta}\right] \tag{3.11}$$

We assume that all revenue generated by the import tariff is transferred to agents in the F-sector. That is,

$$T(p(t)) = [p(t) - p^*][c_f^m(t) - \gamma k(t)] \tag{3.12}$$

Grossman and Helpman (1994) show that $(\hat{B}(\hat{p}), \hat{\tau})$ is an equilibrium pair if and only if it satisfies the following four conditions. First, the policymaker must set the tariff rate to maximize her payoff. Second, the equilibrium price must maximize the joint payoff of the lobbyist and the policymaker. Third, the lobbyist must offer a contribution that induces the policymaker to participate in this game. Last, the contribution function must be feasible in the sense that

[3]If the lobbyist also consumed manufactures, higher import tariffs would increase not only her income, but also the price of her consumption basket. However, adding manufactures to the lobbyist's consumption basket would not alter the result that the optimal tariff is linear in the capital stock.

the lobbyist payoff must be non-negative. Basically, this is an instance of Coase Theorem: the lobbyist and the policymaker maximize their joint payoff and then divide the surplus according to a specific rule.

Since the domestic price of manufactures is $p = p^*[1 + \tau]$, assuming that the contribution function is differentiable, the first condition can be expressed as $\frac{\partial V_g}{\partial p} = 0$, and the second condition as $\frac{\partial V_g}{\partial p} + \frac{\partial V_l}{\partial p} = 0$. Combining both conditions we have that $\frac{\partial V_l}{\partial p} = 0$, which implies $s\frac{\partial \pi}{\partial p} = \frac{\partial B}{\partial p}$. Substituting this expression and $\frac{\partial T}{\partial p} = \frac{1-p}{2\beta} - \gamma k - \frac{\tau p^*}{2\beta}$ in the first condition ($\frac{\partial V_g}{\partial p} = 0$), it follows that

$$\frac{\partial V_g}{\partial p} = s\gamma k + a\left[\frac{1-\hat{p}}{2\beta} - \gamma k - \frac{\hat{\tau} p^*}{2\beta} - \frac{1-\hat{p}}{2\beta}\right] = 0$$

Thus, the equilibrium tariff function is

$$\hat{\tau}(k) = [s - a]\frac{2\beta\gamma}{ap^*}k \tag{3.13}$$

Thus, if the weight attached by the policymaker to the welfare of the $F-$sector (a) is lower than the share of the $M-$sector revenues received by the lobbyist (s), then the politically determined tariff is positive. Throughout the paper we will assume this is the case.[4]

The third condition implies that the contribution must leave the policymaker at least as well off as if the lobbyist's preferences were disregarded, in which case the policymaker would set $p = p^*$ and would receive no contribution. Algebraically, this condition is: $\hat{B}(\hat{p}) + aV^f(\hat{p}) \geq aV^f(p^*)$. We will assume that the

[4]Note that a similar tariff function can be obtained using the Nash bargaining solution. That is, B and p are chosen so that the product $V(t) = V^p(t) \bullet V^l(t)$ is maximized. The first order conditions are

$$B(t) = \frac{1}{2}\left[s\pi(t) + \frac{(1-p(t))^2}{2\beta} - aC(t)\right] \tag{3.14}$$

$$\frac{\partial V(t)}{\partial p(t)} = [B(t) + aC(t)]\left[s\gamma k(t) - \frac{1-p(t)}{2\beta}\right] + a\left[s\pi(t) + \frac{(1-p(t))^2}{2\beta} - B(t)\right]\frac{\partial C(t)}{\partial p(t)} = 0 \tag{3.15}$$

Using (3.14) to replace $[B(t) + aC(t)]$ in (3.15) by $a[s\pi(t) + \frac{(1-p(t))^2}{2\beta} - B(t)]$ and noting that $\frac{\partial C(t)}{\partial p(t)} = -\gamma k(t) - \frac{p^*\tau(t)}{2\beta}$, we can rewrite (3.15) as

$$\hat{\tau}(t) = \frac{\alpha - p}{1 - Z} + \frac{2\beta\gamma[Z - s]}{p[1 - Z]}k(t), \qquad Z = \frac{1-\zeta}{\zeta} \tag{3.16}$$

lobbyist keeps for herself as much of the surplus as possible, i.e., $\hat{B}(\hat{p}) + aV^f(\hat{p}) = aV^f(p^*)$. Substituting (3.4), and $T(p) = p^*\tau\left[\frac{1-p^*(1+\tau)}{2\beta} - \gamma k\right]$ in this last expression we get that the equilibrium contribution function is

$$\hat{B}(\hat{p}) = \frac{1}{2}[s + a]p^*\gamma k\tau(\hat{p}) \tag{3.17}$$

Finally, we check that the fourth condition is satisfied: the political contribution $\hat{B}(\hat{p})$ must be lower than the lobbyist's gross income $s\pi(\hat{p})$. Using (3.6), (3.13) and (3.17) we have that $s\pi(\hat{p}) - B(\hat{p}) = \left[sp^* + [s-a]^2\frac{\beta\gamma k}{a}\right]\gamma k > 0$.

3.2. The Accumulation Game

In this section, we solve the dynamic accumulation game among the n power-holders. We impose the following restrictions. Parameter values are restricted to ensure, first, that the equilibrium import tariff is always positive, and, second, that along the equilibrium path, domestic demand for manufactures is greater than production, so that the expression for revenues (3.6), $p(t)q^m(t) = p(t)\gamma k(t)$ always applies. Lastly, we limit the range of power-holders' appropriation rates.

With regard to the first restriction, it follows from (3.13) that a necessary and sufficient condition for the equilibrium import tariff to be positive is

$$0 < a < s < 1 \tag{3.18}$$

In other words, the weight the policymaker assigns to the welfare of the $F-$sector must be lower than the share of $M-$sector revenues accrued by the lobbyist. Second, we show in the appendix that domestic demand for manufactures is not binding along the equilibrium path if and only if

$$k(0) \in \left[0, \frac{nr - E}{D}\right], \qquad p^*[s^2 - a] \leq s - a - nrs/\gamma \tag{3.19}$$

where E and D are defined in (3.22). The first condition in (3.19) says that at time $t = 0$ the M-sector's capital stock must lie within its two possible steady state values. The second condition implies that when the capital stock is at its upper bound, domestic consumption of manufactures is greater than production (see (5.10) and (5.11)). Since consumption is decreasing in k and production is increasing in k, it follows that $c^m(t) > q^m(t)$ for all t.

To capture the idea that investing in activities not related to steel is inefficient for a steel company, we assume that the raw rate of return in the $M-$sector

$\left(\frac{[1-s]\pi(k)}{k}\right)$ is greater than the interest rate on the internationally traded bond at all levels of k. This assumption holds if and only if

$$r < [1-s]\gamma p^* \tag{3.20}$$

Lastly, we impose the following bounds on the appropriation of each power-holder:

$$\begin{aligned} 0 &\leq w_i(t) \leq \overline{w}(k(t)) = \bar{\rho}_1 k(t) + \bar{\rho}_2 k(t)^2, \\ \bar{\rho}_1 &> \frac{[1-s]\gamma p^* - r}{n-1}, \qquad \bar{\rho}_2 > \frac{[1-s][s-a]2\beta\gamma^2/a}{n-1} \end{aligned} \tag{3.21}$$

The purpose of imposing an upper bound is to rule out appropriations at an infinite rate. The upper bounds on the ρ's are set sufficiently high so that they are not binding along the interior equilibrium we are about to characterize (see (3.25)).

Now we turn to the solution of the dynamic game. Substituting the equilibrium tariff (3.13) into the M-sector's accumulation equation (3.7), it follows that

$$\dot{k}(t) = Ek(t) + Dk(t)^2 - \sum_{i=1}^{n} w_i(t), \qquad E = [1-s]\gamma p^*, \qquad D = \frac{s-a}{a}[1-s]2\beta\gamma^2 \tag{3.22}$$

The first two terms are revenues minus lobbying expenses $p^*[1+\tau(t)][1-s]\gamma k(t)$, and the third term includes the amount appropriated by power-holders (for instance, wage payments, dividends and investments in other sectors out of the reach of labor unions). Note that since $a < s < 1$, revenues are increasing and convex in the capital stock. This is because the equilibrium tariff is increasing in the capital stock, which implies that increasing returns to scale exist in capital from the industry's perspective, although for a given domestic price, revenues are linear in the capital stock (see (3.7)).

If factor markets were perfectly competitive, this sector would grow until the demand constraint became binding. However, we will show that if labor unions have the power to set the wage bill, in equilibrium the capital stock will be decreasing or will follow a logistic path, in which the capital stock is increasing at low levels of capital, but decreasing at high levels of capital.

In this setup the payoff of each power-holder depends on the actions taken by the other power-holders. For instance, if the wage bill is increased by the union, shareholders' profits fall. On the other hand, by setting the reinvestment rate at a low level shareholders can induce a low level of future capital in the M-sector, which will reduce the wage bill that the union will be able to extract in the future.

A difference between this setup and other trade policy models is that the wage bill is not determined in a competitive fashion, but rather by a powerful union. We consider this to be an essential characteristic of industries such as steel which have received trade protection but have not become competitive.

At each instant, each power-holder i chooses an appropriation policy $\{w_i(s)\}$ and a consumption policy $\{c_i(s)\}$ that maximize objective function (3.5) subject to accumulation equations (3.22) and (3.8) and also subject to the appropriation policies followed by the other $n-1$ power-holders. The solution concept we will use is Markov perfect equilibrium (MPE), which limits strategies to functions of payoff-relevant state variables (see Maskin and Tirole (1994)).[5] A strategy of group i consists of an appropriation policy and a consumption policy. An n-tuple of strategies forms a Markov perfect equilibrium if they form a sub-game perfect equilibrium at every level of $k(t), b_1(t), ..., b_n(t)$.

Since each power-holder takes as given the strategies of the others, we can obtain the Markov perfect equilibria of this game by solving simultaneously a set of n Hamiltonian problems, one for each group. The present value Hamiltonian of group i is

$$\begin{aligned} H_i &= \frac{\sigma}{\sigma-1}[c_i^f]^{\frac{\sigma-1}{\sigma}} + \lambda_i[Ek + Dk^2 - w_i - \sum_{j\neq i} \hat{w}_j(k)] \\ &\quad + \phi_i[rb_i + w_i - c_i^f] + \overline{\mu}_i[\overline{w}(k) - w_i] + \underline{\mu}_i w_i \end{aligned} \tag{3.23}$$

In this problem k and b_i are the state variables, while c_i^f and w_i are the control variables. The second and third terms correspond to the accumulation equations for k and b_i, respectively. The last two terms correspond to the restriction imposed on the appropriation rate (3.21), i.e., $0 \leq w_i(k) \leq \overline{w}_i(k)$.

Notice that in deriving the first order conditions for group i, only c_i^f and w_i are treated as control variables, while the appropriation policies of the other $n-1$ groups $\hat{w}_j(k(t))$ are treated as functions of the state variable. In fact, these functions are the equilibrium policies derived from analogous control problems. Thus, to find an MPE it is necessary to find a set of n pairs of appropriation and consumption policies $\{\hat{w}_j(t), \hat{c}_j^f(t)\}_{j=1}^n$ that simultaneously solve n Hamiltonian problems like (3.23). We find a solution by first postulating that the appropriation

[5]Markov strategies do not allow strategies to be history-dependent.

policies are quadratic functions of the common access capital stock[6]

$$w_i(k) = \rho_{i1}k + \rho_{i2}k^2, \qquad i = 1, ..., n \tag{3.24}$$

where the ρ's are unknown coefficients. We then determine the values of these $2n$ undetermined coefficients that simultaneously solve the n Hamiltonian problems. In this way we find a set of n strategies that are best responses to one another. Lastly, we show that this solution candidate satisfies the second order conditions.

There are two types of Markov Perfect equilibria in this game: interior and extreme. In an interior equilibrium all agents set their appropriation rates in the interior of the appropriation set defined in (3.21). This is not true along an extreme equilibrium. In this paper we will concentrate on the interior equilibrium. Since, in extreme equilibria, agents set their appropriation rates at the boundaries, we need a theory of how the bounds are determined to make analysis interesting.

We show in the appendix that there is a unique interior equilibrium within the class of quadratic strategies specified in (3.24). Moreover, the interior equilibrium is symmetric and stable (see next subsection). This equilibrium is given by

$$\hat{w}_i(k(t)) = \frac{E - r}{n - 1}k(t) + \frac{D}{n - 1}k(t)^2 \tag{3.25}$$

$$\hat{c}_{if}(t) = Q\left[k(t) + b_i(t)\right], \qquad Q \equiv r(1 - \sigma) + \delta\sigma > 0 \tag{3.26}$$

Substituting (3.25) and (3.26) into accumulation equations (3.22) and (3.8), we have that the equilibrium capital stocks evolve according to

$$\hat{k}(t) = \left\{\frac{D}{nr - E} + \left[\frac{1}{k_0} - \frac{D}{nr - E}\right]e^{-\frac{nr-E}{n-1}t}\right\}^{-1} \tag{3.27}$$

$$\hat{b}_i(t) = e^{\sigma(r-\delta)t}\left[k(0) + b_i(0)\right] - k(t) \tag{3.28}$$

Next we will provide some intuition for equations (3.25)-(3.28). First, we consider equation (3.25). Define the "post-appropriation rate of return to group i" as the rate of return perceived by group i in the M-sector net of the appropriations made by the other $n-1$ groups, i.e, $\frac{(1-s)\pi(t) - \sum_{j\neq i} w_j(t)}{k(t)}$. Now, consider the problem faced by group i. At each instant, group i must choose the amount of capital it will appropriate from the M-sector. For group i to set its appropriation rate

[6]It is natural to conjecture that $w_i(t)$ is just a function of the common access capital stock, and not of the b_is, because the b_is do not enter the accumulation equation for k, and i's appropriation decision $w_i(t)$ is independent from its consumption decision $c_i(t)$.

within the bounds imposed in (3.21), the post-appropriation rate of return it perceives in the M-sector must be equal to the rate of return (r) of the bond which is off-limits to the other groups. Thus, replacing $\sum_{j \neq i} w_j(t)$ by (3.24) and $(1 - s)\pi(t)$ by $Ek(t) + Dk(t)^2$ (E and D are defined in (3.22)), it follows that unilateral deviations from the interior equilibrium are unprofitable if and only if

$$r = E + Dk(t) - \sum_{j \neq i} [\rho_{j1} + \rho_{j2} k(t)], \qquad \text{for all } i, j \tag{3.29}$$

The unique solution to this set of n equations is given by (3.25). We show in the appendix that if all power-holders set their appropriations equal to (3.25), the present value of the appropriations of each group as of time t is equal to the aggregate capital stock in the $M-$sector. That is, $\int_t^\infty \hat{w}_i(s) e^{-rs} ds = k(t)$ (see (5.9)). This surprising result and (3.29) imply that there are no profitable deviations from the interior equilibrium. First, given that the other $n - 1$ groups follow their equilibrium policies, a power-holder obtains the same rate of return r in the $M-$ sector as from the internationally traded bond. Second, since the present value of its appropriations are equal to the aggregate capital stock in the $M-$sector, the group in question has no incentive to appropriate the entire capital stock from the $M-$sector.

To illustrate, suppose there are only two power-holders: the union and the manager. The above condition states that, given the union's equilibrium wage policy, the manager will receive the same rate of return in the M-sector that would be received from investment in the internationally traded bond (r). Therefore, the manager has no incentive to deviate from the interior equilibrium and reduce investment in the $M-$sector. Similarly, given that the manager is following the equilibrium investment policy, workers have no incentive to increase the wage bill above its equilibrium level. Their gain from deviating unilaterally would be zero.

Now we consider consumption policy (3.26). We have seen that in equilibrium, the rate of return received by each power-holder is r. This implies, as in any standard growth model, that consumption must grow at rate $\sigma(r - \delta)$,[7] and that in any given period, consumption is a fixed proportion of the capital to which the power-holder has access. The power-holder has access to its foreign bond $b_i(t)$ and to the common access capital stock $k(t)$.

Next we show that the n candidate pairs $\{\hat{w}(t), \hat{c}_i^f(t)\}_{i=1}^n$ given by (3.25) and (3.26) are admissible. To see this, note first that this pair generates a unique state

[7] σ is the elasticity of intertemporal substitution in consumption and δ is the subjective discount rate.

trajectory $\{\hat{k}(t), \hat{b}_i(t)\}$ given by (3.27) and (3.28). Second, note that it satisfies the necessary conditions (5.1)- (5.5). Third, note that the appropriation rate satisfies constraint (3.21).

To ensure that this admissible solution is indeed a Markov perfect equilibrium we need to verify that the second order conditions are satisfied. These conditions are satisfied because the control set specified in (3.21) is convex, the instantaneous utility function is strictly concave (because $\sigma > 0$) and the accumulation equation is linear in (c_i, K) (see Seierstad and Sydsaeter (1987)). Finally, since $\hat{w}(k)$ is the unique solution to the system of n equations (3.29), it follows that, within the class of quadratic strategies defined in (3.24), (3.25)-(3.26) is the unique interior Markov perfect equilibrium of our dynamic game.

We show in the appendix that the interior equilibrium we have characterized is stable against unilateral deviations. That is, if a power-holder deviates from the interior equilibrium by not setting its appropriation rate equal to $\hat{w}$ defined in (3.25), then the best response of the other $n-1$ groups is to shift their appropriation rates in the opposite direction. Therefore, a unilateral deviation will not induce a shift from an interior to an extreme equilibrium.

3.3. Evolution of the Capital Stock

Next we consider the evolution of the capital stock in the M sector. The growth rate of the capital stock is:

$$\frac{\dot{k}(t)}{k(t)} = \begin{cases} \left[\frac{nr-E}{n-1}\right]\left[1 - \frac{D}{nr-E}k(t)\right] & \text{if } \ nr \neq E \\ -\frac{D}{n-1}k(t) & \text{if } \ nr = E \end{cases} \tag{3.30}$$

There are two cases to consider depending on the sign of $nr - E$. If $nr > E$, the capital stock follows a logistic path. At low levels of capital the growth rate is positive. However, as the capital stock increases, the growth rate falls. It becomes zero when $k(t)$ reaches the level $\frac{nr-E}{D}$, and thereafter it becomes negative. Thus, in the case where $nr > E$, the capital stock has two steady states: zero if $k(0) = 0$, and $\frac{nr-E}{D}$ if $k(0) > 0$. If $nr \leq E$, the growth rate is always negative. Thus, the capital stock in the M-sector invariably converges to zero. Figure 1 shows the paths of the growth rate of the capital stock.

The capital stock in the M-sector follows a logistic or a declining path. Recall that there are constant returns to scale in the production of manufactures, and that the import tariff is linearly increasing in the capital stock of the M-sector. Therefore, revenues increase at a quadratic rate with the capital stock. They are given by $Ek + Dk^2$ (see (3.22)). The reason why the capital stock follows a logistic path (when $nr > E$) or a declining path (when $nr \leq E$) is that aggregate appropriation $\left(\frac{n}{n-1}\left[[E - r]k + Dk^2\right]\right)$increases faster than revenues as k rises. In other words, there is a "voracity effect" that leads power-holders to become increasingly more voracious as the import tariff increases. Thus, at low levels of capital, appropriation might be less than revenues (if $nr > E$), and the capital stock might be increasing. However, at some point, aggregate appropriation must overtake revenues and the capital stock in the M-sector must start to decline.

The interior equilibrium we have characterized rationalizes the stylized facts mentioned in previous sections, namely, that the higher domestic steel prices generated by trade protection were associated with more than proportional wage increases, and with a decrease in the share of profits reinvested in steel-related activities. Therefore, trade protection did not induce higher growth in the integrated steel industry. Along the interior equilibrium, when the capital stock is small, greater protection may induce more growth. However, when the capital stock reaches a certain threshold $\left(k \geq \frac{nr-E}{D}\right)$further increases in protection have the puzzling effect of inducing more than proportional increases in the wage bill and the dividends rate, which dominate the direct positive effect on revenues. As a result, the growth rate of the industry falls as protection increases. For future reference we summarize our results in the following proposition.

Proposition 1. *Consider a firm with constant returns technology that enjoys trade protection proportional to firm size. If this firm has divided control over the use of revenues, after a certain threshold its growth rate will fall as firm size increases. This is because an increase in the protection rate will lead to an increase in wage demands and dividend distributions that will be more than proportional to the increase in revenues.*

3.4. Adoption of Technological Innovations

Consider a technological innovation that increases productivity in the M-sector, i.e. that increases the value of γ in accumulation equation (3.6). We will show that along the interior equilibrium it is not profitable for the owner-manager to adopt this innovation for any arbitrarily small adoption cost ϵ. To see this note that by replacing consumption policy (3.26) in the utility function (3.5), it follows that along the interior equilibrium the payoff to any power-holder is given by

$$J_i(k(t) + b_i(t)) = \frac{\sigma}{\sigma - 1}\left[k(t) + b_i(t)\right]^{\frac{\sigma-1}{\sigma}} Q^{-\frac{1}{\sigma}} \tag{3.31}$$

Thus, the payoff to group i if it adopts the innovation is $J_i(k(t) + b_i(t)) - \epsilon$. Since $J_i(k(t) + b_i(t))$ is independent of the productivity parameter γ, the payoff of adopting the innovation is $-\epsilon$ for any increase in γ such that the restrictions on parameters necessary for an interior equilibrium to exist are satisfied.

To illustrate the intuition behind this result suppose the innovation is adopted and γ increases to $\gamma + \Delta$. Also suppose that the n power holders engage in the accumulation game defined by (3.5)-(3.8). It follows from (3.22) and (3.25) that along the interior equilibrium, each power-holder will set its appropriation rate equal to

$$\hat{w}_i(k(t); \gamma+\Delta) = \frac{[1-s][\gamma+\Delta]p^* - r}{n-1} k(t) + \frac{2\beta[1-s][s-a][\gamma+\Delta]^2}{a[n-1]} k(t)^2 \quad (3.32)$$

Let group i be the owner-manager, i.e. the group that makes the investment decision. If group i were to make the productivity enhancing investment, the "raw" rate of return in the M-sector would increase. However, the appropriation rates of the other $n-1$ groups would not remain unchanged. Therefore, the "net" rate of return perceived by group i in the M-sector, after the other $n-1$ groups have appropriated, might go up or down. Let us denote this net rate of return by R^i_M. Equation (3.32) implies that

$$\begin{aligned} R^i_M(\gamma+\Delta) &= \frac{[1-s]\pi(t;\gamma+\Delta) - \sum_{j\neq i} \hat{w}_j(t)}{k(t)} = \\ &= \frac{[1-s][\gamma+\Delta]p^* k(t) + \frac{s-a}{a}[1-s]2\beta\gamma^2 k(t)^2 - [n-1]\left[\frac{[1-s][\gamma+\Delta]p^* - r}{n-1} k(t) + \frac{2\beta[1-s][s-a][\gamma+\Delta]^2}{a[n-1]} k(t)^2\right]}{k(t)} \\ &= r \end{aligned} \quad (3.33)$$

Doing the same calculations as in (3.33) we have that i's net rate of return in the M-sector with no innovation is also r. Therefore, with or without the technological innovation, group i obtains the same rate of return in the $M-$sector, which is the interest rate on the internationally traded bond. Hence, i will not find it profitable to adopt the new technology if a positive adoption cost must be incurred to do so.

In other words, although the $M-$sector becomes more productive if the technological innovation is adopted, appropriative activity becomes more acute. In equilibrium, once the owner/manager incurs the cost of adopting a new technology, the other $n-1$ power-holders, *as a group*, will increase their appropriations by an amount equal to the increase in revenues generated by the innovation. Therefore, the net rate of return perceived by group i in the $M-$sector is the same as before the new technology was adopted: it is equal to the interest rate on the internationally traded bond. As a result, i does not have any incentive to adopt new technologies, so there is *rational atrophy*.

If productivity in the $M-$sector (γ) increases, group i will also appropriate more. In such a case, one might ask why, if i will be able to appropriate more from the $M-$sector, does group i find it unprofitable to adopt the new technology, given a sufficiently large increase in γ? The answer is that along the interior equilibrium i perceives the same net rate of return in the $M-$sector as from the internationally traded bond. As a result, i is indifferent as to how its assets are allocated. If the innovation is adopted, the higher appropriation by i just means that i allocates a greater share of its capital to another asset with an identical rate of return! Thus, i's wealth remains unchanged.

Not only does the owner-manager have a negative payoff of adopting the new technology, but the other $n-1$ groups do not experience any gain from the adoption. According to (3.31) their payoffs remain unchanged. Why are the efficiency gains from the innovation dissipated? Greater productivity induces greater aggregate appropriation. Therefore, although the raw rate of return in the $M-$sector is higher after adoption, a greater share of total assets is allocated to the internationally traded bond, which has a lower raw rate of return. In equilibrium these two effects cancel each other out.

As a group the n power-holders would gain if the new technology were adopted. However, ex-ante none of them can commit not to engage in voracious behavior ex-post. Given this lack of commitment, there is room for a new entrant to adopt the new technology and reap the profits.

We summarize the results of this subsection in the following proposition:

Proposition 2. *"Rational Atrophy" occurs when control is divided among several power-holders. In that case, for any adoption cost owners/managers will not find it optimal to adopt cost-reducing technological innovations.*

4. Reactions of Industry Participants and Concluding Remarks

During the 1970s and 1980s the integrated steel industry in the US was successful in obtaining trade protection. However, higher prices were reflected in a higher wage premium relative to the rest of the manufacturing sector, and in a greater share of profits being divested. Furthermore, available technological innovations that had proven to increase productivity in other countries were not adopted on a timely basis. This failure to adopt new technologies, combined with trade protection, allowed new small firms (the minimills) to enter the market. Today the minimills have captured about 40% of the US steel market.

The poor performance of the integrated steel industry has been rationalized in the existing literature by invoking the end-game assumption and the existence of divided control between managers and other stakeholders. The argument is that the steel industry was doomed in the 1970s and 1980s, so powerholders simply tried to extract as much as possible from the steel firms. But the end-game assumption is difficult to defend empirically. During the 1970s expectations were high, and ex-post demand did not collapse and foreigners did not conquer the US market. Moreover, as the experience of the minimills has shown, the US is capable of being a competitive steel producer.

In contrast to the existing literature my argument is not based on the end-game assumption. I assume divided control among powerholders with infinite horizons. In this setup, powerholders do not try extract as much as possible from the firms in every period, and, as observed in reality, there might be some investment to improve the plants. However, price increases do not lead to increased investment, but rather to higher wages and more divestment, as observed during the 1970s and 1980s. Another property of our model is that it delivers rational atrophy. Since ex-post unions and other powerholders appropriate excess returns, managers have no incentive to adopt new technologies. This makes way for new entrants (minimills) to adopt the new technologies and thereby capture a big share of the market.

The industry participants I interviewed agreed that foreign competition was not the only cause of the decline of the integrated US steel industry, that the rise of domestic minimills played an important role, and that the industry should have adopted technological innovations faster. They also agreed that tensions between management and workers played an important role in creating these problems.

Industry participants cautioned me against taking at face value the extreme assumption of divided control among equally powerful groups, and the resulting sharp predictions of the model. They affirmed that workers and management did not always act cooperatively, and that sometimes unions' wage demands were excessive. However, they also asserted that there was some communication between top management and union leaders. Also, some interviewees pointed out that fear of future excessive wage demands was not the only reason for the failure to adopt new technological innovations, as stated in the model. In some cases, the existence of non-depreciated facilities prevented the adoption of upstream or downstream technological innovations because the potential of the innovations could not have been fully exploited. For instance, it was uneconomical to install continuous casters in plants with Open Heart furnaces or old hot strip mills. In other cases, technological innovations implied important labor savings or significant shifts in work practices and stakeholders opposed them. Therefore, responsibility for the failure to adopt new technologies does not rest squarely on the unwillingness of labor to accept more flexible work practices and more moderate wage increases. Often the unwillingness or inability of a bureaucratized management to adopt technological innovation was an equally salient obstacle.

With respect to my argument that minimills captured 40% of the US market so easily because managers did not have incentives to adopt new technologies given that ex-post all excess returns would be appropriated by unions, the industry participants interviewed saw this as a sensible explanation, but cautioned that there are other elements to consider. First, they noted that over the long run the excess supply of scrap (the raw material of minimills) will disappear and the cost of integrated producers will become lower. Therefore, it does not pay to shift away from the current integrated technology based on melting iron and coal. Second, they claim that minimills have captured only the low quality range of the market.

These arguments present the following problems. First, any integrated steel producer, without interrupting its normal production, could have opened new units to replicate minimill production and reaped the profits. Why let an outsider reap them? Second, the minimills recently built by NUCOR produce high quality flat products. Thus, ex post the argument that minimills are necessarily confined to low quality long products has been proven wrong. Third, substitutes for scrap such as iron carbide have been introduced to the market.

5. Appendix

5.1. First Order Conditions

The first order conditions corresponding to group i's problem are:

$$\frac{\partial H_i}{\partial c_{if}} = c_{i_f}(t)^{-\frac{1}{\sigma}} - \phi_i(t) = 0 \tag{5.1}$$

$$\frac{\partial H_i}{\partial w_i} = \phi_i(t) - \lambda_i(t) = 0 \tag{5.2}$$

$$\frac{\dot{\lambda}_i(t)}{\lambda_i(t)} = \delta - E - 2Dk(t) + \sum_{i\neq j}[\rho_{i1} + 2\rho_{i2}k(t)] \tag{5.3}$$

$$\frac{\dot{\phi}_i(t)}{\phi_i(t)} = \delta - r \tag{5.4}$$

$$\lim_{t\to\infty} \lambda_i(t)k(t)e^{-\delta t} = 0, \qquad \lim_{t\to\infty} \phi_i(t)b_i(t)e^{-\delta t} = 0 \tag{5.5}$$

Conditions (5.2)-(5.4) imply that the ρ's must satisfy the following set of n equations

$$r = -E - 2Dk(t) + \sum_{i\neq j}[\rho_{i1} + 2\rho_{i2}k(t)], \qquad i = 1, ..., n \tag{5.6}$$

These n equations are simultaneously satisfied for any value of $k(t) \neq 0$ if and only if $\rho_{i1} = \rho_{j1}$ and $\rho_{i2} = \rho_{j2}$ for all j and i. The solution is then obtained by equalizing coefficients: $r = -E + (n-1)\rho_1$ and $0 = -2Dk + 2(n-1)\rho_2 k$.

Conditions (5.1) and (5.4) imply that $c_{if}(s) = c_{if}(t)e^{\sigma(r-\delta)(s-t)}$. To obtain the value of the constant $c_{if}(t)$ we substitute the expression for $c_{if}(s)$ in the accumulation equation for b_i (3.8). The solution to the differential equation is

$$b_i(t) = \left[\int_0^t z(s)e^{-rs}ds - \frac{c_{if}(0)}{Q}[1 - e^{-Qt}] + b_i(0)\right] e^{rt} \tag{5.7}$$

where $Q \equiv r(1-\sigma) + \delta\sigma > 0$. Substituting (5.7) into the second transversality condition in (5.5) and noting that $\phi_i(s) = c_{if}(s)^{-\frac{1}{\sigma}} e^{(\delta-r)(s-t)}$, we have that

$$0 = \lim_{s\to\infty} \left[\int_t^s z(y)e^{-ry}dy - \frac{c_{if}(t)}{Q}[1 - e^{-Q(s-t)}] + b_i(t)\right] \phi_i(t)$$

This implies that

$$c_{if}(t) = Q\left[b_i(t) + \int_t^{\infty} \hat{z}(s)e^{-r(s-t)}ds\right] \tag{5.8}$$

Since $z(s)$ is a quadratic function of $k(t)$, which in turn is a non-linear function of time, a direct computation of $\int_t^{\infty} \hat{z}(s)e^{-r(s-t)}ds$ is quite complicated. To derive an analytic solution we use the following argument. First, note that along the equilibrium path $\dot{k} = Ek + Dk^2 - n\hat{z}$, and $\hat{z} = \frac{E-r}{n-1}k + \frac{D}{n-1}k^2$. Therefore, $-\hat{z} = \dot{k} - Ek - Dk^2 + [n-1]\left[\frac{E-r}{n-1}k + \frac{D}{n-1}k^2\right] = \dot{k} - rk$. Multiplying both sides by e^{-rs} and integrating we get

$$-\int_t^{\infty} \hat{z}(s)e^{-r(s-t)}ds = \lim_{s\to\infty} k(s)e^{-rs} - k(t) = -k(t) \qquad \text{for all } t \tag{5.9}$$

The second equality follows from the fact that $\lim_{s\to\infty} k(s)$ is a finite number. Replacing (5.9) in (5.8) we obtain (3.26). By substituting (5.8) and (5.9) in (5.7) we obtain the expression for $b_i(t)$ in the text.

To check that the first transversality condition in (5.5) is satisfied, note that (5.2) and (5.4) imply that $\lambda_i(t) = \lambda_i(0)e^{(\delta-r)t}$. Thus $\lim_{t\to\infty} \lambda_i(t)k(t)e^{-\delta t} = \lambda_i(0)\lim_{t\to\infty} e^{-rt}k(t)$. Since $k(t)$ converges to zero if $nr - E < 0$ or to $\frac{nr-E}{D}$ if $nr - E > 0$, it follows that $\lim_{t\to\infty} e^{-rt}k(t) = 0$.

5.1.1. Stability of the Interior Equilibrium

Here we will show that if a group deviates from the interior equilibrium by setting its appropriation rate different from $\hat{w}$ defined in (3.25), then the best response of the other $n-1$ groups is to shift their appropriation rates in the opposite direction. Therefore, a unilateral deviation will not induce a shift from an interior to an extreme equilibrium.

Suppose that agent n deviates from the interior equilibrium and sets its appropriation policy equal to $w^d(k) = \rho_1^d k + \rho_2^d k^2 \neq \hat{w}(k)$. The remaining $n-1$ groups solve the same accumulation game as before taking as given that $w_n(k) = w^d(k)$. Denote the equilibrium appropriation policies of this new game as $\tilde{w}_i(k, \rho^d)$. Following the same steps as before it follows that the appropriation policies of the remaining $n-1$ groups must satisfy a set of $n-1$ linear equations analogous to (3.29)

$$r = E + 2Dk(t) - \sum_{j\neq i,n}[\rho_{j1} + 2\rho_{j2}k(t)] - \rho_1^d - 2\rho_2^d k, \qquad i, j = 1, \ldots, n-1$$

As before, the unique solution to this set of equations is symmetric and given by

$$\tilde{w}_j(k, \rho^d) = \frac{E - r - \rho_1^d}{n - 2}k + \frac{D - \rho_2^d}{n - 2}k^2 \qquad for\ n > 2$$

Note that if group n does not deviate from the original interior equilibrium (i.e, $\rho_1^d = \hat{\rho}_1$ and $\rho_2^d = \hat{\rho}_2$), then the best response of the other $n - 1$ groups is $\tilde{w}_j(k, \hat{\rho}) = \hat{w}(k)$. Furthermore, $\frac{\partial \tilde{w}_j(k,\rho^d)}{\partial \rho_1^d} < 0$ and $\frac{\partial \tilde{w}_j(k,\rho^d)}{\partial \rho_2^d} < 0$. Thus, the best response to a unilateral increase in another group's appropriation is to reduce one's own group's appropriation relative to the original interior equilibrium. The exact reverse applies to a unilateral reduction of the appropriation rate. Therefore, a change in the appropriation rate by one group induces others to shift their appropriations in the opposite direction, and hence it does not initiate a process that converges to an extreme equilibrium. Since there are no other interior equilibria, the equilibrium (3.25)-(3.28) is robust against unilateral deviations.

5.1.2. Proof that $q^m < c^m$

Here we show that restriction (3.19) is satisfied, and that along the equilibrium path, the consumption of manufactures is greater than production for all t. Thus, it is admissible to set revenues in the m-sector equal to $\pi(t) = p(t)\gamma k(t)$. Equation (3.27) implies that the capital stock is never greater than $\bar{k} = \frac{nr-E}{D}$. Thus (3.6), (3.3) and (3.13) imply that

$$q_m \leq \gamma\bar{k} \qquad c_m \geq \frac{1 - p^*[1 + \frac{(s-a)2\beta\gamma}{ap^*}\bar{k}]}{2\beta} \tag{5.10}$$

Replacing D and E by their values given in (3.22), it follows that

$$c_m(t) > q_m(t)\ \forall\ t \iff p^*[s^2 - a] \leq s - a - nrs/\gamma \tag{5.11}$$

This is condition (3.19) in the text.

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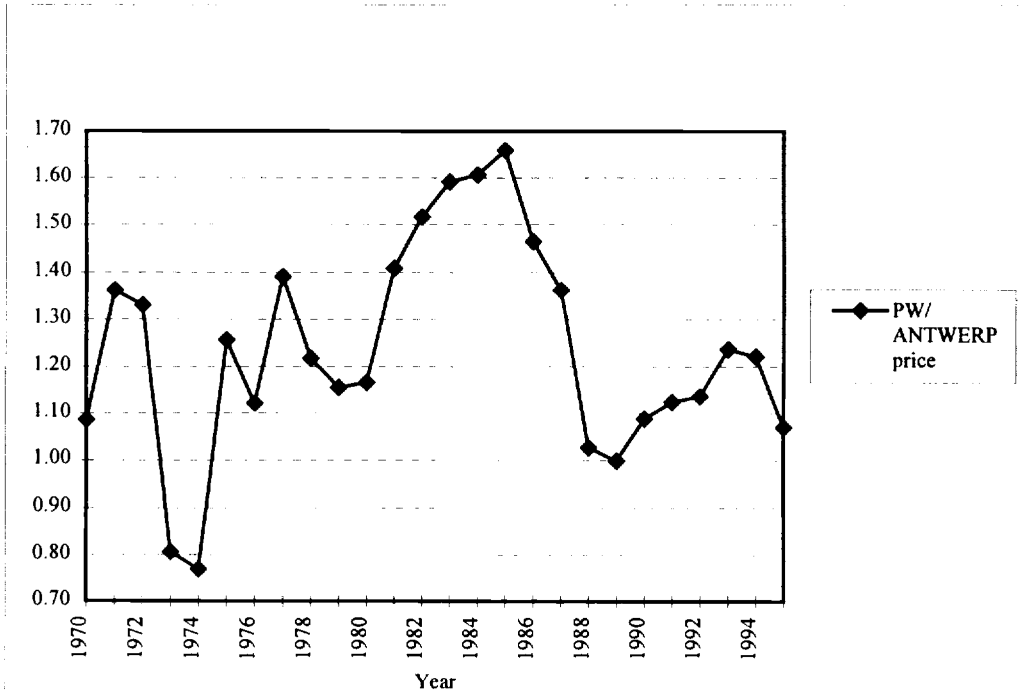
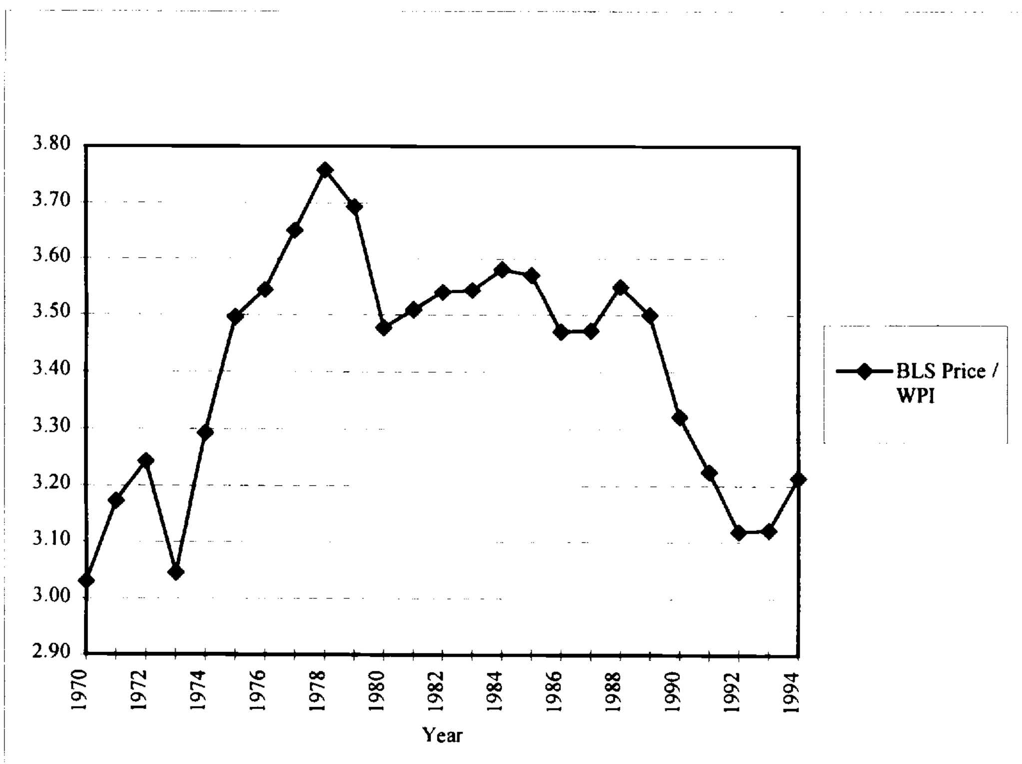
Figure 1. Paine Webber and BLS Steel Prices deflated by wholesale price index (WPI) and ANTWERP price, respectively





Note

ANTWERP is the free market world price.

ure 2. Wages and Productivity

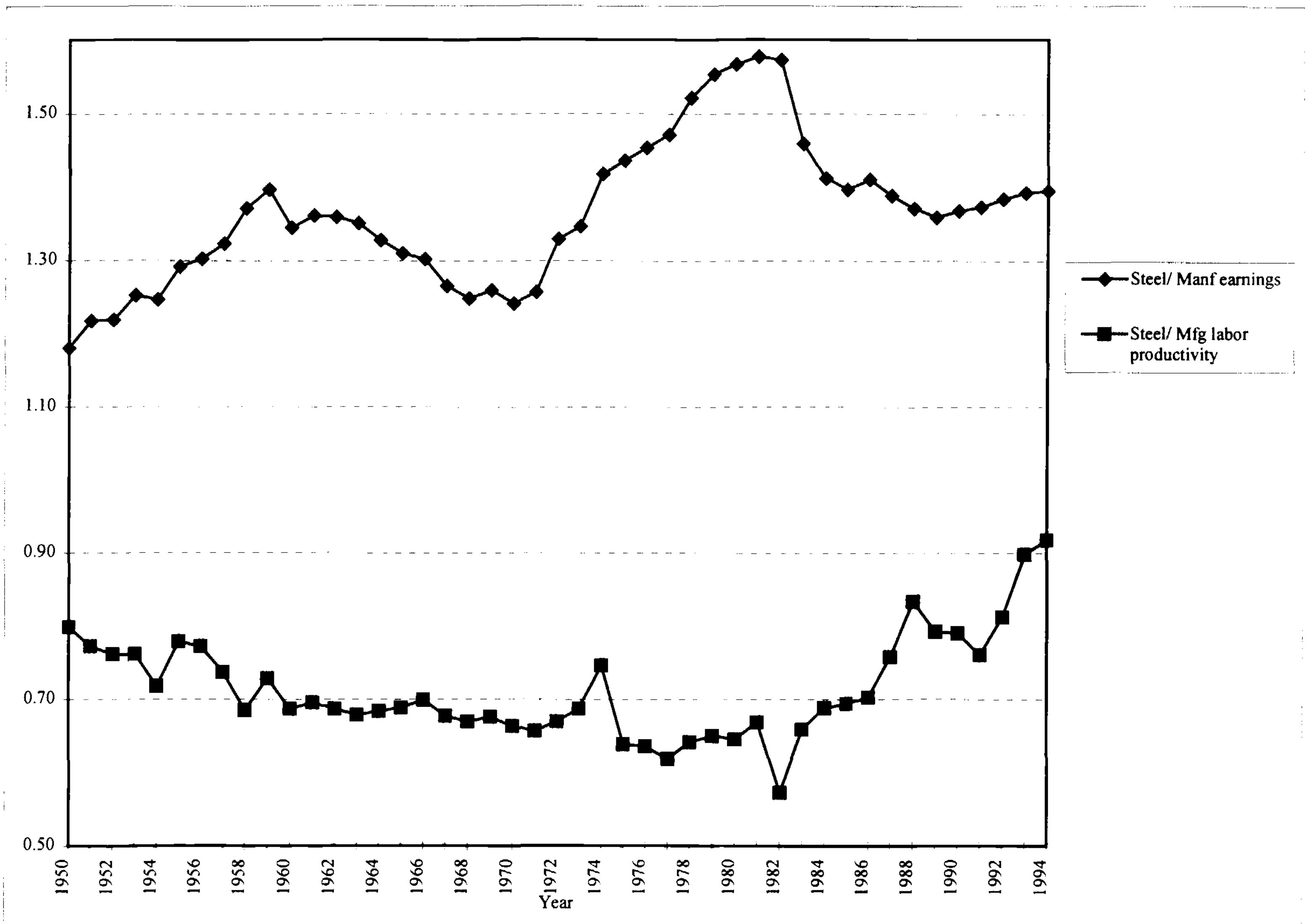
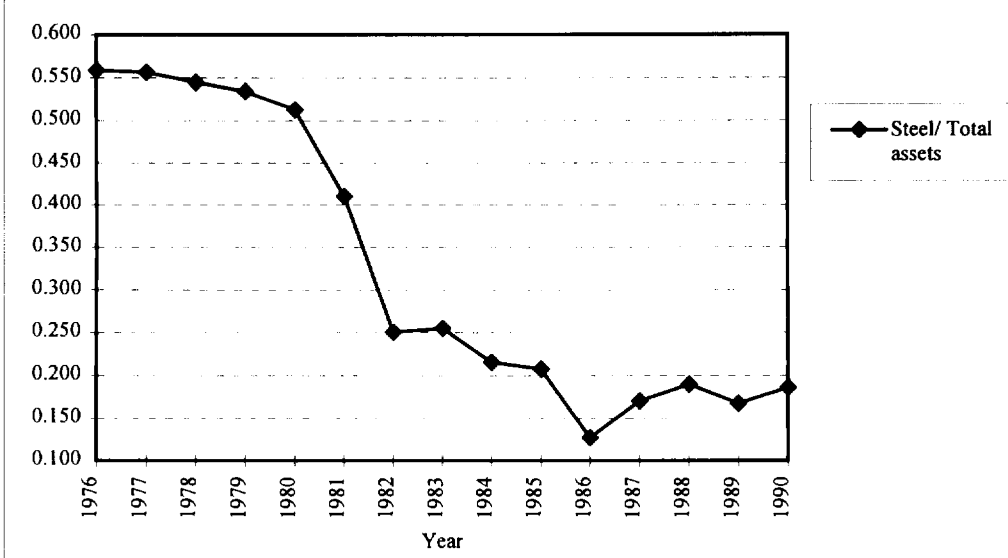
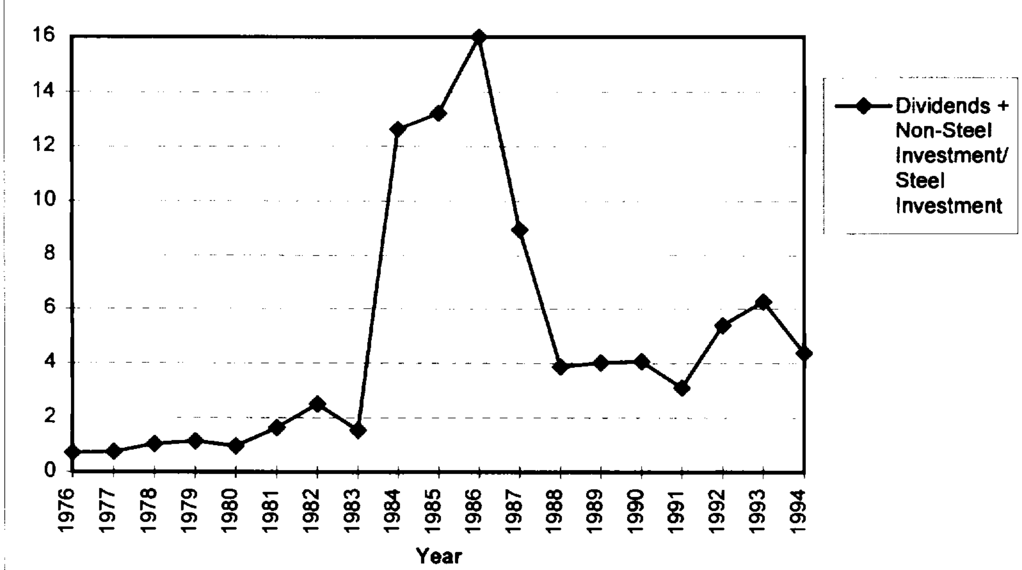


Figure 3. Divestiture of US Steel

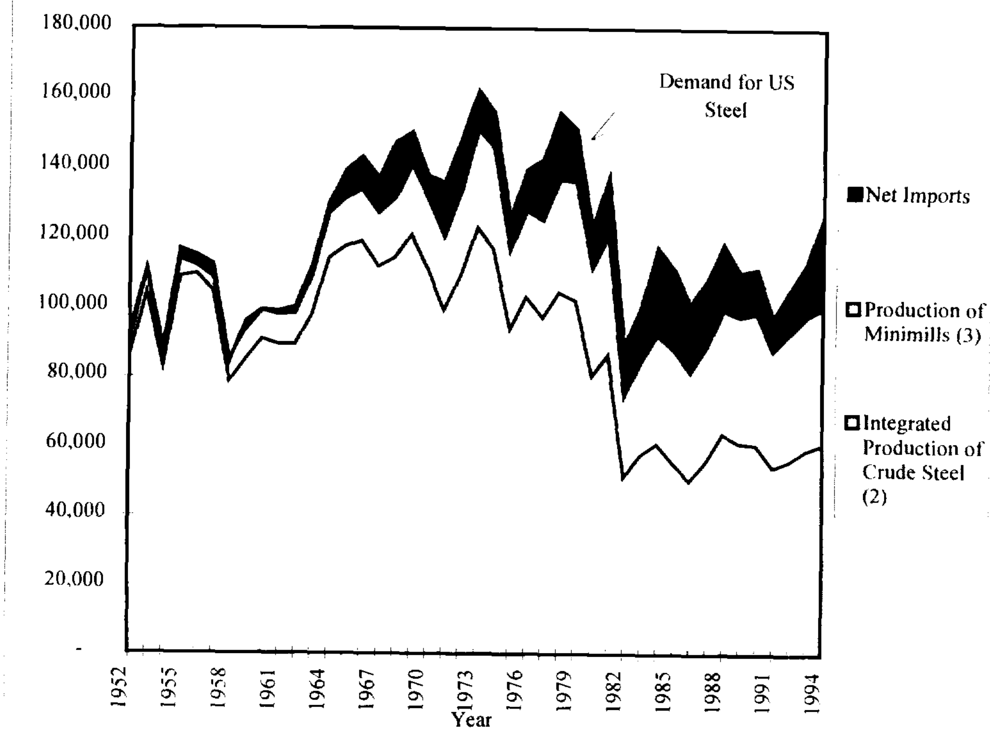




Note

Actual value for 1986 is 26.90.

Figure 4. Composition of Demand for Steel in US



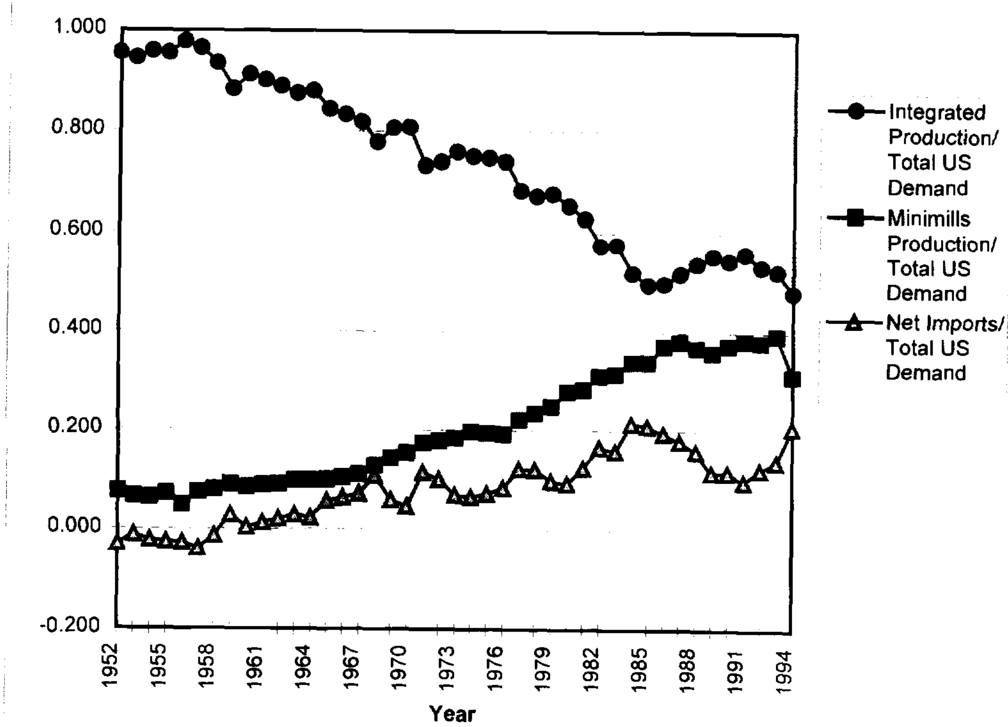


Figure 5. Minimill's Share of Production

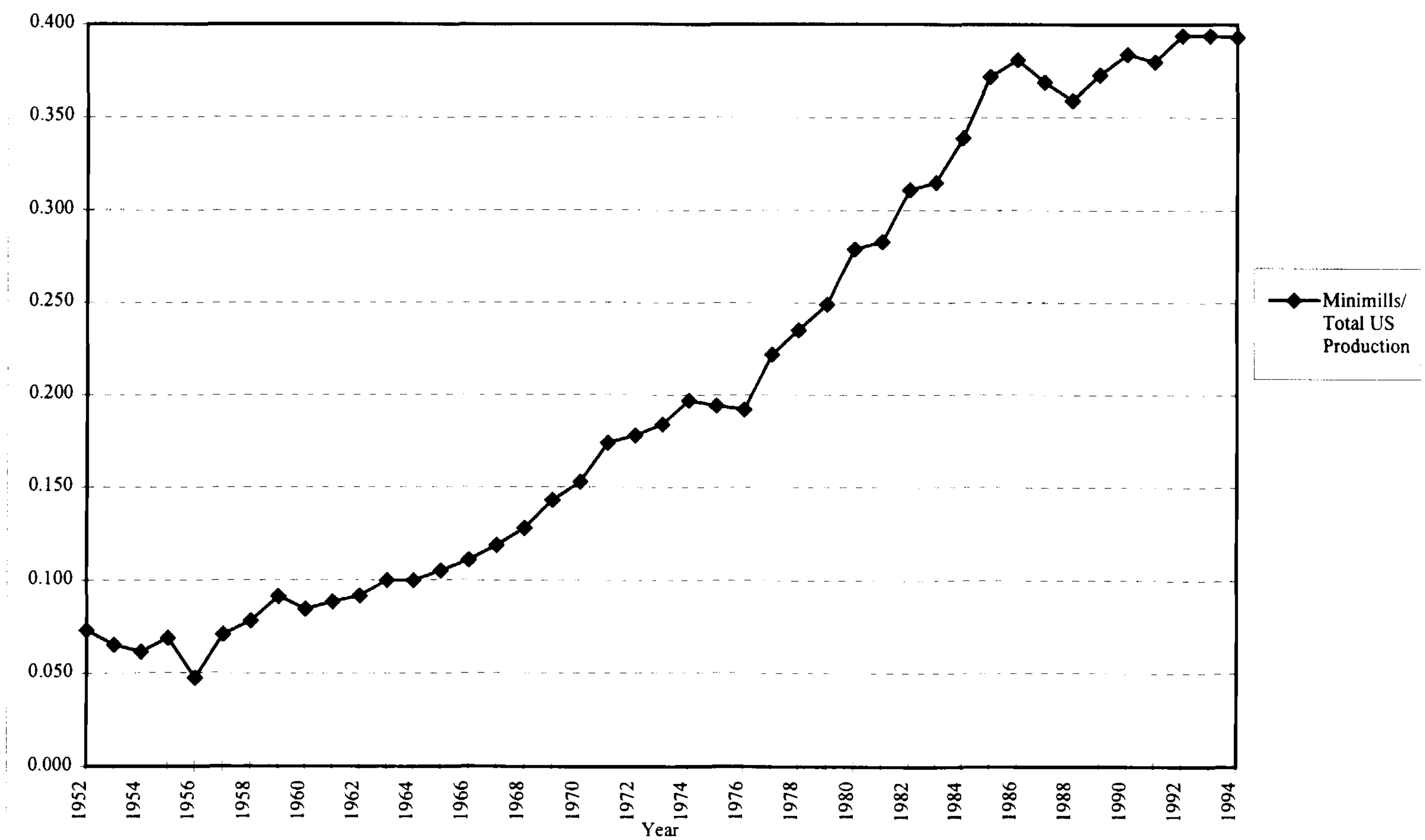
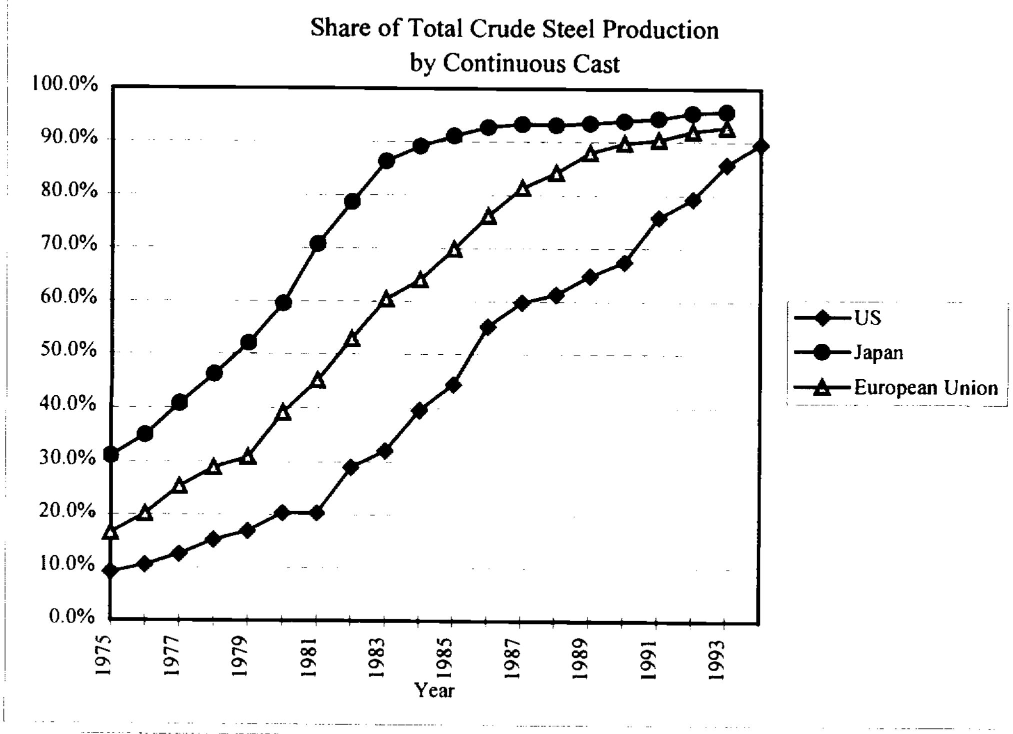


Figure 6. Speed of Adoption of New Technology



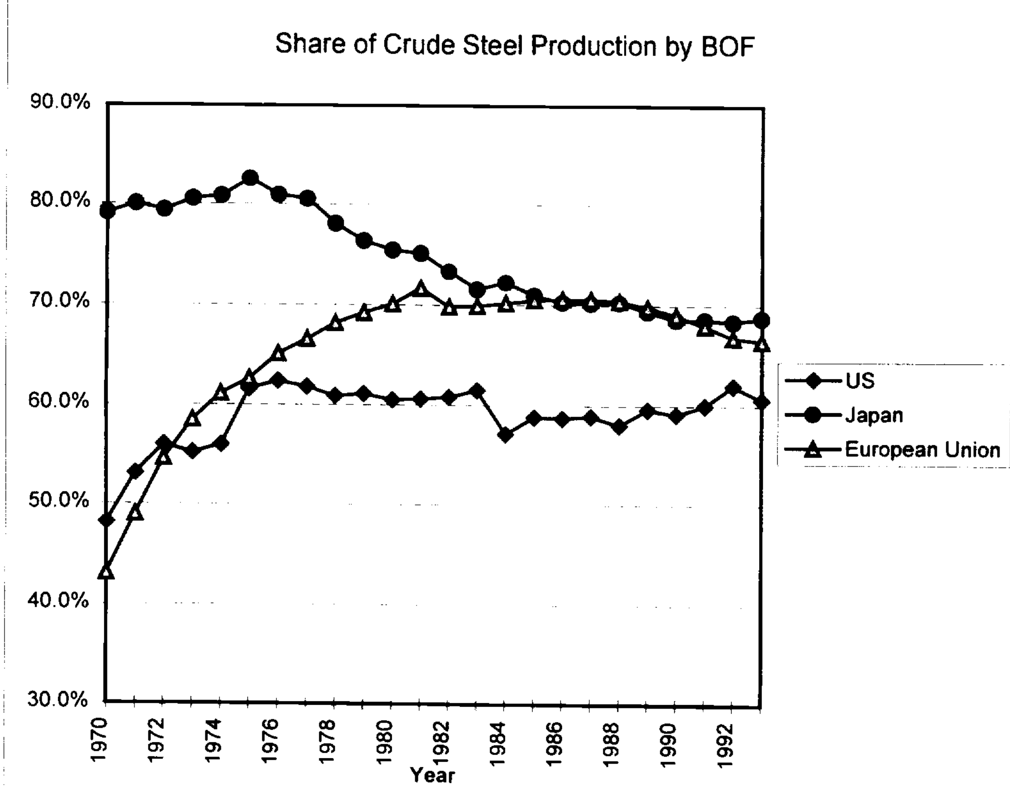
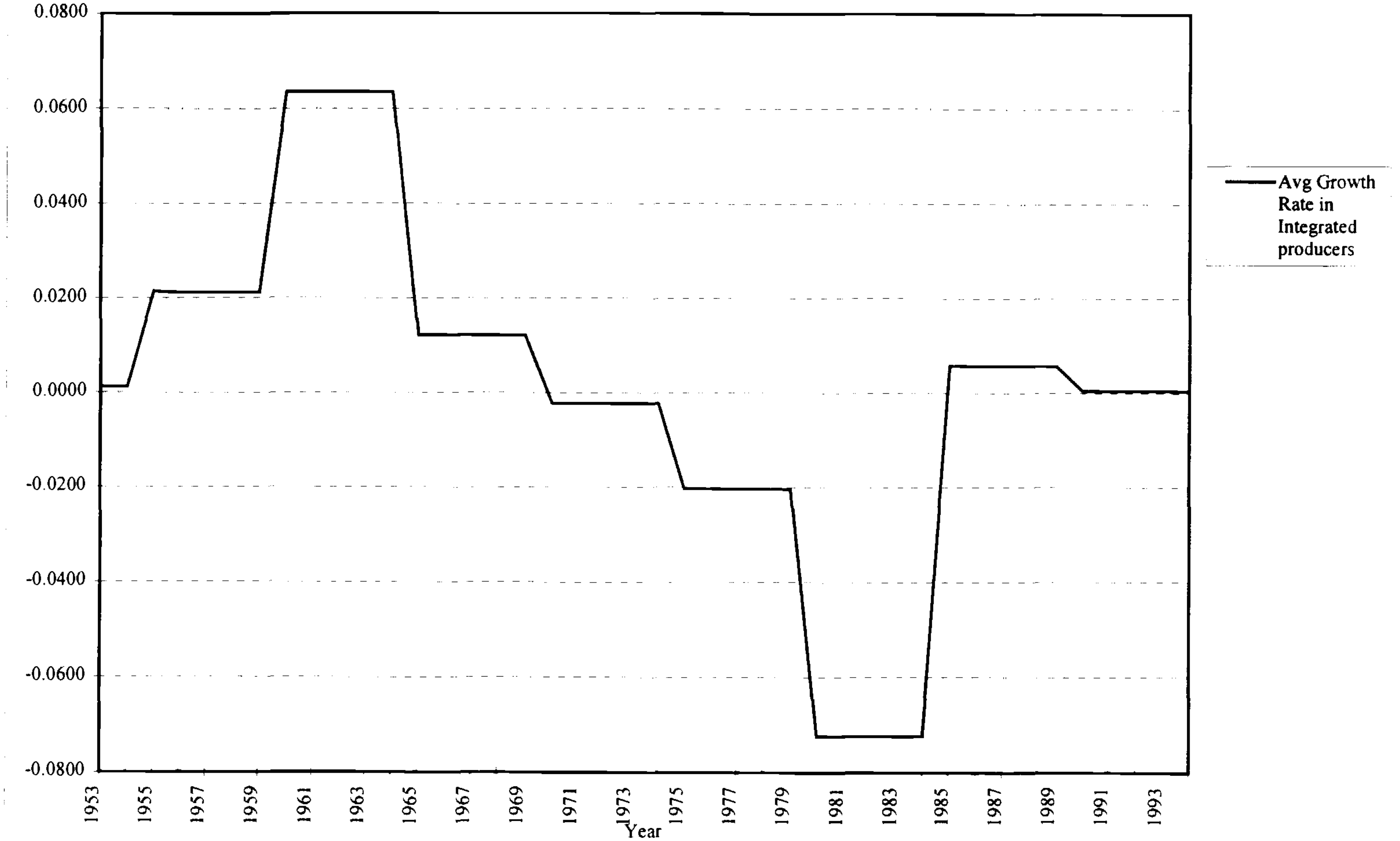


Figure 7. Growth rate in the Output of Integrated Producers



gure 9. Employment in Steel

Table 1. Augmented Dickey-Fuller Unit Root Test

Variable	
steel wages (w)	-0.08*
steel prices (pri)	0.42*
steel productivity (pro)	-0.62*
First difference of w	-2.25
First difference of pri	-2.55
First difference of pro	-3.45
Critical Value (5%)	-1.95

Notes:

w is the log of the ratio of steel wages to the average in manufacturing.
pri is the log of the ratio of steel prices to the wholesale price index.
pro is the log of the ratio of labor productivity in steel to the average in manufacturing.

The test was done assuming 3 lags, no intercept and no trend in the series.

* means that the null hypothesis of no unit roots is rejected at the 5% level of significance.

Table 2: Johansen Cointegration tests

(Wages and Prices)

(a) Likelihood Ratio Test

Eigenvalue	Likelihood ratio	5% Critical Value	1% Critical Value	Hypothesized Number of Cointegration Equations
0.26	20.45	15.41	20.04	None **
0.18	8.20	3.76	6.65	At most 1 **

The Likelihood Ratio test indicates 2 cointegrating equations at the 5% significance level.

(b) Coefficient of the Cointegration Equation

Wages	Prices	Constant
1.00	-0.48 (0.08)	0.24

Log likelihood: 245.98

(Wages and Productivity)

(a) Likelihood Ratio Test

Eigenvalue	Likelihood ratio	5% Critical Value	1% Critical Value	Hypothesized Number of Cointegration Equations
0.19	8.80	15.41	20.04	None
0.002	0.10	3.76	6.65	At most 1

The Likelihood Ratio test rejects any cointegration at the 5% significance level.

(b) Coefficient of the Cointegration Equation

Wages	Productivity	Constant
1.00	3.09 (2.44)	-0.63

Log likelihood: 210.27

Notes:

Standard errors in parentheses.
The tests were done with 3 lags, a deterministic trend and an intercept.
The cointegration equation is expressed in the form y-bx, where y represents wages.
** means rejection of the null hypothesis at the 1% significance level.

Table 3. Vector Error Correction Regressions

	Right Hand Side Variable	
Left Hand Side Variables	steel wages	steel prices
cointegrating equation	-0.30**	-0.05
	(0.09)	(0.14)
Δ wages (t-1)	0.36**	-0.31
	(0.15)	(0.23)
Δ wages (t-2)	0.16	0.44
	(0.16)	(0.25)
Δ wages (t-3)	0.24	0.22
	(0.17)	(0.25)
Δ prices (t-1)	-0.07	0.41**
	(0.12)	(0.18)
Δ prices (t-2)	0.07	-0.24
	(0.11)	(0.17)
Δ prices (t-3)	0.16	0.23
	(0.10)	(0.16)
Constant	-0.001	0.002
	(0.003)	(0.005)
R^2	0.47	0.31

Notes:

The first variable corresponds to the cointegration equation in table 2.
Standard errors are in parenthesis.
* means significant at the 10% level.
** means significant at the 5% level.

DATA APPENDIX

US and World Steel Prices

Year	Paine Weber (PW) price of steel	ANTWERP Price	BLS price of steel (SIC 3312)	BLS Wholesale Price Index	PW/ ANTWERP price	BLS Price / WPI
1950	-	-	59.40	26.80	-	2.22
1951	-	-	64.00	29.69	-	2.16
1952	-	-	65.40	29.04	-	2.25
1953	-	-	70.50	29.01	-	2.43
1954	-	-	73.80	29.25	-	2.52
1955	-	-	77.20	29.60	-	2.61
1956	-	-	83.80	30.72	-	2.73
1957	-	-	91.80	31.67	-	2.90
1958	-	-	95.00	32.01	-	2.97
1959	-	-	97.00	32.29	-	3.00
1960	-	-	96.80	32.40	-	2.99
1961	157.73	-	96.50	32.20	-	3.00
1962	157.51	-	96.10	32.30	-	2.98
1963	158.97	-	96.30	32.20	-	2.99
1964	161.59	-	97.10	32.40	-	3.00
1965	161.99	-	97.60	32.90	-	2.97
1966	163.74	-	98.90	33.80	-	2.93
1967	165.55	-	100.00	34.20	-	2.92
1968	169.73	-	102.30	35.10	-	2.91
1969	175.49	-	107.00	36.30	-	2.95
1970	188.45	173.54	114.20	37.70	1.09	3.03
1971	200.31	147.09	123.40	38.90	1.36	3.17
1972	215.23	161.87	130.70	40.30	1.33	3.24
1973	226.17	280.69	134.30	44.10	0.81	3.05
1974	296.79	386.06	173.20	52.60	0.77	3.29
1975	339.47	270.38	204.50	58.50	1.26	3.50
1976	352.55	314.42	216.90	61.20	1.12	3.54
1977	384.30	276.32	236.90	64.90	1.39	3.65
1978	422.73	347.21	262.30	69.80	1.22	3.76
1979	470.38	407.15	288.80	78.20	1.16	3.69
1980	491.33	421.26	310.50	89.30	1.17	3.48
1981	555.04	394.04	342.80	97.70	1.41	3.51
1982	554.02	365.52	354.00	100.00	1.52	3.54
1983	513.97	323.03	357.89	101.00	1.59	3.54
1984	524.76	326.73	370.64	103.50	1.61	3.58

US LABOR

Year	Earnings in Steel (SIC 331)	Earnings in Mfg	Labor productivity in steel (SIC 331)	Labor productivity in mfg	Steel/ Manf earnings	Steel/ Mfg labor productivity	Total Employment in Steel (SIC 331)	Employment in Mfg
1950	1.70	1.44	40.80	51.10	1.18	0.80	674.4	15241
1951	1.90	1.56	41.00	53.10	1.22	0.77	714.4	16393
1952	2.00	1.64	41.20	54.10	1.22	0.76	638	16632
1953	2.18	1.74	42.10	55.30	1.25	0.76	726.1	17549
1954	2.22	1.78	40.20	56.00	1.25	0.72	645.5	16314
1955	2.39	1.85	45.70	58.70	1.29	0.78	706.9	16882
1956	2.54	1.95	45.00	58.30	1.30	0.77	706.6	17243
1957	2.70	2.04	43.90	59.60	1.32	0.74	719.9	17174
1958	2.88	2.10	40.60	59.30	1.37	0.68	601.1	15945
1959	3.06	2.19	45.10	61.90	1.40	0.73	587.3	16675
1960	3.04	2.26	42.70	62.20	1.35	0.69	651.4	16796
1961	3.16	2.32	44.50	64.00	1.36	0.70	595.5	16326
1962	3.25	2.39	45.80	66.70	1.36	0.69	592.8	16853
1963	3.31	2.45	48.30	71.20	1.35	0.68	589.9	16995
1964	3.36	2.53	51.00	74.60	1.33	0.68	629.2	17274
1965	3.42	2.61	52.70	76.60	1.31	0.69	657.3	18062
1966	3.53	2.71	54.10	77.40	1.30	0.70	651.9	19214
1967	3.57	2.82	52.40	77.40	1.27	0.68	635.2	19447
1968	3.76	3.01	53.40	79.80	1.25	0.67	635.9	19781
1969	4.02	3.19	54.60	80.80	1.26	0.68	643.8	20167
1970	4.16	3.35	53.60	80.80	1.24	0.66	627	19367
1971	4.49	3.57	56.00	85.30	1.26	0.66	573.9	18623
1972	5.08	3.82	59.60	89.00	1.33	0.67	568.4	19151
1973	5.51	4.09	64.20	93.40	1.35	0.69	604.6	20154
1974	6.27	4.42	67.60	90.60	1.42	0.75	609.5	20077
1975	6.94	4.83	59.30	92.90	1.44	0.64	548.2	18323
1976	7.59	5.22	61.70	97.10	1.45	0.64	549.4	18997
1977	8.36	5.68	61.80	100.00	1.47	0.62	554.3	19682
1978	9.39	6.17	65.10	101.50	1.52	0.64	560.5	20505
1979	10.41	6.70	65.90	101.40	1.55	0.65	570.5	21040
1980	11.39	7.27	65.40	101.40	1.57	0.64	511.9	20285
1981	12.60	7.99	69.30	103.60	1.58	0.67	506.1	20170
1982	13.35	8.49	60.60	105.90	1.57	0.57	396.2	18780
1983	12.89	8.83	73.80	112.00	1.46	0.66	340.8	18432
1984	12.98	9.19	81.30	118.10	1.41	0.69	334.1	19372

1985	500.16	301.39	371.35	104.00	1.66	3.57
1986	487.00	332.56	352.94	101.70	1.46	3.47
1987	508.43	373.33	362.50	104.40	1.36	3.47
1988	534.89	520.91	387.28	109.10	1.03	3.55
1989	542.32	542.77	400.02	114.30	1.00	3.50
1990	504.03	463.23	392.23	118.10	1.09	3.32
1991	493.68	439.33	383.74	119.00	1.12	3.22
1992	465.05	409.27	374.53	120.10	1.14	3.12
1993	499.33	403.84	380.20	121.80	1.24	3.12
1994	526.08	430.75	397.90	123.80	1.22	3.21
1995	595.24	556.37	-	-	1.07	-

Notes

ANTWERP and Paine Webber prices are 12-month averages.

The ANTWERP price is the world price of steel.

Sources

ANTWERP and Paine Webber prices: Paine Webber Inc./ World Steel Dynamics

BLS wholesale price index:

1950-9: Handbook of Labor Statistics 1975 Reference Edition. US Department of Labor, BLS. Bulletin 1865. "Wholesale Price Indices, by Durability of Product."

1960-1988: Handbook of Labor Statistics, US Department of Labor, BLS. August 1989, Bulletin 2340.

1989-1994: Producer Price Indexes (Annual.) US Department of Labor, BLS. September 1990.

Comment:

The published 1950-1959 wholesale price index values have been divided by 2.93 to redefine the base year as 1982, the same base year of the published 1960-1988 and 1989-1994 wholesale price index values.

BLS steel prices:

1950-8: American Iron and Steel Institute Annual Statistical Yearbook (pub 1995)

1959-1981: Handbook of Labor Statistics 1975 Reference Edition. US Department of Labor, BLS. Bulletin 1865. "Wholesale Price Indices, by Durability of Product."

1982-1994: Producer Price Indexes (Annual.) US Department of Labor, BLS. September 1990.

Comment:

The published 1982-1988 and 1989-1994 steel price values have been multiplied by 3.54 to redefine the base year as 1967, the same base year of the 1950-1958 and the 1959-1981 steel price values.

1985	13.33	9.54	85.8	123.6	1.40	0.69	302.6	19248
1986	13.73	9.73	89.7	127.7	1.41	0.70	273.4	18947
1987	13.77	9.91	100	132	1.39	0.76	268.3	18999
1988	13.98	10.19	113.5	136.2	1.37	0.83	278.4	19314
1989	14.25	10.48	108.5	137	1.36	0.79	279.1	19391
1990	14.82	10.83	110.5	139.3	1.37	0.79	276.2	19076
1991	15.36	11.18	108.2	142.3	1.37	0.76	262.7	18406
1992	15.87	11.46	117.7	145	1.38	0.81	250.3	18104
1993	16.36	11.74	134.5	149.8	1.39	0.90	240.3	18075
1994	16.85	12.07	142.7	155.5	1.40	0.92	239.2	18321
1995	17.35	12.37	-	-	1.40	-	240.7	-

Notes

Employment units: thousands of workers

Earnings units: dollars per hour.

Sources

Labor productivity data for steel industry: BLS (http://stats.bls.gov/sahome.html)

Series ID : piu42501

Labor productivity data for manufacturing industry: until 1988, Handbook of Labor Statistics; data from 1989 onward is taken from the Monthly Labor Review

Employment data for steel industry: BLS (http://stats.bls.gov/sahome.html)

SIC 3312 Series ID : eeu31331201

SIC 331 Series ID : eeu31331001

Employment data for manufacturing industry: BLS (http://stats.bls.gov/sahome.html)

Series ID : eeu30000001

Average hourly earnings in steel:

SIC 331 Series ID: eeu31331006

SIC 3312 Series ID: eeu31331206

Average hourly earnings in manufacturing:

Series ID: eeu30000006

Comment on the classification of steel:

The employment series used in the TSP regressions relates to employees falling in the category "Blast Furnaces and Steel Mills", SIC 3312. The steel earnings, steel labor productivity, and steel price series used in these TSP regressions, however, relate to employees belonging to the broader classification "Blast Furnaces and Basic Products", SIC 331.

Production of Steel in US, Japan and Europe

Year	*United States*	Production (1)	Integrated Production of Crude Steel (2)	Growth rate in Integrated Producers	Avg Growth Rate in Integrated producers	Production of Minimills (3)	Exports (4)	Imports (5)	Net Imports	Integrated + Minimills Production	Total US Demand	Integrated Production/ Total US Demand	Minimills Production/ Total US Demand	Minimills/ Total US Production	Net Imports/ Total US Demand
1952		93,168	86,371	-	-	6,797	3,918	1,186	(2,732)	93,168	90,436	0.955	0.075	0.073	-0.030
1953		111,610	104,330	0.2079	0.0011	7,280	2,907	1,674	(1,233)	111,610	110,377	0.945	0.066	0.065	-0.011
1954		88,311	82,875	-0.2056	0.0011	5,436	2,659	788	(1,871)	88,311	86,440	0.959	0.063	0.062	-0.022
1955		117,036	108,679	0.3114	0.0211	8,357	3,871	976	(2,895)	117,036	114,141	0.952	0.073	0.071	-0.025
1956		115,216	105,575	-0.0286	0.0211	9,641	4,378	1,341	(3,037)	115,216	112,179	0.941	0.086	0.084	-0.027
1957		112,715	104,741	-0.0079	0.0211	7,974	5,347	1,155	(4,192)	112,715	108,523	0.965	0.073	0.071	-0.039
1958		85,255	78,599	-0.2496	0.0211	6,656	2,823	1,707	(1,116)	85,255	84,139	0.934	0.079	0.078	-0.013
1959		93,446	84,913	0.0803	0.0211	8,533	1,677	4,396	2,719	93,446	96,165	0.883	0.089	0.091	0.028
1960		99,282	90,903	0.0705	0.0635	8,379	2,977	3,359	382	99,282	99,664	0.912	0.084	0.084	0.004
1961		98,014	89,350	-0.0171	0.0635	8,664	1,990	3,163	1,173	98,014	99,187	0.901	0.087	0.088	0.012
1962		98,328	89,315	-0.0004	0.0635	9,013	2,013	4,100	2,087	98,328	100,415	0.889	0.090	0.092	0.021
1963		109,261	98,341	0.1011	0.0635	10,920	2,224	5,446	3,222	109,261	112,483	0.874	0.097	0.100	0.029
1964		127,076	114,398	0.1633	0.0635	12,678	3,442	6,440	2,998	127,076	130,074	0.879	0.097	0.100	0.023
1965		131,462	117,658	0.0285	0.0121	13,804	2,496	10,383	7,887	131,462	139,349	0.844	0.099	0.105	0.057
1966		134,101	119,231	0.0134	0.0121	14,870	1,724	10,753	9,029	134,101	143,130	0.833	0.104	0.111	0.063
1967		127,213	112,124	-0.0596	0.0121	15,089	1,685	11,455	9,770	127,213	136,983	0.819	0.110	0.119	0.071
1968		131,462	114,648	0.0225	0.0121	16,814	2,170	14,034	11,864	131,462	143,326	0.800	0.128	0.128	0.083
1969		141,262	121,062	0.0559	0.0121	20,200	5,229	13,364	8,135	141,262	149,397	0.810	0.143	0.143	0.054
1970		131,514	111,392	-0.0799	-0.0023	20,122	7,062	18,304	11,242	131,514	142,756	0.780	0.153	0.153	0.079
1971		120,443	99,486	-0.1069	-0.0023	20,957	2,827	18,304	15,477	120,443	135,920	0.732	0.174	0.174	0.114
1972		133,241	109,524	0.1009	-0.0023	23,717	2,873	17,681	14,808	133,241	148,049	0.740	0.178	0.178	0.100
1973		150,799	123,052	0.1235	-0.0023	27,747	4,052	15,150	11,098	150,799	161,897	0.760	0.184	0.184	0.069
1974		145,720	117,013	-0.0491	-0.0023	28,707	5,833	15,970	10,137	145,720	155,857	0.751	0.197	0.197	0.065
1975		116,642	94,013	-0.1966	-0.0204	22,629	2,953	12,012	9,059	116,642	125,701	0.748	0.194	0.194	0.072
1976		128,000	103,424	0.1001	-0.0204	24,576	2,654	14,285	11,631	128,000	139,631	0.741	0.192	0.192	0.083
1977		125,333	97,509	-0.0572	-0.0204	27,824	2,003	19,307	17,304	125,333	142,637	0.684	0.222	0.222	0.121
1978		137,031	104,829	0.0751	-0.0204	32,202	2,422	21,135	18,713	137,031	155,744	0.673	0.235	0.235	0.120
1979		136,341	102,392	-0.0232	-0.0204	33,949	2,818	17,518	14,700	136,341	151,041	0.678	0.249	0.249	0.097
1980		111,835	80,633	-0.2125	-0.0724	31,202	4,101	15,495	11,394	111,835	123,229	0.654	0.279	0.279	0.092
1981		120,828	86,634	0.0744	-0.0724	34,194	2,904	19,898	16,994	120,828	137,822	0.629	0.283	0.283	0.123
1982		74,577	51,384	-0.4069	-0.0724	23,193	1,842	16,663	14,821	74,577	89,398	0.575	0.311	0.311	0.166
1983		84,615	57,961	0.1280	-0.0724	26,654	1,199	17,070	15,871	84,615	100,486	0.577	0.315	0.315	0.158
1984		92,528	61,161	0.0552	-0.0724	31,367	980	26,163	25,183	92,528	117,711	0.520	0.339	0.339	0.214
1985		88,259	55,427	-0.0938	0.0057	32,832	932	24,256	23,324	88,259	111,583	0.497	0.339	0.372	0.209
1986		81,606	50,514	-0.0886	0.0057	31,092	929	20,692	19,763	81,606	101,369	0.498	0.372	0.381	0.195
1987		89,151	56,254	0.1136	0.0057	32,897	1,129	20,414	19,285	89,151	108,436	0.519	0.381	0.369	0.178
1988		99,924	64,051	0.1386	0.0057	35,873	2,069	20,891	18,822	99,924	118,746	0.539	0.369	0.359	0.159
1989		97,943	61,410	-0.0412	0.0057	36,533	4,578	17,321	12,743	97,943	110,686	0.555	0.359	0.373	0.115
1990		98,906	60,926	-0.0079	0.0004	37,980	4,303	17,169	12,866	98,906	111,772	0.545	0.373	0.384	0.115
1991		87,896	54,496	-0.1055	0.0004	33,400	6,346	15,845	9,499	87,896	97,395	0.560	0.384	0.380	0.098
1992		92,949	56,327	0.0336	0.0004	36,622	4,288	17,075	12,787	92,949	105,736	0.533	0.380	0.394	0.121
1993		97,877	59,313	0.0530	0.0004	38,564	3,968	19,501	15,533	97,877	113,410	0.523	0.394	0.394	0.137
1994		100,579	61,028	0.0289	0.0004	39,551	3,826	30,066	26,240	100,579	126,819	0.481	0.312	0.393	0.207

Notes

(1) to (7): units in 1,000 tons

(3): defined as (6)*(1)

Sources

(1) through (7) except (3): Annual Statistical Report (AISI)

(8) through (10): Steel Statistical Yearbook (IISI) 1968-1969: Annual Statistical Report (AISI)