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# ON THE EXPLANATION OF THE EFFICIENT DIFFUSION OF TECHNOLOGY ACROSS NATIONS

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# ON THE EXPLANATION OF THE EFFICIENT DIFFUSION OF STEEL TECHNOLOGY ACROSS NATIONS

## I. INTRODUCTION

The question of the diffusion of steelmaking technology has been a subject of controversy in the economics literature. A number of authors [e.g., Adams and Dirlam (1966), Ault (1973) and Baumann (1974)] have argued that inefficient decisions, with respect to technology adoption, have resulted in a decline in the international competitiveness of the United States steel industry.1/ The controversy first focused on the diffusion of the basic oxygen furnace (BOF) and more recently has turned to the adoption of continuous casting (CC).

Whereas the literature has examined in detail the U.S. steel industry as a test of the so-called Schumpeterian hypothesis (that innovation will occur fastest in larger firms) little effort has been made to explain the differing rates of diffusion amongst the steel industries of the world. Two notable exceptions are the studies by Myer and Herregat (1974) and Maddala and Knight (1967). The Myer and Herregat study is an extermely thorough and detailed analysis of the diffusion of the basic oxygen process throughout eleven OECD nations. It did not, however, attempt to analyze the effects of different economic institutions. On the other hand, the Maddala and Knight paper suggested that two of their hypotheses were supported by the data. In particular, the efficient adoption of technology will be higher in those countries where: (1) the government's ownership share in the industry is lower, and (2) the industry is more heavily engaged in international competition for markets. Since Maddala and Knight never tested their hypotheses, the subject of how different institutional conditions in the steel producing nations have influenced adoption rates has never been tested. This paper tests these two hypotheses.

Moreover, one would want to make a theoretical distinction between the onwership of a steel firm by the government in countries such as Italy, the Netherlands or Austria and countries such as the Soviet Union, China or Bulgaria. In the latter cases, central planning adds an important additional institutional element in the decision making process. Since countries that have central planning, also have government ownership of their steel industries, regressions run with a government ownership explanatory variable but without a central planning explanatory variable might attribute effects to government ownership that are central planning effects. Thus, this paper will also test the effect of central planning on the efficient diffusion of steel technology.

This paper develops and explains measures of a nation's BOF and CC adoption rates (and analyzes previous measures) which are appropriate for a test of whether the adoption rates contributed to international competitiveness. The calculated adoption rates are presented for 28 countries for the BOF, in each of the two time periods, and for 27 countries for CC. Moreover, since the appearance of the papers on continuous casting, a significantly superior data set has become available. 3/ Since Ault (1973, p.271) appropriately stated that the principal difference between himself and his critic (Huettner) was "on the interpretation of the trade literature as to continuous casting capacity that was able to produce commercial quality steel in the period 1960-1972," 4/ these data should facilitate the resolution of the issues. 5/

In sections II the three measures of adoption, which have been employed in the literature, are examined theoretically. It is argued that all three are useful indices in some appropriate context. One index, however, is superior for measuring efficient decisions. This index is calculated and presented for BOF diffusion in the 1956-1964 and 1964-74 periods and for CC adoption from 1969-74. As a byproduct of these calculations, further insight is obtained into the question of whether technological decisions by U.S. managers have resulted in a loss of international competitiveness. Utilizing these indices, the diffusion hypotheses are explained and tested in section III.

## II. ADOPTION RATES

### Construction of an Index of Efficient Decisions

What is sought is an index of investment decisions which reflects whether the investment led to a decline in international competitiveness. Thus, an index of efficient decisions is required. Data are presented below which reveal that there are circumstances in which the installation of a BOF or CC would raise costs. Investment in a BOF in these circumstances can be presumed to lower international competitiveness and an index which fails to distinguish these circumstances from the cost reducing ones is inadequate for our purposes.

The key point is the distinction between replacement investment and investment to expand capacity. Whereas no new open hearth capacity should have been constructed after 1956, the decision on when to replace open hearth furnaces with BOF's is not as favorable to the BOF. This is because in the replacement decision the capital costs of the open hearth have been incurred. Thus open hearths could not profitably have been replaced by BOF's until the marginal rate of flow of quasi-rents on open hearths fell below the average return per year on BOF investments.

### Measures of Adoption

Date of First Installation. One measure which has been suggested as a measure of adoption is the date of the initial installation of a continuous casting or BOF unit. 6/ This is obviously an inadequate measure for the purpose of determining whether a country has an efficient steel industry or has made efficient decisions; a country might be an early adopter, but install little of the new technology thereafter. 7/ While this measure will not be employed here, it does provide some insight in a test of the Schumpeterian hypothesis.

BOF or CC Capacity as a Percentage of Output. The second criterion which has been employed is the percentage of crude steel output which is continuously cast or made by the BOF. This is also an inadequate measure of efficient investment decisions; it fails to distinguish between an investment decision to expand capacity and one to replace existing capacity.

In the BOF case, the best publicly available study was done by Vaughan and Russell, who argue that:

> at best the variable cost advantage of the BOF never exceeds $1.10 per ton (in 1968 dollars) and, at low scrap-hot metal price relatives, actually becomes a disadvantage--the BOF costs over $7 per ton more than the open hearth. In sum, then, our evidence indicates that in order for the BOF to displace new, efficient, open hearth capacity in the 1950's, . . . implies an interest rate no higher than about 2 percent, given a (1968 dollar) investment cost of $18.00 per ton and a scrap price 40 percent above the cost of molten iron.

In addition, Dilley and McBride (1967, p.132), of U.S. Steel, argue that "although BOP [BOF] vessels are economically attractive where new steelmaking facilities are being replaced, they were not and are not sufficiently attractive to warrant scrapping modern, efficient open hearths." I conclude that it was not efficient to replace new open hearths with the BOF.

On the other hand, there is a wide consensus that a BOF vessel is economically superior to an open hearth when construction of a new facility is planned. In addition to the above mentioned studies by Vaughan and Russell and by Dilley and McBride, two studies by the United Nations' Economic Commission for Europe (1959; 1962) concluded that no new open hearths should be built. Similarly, three studies on steel process construction in Latin America, done between 1962 and 1965, concluded that the BOF enjoyed between a three and twenty percent cost per ton advantage over the open hearth. 8/ I conclude that no new open hearths should have been constructed after 1956. As Maddala and Knight argue, whereas the process could not be said to be commercially proven before 1959, it had been in operation on a commercial scale since 1952 and thus should have been considered in investment decisions by 1956.

In the case of continuous casting, the same distinction between replacement and expansion investment must be made. 9/ Moreover, given the state of technology today, it is difficult to continuously cast high alloy steel and rimmed carbon steels. 10/ Japan, which has the highest share of total output manufactured by continuous casting (except for Finland), continues to construct primary rolling mills in some of its newest plants (e.g., Nippon Kokan's Ogishima works). Thus Vaughan, Russell and Cochran conclude that "unless research on the development of new families of continuously castable steels with rimmed steel's desirable properties is successful, as much as half our total carbon steel output may continue to require conventional casting." 11/.

This measure, (the percentage of output which is BOF or CC) is useful for some purposes. A nation which has mostly BOF and only a small share of capacity which is open hearth will, ceterus paribus, be able to produce steel more cheaply than one which has the inverse BOF to open hearth ratio. Whereas this measure is a reflection of the efficiency of the nations steel technology (or the capital stock in place), it is not an index of efficient decisions.

Percentage of New Investment Which is BOF(CC). The measure of BOF (CC) adoption chosen is the change in BOF (CC) output (during 1956-64 or 1964-74 for BOF and 1969-74 for CC) divided by the change in total crude steel output over the corresponding period. 12/ This is a measure of the proportion of new melt shop capacity which is BOF and correspondingly of new primary rolling investment which is continuous casting. Thus it circumvents the problem of determining when conventional capacity should be efficiently replaced. 13/ Moreover, support for this index can be found in the regression results of Meyer and Herregat (p.184): "The strongest single positive finding is the influence [on BOF adoption] of the general rate of expansion of the steel industry as expressed by lagged investment."

As a measure of efficient investment decisions, these indices possess two biases: (1) Replacement of existing open hearths (conventional rolling mills) with BOF's (CC) raises a country's efficiency index (efficiency percentages above 100 are possible); and (2) the construction of an electric arc furnace to increase melt shop capacity or a primary rolling mill to produce rimmed steel lowers a country's efficiency index. Regarding (1), Meyer and Herregat (p.167) found:

> Ideally, of course, one would like to separate new investment to expand total output from investment to replace outmoded, inefficient or retired capacity . . . Data limitations as well as conceptual difficulties, however, effectively rule this out.

Our data limitations are at least as severe, since we seek data for Latin American and Eastern European nations in addition to the OECD nations of the Meyer and Herregat study. The second bias is not likely to be significant because Meyer and Herregat's empirical results show that electric arc furnace production as an explanatory variable for BOF adoption had an incorrect sign in two of their twelve cases and was insignificant in some of the cases for which it had the correct sign. 14/ These two biases counteract the influence of each other, so that the indices are not, on a priori grounds, biased in one direction. Ceteris paribus, this measure favors those countries with a relatively large share of replacement investment. With respect to our regression results in the following section, however, there is not any reason to believe that the index is systematically biased toward or against countries with government ownership or central planning.

Calculated Adoption Rates

The results of the calculations are presented in tables 1 and 2. With respect to the BOF, the United States has the highest efficiency index in both periods. 15/ It has the third highest for continuous casting. Belgium, Luxembourg and France have relatively low BOF adoption rates in the first period, but relatively high BOF adoption rates in the second period. This is partly explained by the fact that these countries rely on local iron ore which is high in phosphorus content and the modification in the basic BOF design to accommodate these ores came about two years later than the original process.

Caution must be exercised in interpreting these results. In view of the above discussion, they do not imply that the U.S. has, ceteris paribus, a very productive capital stock. Rather they imply that, compared with other steel industries in the world, U.S. managers have made efficient decisions. Thus the fact that a number of nations have greater shares of capacity which is BOF or CC, is primarily explained by a faster overall expansion of their industries. In addition, it is

TABLE 1

New BOF Capacity Divided by the Change in Total Steelmaking Capacity, Various Countries 1956-64 and 1964-74

| Country | BOF Adoption Percentage 1956-64 | BOF Adoption Percentage 1964-74 |
|---|---|---|
| Argentina | 0 | 50.7 |
| Austria | 99.6 | 98.2 |
| Belgium | 27.1 | 163.9 |
| Brazil | . | 78.4 |
| Bulgaria | 0 | 73.6 |
| Canada | 67.7 | 85.0 |
| Chile | 0 | 0 |
| China | 0 | . |
| Czechoslovakia | 0 | 0 |
| Denmark | 0 | 0 |
| Finland | 0 | 93.5 |
| France | 34.8 | 187.4 |
| Germany, East | 0 | 14.2 |
| Germany, West | 36.9 | 197.5 |
| Hungary | 0 | 0 |
| Italy | 5.9 | 72.8 |
| Japan | 61.3 | 99.7 |
| Luxembourg | 24.6 | 207.9 |
| Mexico | 0 | 26.9 |
| Netherlands | 115.3 | 110.6 |
| Norway | . | 64.1 |
| Poland | 0 | 55.4 |
| Romania | 0 | 55.2 |
| Spain | 21.5 | 66.0 |
| Sweden | 35.7 | 102.5 |
| U.S.S.R. | 8.9 | 53.9 |
| United Kingdom | 53.6 | . |
| United States | 131.8 | 356.1 |
| Venezuela | 0 | 0 |
| Yugoslavia | 0 | 27.6 |

a/ A dot indicates no data or estimate.

Source: Calculated from data available in United Nations, Economic Commission for Europe, Quarterly Bulletin of Steel Statistics, various issues; Kaiser Engineers, L-D Process Newsletter, various issues; see also the appendix.

TABLE 2

New Continuous Casting Capacity Divided by the Change in Total Steelmaking Capacity, Various Countries 1969-74.

| Country | Continuous Casting Adoption Percentage |
|---|---|
| Argentina | 113.7 |
| Austria | 70.6 |
| Belgium | 6.6 |
| Brazil | 12.7 |
| Bulgaria | 0.0 |
| Canada | 16.8 |
| Chile | 28.6 |
| China | 0.0 |
| Czechoslovakia | 1.7 |
| Denmark | 137.7 |
| Finland | 99.4 |
| France | 56.6 |
| Germany, East | 35.8 |
| Germany, West | 88.2 |
| Hungary | 34.6 |
| Italy | 61.1 |
| Japan | 75.7 |
| Luxembourg | 0.0 |
| Netherlands | 0.0 |
| Poland | 2.5 |
| Romania | 0.0 |
| Spain | 30.8 |
| Sweden | 75.5 |
| U.S.S.R. | 11.7 |
| United States | 109.2 |
| Venezuela | 0.0 |
| Yugoslavia | 30.0 |

Sources: Estimated from data available in International Iron and Steel Institute, mimeo, April 14, 1976; Metal Bulletin Monthly," Continuous Casting Reference List," July, Aug., and Sept. 1975 issues; 33 Magazine, "Worldwide Continuous Casting Roundup," Oct., Nov. and Dec. 1975 issues. See also the appendix.

possible that the U.S. had a larger share of replacement investment is an important explanation of the data for this period.

## III. DIFFUSION HYPOTHESES

### The Model

Maddala and Knight examined hypotheses which would explain differing adoption percentages across countries. Most of these hypotheses were refuted by the data; 16/ two hypotheses they suggested as explanations, however, were that adoption rates will tend to be higher in those countries where: (1) the share of government ownership is lower, and (2) the industry is involved in international competition. These two hypotheses will be tested.

Government Ownership and Central Planning. The first hypothesis appears to be unreasonably broad. In particular, one would wish to examine the distinction between government ownership of steel companies in countries such as Austria, the Netherlands and Italy and government ownership in countries such as Bulgaria, Romania and the Soviet Union. In the latter cases, central planning adds an additional level of decision making into the process of steel technology adoption.

In the non-central planning nations, it is reasonable to hypothesize that government ownership retards the efficient adoption of technology. A number of arguments can be made at the theoretical level to justify this hypothesis. First, the lack of a profit motive is likely to reduce the incentives of the firm's managers to plan effectively. They are likely to be rewarded less for taking the risky decision that results in profits for the firm and probably more importantly are likely to be penalized less severely for inaction that leads to lost profits. Second, the decision making of a government owned steel firm is subject to the political process. For example, if a steel firm wishes to modernize its plant and equipment by consolidating production, it may receive staunch opposition from prospective displaced workers who in turn may persuade the government to halt or retard the project. 17/

Central planning itself, however, can be expected to add delays and rigidities to the steel technology adoption process. The fact that plans are formulated some years before they officially begin and then are expected to be fulfilled as centrally directed, can retard the implementation of technical and economic decisions made at the firm level (even if the firm is government owned). There is evidence that this is an important explanation for the Soviet Union. Whereas the Soviets first commercially produced steel via a modified BOF process in 1956, considerable delays were encountered in devoting resources to BOF production. A.F. Myrtsymov served as the Soviet Union's representative to the United Nation's Economic Commission for Europe's (UNECE) steel committee, the body that produced two documents, UNECE (1959, 1962), that concluded no new open hearths should be built. Writing in the January 1961 issue of the Soviet trade publication Stal, Myrtsymov criticized the seven-year plan for 1959-65 for devoting 79 percent of new steelmaking capacity to open hearths. During the following years, he and his critics engaged in a debate in Stal on the relative merits of open hearth versus BOF which evidently reached the highest levels of government. In January 1962, Myrtsymov wrote:

> The new year must become the turning point as regards the transition to the wide construction of oxygen converter shops. At the 22nd Congress of the CPSU, Khruschev said that compared with building open hearth shops this would enable six million roubles to be saved in capital investment alone for each million tons of annual steel production, and over a million roubles of operating costs. 18/

As Maddala and Knight (p.555) state:

> With the purely technical decision to accelerate the introduction of oxygen converters apparently being made at the highest level of the political system, it is obvious to what extent centralization had been carried and what kinds of delays and rigidities are inherent in a centrally planned economy.

Since countries that have central planning also have government ownership of their steel industries, regressions run with government ownership as an explanatory variable but without central planning might attribute effects to government ownership that are central planning effects. The effects of government ownership in non-centrally planned economies would not have been adequately tested. Thus models which include both government ownersip and central planning as explanatory variables will be tested below.

Subsidies. In addition to these variables, one could reasonably inquire about whether government subsidies to private steel firms might involve the government in the decision making process and thereby retard efficient decisions. It is widely alleged by the American Iron and Steel Institute 19/ and others that non-U.S. steel producers are subsidized by their governments and that these companies often act as instruments of national policy. However, other than the 160 pages published by my colleagues and I as part of our steel report to the FTC, no systematic effort has been made to assess these subsidies. 20/ Government subsidies to non-U.S. producers has simply been alleged for so long and so often that it is now taken as a fact by many steel industry analysts and U.S. government policymakers. 21/ We devoted approximately one and one-half manyears of effort into discovering subsidies in ten countries: The U.S., Japan, W. Germany, France, Italy, the U.S., Belgium, Luxembourg, the Netherlands, and Canada. Only for the U.K. (British Steel Corporation only) were subsidies in excess of one percent of the value of steel. For all other countries, with the possible exception of Italy, (Finsider only) subsidies were assessed to be negligible. 22/ Thus there are at most two instances of non-negligible subsidies: the British Steel

Corporation and possibly Finsider. Since these are government owned firms, and since government ownership is already included in the regressions, it is not useful to add subsidies.

Measurement of Government Ownership (Control) and Central Planning. Consider companies such as Rautaruakki Oy in Finland or Empressa in Spain which are 75 percent and 90 percent government owned respectively. One might argue that since only 75 percent of Rautaruuki Oy's output is government owned, only that portion of its output should be counted in the computation of the government ownership share of Finland. If the government owns over 50 percent of a company, however, then it has control over that companies output and technology decisions. For that reason, all the output of a company with over 50 percent government ownership was counted as government owned. Perhaps government control is a better word to use, but with this understanding no confusion should arise.

Possibly more difficult is the fact that government control may exist with less than fifty percent ownership. As a practical matter, however, virtually no capacity fell in the category of government participation at less than fifty percent. One exception is the Province of Saskatchewan's twenty percent ownership of IPSCO which has three percent of Canada's capacity. IPSCO was assumed to be under private control. The data on government ownership in three different years corresponding to the time periods of technology adoption are presented in table 3. 23/

TABLE 3

Estimated Raw Steel Production Under
Government Control in 1956, 1968, and 1972 for Thirty Countries

| | Year | | |
|---|---|---|---|
| Country | 1956 | 1968 | 1972 |
| Argentina | 28 | 54 | 63 |
| Austria | 98 | 98 | 99 |
| Belgium | 0 | 0 | 0 |
| Brazil | 81 | 52 | 49 |
| Bulgaria | 100 | 100 | 100 |
| Canada | 0 | 0 | 14 |
| Chile | 96 | 100 | 100 |
| China | 100 | 100 | 100 |
| Czechoslovakia | 100 | 100 | 100 |
| Denmark | 0 | 0 | 0 |
| Finland | 0 | 49 | 59 |
| France | 0 | 0 | 0 |
| Germany, East | 100 | 100 | 100 |
| Germany, West | 1 | 4 | 10 |
| Hungary | 100 | 100 | 100 |
| Italy | 55 | 55 | 60 |
| Japan | 0 | 0 | 0 |
| Luxembourg | 0 | 0 | 0 |
| Mexico | 44 | 38 | 39 |
| Netherlands | 76 | 89 | 91 |
| Norway | 59 | 71 | 71 |
| Poland | 100 | 100 | 100 |
| Romania | 100 | 100 | 100 |
| Spain | 25 | 28 | 45 |
| Sweden | 21 | 21 | 21 |
| United Kingdom | 5 | 5 | 90 |
| United States | 0 | 0 | 0 |
| U. S. S. R. | 100 | 100 | 100 |
| Venezuela | 0 | 90 | 81 |
| Yugoslavia | 100 | 100 | 100 |

Source: See Appendix.

Central planning (CP) was run in the regressions as a zero, one dummy variable. CP was defined to be one for Bulgaria, China Czechoslavakia, East Germany, Hungary Poland, Romania and the Soviet Union for all three time periods and zero for all other countries in table 3. The one exception was that CP was taken to be one for Yugoslavia in the 1954-64 BOF regression, but zero for the later regressions.

International Competition Variables. The second hypothesis suggested by Maddala and Knight is motivated by the theory that international competition compels an industry to become efficient; otherwise the firms face the prospect of losing their markets.

There is a problem of casuality, however, at the theoretical level, about the hypothesis that international competition induces an increase in efficient decisions. Alternatively one could reasonably argue that an increase of efficient decisions lowers cost, making the firm more capable of competing with foreign competition; the result is a greater share of exports and a smaller share of imports. Both theories suggest that exports and BOF (CC) adoption are positively correlated. The two theories yield opposite predictions, however, concerning the relationship between imports and BOF (CC) adoption.

As measures of a country's involvement in international competition, this paper employs two independent variables in the same regression: exports divided by domestic shipments, and imports divided by domestic shipments. In all cases, final steel mill products are selected. The argument is that a country which is involved in either exporting or importing is involved in international competition.

TABLE 4

Regression Results: BOF and CC Adoption Rates As a Function of Government Ownership, Central Planning, Share of Imports and Share of Exports.

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$$BOF_1 = 37.5 - .24G_1 \qquad R^2=.08$$
$$\qquad\qquad (-1.55)$$

$$BOF_1 = 33.7 + .17G_1 - 49.61CP \qquad R^2=.23$$
$$\qquad\qquad (.71) \quad (-2.15)^{**}$$

$$BOF_1 = 42.2 + .49G_1 - 86.34CP - .11I_1 + .04X_1 \qquad R^2=.45$$
$$\qquad\qquad (1.72) \quad (-3.01)^{*} \quad (-1.08) \quad (.12)$$

$$BOF_2 = 147.6 - 1.16G_2 \qquad R^2=.38$$
$$\qquad\qquad (-3.97)^{*}$$

$$BOF_2 = 148.5 - 1.21G_2 + 8.79CP \qquad R^2=.38$$
$$\qquad\qquad (-3.22)^{*} \quad (.24)$$

$$BOF_2 = 145.4 - 1.09G_2 - 3.59CP - .43I_2 + .72X_2 \qquad R^2=.53$$
$$\qquad\qquad (-3.13)^{*} \quad (-.11) \quad (-2.59)^{*} \quad (1.47)$$

$$\Delta CC = 68.3 - .47G_3 \qquad R^2=.22$$
$$\qquad\qquad (-2.68)^{*}$$

$$\Delta CC = 65.3 - .29G_3 - 25.82CP \qquad R^2=.27$$
$$\qquad\qquad (-1.28) \quad (-1.27)$$

$$\Delta CC = 68.7 - .32G_3 - 20.97CP + 24I_3 - .41X_3 \qquad R^2=.44$$
$$\qquad\qquad (-1.50) \quad (-1.08) \quad (2.51)^{*} \quad (-1.40)$$

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*, ** Values in parentheses are the estimated t values; a single star indicates the estimated coefficient is significantly different from zero at the one percent or better significance level. A double star indicates significance at the five percent level.

Summary. $BOF_1$ and $BOF_2$ are defined as a country's BOF efficiency indices in the 1956-1964 and 1964-74 periods, respectively. $\Delta CC$ is the continuous casting efficiency index. $G_1$, $G_2$ and $G_3$ are the percentages of government ownership in a country's steel industry in 1956, 1968 and 1972, respectively. Finally $I_1$ and $X_1$ and $I_2$ and $X_2$ are the measures of import and export involvment in international competition during the early and late BOF periods, respectively, whereas $I_3$ and $X_3$ are the corresponding measures for CC.

A total of nine regressions were run. Each index of efficient technological decisions was regressed in a cumulative sequential manner on the explanatory variables. First on government ownership alone, next on government ownership and central planning and finally on government ownership, central planning, the share of imports and the share of exports. The sample sizes for the regressions with government ownership alone and government ownership and central planning together were 28 countries for $BOF_1$, 28 countries for $BOF_2$ and 27 countries for $\Delta CC$. The sample sizes for the regressions with the measure of involvment in international competition were: 22 countries for $BOF_1$, 28 countries for $BOF_2$ and 26 countries for $\Delta CC$. Due to lack of data on exports and imports, for the 1956-1964 period, the five Latin American countries in table 1, and East Germany and China were excluded from the $BOF_1$ regression; China also was excluded in the analogous $\Delta CC$ regression for the same reason.

Results

The results of the nine regressions are presented in table 4. Since it was hypothesized that the variables had a certain sign, for example, the estimated coefficient on government ownership is expected to be negative, rather than simply being different from zero, one-tailed t-tests were performed on the estimated coefficients.

Government Ownership and Central Planning. The estimated coefficient for government ownership has the hypothesized sign in seven out of nine cases. In the two cases where it is positive, the coefficient is not significant at .05 or better.24/ On the contrary, when the estimated coefficient is negative, it is significant at .01 or better in four cases and, although not reported in the table, it is significant at the .1 level in the first and last regressions as well.

The central planning variable has the hypothesized sign in five out of six cases. It is significant in both $BOF_1$ regressions. The $BOF_2$ regression results may seem surprising in view of the fact that the average $BOF_2$ adoption index for non-centrally planned economies in table 1 is 100, but only 33 for centrally planned economies. Despite this wide difference between the adoption rates, the coefficient of central planning is negative in only one of the two cases and is significant in neither of the $BOF_2$ regressions. This is explained by the fact that the government ownership effect is extremely strong in the $BOF_2$ regressions (resulting in coefficients significant at the lowest significance levels in the table).

Belgium, France, Luxembourg, W. Germany and the United States had $BOF_2$ indices ranging from 164 to 356. W. Germany had only four percent government ownership and the remaining countries had none during the period. These countries, and to a lesser extent Japan and Venezuela (for the opposite reason), strongly influenced the very significant estimate of the government ownership variable. Thus after adjusting for the effects of government ownership in the centrally planned economies, there was not much left for the central planning variable to explain.25/ (In fact the $R^2$ increased by only .0014 after adding CP alone.)

Thus in an overall assessment, it appears that both government ownership and central planning have retarded efficient steel technology decisions. The data do not, however, distinguish which is the more important explanation and does not allow both variables to be significant simultaneously. In the $BOF_1$ period, central planning was the dominant influence, and government ownership was insignificant, but the reverse was true in the $BOF_2$ period. In the continuous casting regressions, government ownership is significant by itself, but with central planning added the four estimated coefficients all have the hypohtesized sign but lie just outside the border of usual significance.26/

International Competition Variables. Four of the six coefficients measuring the impact of international competition are not significant. The coefficient for imports is significant in two regressions, but it is of opposite sign in the two.

In view of the theoretical reservations about the appropriateness of international trade variables in this form, the fact that they have not been supported by the data should not be surprising. It is possible, however, that a simultaneous equation model would yield different results with respect to the international trade variables.

## APPENDIX: DATA SOURCES

### Continuous Casting Adoption Rates

Continuous casting adoption rates were measured by the change in continuous casting output between 1969 and 1974 divided by the change in crude steel output over that period. This procedure is justified by the fact that 1969 and 1974 were synchronized peaks in world steel production; thus production should approximate capacity in these years.

The basic source was mimeographed data obtained from the International Iron and Steel Institute (IISI). This source was also used for output data. Where the IISI source failed to provide output data (Belgium, Luxembourg, The Netherlands, Denmark, Hungary, and Yugoslavia), the source used was the United Nations *Annual Bulletin of Steel Statistics for Europe 1975*. For Argentina and the Soviet Union, 1969 output was estimated by 1970 output.

*Metal Bulletin Monthly*, in the July, August, and September 1975 issues, and 33 Magazine in October, November, and December 1975 issues published their worldwide reference lists of continuous casting machines in operation. These sources were used to supplement the IISI source. In particular, these were used to fill in gaps in the IISI data; in general, this meant verifying that the country had no continuous casting capacity throughout the period. However, through the magazine sources, it was estimated that Hungary had 150 thousand metric tons of continuous casting capacity in operation in 1974, and Yugoslavia had 185 thousand metric tons in 1974. Conversion factors for operating capacity from engineer's estimated capacity were obtained from data available in the European Coal and Steel Community Investment in the Community Coalmining and Iron and Steel Industries, Report on the 1976 Survey, August 1976. These data are available in Duke, Johnson, Mueller, Qualls, Roush and Tarr (1978, Ch.7).

Countries with an insignificant change in steel production were excluded from the sample. This was defined as a country whose change in output was less than 50 thousand tons. On this basis Denmark, with a change in steel output of 53,000 tons, was included in the sample. The IISI estimate of Denmark's 1977 CC output, 73 thousand tons, was used for our 1974 estimate, yielding an adoption percentage of 137.7 (the highest of all countries in the sample). This estimate is supported by the ECSC Commission's Investment in the European Coalming and Iron and Steel Industries which reported that Denmark achieved actual production of 100 thousand tons after rounding of CC output. Two alternative measures were considered for Denmark: (1) Employ the two magazine reference list estimates for 1975 CC capacity, which would yield an adoption percentage of 924.5; or (2) employ the IISI estimate for 1974 CC capacity, yielding an adoption percentage of zero. Neither of the latter two measures was deemed an appropriate measure of the adoption responsiveness of the Danish steel industry to CC during the 1969-74 period.

Basic Oxygen Furnace and International Competition Variables

Except as noted below, data on BOF output, crude steel production, and domestic shipments, exports and imports of steel mill products were derived from publications of the United Nations, Economic Commission for Europe: The Quarterly Bulletin of Steel Statistics for Europe, The Annual Bulletin of Steel Statistics for Europe and The European Steel Market, 1958.

For the five Latin American countries BOF and crude steel data were obtained from the International Iron and Steel Institute's 1975 publication Steel in Latin America and Kaiser Engineers' L.-D. Process Newsletter; shipments and imports data came from the Instituto Latino Americano del Fierro y el Acero publication entitled La Siderurgia de America Latina en 1973-74 y sus Perspectivas Hacia 1980. Data on Latin American exports were derived from the March 1976 issue of Siderurgia Latin America. Some Canadian data were obtained from the American Iron and Steel Institute's Annual Statistical Report and especially the Canadian Minerals Yearbook, 1964.

I and X were measured by imports divided by shipments and exports divided by shipments (in tons). $I_1$ and $X_1$, and $I_3$ and $X_3$ were the averages of these variables over 1962-64 and 1972-74, respectively, whereas $I_2$ was $\frac{I_1 + I_3}{2}$ and $X_2 = \frac{X_1 + X_3}{2}$. For East Germany and the U.S.S.R., $I_3$ and $X_3$ were computed for the two years 1973 and 1974. The data available reports imports and exports of Belgium and Luxembourg in combined form. For these two countries exports and imports were allocated between the two on the basis of the share of shipments for each year.

Government Ownership

Data on government ownership for the 1969-74 period were obtained from the American Iron and Steel Institute's (AISI) 1974 publication entitled Steel Industry Economics and Federal Income Tax Policy. A table representing the percentage of raw steel production under government control in 1972, for all countries in our sample is presented there. On the basis of data available in the 1968 and 1974 editions of Iron and Steel Works of the World (ISWW), I lowered AISI's estimate for Canada, Austria and Finland by one, one and three percent, respectively and raised it for Sweden by ten percent.

The estimates of government control for the earlier two years in table 3, were calculated from data available in the 1956, 1964 and 1968 editions of ISWW. The numerator, for a particular country was obtained by summing the raw steel capacity for all plants under government control; analogously, the demoninator was the sum of the raw steel capacity for all plants listed in ISWW. Obviously, these calculations were unnecessary for countries with either no or all government control.

## Footnotes

* I would like to thank Darius W. Gaskins, my coauthors of the FTC steel study (1978) (especially Richard Johnson) Vera E. Chase, Mary Brown, Emily Robinson and Allen Jefferson for their help. The remarks in this statement represent only my personal views. They are not intended to be, and should not be construed as representative of the views of any other member of the Federal Trade Commission staff or individual Commissioners.

1/ These articles have led to a number of rejoinders (e.g., McAdams (1967), Dilley and McBride (1967) and Huettner (1974).

2/ Given the comparative similarity of the economic institutions in the nations selected, it would have been difficult.

3/ The International Iron and Steel Institute (IISI) in Brussels has released continuous casting output data for all the significant steel producers in the world.

4/ In particular, Ault appropriately objected that a distinction must be made between theoretical engineering estimates of capacity that appear in the trade press and actual continuous casting output.

5/ Both Ault and Huettner bemoaned the unavailability of the U.S. data via the American Iron and Steel Institute (AISI); AISI now makes these data available to IISI. In addition to the IISI data, Iron and Steel Works of the World (1974) and two trade journals' (33 and Metal Bulletin Monthly) worldwide listing of continuous casting installations are now available.

6/ See Adams and Dirlam (1966, pp.175-184), Ault (1973, p.271) and Huettner (1974, p.265).

7/ Norway, for example, installed a single strand billet caster in 1959 but since then has installed only one other continuous casting unit; see Metal Bulletin Monthly (1975) and 33 (1975).

8/ The cost advantage varies with the relative price of scrap to pig iron and with whether the open hearth is assumed to possess oxygen lancing. See Maddala and Knight (pp. 537-539) or Duke et al. (pp.484-487) for further details regarding these data. The studies mentioned are: Economic Commission for Latin America, "The Iron and Steel Industry in Mexico, Plans and Perspectives," Steel Symposium (footnote continued)

1963; Quintana, Bueno and Vargas," Process and Site Evaluation for the Iron and Steel Industry in Mexico," paper prepared for the United National Center for Industrial Development Inter-Regional Symposium on Industrial Project Evaluation," Prague, October, 1965; and Comite' para la programacion de la industria siderurgica, Programicion del Desarallo de la Industria Siderurgica Mexicana, Mexico, November, 1962. Similar results were found by the Battelle Memorial Institute (1964).

9/ The best publicly available study of the economics of continuous casting is Vaughan, Russell and Cochran (1976). They show that the replacement decision is more favorable toward CC than it was in the BOF case, and some conventional capacity can be efficiently displaced at the margin. They state: "technical barriers and cost uncertainties temper the conclusion that it [continuous casting] should be installed to displace existing conventional casting equipment."

10/ See Schenk (1974), United Nations, ECE (1968) and Battelle (1964).

11/ The Japanese engineers, that the author interviewed, supported this assessment.

12/ Production in the international peak years of 1956, 1964, 1969 and 1974 is taken as the estimate of capacity.

13/ For the same reasons, this is the measure chosen by Maddala and Knight in their study of BOF adoption between 1956 and 1964.

14/ Another variable which is alleged to effect BOF adoption is the size of the plants in a nation. Here again the Meyer and Herregat results show this to be unimportant: the estimated coefficient for small plants has the hypothesized negative effect on BOF adoption in only ten of the eighteen regressions.

15/ As Adams and Dirlam (1966) noted, however, within the U.S. the largest firms were relatively slowest during the first BOF adoption period.

16/ One of the more significant of these hypohteses, which comes from the literature of economic development, is that slower rates of adoption for the developing nations is to be expected; innovations which come from the developed nations are designed to meet the needs of the developed nations, i.e., they are biased toward saving labor. Developing nations would adopt new technology faster if it were biased toward saving capital. However, since the BOF saves capital and labor in approximately equal proportions, this explanation does not apply to the BOF adoption rates.

17/ My interviews with economic planning managers of the British Steel Corporation confirm that this type of problem has been a severe one for them.

18/ A. F. Myrtsymov, "More Metal to Create the Material and Technical Base for Communism," Stal in English, January, 1962. The information regarding the Myrtsymov debate is taken from Maddala and Knight (pp.554, 555). By way of anecdote, when I was scheduling my interviews for Moscow (as part of the FTC steel investigation), I attempted to arrange an interview with Myrtsymov through the U.S. Embassy in Moscow and through the Soviet representatives at the UNECE in Geneva and Moscow. Unfortunately, I was told no such person exists.

19/ See, for example, American Iron and Steel Institute (1975, p.15; 1980, pp.76-78).

20/ See Chapter 6, entitled "Subsidies," of Duke et al. (pp.310-471). Whereas we do not believe our work should be regarded as the final word on the subject, we hope that it will raise the debate above the allegation level.

21/ Similarly it is alleged that because they are instruments of national policy, non-U.S. steel firms, especially the Japanese and members of the European Community, dump steel in U.S. markets. My investigation does not support this hypothesis. See Tarr (1979).

22/ See Duke et al. (pp.367-369) for a summary.

23/ Further details on the computation of these data and on the other variables in the regressions are available in the appendix.

24/ It is significant at the .1 level in the third $BOF_1$ regression.

25/ As mentioned in section II, the data reflect a significant share of replacement investment by the five countries with $BOF_2$ indices from 164 to 356. If it were possible to adjust for this replacement investment worldwide, the indices could not exceed 100 and a considerable absolute decline would result in the indices of these five countries. It is likely then that the government ownership effect would not be as strong and then central planning might become significant.

26/ They are all significant at levels from .1 to .2.

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