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ROBERT C. ALLEN

This paper investigates the causes of Britain's relative decline as an iron and steel exporter in the late nineteenth century, and the concomitant emergence of Germany and the United States as successful exporters. Britain's mid-nineteenth-century dominance of export markets was due to its superior technical efficiency and low raw material costs, and to the high excess profits earned by the German iron industry. By 1913, however, Germany and America had surpassed Britain in productivity and had access to lower cost raw materials. As a result, German and American exports displaced British exports.

IN the middle of the nineteenth century Britain was the major supplier of iron and steel to the world market, while Germany and the United States were substantial importers. But by 1913 German exports had exceeded British exports—with American exports not far behind—and Britain had become a major importer of steel. The goal of this paper is to explain this change in the pattern of trade. Its method is, first, to establish that the pattern of trade reflected the pattern of iron and steel prices prevailing in the three countries, and, second, to account for the pricing pattern in terms of international differences in input prices, technical efficiency, and deviations between price and unit production costs. I shall demonstrate that Britain's mid-century export success was due to its superior technical efficiency and lower raw material prices, and to the enormous excess profits earned by the German iron industry during its mid-century period of rapid economic growth. Britain's decline as an exporter was due to a reversal of this favorable situation: after 1900 the British industry was considerably less efficient than the German and American industries, and it labored under the burden of higher raw material prices. I shall argue, however, that vigorous entrepreneurs could have overcome both of these disadvantages.

The British, German, and American foreign trade statistics indicate that the pattern of trade passed through three stages.[1] The first stage began as early as the 1830s; the second stage began in the late 1870s and ex-

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[1] The trade statistics are tabulated in Robert C. Allen, "International Competition and the Growth of the British Iron and Steel Industry: 1830–1913" (Ph.D. diss., Harvard Univ., 1975), pp. 420–23. The British product classification was used for all countries.

TABLE 1
IRON AND STEEL PRICES, 1856-1913
(shillings per long or metric ton)

Years	*British*	*American*	*German Domestic*	*German Export*
1856-1865				
foundry pig iron	57	103	83	—
iron bars	128	275	} 227	—
iron rails	129	224		—
1881-1890				
foundry pig iron	37	85	57[b]	—
iron bars[a]	105	192	119	109
steel rails	97	152	136	109
1906-1913				
foundry pig iron	52	78[c]	74	—
steel rails	121	115	—	110
steel bars	139	127	106	106
heavy plates	139	132	124	119
structural steel	130	133	114	107

[a] Average for years 1882, 1884–89.
[b] Average for years 1882–1890.
[c] Average for years 1906–1911.
Sources: See Robert C. Allen, "International Competition in Iron and Steel,1850–1913," Dept. of Economics, Univ. of British Columbia, Discussion Paper No. 78–12 (April 1978), pp. 5–6. Detailed sources are given in that paper.

tended until 1895; and the third stage ran from 1895 to 1913. The history of iron and steel prices in the three countries, as summarized in Table 1, divides neatly into the same three stages.

During the first stage Britain was the major exporter of iron, and even as late as 1881 it exported 3,820 thousand tons of iron and steel, 47 percent of its total output.[2] Before the late 1870s exports from Germany and the U.S. were always negligible, and those countries frequently imported large quantities of British iron. This trade pattern is hardly surprising since, as Table 1 indicates, German and American prices were frequently double British prices in the 1850s and 1860s.

The second stage in the history of the iron and steel trade lasted from the late 1870s to 1895. The major development of the period was the emergence of Germany as a major exporter of iron and steel. Between 1871 and 1881 Germany's exports increased from 241 thousand tons to 1,136 thousand tons, and its imports shrank from 509 thousand tons to 280 thousand tons. During the 1880s Britain exported about 4 million tons

[2] In this paper, iron and steel production for all countries in 1881 and later years equals the total tonnage of final products produced by the iron and steel sector. Final products includes final rolling mill products, iron castings (or pig iron consumption by foundries), exports of pig iron, and exports of semifinished products. The underlying data were derived from the mineral and trade statistics of the countries concerned. Details of the sources and calculations are available in ibid., pp. 132–39. It should be noted that the divergence between final iron and steel production and pig iron production is not large. For 1880 and earlier years, pig iron production is used in this paper as a proxy for final iron and steel production. Pig iron production figures are tabulated in ibid., pp. 404–07.

of steel per year and Germany about 1 million, with neither country importing appreciable quantities, whereas American trade continued its mid-century pattern of large imports (about one million tons annually) and negligible exports. The proximate cause of Germany's emergence as an exporter was a decline in its iron and steel prices, which were only marginally higher than Britain's in the 1880s. The United States continued to be a substantial importer because American prices remained far above European prices.

The third stage in the history of the iron and steel trade extended from 1895 to 1913. In that period Britain's share of world iron and steel exports shrank rapidly. During the depression of the 1890s, British exports dropped sharply to a low of 2.65 million tons in 1894. Recovery was slow: in the five years before the First World War exports fluctuated between 4 and 5 million tons, little above the level prevailing in the 1880s. In 1913 exports still accounted for 41 percent of British production. Stagnating exports were accompanied by rising imports, as Britain, for the first time, became a major importer of steel. Whereas in the 1880s imports had run a bit over 200 thousand tons per year, in 1913 over 2 million tons of iron and steel were imported.

The course of German and American trade between 1895 and 1913 was the opposite. German exports actually increased during the depression of the 1890s. They continued to grow after 1900, and in 1913 exceeded 5 million tons, which amounted to 30 percent of production. During the 1890s America also emerged as a major exporter. By 1913 it exported almost 3 million tons annually; these sales, however, represented only 9 percent of American production. Except for the boom of 1902–03, when over 1 million tons were imported annually, American imports after the mid-1890s were modest compared to their 1880 levels.

Again, the pattern of trade reflected the pattern of prices prevailing in the three countries. After the mid-1890s both German and American prices fell with respect to British prices. During the period 1906–1913, for which we have the most reliable German price data, German export prices of most rolled products (for example, bars, plates, and structural steel) were 20 percent below British prices. Even Germany's domestic prices were lower than British prices after 1906. In the depression of the 1890s American steel prices dropped sharply—temporarily to the lowest in the world—and never again did they rise much above British prices. There was some variation between products, but generally American prices were similar to British early in the twentieth century. After 1910, however, they fell decisively below British prices.[3]

What is most surprising about Britain's trade in the early twentieth century is that the country exported as much as it did, and did not import more. Two factors account for that phenomenon. Britain's sales declined

[3] See Table 8.

most dramatically in non-Empire markets.[4] But in Empire and home markets, purchasers were apparently willing to pay a premium for British steel which prevented a similar collapse in those areas and cushioned the deterioration of British trade.[5] Empire preference, the necessity to design engineering projects in metric units, the need for the Germans to develop an English-language sales system, and unfamiliarity with the quality of German steel would all slow the response of sales to the price change. The second factor that attenuated Britain's decline was its success in exporting three products—pig iron, tin plate, and rails—which together accounted for 49 percent of British exports in 1910–13.[6] In the case of rails the International Railmaker's Association, an international cartel, maintained high and relatively uniform prices.[7] As Table 1 indicates, Britain was not at nearly the price disadvantage in rails as in other rolled products. It was also the world's low-price producer of tin plate, largely because that industry required a uniquely skilled work force which only Britain had developed.[8] Britain dominated the world's pig iron trade (chiefly trade in foundry pig iron), again because British prices were lower than any other countries' (see Table 1). How Britain managed to be the world's low-price supplier of foundry pig iron while being the high-price supplier of most rolled products is a conundrum we shall return to later.

This review of the trade and price history indicates that the pattern of trade responded to changes in prices in the major producing countries. To explain the changes in the pattern of trade, it is necessary to explain the changes in iron and steel prices. In general, price changes can be accounted for in terms of changes in unit costs and in markups, that is, the ratio of price to average total cost. Cost changes, in turn, can be attributed to changes in production efficiency and in the prices of inputs like iron ore, fuel, labor, and capital. The remainder of this paper is therefore concerned with accounting for the changes in German, American, and British iron and steel prices in terms of changes in those countries' efficiency, input prices, and markups.

Section I aims to measure the growth and relative levels of efficiency in Britain, America, and Germany between 1860 and 1913. These measurements sustain the venerable view that the British iron industry was the most efficient in the mid-nineteenth century, but was surpassed by Germany and America by the First World War. But the change in relative efficiency alone was not enough to account for the changes in the pattern of

[4] Peter L. Payne, "Iron and Steel Manufactures," in Derek H. Aldcroft, ed., *The Development of British Industry and Foreign Competition: 1875–1914* (Toronto, 1968), p. 85.

[5] This phenomenon has been noted in other trades as well. See Aldcroft, *Development,* passim.

[6] Brian R. Mitchell and Phyllis Deane, *Abstract of British Historical Statistics* (Cambridge, 1971), p. 148.

[7] James C. Carr and Walter Taplin, *History of the British Steel Industry* (Cambridge, 1962), pp. 251–53.

[8] C. Knick Harley, "Skilled Labour and the Choice of Technique in Edwardian England," *Explorations in Economic History,* 11 (Summer 1974), 391–414.

trade. Sections II, III, and IV explore the relationship between product prices, costs, efficiency, input prices, and markups between 1850 and 1913. At mid-century America's prices exceeded Britain's because American costs were higher; German prices exceeded Britain's because of the enormous excess profits earned by the German industry during the 1850s and 1860s. Thus Britain's superior efficiency was relatively unimportant as a cause of its extraordinary export performance. By 1913 German and American costs had fallen below British costs, partly due to Britain's relative inefficiency, but more importantly to lower input prices in America and Germany. Section V considers the intriguing question whether Britain could have overcome these impediments, by modernizing its plants and availing itself of cheaper raw materials. Indeed, the prospects seem to have been favorable.

I

One long-standing explanation for Britain's relative decline follows a line of argument that I shall call the productivity hypothesis.[9] It contends that the British iron industry was the most efficient in the world at mid-century, but that by 1913 it had been overtaken in efficiency by the German and American industries. The relative rise in British prices is then seen as a consequence of the decline in Britain's relative efficiency. McCloskey's recent comparisons of British and American efficiency in the early twentieth century have cast serious doubt on the productivity hypothesis, since he concluded that those two countries were equally efficient.[10] In this section I compare British, German, and American efficiency for the years 1907–09, employing different data than those used by McCloskey. The calculations presented here lead to the conclusion that the Americans and Germans were 15 percent more efficient than the British. Efficiency comparisons for 1860 are also undertaken, which show the British to have been more efficient than the Germans and Americans. My calculations, therefore, lend support to the productivity hypothesis. One way of reconciling these results with McCloskey's calculations is proposed in section V.

Even under the best of circumstances, international productivity comparisons are hazardous. The incompleteness of pre-World War I data compounds the problems, and some judgment is required in interpreting what data there are. As a guide for those judgments it is useful to review

[9] Notable advocates include David S. Landes, *The Unbound Prometheus* (Cambridge, 1969), and Derek H. Aldcroft, "The Entrepreneur and the British Economy, 1870–1914," *Economic History Review*, 2nd ser., 17 (April 1964), 113–34. Donald N. McCloskey and Lars G. Sandberg, "From Damnation to Redemption: Judgments on the Late Victorian Entrepreneur," *Explorations in Economic History*, 9 (Fall 1971), 89–108, summarize the literature and vigorously defend the British entrepreneur. Duncan L. Burn, *The Economic History of Steelmaking: 1867-1939* (Cambridge, 1961), develops the productivity hypothesis in the context of iron and steel.

[10] Donald N. McCloskey, *Economic Maturity and Entrepreneurial Decline* (Cambridge, 1974).

the history of productivity growth in American rolling mills (including the antecedent bloomery, puddling, Bessemer, and open hearth furnaces), for the American censuses provide more complete information than the statistics of other countries.

Efficiency differences can be measured by a total factor productivity in83edex. The following index is suitable for the iron and steel industry:

$$\frac{A_2}{A_1} = \left[\frac{Q_2/L_2}{Q_1/L_1}\right]^{s_L} \left[\frac{Q_2/K_2}{Q_1/K_1}\right]^{s_K} \left[\frac{Q_2/M_2}{Q_1/M_1}\right]^{s_M} \left[\frac{Q_2/F_2}{Q_1/F_1}\right]^{s_F} \tag{1}$$

A_2/A_1 measures relative efficiency. The subscripts 1 and 2 denote the two years or countries whose efficiency is being compared. Q is tons of product net of intra-industry transactions, L is the labor used, K is the capital used (as measured by installed horsepower), M is the net consumption of metallic inputs (in tons), and F is the fuel consumption (in BTU's). The shares in costs of the corresponding inputs are represented by s_L, s_K, s_M, and s_F. In United States steelworks and rolling mills between 1860 and 1909, the average shares were .24, .09, .48, and .06, respectively.[11] From year to year there was only small variation in the shares.[12] When shares for Britain and Germany can be computed, they are quite similar to these American shares.[13]

Table 2 presents productivity estimates for American rolling mills between 1860 and 1909. Total factor productivity increased 35 percent in that period, with most of the increase occurring after 1879. The increase in total factor productivity was primarily due to the rise in labor productivity, and secondarily (given its smaller share) to the rise in fuel productivity. These increases were slightly offset by a fall in the productivity of capital. One suspects that the rise in fuel productivity, which occurred between 1860 and 1890, was due at least in part to the shift from iron to steel—Bessemer's original paper, after all, was entitled "The Manufacture of Iron without Fuel."[14] The rise in labor productivity after 1879 was associated with a sharp rise in capital per worker. Since total productivity was growing, however, the rise in labor productivity cannot be attributed simply to factor substitution.

Another feature of Table 2, which is a useful pointer for international comparisons, is the constant average product of metallic inputs. The same

[11] Other, miscellaneous inputs had an average share in costs of .13. Excluding these inputs from equation (1) is equivalent to assuming that their productivity was the same in the two situations compared.

[12] Same sources as Table 2.

[13] According to the United Kingdom, *Final Report on the First Census of Production of the United Kingdom (1907)* (1912), p. 175, sales by the iron and steel industry were £105,322,000 and material costs were £75,274,000. Employment was 261,666. In conjunction with the annual earnings per worker estimate of £84.5 in McCloskey, *Economic Maturity,* p. 122, the implied cost shares are 8 percent for capital, 21 percent for labor, and 71 percent for other inputs. For German shares, see the iron and steel production statistics in *Statistisches Jahrbuch für das Deutsche Reich,* annually.

[14] Landes, *Unbound Prometheus,* p. 255.

TABLE 2
PRODUCTIVITY GROWTH IN AMERICAN ROLLING MILLS

Year[a]	*Q/L*	*Q/K*	*Q/M*	*Q/F*	*A*
1860	22.77	16.88	.8047	12.71	1.000
1870	25.28	12.19	.7994	16.33	1.0264
1879	29.37	11.18	.7633	18.40	1.0420
1889	43.96	11.54	.7880	24.72	1.1935
1899	61.03	9.99	.7893	24.80	1.2803
1909	73.13	9.08	.8230	25.64	1.3497

Q = production, measured as the tonnage of products less the tonnage of rolled products consumed by the industry.
L = labor, measured as the number of wage earners plus the number of salaried employees.
K = capital, measured by installed horsepower in operating establishments.
M = metallic input, measured as the tonnage of pig iron and ferromanganese consumed plus the tonnage of scrap plus half the tonnage of iron ore.
F = fuel consumption, measured in billions of BTUs.
A = index of total factor productivity computed with equation (1).
[a] In 1860, 1870, and 1879, "rolling mills" includes the census categories "iron works and rolling mills," "Bessemer and open hearth steelworks," "crucible steelworks," "nail factories," and "bloomeries." In subsequent years "rolling mills" refers to the category "steelworks and rolling mills."
Sources: Inputs and outputs were obtained from: *Manufactures of the United States in 1860* (1865), pp. clxxviii–lxxxvii, cxcii–vi; *Ninth Census*, Vol. III, *The Statistics of the Wealth and Industry of the United States* (1872), pp. 601–08, 617, 625; *Report on the Manufactures of the United States at the Tenth Census* (1883), pp. 748–60; *Eleventh Census of the United States*, Vol. VI, *Manufacturing Industries, Part III: Selected Industries* (1895); *Twelfth Census of the United States*, Vol. X, *Manufactures, Part IV: Special Reports on Selected Industries* (1902), pp. 84–89; *Thirteenth Census of the United States*, Vol. X, *Manufactures: Reports for Principal Industries* (1913), pp. 252–59. The energy content of the various fuels was given in *Kirk-Othmer Encyclopedia of Chemical Technology* (New York, 1966), Vol. 10, p. 280, and R. H. Perry and C. H. Chilton, *Chemical Engineers' Handbook* (New York, 1973), p. 9–7.

input-output coefficient recurs in the German mineral statistics and in the available British data.[15] Since the same ratio was found under very different relative factor prices, it was a technical constant.

If the subscripts 1 and 2 are interpreted to denote countries, equation (1) provides an appropriate formula for comparing the levels of efficiency achieved by the British, German, and American industries in the mid-nineteenth century and in the early twentieth century. The mid-nineteenth-century data, though fragmentary, support the view that the British iron industry was the most efficient at that time. Labor productivity is the only average product that can be comprehensively measured for the three countries, but, as the American record shows, output per worker was decisive for shifts in total factor productivity. The mineral statistics and censuses of the three countries show that in 1860 output per worker in the iron and steel industry as a whole (that is, blast furnaces, rolling mills, and foundries) was 23.9 tons in Britain, 16.2 tons in America, and only 10.1

[15] For German data, see the production statistics annually recorded in *Statistisches Jahrbuch*. For United States, British, and Continental data in 1888–89, see U.S. Commissioner of Labor, *Sixth Annual Report. Cost of Production: Iron, Coal, Steel, Etc.* (Washington, 1891), pp. 152–54, 183–86. These sources are summarized in Allen, "International Competition," pp. 260–64. For mid-nineteenth-century American and British figures, see Table 5 in this paper.

tons in Prussia.[16] By using a French engineering study and the American census, I was also able to compare the productivity of metallic inputs and fuel in British and American rolling mills in 1860. The productivity of metallic inputs was very similar, as indicated by the figures for rail mills in Table 5. In British rolling mills producing a variety of products, the average product of fuel was 14 tons of iron per billion BTU's, a figure which exceeds the corresponding American ratio in Table 2.[17] The average product of fuel in British blast furnaces also substantially exceeded American productivity.[18] Although these figures are not complete enough to compute equation (1), they are consistent with the position that the German and American industries were less efficient than Britain's in 1860.

Between 1870 and the First World War productivity increased much more rapidly in the United States and Germany than in Britain. As a result the British steel industry became far less efficient than either of its competitors, just as the productivity hypothesis contends. One indication of this reversal is that, on the eve of the war, annual output per worker in British steelworks and rolling mills was about 44 tons,[19] whereas it had

[16] For Britain, production is taken to equal pig iron production as given by Mitchell and Deane, *British Statistics,* pp. 131–32. The number of workers equals the number of people in England, Wales, and Scotland returned in the 1861 census with the occupations "iron manufacture (including moulders and founders)," "steel manufacturing workers," and "tin plate workers." In fact, the 1861 occupational statistics record the industry in which an individual was employed rather than his occupation *per se.* See W. Alan Armstrong, "The Use of Information about Occupation," in Edward A. Wrigley, ed., *Nineteenth Century Society: Essays in the Use of Quantitative Methods for the Study of Social Data* (Cambridge, 1972), pp. 191–310. It should be noted that the iron and steel employment figures used here are larger than the employment estimates for that industry made by Armstrong (p. 260). For the United States, production and employment were derived from the 1860 and 1870 censuses. Production equals the output of rolling mills (exclusive of nail plate), nail factories, steelworks, and foundries. Casting production was estimated to equal pig iron production less pig iron consumption by rolling mills and steelworks. Number of workers equals the number employed in these industries plus the number of blast furnace workers. Foundry employment was estimated by dividing casting production by output per worker in foundries in 1870. For Prussia, all data were derived from Prussia, *Zeitschrift für das Berg-, Hütten-, und Salinenwesen* (1861) pp. 28–32, table entitled "Produktion der Hütten in dem Preussischen Staate M. J. 1860," pt. II: *Hütten,* sect. 1: Eisen. Employment equals total employment in that category. Production equals total production in that category less pig iron production.

[17] The British figures were computed from the regional production figures and input-output coefficients given in Louis E. Gruner and Charles Lan, *Etat présent de la métallurgie du fer en Angleterre* (Paris, 1862). The national fuel productivity figure is a weighted average of the average product of fuel for the following products, given the weights shown in parentheses: Staffordshire bars (.252), South Wales bars (.1125), Scottish bars (.0855), South Wales rails (.2739), Cleveland rails (.0561), Staffordshire plates (.2200). The energy content of coal was taken to be 14,135 BTU per pound. The regional product weights are from ibid., pp. 516, 551, 553, 617–18, 632, 661. Input-output coefficients for each product were derived from ibid., pp. 530, 548, 554, 554–55, 621–22, 628, 662.

[18] Robert C. Allen, "The Peculiar Productivity History of American Blast Furnaces, 1840–1913," this JOURNAL, 37 (Sept. 1977), 605–33.

[19] Great Britain, *Final Report on the Third Census of Production of the United Kingdom (1924): The Iron and Steel Trades, the Engineering Trades, and the Non-Ferrous Metals Trades* (1931), reports the returns for the aborted 1912 census of production. The returns for the iron and steel industry were unusually complete. Steelworks and rolling mill production equals tonnage reported on p. 36 for categories d through p, inflated in proportion to value to account for unenumerated production (category r). Employment equals the total on p. 54 less estimated blast furnace employment derived from Ministry of Labor, *Gazette.*

TABLE 3
PRODUCTIVITY COMPARISONS, 1907/09

	Britain	*Germany*	*United States*
Production (tons)[a]	12,418,000	12,050,361	25,643,871
Employment[b]	261,666	170,614	303,823
Horsepower[b]	1,383,586	823,822	3,274,400
Output per worker	47.5	70.6	84.4
Output per horsepower	9.0	14.6	7.8
Horsepower per worker	5.3	4.8	10.8
Total factor productivity[c]	1.00	1.15	1.15

[a] Production is the net output of blast furnaces, iron and steelworks, and rolling mills. To account for the heterogeneity of industry output, 13 product classes were distinguished and a number of common indexes of output were computed. The best founded of these, the Fisher ideal, indicated relative production to be very similar to relative tonnage.

[b] Employment equals the number of workers in the industry, and horsepower equals installed horsepower in operating establishments.

[c] Total factor productivity computed as

$$\frac{A_i}{A_B} = \left[\frac{Q_i/L_i}{Q_B/L_B}\right]^{.26} \left[\frac{Q_i/K_i}{Q_B/K_B}\right]^{.08}$$

where A is the index of total factor productivity, Q is production, L is labor, and K is capital, as measured by horsepower. The subscript B denotes Britain and the subscript i denotes either Germany or the United States. The shares (.26 and .08) are American shares, which are close to European shares.

Sources: Great Britain, *Final Report on the Third Census of Production of the United Kingdom (1924): The Iron and Steel Trades, the Engineering Trades, and the Non-Ferrous Metals Trades* (1931), pp. 1–66; German, *Statistisches Jahrbuch für das Deutsche Reich* (1913), pp. 82–85, and *Statistik des Deutschen Reichs,* N.F., Vol. 214, pp. 6, 266; U.S. Census Bureau, *Thirteenth Census of the United States,* Vol. X, *Manufactures: Reports for Principal Industries,* pp. 208–61.

reached 79 tons in Germany[20] and 69 tons in the United States.[21] By using slightly earlier years (1907 for Britain and Germany, and 1909 for the United States) and by measuring the productivity of blast furnaces, steelworks, and rolling mills together, one can also compare output per horsepower in the three countries. The relevant figures are presented in Table 3. America had the highest labor productivity, with Germany a close second and Britain a distant third. America's lead in labor productivity was in part due to a higher horsepower per labor ratio than in either European country. The total factor productivity index incorporates that effect and shows both the American and German industries to be 15 percent more efficient than the British.

These total factor productivity indices presume that the productivity of materials was the same in all three countries. Data for 1907 are not avail-

[20] Germany, *Produktion der Kohlen-, Eisen-, und Hüttenindustrie, im Jahre 1912, Vierteljahreshefte zur Statistiks des Deutschen Reichs* (1914), Vol. I, pp. 360–65. Production is tonnage of finished rolling mill products plus exports of semi-rolled products (from *Statistisches Jahrbuch für das Deutschen Reich* [1913], p. 214). The number of workers equals employment in puddling works, steelworks, and rolling mills.

[21] U.S. Bureau of the Census, *Census of Manufactures, 1914* (1919), Vol. II, pp. 199–267. Production is the output of finished rolled products plus the net output of semi-products. The number of workers equals employment in steelworks and rolling mills. In 1914 American productivity was unusually low for cyclical reasons. As Table 2 indicates, output per worker had been 73 tons in 1909.

able for measuring the average product of fuel in Germany, or either fuel or metallic inputs in Britain. Since the average product of metallic inputs in Britain at earlier and later dates when it can be measured equalled about .8, the value it always equalled in Germany and America, it seems likely that ratio was the same in the three countries in 1907–09. As Table 2 indicates, the productivity of fuel was, however, not rigidly fixed. It might have differed among the countries as input mixes were varied in response to different relative prices. Britain and the United States would be the extreme pair, for fuel in Britain was particularly expensive compared to capital and labor. As a consequence, the consumption of fuel relative to capital and labor might have been less in Britain, and the average product correspondingly higher than in America. But such factor substitution did not occur. In 1913 the average product of fuel in British steelworks and rolling mills was 24.72 tons of product per billion BTU's of fuel. That performance is almost identical to the American rate of 25.64 in 1909, a rate which had remained constant for twenty years, as Table 2 shows. The productivity of fuel was likewise very similar in British and American blast furnaces.[22]

The data surveyed in this section are consistent with the productivity hypothesis. They show the British industry to have been more efficient than the German and American industries in mid-century, and less efficient by the First World War. One must be cautious in drawing conclusions from aggregate data collected at different times or in different places, since it is impossible to be certain the collection methods were the same. The safest course is to examine other sorts of information that might corroborate the conclusions suggested by the aggregate data. It is fortunate that most of the variation in efficiency in the nineteenth-century iron and steel industry was due to variations in labor productivity, for there is considerable information on unit labor costs and wage rates. That information, it will be shown, is consistent with the conclusions advanced here.

II

During the 1850s and 1860s British exports dominated world trade in iron because British prices were by far the lowest in the world. The superior efficiency of the British industry contributed to this situation, but was not the decisive cause. In the 1850s, German prices exceeded British prices because of the high excess profits earned by the German industry; American prices exceeded British prices because American costs were greater. After 1860 Britain's competitive position was enhanced by techni-

[22] The productivity of fuel in British steelworks was computed by dividing the production of final products by energy consumption computed from J. H. Jones, "The Present Position of the British Coal Trade," *Journal of the Royal Statistical Society*, 93 (1930), 33. On the productivity of fuel in blast furnaces, see Allen, "Peculiar Productivity," and Peter Berck, "Hard Driving and Efficiency: Iron Production in 1890," this JOURNAL, 38 (Dec. 1978), 879–900.

TABLE 4
PIG IRON PRODUCTION COSTS, 1850s

	Cleveland, England			*Scotland*			*South Wales*		
	tons	*price*	*cost*	*tons*	*price*	*cost*	*tons*	*price*	*cost*
Ore	2.5	6	15.0	1.73	16.8	29.0	2.4	13.3	32.0
Fuel in furnace	1.6	10	16.0	2.1	4.6	9.7	2.0	4.0	8.0
Other fuel	.5	4	2.0	1.4	1.4	.7	.3	2.0	.6
Limestone	.7	4	2.8	.4	3.8	1.5	.7	1.9	1.3
Labor			5.5			2.8			6.0
General			} 4.0			3.4			} 2.1
Depreciation						} 1.6			
Interest			2.0						1.8
Total			47.3			48.7			51.8
Price			53.3			53.3			53.8

	Pennsylvania Anthracite			*Westphalia (near ore)*			*Westphalia (near coal)*		
	tons	*price*	*cost*	*tons*	*price*	*cost*	*tons*	*price*	*cost*
Ore	2.62	11.13	29.2	2.5	6.7	16.7	2.5	9.9	24.7
Fuel	2.49	10.51	26.2	1.25	19.0	23.8	1.25	14.0	17.5
Limestone	1.33	2.83	3.8			2.1			2.1
Labor			12.7			} 9.6			} 9.6
Miscellaneous			8.2						
Capital			9.2						
Total			89.3			52.2			53.9
Price			80.7			80.8			80.8

Sources: Gruner and Lan, *Métallurgie du fer,* pp. 251, 314, 318, 390; manuscript schedules to the 1860 U.S. Census; Carl Hartmann, *Ergänzungsheft zu B. Valerius' Theoretisch-Praktisches Handbuch der Roheisen-fabrikation* (Freiberg, 1853), pp. 162–63; Great Britian, *Mineral Statistics,* 1860; Mitchell and Deane, *British Statistics,* p. 493; Prussia, *Zeitschrift,* 1860.

cal change in its Cleveland blast furnace industry. The development of the eighty-feet-tall furnace and the superheated blast meant that the Cleveland district had substantially lower costs than any other district in the world.

Table 4 illustrates the relationship between prices and costs in pig iron production in the 1850s. The American figures in the table are averages from the manuscript census schedules, and the British figures are from the French engineering study (see note 17). This study, encyclopedic in scope, was based on the cost accounts of a large number of firms; it therefore appears to be a reasonable basis for establishing British costs. The German figures are not as broadly based, but when they can be compared to other figures they appear accurate.[23]

[23] In particular, the price of iron ore for Westphalian furnaces near the ore is very similar to the value per ton of ore at the mine in the early 1860s given annually in Prussia, *Zeitschrift.*

Table 4 indicates that production costs were similar in Britain and Germany, but much higher in America. The high fuel consumption rate of American blast furnaces accounted for the country's greater mineral costs. U.S. nominal wage rates were also higher than in Britain, while labor productivity was lower. British labor productivity exceeded Germany's as well, but nominal wage rates were lower in Germany, so a rough balance in unit labor costs was struck.[24]

German prices exceeded British prices because the German industry was earning very high excess profits. The ratio of price to unit costs ranged between .9 and 1.1 in Britain and the United States. In Germany, however, the ratio equalled 1.5. Such a high value, indeed, seems to have characterized the Germany industry throughout the 1850s and early 1860s. In the mid-1860s, however, ore prices began to rise and pig iron prices to fall. The combined effect of these changes would have reduced excess profits twenty shillings per ton by the early 1870s, thereby equating price and unit costs.

If excess profits in Germany were at the high rate suggested by Table 4, one would expect enormous investment in the iron industry. Indeed, between 1850 and 1872 output increased in almost every single year, rising from 219 thousand to 2,241 thousand tons, or at an average annual compound growth rate of 11 percent. Moreover, it was after 1873, when excess profits seem finally to have been competed away, that production stopped growing. The rapid growth of the German iron industry at mid-century must have been the result of an enormous increase in demand, which the protective Zollverein tariff and inland transport costs prevented British exports from satisfying.

The growth records of the British and American industries are also consistent with Table 4. The American industry was not very profitable, and its output increased only very slowly in the 1850s and the early 1860s.[25] At first glance Table 4 seems inconsistent with the British growth record: excess profits were not large, yet the industry grew rapidly and steadily. This seeming paradox is resolved if one examines the regional production figures.[26] It is clear that most of Britain's growth occurred on the Northwest coast (Cumberland and Lancashire) and in the Cleveland district. The growth in the Northwest, which was based on the exploitation of its high-grade hematite ores, was largely due to the growth in demand for Bessemer steel. Growth occurred in the Cleveland district because of a fall in that district's supply curve. Table 4 shows its costs to have been only a little below those in Scotland and South Wales. The similarity is a consequence of the presumption that 1.6 tons of coke were required to smelt

[24] For the wage rates of puddlers and rollers in the three countries, see U.S. Commissioner of Labor, *Fifteenth Annual Report: Wages in Commercial Countries,* Vol. 2 (1900), pp. 1174, 1218.

[25] Peter Temin, *Iron and Steel in Nineteenth-Century America: An Economic Inquiry* (Cambridge, 1964), pp. 266–67.

[26] Mitchell and Deane, *British Statistics,* p. 131.

one ton of iron. In the late 1850s the Cleveland district average was probably close to this figure; however, the development of the eighty-feet-tall furnace and the use of high blast temperatures, both introduced about 1860, dropped fuel requirements to 1.1 tons of coke per ton of iron. It was only in Cleveland that these changes in technique had this beneficial impact.[27] When the coke rate fell, the Cleveland district's costs fell 5 shillings per ton in 1860 prices, giving the district a decisive cost advantage. This cost advantage in pig iron production also benefited the wrought iron rolling mills that fabricated pig iron. Consequently, most new non-Bessemer (that is, foundry pig iron and wrought iron) capacity was concentrated there.

The same factors that determined the pattern of pig iron prices determined the similar pattern of rolled iron prices. Given the pig iron prices and Britain's high labor productivity, combined with Germany's lower wage rates, it seems quite unlikely that the differential between German and British rolled iron prices could be due to cost differences. The German wrought iron industry must have been earning high excess profits, just as the pig iron industry was.

In America, it was higher production costs—not excess profits—that caused its rolled iron prices to exceed Britain's. Table 5 presents a detailed comparison of rail costs in Cleveland, South Wales, and Pennsylvania which shows that prices were almost identical to unit costs in Britain, and only 10 percent higher in Pennsylvania. Higher American pig iron costs were the main reason for higher rail costs, but higher American fuel costs, due to higher fuel prices, were also a factor. American unit labor costs, too, surpassed Britain's in part because American wage rates were greater, but mainly because its labor productivity was lower. The American rail mills whose costs were aggregated in Table 5 paid an average monthly wage of 125 s. per worker. At the same time, a leading Welsh rail mill paid its employees an average wage of 110 s. per month.[28] These wage rates, in conjunction with the unit labor costs in Table 5, imply that British labor productivity was 60 percent greater than American. The close similarity of this differential to that computed for 1860 (see section I) provides important confirmation for my earlier result.

Neither Germany nor America exported iron before 1870, but for different reasons. Germany's position as a net importer had very little to do with its productivity being lower than Britain's. Rather, the effect of very rapidly growing domestic demand combined with the Zollverein tariff and overland transport costs meant that German domestic prices greatly exceeded those prevailing in the world market. American prices, on the other hand, exceeded British prices because American costs exceeded British costs. A perusal of Tables 4 and 5 indicates two important sources

[27] Robert C. Allen, "Entrepreneurship and Technical Progress in the Northeast Coast Pig Iron Industry, 1850–1913," *Research in Economic History,* vol. 7, forthcoming.

[28] Gruner and Lan, *Métallurgie du fer,* pp. 593–94.

TABLE 5
RAIL COSTS, 1859/60

Input	Cleveland tons	Cleveland price	Cleveland cost	South Wales tons	South Wales price	South Wales cost	Pennsylvania tons	Pennsylvania price	Pennsylvania cost
Pig iron	1.31	47.4	61.9	1.32	46.8	61.8	1.25	78.4	98.0
Coal	1.59	4.0	6.4	2.22	3.99	8.9	2.15	7.4	16.0
Labor			25.6			21.9			39.9
Miscellaneous			9.2			9.2			8.0
Capital			14.9			14.9			9.0
Total			118.0			116.7			170.9
Price of rails at works			120.0			117.0			191.5

Sources: Britain: Gruner and Lan, *Métallurgie du fer,* pp. 554, 621–22, 628–31. Pennsylvania: 1860 United States Census, manuscript schedules.

of higher American costs: higher American blast furnace fuel costs, due to greater American fuel consumption; and higher American labor costs in both blast furnaces and rolling mills. The low productivity of American fuel reflected the chemistry of American ores and not an incorrect choice of technique. Higher American labor costs were partly due to higher American wage rates, but mainly to lower American labor productivity. This result is surprising in view of much recent work in Anglo-American economic history, which has been concerned with explaining supposed higher American capital-labor ratios and labor productivity in the mid-nineteenth century.[29] Yet a recurring theme in the mid-century engineering literature is the greater extent of mechanization in British iron works.[30] Those observations are consistent with my labor productivity estimates. Whether it would have been profitable to mechanize American ironworks more fully is too intricate a question to pursue here. It is evident, however, that low American labor productivity contributed to high American costs and prices, as the productivity hypothesis suggests. America's low labor productivity may have reflected an incorrect choice of technique.[31]

III

The immediate cause of Germany's emergence as a major exporter of iron and steel by 1880 was the drop in German prices from their high mid-century levels. While German prices were still higher than British prices, they were low enough so that Germany could successfully compete

[29] H. J. Habakkuk, *American and British Technology in the Nineteenth Century* (Cambridge, 1962), and the vast literature it spawned.
[30] I. Lowthian Bell, *Principles of the Manufacture of Iron and Steel* (London, 1884), p. 562. See also Temin, *Iron and Steel,* p. 116.
[31] Ibid.

against Britain in European (but not extra-European) markets. American prices, on the other hand, remained greatly above European levels, and the United States continued to be a major importer of steel. Two developments were responsible for this new pattern of trade. First, the high excess profits earned by the German industry in mid-century were eliminated. Second, the steelmaking technologies available before 1900 could not cheaply produce satisfactory steel from Cleveland ironstone. Consequently, Britain lost the cost advantage in the production of rolled products which it had enjoyed in that district during the 1860s.

Raw materials accounted for the largest share of iron and steelmaking costs. Between 1860 and the 1880s the raw material base of the world iron industry greatly expanded, both because new deposits successfully competed against old ones in supplying the foundry and wrought iron sectors,[32] and because the development of the acid and basic Bessemer and the acid open hearth processes shifted the structure of demand for the various qualities of ore. As a result of these developments the Spanish hematite, minette, and Lake Superior iron ore deposits were brought into large-scale production, and Connellsville coke made great strides in displacing anthracite as the chief American blast furnace fuel. Yet—with the exception of its impact on the Cleveland iron industry—these changes in material sources and technology had little impact on international differences in iron and steelmaking costs.

Table 6 shows the average price of blast furnace coke, the average cost of ore per extractable ton of iron, and the combined ore and coke costs of smelting a ton of pig iron in the principal steelmaking centers in 1883–89. The combined ore and coke costs of making hematite pig iron suitable for acid Bessemer and open hearth steel in Britain's major producing districts was very similar to the ore and coke cost of making basic pig iron in Westphalia. In spite of the different ores and fuels involved, the same equality in raw material costs had prevailed in the 1850s among Scotland, Wales, and Westphalia. Table 6 also indicates that American material costs remained greatly above European costs, even though the center of production was shifting from eastern Pennsylvania to Pittsburgh, and Connellsville coke and Lake Superior ore were displacing anthracite and eastern ore. The advent of lake ores allowed a reduction in fuel consumption (and hence costs), but that gain was neutralized because lake ores cost more than ores mined in eastern Pennsylvania.

The district whose competitive position deteriorated because of the new technologies and resources was the Cleveland district. In the 1880s Cleveland ironstone was the cheapest ore in the world, just as it had been in the 1860s. Little steel was made from it, however.[33] Cleveland pig iron was so

[32] Gruner and Lan, *Métallurgie du fer,* pp. 84, 249, 287.

[33] Until just before World War I less than one fifth of the Cleveland ironstone mined each year was converted into steel. This result is obtained by dividing basic steel ingot production on the Northeast coast (as given in British Iron Trade Association, *Annual Statistical Report*) by one third (the ore yield) times the output of Cleveland ore (as given by Mitchell and Deane, *British Statistics,* pp. 129–30).

TABLE 6
RAW MATERIAL COSTS
(shillings)

	Coke Cost	Ore Cost	Ore and Coke Cost[a]
1883-89			
N.W. Coast hematite	17.8	24.0	41.8
N.E. Coast hematite	13.4	25.1	38.5
Cleveland foundry	13.4	13.6	27.0
Westphalia basic	9.0	29.8	38.8
Pittsburgh Bessemer	9.6	48.7	58.3
Pittsburgh basic	9.6	42.6	52.2
1906-13			
N.W. Coast hematite	23.8	36.5	59.8
N.E. Coast hematite	18.3	39.6	57.9
Cleveland foundry	18.3	17.9	36.2
Westphalia basic	16.1	27.5	43.6
Pittsburgh Bessemer	12.6	39.6	52.2
Pittsburgh basic	12.6	36.5	49.1

[a] The cost of coke is the cost of one ton of coke delivered at the blast furnace. The cost of ore is the cost of ore delivered at the blast furnace divided by the iron content of the ore. The cost of ore is, therefore, the cost per extractable ton of iron. Ore and coke cost is the cost of coke plus the cost of ore. Adding the prices in this way assumes one ton of coke was consumed per ton of pig iron.

Sources: Detailed sources are given in Robert C. Allen, "International Competition in Iron and Steel, 1850–1913," Univ. of British Columbia, Dept. of Economics Discussion Paper No. 78–12 (1978), pp. 61–67.

phosphoric and siliceous that it could not be used to make open hearth steel before the development of the mixer in the 1890s. This was a serious limitation, since the demand for open hearth steel was growing rapidly. On the other hand, Cleveland pig iron was not sufficiently phosphoric for the basic Bessemer furnace unless the smelting process was modified at considerable expense. To produce a satisfactory basic Bessemer pig from Cleveland ironstone, it proved necessary to add extra limestone to the blast furnace charge, puddle cinder, which was rich in phosphorous, in order to flux as much silicon as possible, and to add imported magniferous ores to raise the manganese content of the pig. Kirchoff, the editor of *Iron Age*, estimated that this burden raised the cost of basic Bessemer pig iron four to six shillings per ton above the cost of foundry pig.[34] Furthermore, the costs of operating a basic Bessemer plant exceeded the costs of an acid Bessemer plant by several shillings per ton of steel. Table 6 indicates that these extra costs eliminated most of the iron ore cost advantage attendant upon using Cleveland ironstone. Rails were the product for which Bessemer steel was particularly well adapted, and new railmaking capacity built after the late 1870s (principally by Bolckow-Vaughn and the Northeastern Steel Company) was, indeed, basic Bessemer. Otherwise, little basic steel was made in Cleveland. The district was no longer the world's

[34] Harry H. Campbell, *The Manufacture and Properties of Iron and Steel* (New York, 1903), p. 706.

TABLE 7
BELL'S LABOR PRODUCTIVITY INVESTIGATION, ABOUT 1880

Blast Furnaces	*Cleveland, England*	*Germany, Firm A*	*Germany, Firm B*	*U.S.A.*
output per worker	1.00	.67	.56	.47
wages per worker	1.00	.54	.52	1.27
wages per ton	1.00	.80	.93	2.71
Iron Plates	*Britain*	*Germany*		
output per worker	1.00	.36		
wages per worker	1.00	.45		
wages per ton	1.00	1.24		
Bessemer Converters	*England*	*Germany*	*U.S.A., Firm I*	*U.S.A., Firm II*
output per worker	1.00	.67	.61	.91
wages per worker	1.00	.45	1.37	1.31
wages per ton	1.00	.67	2.25	1.45
Steel Rail Mills	*England*	*Germany*	*U.S.A., Firm I*	*U.S.A., Firm II*
output per worker	1.00	.49	.59	.77
wages per worker	1.00	.65	1.38	1.28
wages per ton	1.00	1.33	2.34	1.66

Sources: I. Lowthian Bell, *Principles of the Manufacture of Iron and Steel* (London, 1884), pp. 534, 565, 573.

low-cost producer of rolled products. It remained the low-cost producer of foundry pig iron, however.[35]

After raw materials, labor costs constituted the largest share of steel-making costs. In the 1880s the pattern of relative labor productivity, wage rates, and unit labor costs was the same as it had been in mid-century. I. Lowthian Bell, one of Britain's most prominent ironmasters and applied scientists, used the cost accounts of firms in several countries to explore the interrelationships among these variables. Table 7 summarizes the results of Bell's inquiry. In all processes, output per worker was greater in Britain than anywhere else. Nominal German wages were less than British, with the result that, on average, German and British unit labor costs were about equal. American labor costs, however, exceeded British costs because American wage rates were higher than British.

The pattern of international production costs in the 1880s was similar to that prevailing in the 1850s.[36] Germany's lower prices, then, were not a

[35] Ibid., p. 701.

[36] The cost data for 1888–89 reported in U.S. Commissioner of Labor, *Sixth Annual Report,* pp. 33–193, also confirm this contention. Average costs computed from these data are reported and discussed in Allen, "International Competition," pp. 314–15.

consequence of lowering production costs, but of aligning the prices much more closely with costs. To establish this conclusion, the average total costs of producing steel rails in Britain, the United States, and Germany were estimated and compared to prices prevailing in the early 1880s.[37] American rails sold at 13 percent above cost; British rails at 19–20 percent. German domestic prices exceeded costs by 24 percent, but export prices equalled only 92 percent of costs. The high price realized on domestic sales was enough to make German rail production as a whole profitable: the ratio of the average value per ton of rails produced in Prussia in 1882 to the cost estimate in Table 8 was 1.17. [38] In the 1880s the relationship between steel rail prices and costs was similar in Germany, Britain, and America.

German prices fell relative to costs when the immense excess profits earned in the frantic boom of the 1850s and 1860s disappeared in the depression of the 1870s. This depression coincided with a brief free trade period, and iron and steel producers blamed their plight on an influx of cheap British iron.[39] The production and trade statistics show imports were not the cause of their plight. German production fell because domestic consumption collapsed. As German prices fell, Germany's trade position improved. In 1877, the first year of free trade following repeal of the Zollverein tariff, Germany ran its first iron and steel export surplus. In 1879, the last year of free trade, Germany exported 19 percent of its production. German costs were clearly low enough for the steel industry to compete at world prices. Thereafter, prices (particularly export prices when separate domestic and export prices were quoted, as in the case of rails) never rose enough above costs to impede German exports.

IV

After 1895 American prices dropped to British levels and German prices dropped below British prices. These price changes reflected the fact that American and German unit costs had fallen below British costs, which decrease was in turn a consequence of changes in iron ore prices and of the rapid productivity growth of the German and American industries.

In the 1880s the combined fuel and ore costs of British hematite pig iron and Westphalian basic pig had been similar. American costs were, of course, much higher. As Table 6 indicates, however, both Germany and

[37] A. L. Holley, *Holley's Reports to the Bessemer Steel Co., Limited* (New York, 1881), Hans Ehrenberg, *Die Eisenhüttentechnik und der Deutsche Hüttenarbeiter,* Müchener Volkswirtschaftliche Studien, Vol. 80 (Stuttgart, 1906), pp. 177–86; and the prices averaged to form Table 1. Berck, "Hard Driving," however, computed high ratios of price to average total cost for American blast furnaces in the mid-1880s.

[38] Prussia, *Zeitschrift,* 1882.

[39] Ivo N. Lambi, "The Protectionist Interests of the German Iron and Steel Industry," this JOURNAL, 22 (March 1962), 59–70.

the United States had much lower raw material costs than Britain in the early twentieth century. The fundamental changes were in iron ore, not in fuel. Indeed, changes in fuel prices marginally benefited the British iron industry.

After 1895 the cost of Spanish hematite rose sharply in Britain. Britain's commitment to acid steelmaking meant that it was becoming more and more dependent on this ore. Even Lancashire and Cumberland, Britain's own hematite mining districts, began importing it in the 1890s. In contrast, the German steel industry diversified its ore supplies by importing Swedish ore on a large scale.[40] After the mid-1890s, Swedish-minette ore mixtures were standard in Westphalia,[41] which meant that German ore costs were slightly lower in 1906–13 than they had been in 1883–89. The divergent movement of British hematite and German basic ore costs put the British steel industry at a serious disadvantage.

Pittsburgh iron ore costs dropped to the level of British hematite costs in the depression of the 1890s. Never again did American costs rise above British costs. The reasons American ore prices fell include the discovery of new, low-cost ore fields (particularly the Mesabi), the development of highly capital-intensive, open pit mining methods, and a highly efficient lake shipping system. The comparison of American and British ore prices is complicated by the cartellization of the Lake Superior ore trade. After the solidification of the cartel, which followed the U.S. Steel merger in 1901, all furnaces smelting lake ore purchased it from the cartel at prices which greatly exceeded cost. Even at these market prices, American ore was usually cheaper than Spanish ore in Britain. At cost-price (as ascertained by the U.S. Bureau of Corporations from the cost accounts of major ore companies for the years 1900–1910) American ore was cheaper than any in the world, with the exception of Cleveland ironstone.[42] In combination with America's low fuel costs, the mineral costs of one ton of pig iron were decisively less than Britain's and moderately less than Germany's.

The low price of German and American raw materials was one factor that contributed to their low steel prices. A second was their much higher productivity *vis-à-vis* Britain, the evidence for which was presented in section I. Sufficient data are available for the early twentieth century so that one can systematically sort out the relative importance of these and other

[40] Martin Fritz, "Järnmalmsproduktion och järnmalmsmarknad, 1883–1913," Meddelanden från Ekonomisk-historiska institutionen vid Göteborgs Universitet, 11 (Göteborg, 1967), 40–41; and Martin Fritz, "Svensk järnmalmsexport, 1883–1913," ibid., 12 (1967), 154–59.

[41] Fritz, "Järnmalmsproduktion," p. 25; Campbell, *Iron and Steel,* p. 745; Norman J. G. Pounds, *The Ruhr* (Bloomington, Ind., 1952), pp. 111–12; Germany, *Produktion der Kohlen-, Eisen-, and Hüttenindustrie,* 1913.

[42] Henry R. Mussey, *Combination in the Mining Industry* (New York, 1905); U.S. Bureau of Corporations, *Report of the Commissioner of Corporations on the Steel Industry,* Vol. I (1911), pp. 377–82, and Vol. III (1913), pp. 351–52, 377–90, 480–507.

factors in the determination of steel price differences. An accounting scheme is necessary to accomplish that task.[43] In specifying that accounting scheme, it is important to recognize that prices in any particular year need not equal production costs. We will concentrate for the moment on the comparison of German and British steel prices. In the case of Germany, the inequality of price and unit costs can be recognized by a variable M_G so that $P_G = M_G \cdot C_G$. Here P_G is the price of steel in Germany, C_G is the average total cost of producing steel in Germany, and M_G is the German markup or ratio of price to cost. Similarly in Britain, $P_B = M_B \cdot C_B$. Given these relationships, it is the case that the price of German steel relative to the price of British steel equals relative markups multiplied by relative costs:

$$\frac{P_G}{P_B} = \frac{M_G}{M_B} \cdot \frac{C_G}{C_B} \tag{2}$$

Relative costs (C_G/C_B) in their turn depend on relative input prices and technical efficiency. It is apparent that lower input prices in Germany will lower German costs relative to British costs. Higher German technical efficiency will have the same effect. Recent work in the theory of index numbers has formalized these intuitions in a convenient way: it has been shown that C_G/C_B equals an index of German input prices relative to British input prices divided by a total factor productivity index such as that used in section I. If the input index is computed as a geometric average of the relative prices of the principal inputs, then C_G/C_B can be computed as:

$$\frac{C_G}{C_B} = \left[\left(\frac{W_{GO}}{W_{BO}}\right)^{s_O}\left(\frac{W_{GF}}{W_{BF}}\right)^{s_F}\left(\frac{W_{GS}}{W_{BS}}\right)^{s_S}\left(\frac{W_{GL}}{W_{BL}}\right)^{s_L}\right] \Big/ \frac{A_G}{A_B} \tag{3}$$

The term in brackets is the input price index. W_{GO}, W_{GF}, W_{GS}, and W_{GL} are the German prices of ore, fuel, scrap, and labor; W_{BO}, W_{BF}, W_{BS}, and W_{BL} are the corresponding British prices. The shares in unit costs of these inputs are represented by s_O, s_F, s_S, and s_L.

Equations (2) and (3) can be combined to provide a complete accounting scheme.

$$\frac{P_G}{P_B} = \frac{M_G}{M_B}\left[\left(\frac{W_{GO}}{W_{BO}}\right)^{s_O}\left(\frac{W_{GF}}{W_{BF}}\right)^{s_F}\left(\frac{W_{GS}}{W_{BS}}\right)^{s_S}\left(\frac{W_{GL}}{W_{BL}}\right)^{s_L}\right] \Big/ \frac{A_G}{A_B} \tag{4}$$

German prices relative to British prices equal German markups relative to British markups multiplied by the difference in relative production costs, which, in equation (4), are expressed as the input price index di-

[43] The accounting scheme used here is developed formally in Robert C. Allen, "Accounting for Price Changes," Univ. of British Columbia, Dept. of Economics Discussion Paper, No. 78–14 (1978).

vided by the total factor productivity index defined in equation (1). If the subscript G is interpreted to represent the United States, equations (2), (3), and (4) can also be used to account for the relative difference in British and American prices.

Table 8 sets out the computations of the various terms in equations (2), (3), and (4). Separate comparisons using German export and domestic prices for 1906–13 are presented to explore German price discrimination. Separate American-British comparisons for 1906–09 and 1910–13 are presented, since American prices were considerably lower in the second period than in the first.

Line 1 of the table shows the prices of the chief steelmaking inputs in Germany and America relative to the prices in Britain. In line 2 these price relatives are combined into the input price index in equation (3). The prices of all inputs were lower in Germany than in Britain. If efficiency had been equal in the two countries, German unit costs would have been 83 percent of British costs, the value of the input price index in line 2. The German steel industry was, however, 15 percent more efficient than the British, so German costs were 72 percent of British costs, as line 4 indicates. Germany's competitive strength in the early twentieth century did reflect lower production costs, which were caused in equal measure by lower input prices and greater efficiency.

America's competitive strength was not the result of low input prices. Table 8 uses market prices for American ore. Line 2 indicates that, when those prices are used, American input prices exceeded British prices, since nominal American wage rates were so high. The greater efficiency of American industry, however, meant that American costs were less than British costs, as shown in line 4.

The impact on costs of high German and American efficiency can be seen more concretely by considering unit labor costs. Of course, Germany's higher labor productivity combined with its lower wage rates meant that German labor costs were less than British in the early twentieth century. The American case is more interesting. I have shown for earlier years that unit labor costs in America exceeded those in Britain. Between 1880 and the early twentieth century, the ratio of average American to average British nominal wage rates increased from 1.32 to 1.70.[44] Yet American labor productivity increased enough over the same period so that American unit labor costs were slightly less than British costs in 1907–09. Dividing the relative wage rates in Table 8 by the relative labor productivities in Table 3 indicates that American unit labor costs were 96 percent of British costs.

A rough check on this figure is possible in the cases of pig iron and rails. In his submission to the Tariff Commission, J. S. Jeans, secretary of the British Iron Trade Association, stated that in 1903–04 the labor cost

[44] Tables 7 and 8.

TABLE 8
ACCOUNTING FOR PRICE DIFFERENCES

	American 1906–09	*American 1910–13*	*German 1906–13*
1. *German and American input prices relative to British prices*			
ore	.98	.87	.69
fuel	.73	.65	.88
scrap	1.13	.99	.95
labor	1.70	1.70	.72
2. *Indexes of German and American input prices relative to British input prices*			
	1.09	1.03	.83
3. *German and American total factor productivity relative to British*			
	1.15	1.15	1.15
4. *German and American unit costs relative to British unit costs*			
	95	.90	.72

	American 1906–09	*American 1910–13*	*German Export 1906–13*	*German Domestic 1906–13*
5. *German and American prices relative to British prices*				
structural steel	1.15	.918	.785	.877
bars	.98	.845	.727	.763
plates	1.07	.842	.820	.892
6. *German and American markups relative to British markups*				
structural steel	1.21	1.02	1.09	1.22
bars	1.03	.94	1.01	1.06
plates	1.13	.94	1.14	1.24

Sources: Line 1: Ore computed from Table 6 and its sources. The American price is Pittsburgh basic, and the British is Northeast coast hematite. Fuel computed from Table 6 and its sources. The prices of blast furnace coke at the furnace on the Northeast coast, Pittsburgh, and Westphalia were used. The scrap price for America is heavy steel scrap in Pittsburgh averaged from quotations in *Iron Age.* The British price is for heavy steel melting scrap in Middlesborough as averaged from quotations in the *Iron and Coal Trades Review.* The German price is from Germany, *Produktion der Kohlen-, Eisen-, and Hüttenindustrie,* 1912 and 1913. These prices are compared to British prices for the same years. Labor entries in the table are relative earnings in 1906. The American figures are from Paul H. Douglas, *Real Wages in the United States, 1890-1926* (Boston and New York, 1930), p. 271. The British figure is from *Report of Board of Trade Enquiry into Earnings and Hours of Labor in the Metal Industries, Engineering and Shipbuilding Industries in 1906.* The German figure is from Ashok V. Desai, *Real Wages in Germany, 1871-1913* (Oxford, 1968), p. 110.

Line 2 computed from line 1 as

$$\left(\frac{W_{GO}}{W_{BO}}\right)^{s_O}\left(\frac{W_{GF}}{W_{BF}}\right)^{s_F}\left(\frac{W_{GS}}{W_{BS}}\right)^{s_S}\left(\frac{W_{GL}}{W_{BL}}\right)^{s_L}$$

Line 3 is from Table 3.

Line 4 = line 2 divided by line 3.

Line 5 computed from Table 1 and its sources. 5 s. per ton subtracted from German export figures (which are f.o.b. Antwerp) to deduce the price at the works. See Burn, *Steelmaking,* p. 160.

Line 6 = line 5 divided by line 4.

per ton of west coast hermatite pig iron was 4 shillings, the labor cost of Bessemer ingots was 2.8 shillings per ton, and the labor cost of rails was 6.8 shillings per ton.[45] According to the U.S. Bureau of Corporations *Report,* in 1903 the corresponding cost for American Bessemer pig iron was 3.6 shillings, for Bessemer rail ingots 2.6 shillings, and for Bessemer rails 5.4 shillings.[46] The American labor costs are all marginally less than the corresponding British costs. This respresents an enormous change from 1880 and earlier. Jeans also stated that labor cost per ton of pig iron in Germany was only 3 shillings per ton,[47] which is less than the British and American costs just given. That finding is consistent with the aggregate data in Tables 3 and 8, and thus corroborates them.

Line 5 shows the price of steel in America and Germany relative to the price in Britain. In line 6 relative markups are computed by dividing the relative prices in line 5 by the relative costs in line 4. Since these markups are relative and not absolute markups, they do not, in themselves, indicate whether price exceeded or fell short of unit cost. The British industry was competitively organized and grew very little (in particular the acid sector, whose ore price is used in Table 8), so it is natural to assume price was close to unit cost, that is, $M_B = 1$. In that case the relative markups in line 6 are absolute markups. The U.S. Bureau of Corporations collected extensive information on the costs of producing various steel products in the United States in 1902–06. The markups implied by those cost figures are similar to those shown in line 6 for 1906–09, and thus corroborate the assumption that British prices were close to unit costs.[48] Although American markups after 1910 were less than one, this does not imply that steel production in the United States was unprofitable. Rather, it means that from an accounting point of view the American steel industry was earning its profits in ore sales rather than steel production. It might be further noted that an implication of the assumption that British prices equalled costs is that German export prices were considerably greater than unit costs. In 1906–13 the Germans undersold the British because their costs were less, not because they were "dumping" as they had been in the early 1880s.

Recently McCloskey measured the difference in efficiency between the

[45] *Report of the Tariff Commission,* Vol. I, *The Iron and Steel Trades* (London, 1904), paragraphs 992, 1015.

[46] U.S. Bureau of Corporations, *Report,* Vol. 3, pp. 86, 144, 211.

[47] *Tariff Commission,* paragraph 993.

[48] The ratio of average realized price to unit cost in 1902–06 was 1.16 for structural shapes, 1.11 for steel merchant bars, and 1.15 for plates. Cost in these calculations is book cost (which includes depreciation but not interest on investment) plus interest at 5% on industrial fixed capital and working capital. Price and book cost from U.S. Bureau of Corporations, *Report,* Vol. 3, pp. 223, 230, and 236; investment costs from ibid., pp. 529–33. In the absence of investment costs for bars, the costs for Bessemer steel rails were used. It should be noted that the markups for structural steel and plates reported in this note are similar to those in Table 8. The markup for bars in Table 8 is less than that reported here. That anomaly is a consequence of the abnormally high relative price of British steel bars (see Table 1). Burn, *Steelmaking,* p. 110, n. 3, noted the same phenomenon in a different context, but could not account for it.

American and British steel industries in the early twentieth century, and concluded they were equally efficient. Equation (4) and Table 8 indicate one way to reconcile McCloskey's results with the very different results presented in this paper. Using 1907–09 data, McCloskey compared relative American-British product prices to an index of relative American-British input prices.[49] While his formulae and industry definition were somewhat different, the analogous calculation using the framework of this paper is to divide the input price index in line 2 by the product prices in line 5. The results of that calculation, using the values of 1906–09, show American "efficiency" relative to British to be .95 for structural steel, 1.02 for plates, and 1.11 for bars. These numbers are close to those McCloskey computed and would seem, therefore, to support his contention that Britain and America were equally efficient. The numbers do not, however, measure relative efficiency. Reference to equation (4) indicates that they measure relative efficiency divided by relative markups. I have argued that, in fact, markups were not equal. If we measure efficiency with equation (1), the assumption (implicit in McCloskey's calculation) of equal markups can be avoided. For this reason I have used equation (1), and found that the Germans and Americans were indeed more efficient than the British in the early twentieth century.

V

The emergence of Germany and America as major iron and steel exporters had a profound effect on British and German output levels on the eve of the First World War. Historically, Britain produced 12,037 thousand tons of iron and steel in 1913, and Germany produced 18,045 thousand tons, or 50 percent more. Had Britain dominated the world market in 1913 as it had before 1870, it would have supplied the exports that Germany and America actually supplied.[50] If German and American net exports are subtracted from these countries' production levels in 1913, and are added to Britain's production level instead, then Britain's production is raised to 19,562 thousand tons and Germany's is lowered to 12,998 thousand. This hypothetical reallocation of trade has little effect on American production—it is lowered from 30,844 thousand tons to 28,416 thousand tons. In the hypothetical situation, the American steel industry is still the largest in the world, but the positions of the British and German industries are reversed, with the British 50 percent larger than the German. This reallocation of 1913 trade indicates the impact on 1913 production levels of Britain's shifting from being the world's low-price to its high-price producer of steel.

Were there actions the British industry might have taken to have pre-

[49] McCloskey, *Economic Maturity*, pp. 120–24.

[50] This reallocation of exports presumes the price elasticity of demand for iron and steel is zero.

vented this deterioration? Restoring the mid-century price pattern was out of the question, but the British might have hoped to have matched German prices. If British prices had been as low as German prices, then surely increased British production would have displaced most imports into Britain. British producers would also have satisfied most of the Empire demand. In addition, their exports to such markets as Latin America and the Far East would have expanded. The magnitude of these increases (and the concomitant reductions in German and American sales) cannot be known with certainty, but Britain's trade performance would have been far more impressive.[51]

Could Britain have profitably produced steel at German prices? To have done so, it would have had to have overcome the cost disadvantages under which it labored in the early twentieth century. There were three main sources of higher costs in Britain: first, British wage rates exceeded German wage rates; second, British acid ore cost more than ore in Westphalia; third, British industry was less efficient. High British wage rates reflected higher British per capita incomes, and were thus beyond the control of the steel industry. The other two factors, however, were controllable. The British did have access to cheaper iron ores than Westphalian producers. Burn sensed this and suggested that the failure to make steel from the East Midlands ore was a serious blunder.[52] McCloskey convincingly argued that Burn was wrong, by demonstrating that pig iron made from Cleveland ore was cheaper.[53] Yet his finding does not dispose of the underlying problem, for the British made little steel from Cleveland ironstone either. Since Cleveland ironstone was cheaper than both the Swedish-minette mixtures common in Westphalia and the Spanish ore burdens used in Britain, the reluctance of the British steel industry is puzzling.

Before the late 1890s, the failure to make open hearth steel (the variety of steel where demand was growing) from Cleveland ironstone can be explained by the limitations of the available technology. Making open hearth steel from Cleveland pig iron posed exceptional problems to the metallurgist. Not only was Cleveland pig iron high in phosphorous (which had to be removed in the steelmaking process), but it was high in silicon. Limestone was added to the charge to remove phosphorous: the limestone and phosphorous reacted to form a slag which floated on the molten steel in the open hearth furnace. But silicon reacted with limestone in a similar way, and, indeed, the silicon reaction took precedence over the phosphorous reaction. Consequently, enough limestone had to be added to the

[51] Peter Temin, "The Relative Decline of the British Steel Industry, 1880–1913," in Henry Rosovsky, ed., *Industrialization in Two Systems* (New York, 1966), pp. 140–55, explored this question. Berck, "Hard Driving," also considered it, but discussed only the consequences of Britain's using hard driving extensively.

[52] Burn, *Steelmaking,* pp. 167–82.

[53] McCloskey, *Economic Maturity,* pp. 56–72.

furnace to flux both the silicon and the phosphorous. And the combined reactions produced so much slag in the open hearth furnace that the thermal and chemical interplay between the bath of molten steel and the gases burning above it was impeded, which ultimately resulted in incomplete refining and poor metal.

The solution to the problem lay in arranging for a series of small slags rather than relying on one large slag. Several machines were helpful in accomplishing this "flush slag" process. All basic steelworks used mixers. The mixer, which was independently discovered in Germany and the United States in 1890, was a large ladle that collected molten iron from the blast furnaces and delivered it to the open hearth furnaces. Considerable refining could be achieved by heating and adding limestone to the molten iron before it was charged into the open hearth. The Talbot tilting open hearth furnace developed early in the twentieth century was a second helpful machine; it allowed slag to be removed before it became thick enough to interfere with the refining in the open hearth furnace.[54]

Cleveland ironstone was sufficiently cheap that British firms that availed themselves of the new basic open hearth technology could have overcome the cost advantage the Germans derived from lower labor, scrap, and fuel costs. I arrived at this result by using the price of Cleveland ironstone instead of the price of British acid ore in computing the index of Germany's input prices relative to Britain's. This recomputed index equals .98, which indicates that the aggregate price of basic steel inputs was virtually identical in Cleveland and in Westphalia. Was the supply of ore sufficiently expandable to allow extended production at these prices? It seems to have been. At the time of the First World War proven reserves extractable at prevailing prices totalled 190 million tons, and reserves that were probably extractable at the same cost but which had not been fully explored equalled another 190 million tons. Reserves extractable at somewhat higher cost were roughly estimated at 400 million tons. With annual production running at 6 million tons, there was no obvious constraint posed by a limited ore supply.[55] Indeed, the prospects for profitable basic steel production were bright enough to encourage several firms (for example, Cargo Fleet and Skinningrove) to build new integrated basic steelworks.

[54] On the technology of the basic open hearth process see ibid., pp. 68–72; Arthur E. Pratt, "The Future Development of the Metal-Mixer and the Open-Hearth Process," *Journal of the Iron and Steel Institute,* 3 (1908), 156–92, and "Correspondence," 193–205; Arthur W. Richards, "Manufacture of Steel from High-Silicon Phosphoric Pig Iron by the Basic Bessemer Process," ibid., 1 (1907), 104–08, and "Discussion," 109–13; Robert G. Ward, *An Introduction to the Physical Chemistry of Iron and Steelmaking* (London, 1962); Committee on Physical Chemistry of Steelmaking, *Basic Open Hearth Steelmaking* (New York, 1944), pp. 504–49.

[55] Reserve estimates from Max Roesler, *The Iron-Ore Resources of Europe,* U.S. Geological Survey, Bulletin 706 (1921), pp. 12, 45–46. Less conservative estimates are found in Henry Louis, "The Iron Ore Resources of the United Kingdom of Great Britain and Ireland," in *The Iron Ore Resources of the World,* XI International Geological Congress (Stockholm, 1910), Vol. II, pp. 623–41. Production of ore from Mitchell and Deane, *British Statistics,* p. 130.

Could the British have closed the efficiency gap that existed with respect to Germany and the United States? The answer depends on what one believes caused the gap. If it was entrepreneurial inertia, then there is no reason to be sanguine. Moreover, the failure to use Cleveland ironstone for steelmaking is also explained by that hypothesis. One might, on the other hand, argue that Britain's measured inefficiency was the result of rational decisions. The slow growth in demand for foundry iron and the rising cost of Spanish ore after 1895 meant that much of the iron and steel industry was not particularly profitable, so the construction of new capacity was limited. If high efficiency in Germany and America was the result of improvements embodied in the new plants, then the British industry would have become continuously less efficient precisely because British entrepreneurs were rational enough not to invest in an unprofitable industry.[56]

If the embodiment hypothesis is correct, then one would expect that the use of Cleveland ironstone (and other basic ores) for steelmaking and the construction of new, high-efficiency plants would have been linked. In fact they were, and the link is explicit in the case of Northeast coast blast furnaces.[57] Very little new capacity was built in that sector between 1880 and 1900; after 1900, however, more than a dozen American-style blast furnaces were constructed as part of integrated plants to make basic steel from Cleveland ironstone. Those producers enjoyed high profits, since they used the cheapest raw materials in the world and could sell steel at the high prices many British and Empire purchasers were willing to pay. While the growth of British basic steel production was consequently impressive, it was not enough to drive British prices down to German levels, which would have necessitated an even higher rate of investment.

[56] Temin, "Relative Decline," p. 151, produced some calculations in support of an argument of this kind. McCloskey, *Economic Maturity,* pp. 105–13, has recently remedied several difficulties with Temin's calculations and, on the basis of the revised calculations, rejected the possibility that differences in the average age of capital in Britain, America, and Germany could have been important. It is important to realize that neither Temin nor McCloskey ever measured the average age of capital in these countries. They only computed estimates on the basis of certain equilibrium assumptions. Richard R. Nelson, "Aggregate Production Functions and Medium-Range Growth Projections," *American Economic Review,* 54 (Sept. 1964), 575–605, derives the requisite formulae and clarifies the relevant economic assumptions. The assumption that the rate of fall of unit costs is independent of the scale of new investment is questionable for the steel industry. Moreover, in their calculations, both Temin and McCloskey assume the depreciation rate *exclusive of obsolescence* to be 5% per year. No justification for this value is offered. Since other plausible values lead to widely different average ages, estimates of the equilibrium ages of capital must be regarded as inconclusive evaluations of the embodiment hypothesis.

[57] Allen, "Entrepreneurship and Technical Progress."