

Tariffs and the Expansion of the American Pig Iron Industry, 1870-1940

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Abstract

This paper attempts to assess the impact on protection of the domestic pig iron industry in 1870-1940. First, we provide evidence that imported and domestic pig iron of the same variety are perfect substitutes. Next, we estimate the taste parameter associated with different varieties using a monopolistic competition model. Then we simulate a hypothetical situation, in which the U.S. removed the duty on pig iron in 1870, using the estimated taste parameters. The finding contradicts the recent work by Douglas Irwin, which relies on the assumption of imperfect substitutes. A substantial part of the American pig iron industry could not have survived, if the U.S. had moved to free trade in 1870. Finally, we provide empirical evidence that there existed dynamic learning effects behind the tariff wall. Without protection, the import market share could be as high as 42 percent.

Key words: Pig iron trade, protection, monopolistic competition

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1 Introduction

This paper re-examines the role of protection in the expansion of the American pig iron industry from 1870 to 1940. Pig iron is the basic building block of the iron and steel industry. It is a major intermediate input used in various iron and steel mills. Moreover, the emergence of inexpensive pig iron and steel at the end of the nineteenth century played a significant role in American industrialization (Wright, 1990). The productivity of the American pig iron industry began rising substantially in the 1880s (Allen, 1977). By 1890, American pig iron production has surpassed that of Great Britain and since then the U.S. emerged as the leading producer of pig iron. Pig iron received substantial tariff protection as early as the 1820s, the rates rising to more than 50 percent at the time of the Civil War. The duty on pig iron had been in place long before the invention of Bessemer (or Kelly) process and the discoveries of rich iron ore deposits. Nevertheless, the degree to which the domestic pig iron industry benefited from tariffs remains an open question.

Early works on protection in the domestic pig iron industry in the post-bellum period tended to view the effects of tariffs on the industry as marginal. Taussig (1915) and Temin (1964) acknowledge the effects of protective tariffs but they are quite skeptical about the scale of such effects.¹ Sundararajan (1970), and Baack and Ray (1973), in contrast, find that tariffs significantly helped expand the domestic pig iron industry in the post-bellum period. Sundararajan (1970) uses effective protective rates as measures of protection and find that the effective protective rates are significantly correlated to the reduction of imported pig iron in 1870-1914. In addition, he finds that the tariff structure played a particularly significant role in the growth of pig iron plants in New York and New Jersey, which is a seaboard manufacturing area facing stiff foreign competition. Baack

¹Taussig (1931, p.151) stated that “The same sort of growth would doubtless have taken place eventually, tariff or no tariff; but not so soon or on so great a scale.” Temin (1964, p.213) shares a similar comment; “The tariff increased the incentive of American manufactures to expand their production, although the extent of this increase cannot be known.”

and Ray (1973) find that tariff policy did play a crucial role in promoting the domestic pig iron production in 1870-1929. It should be noted that both Sundararajan (1970) and Baack and Ray (1973) use ad-hoc reduced form regression equations without structural specifications.

Irwin (2000a) presents the best-developed critique of the infant-industry argument. The exploration of the so-called infant-industry hypothesis has two elements. One is whether the industry required protection to survive in such a large scale that learning could take place. The other is whether the dynamic learning effects realized subsequently. Nevertheless, Irwin (2000a) focuses on the first element of the hypothesis. He did not attempt to estimate dynamic learning effects, which is the core of an infant-industry hypothesis, as done in Head (1994).² He identifies structural equations for the domestic pig iron industry in 1867-1889, estimates the elasticity of substitution between domestic and imported pig iron and then uses a partial equilibrium analysis to assess the effects of tariff reductions on the domestic pig iron industry.³ The framework is based on a national product differentiation model (Armington, 1969), which assumes that imported and domestic pig irons are differentiated products and therefore implies imperfect substitutability between the two products. He concludes that the domestic industry would have sustained approximately 70 percent of market share, even if the U.S. had moved to a free trade regime in 1869. Lastly, he did a cost-benefit analysis of protection policies to test the infant-industry hypothesis. According to his result, the protection policies did not appear to have a substantial net welfare gain. He proceeded to argue to dismiss the importance of the dynamic learning effects. That is, if the bulk of the industry did not depend on the tariff for survival, then the dynamic learning effects could not have been significant either. However, Irwin (2000a) did not provide supporting evidence for the underlying assumption of imperfect substitution between American and British pig

²An alternative method to test an infant-industry hypothesis is to use a probability model to assess the likelihood of a rise of a new industry behind tariff walls. See Irwin (2000b) for an example

³Irwin (2000a) actually uses a similar specification to Fogel and Engerman (1969). Fogel and Engerman (1969) specify the structural equations for the pig iron industry in the ante-bellum period.

iron. In addition, he implicitly assumes that the British pig iron was the main threat throughout the 1880s by basing his calculation on the British supply condition.

This paper attempts to re-examine the two key assumptions in Irwin (2000a). First, we explore the degree of heterogeneity of imported and domestic pig iron and hence the validity of applying the Armington model to his argument. Next, we evaluate the role of Germany, besides Great Britain, in competing with the American producers in international markets. We extend the sample period to 1940 and use different time series. None of papers in the literature attempt to measure the effect of tariffs over this period. Despite the abolition of pig iron duties in 1913, the duty was introduced again in 1922 and raised in 1930 (Berglund and Wright, 1929). The reintroduction of pig iron duty illustrates the possibility that tariffs might have been crucial for the expansion of the industry in some regions. Indeed, we find that the expansion of the domestic pig iron industry highly depended on the tariff structure of the U.S. Our conclusion relies on the fact that imported and domestic pig iron are perfect substitutes, against which Irwin (2000a) argues. Moreover, his results underestimate the benefits from protection, because Germany replaced Great Britain as the most important competitor from the late 1870s to the onset of the first World War. Having established that the expansion of the American pig iron industry mainly relied on protection, we empirically confirm the presence of dynamic learning effects. If the U.S. had moved to free trade from 1870, market share of imported pig iron would have been as high as 42 percent in 1940. Our findings clearly support the notion that the American pig iron industry was an infant-industry. These are the major contributions of this study.

The next section describes characteristics of production, price, international trade and protection in the American pig iron industry from 1870 to 1940. Then we provide evidence against the assumption of imperfect substitution between imported and domestic pig iron in Section 3. In Section 4, we discuss a better approach to measure the size of protection in light of international trade theory and compare our result with Irwin (2000a). The

estimation of dynamic learning effects is in Section 5. Section 6 concludes the analysis.

2 Characteristics of the American Pig Iron Trade

This section gives an overview about production, price, trade pattern and protection of pig iron.

2.1 Production

The production of pig iron and ferro-alloys in the United States and the United Kingdom for selected years is tabulated in Table 1.⁴ Figure 1 provides the annual movements of U.S. pig iron production. The annual production of the domestic pig iron doubled in every decade from 1870 to 1890. Domestic pig iron production increased from 1.7 million gross tons in 1870 to 3.8 million gross tons in 1880, and it became 9.2 million gross tons in 1890. In fact, the U.S. surpassed Great Britain and became the world leading pig iron producer in 1890. At this point, the share of American production in world production was 34.4 percent while that of Great Britain was 29.4 percent. The industry slowed down during the depression in the 1890s but resumed its growth in the end of the century.

In the early twentieth century, domestic pig iron production continued to expand although there were declines in production in 1908, 1911 and 1914. In 1913 when the pig iron duty was temporarily removed, the U.S. accounted for approximately 40 percent of world production. The U.S. share of world pig iron production reached its peak in 1918, when the share was as high as 60 percent. After the industry recovered from the great depression in 1933, it returned to its pre-depression level in 1937. By 1940, the production of the domestic pig iron had tripled its 1900 level to 4.2 million gross tons. In contrast, the 1940 U.K. production remained approximately the same as its 1900 level or only one-fifth of the 1940 U.S. production.

⁴We do not exclude the production of ferro-alloys because of the limitation of data.

In terms of geographical distribution, main locations of production moved away from coal deposits towards iron ore deposits in the late 1870s. The reason is rising fuel economy, a fall in coal transport costs and the discovery of rich ore deposits in Great Lakes area, and subsequently in the South (Isard, 1948; Wright 1986). Table 2 gives details on the share of major iron-producing states. In the late nineteenth century, almost 50 percent of pig iron was produced in Pennsylvania. Clearly, we see a downward trend in New York-New Jersey and Pennsylvania. To the contrary, the Great Lakes states and Alabama showed an upward trend. However, Pennsylvania was still by far the most important state by the end of the nineteenth century. By 1920, the Great Lakes states combined share was 42 percent and surpassed Pennsylvania's 40 percent. Ohio was the fastest growing state among the Great Lakes. Alabama's share continued to grow and remained at 7 percent in 1940.

2.2 International Trade

The domestic pig iron was produced mostly for domestic demand. The U.S. was a net importer almost all the time and her export remained below 3 percent of production. Figure 2 shows the net imports of pig iron. The U.S. was Britain's one of the most important importers until the mid 1880s. In 1894, the U.S. became a net exporter of pig iron for the first time. The American producers continued to produce for domestic demand throughout 1940, although the U.S. became a net exporter of pig iron sporadically. By any standard, the pig iron import substitution for the U.S. experience was a great success.

Table 3. gives geographical breakdown of countries exporting pig iron to the U.S. in net term. Great Britain had been the main exporter from the late nineteenth century. Although Belgium, Germany and Netherlands became net exports to the U.S. by 1910, their shares were far smaller than that of Britain. British India rose as a new exporter in the mid 1910s. However, the U.S. became a net exporter against these trading partners temporarily in 1917. In the 1920s, the main exporters were British India, Great Britain

and Germany. In the 1930s, Netherlands led British India and Canada, while Britain turned to import pig iron from the U.S. through the second half of the decade.

2.3 Price

The average prices of the domestic pig iron in each decade are summarized in Table 4. While the production expanded rapidly in 1870-1990, the domestic price of pig iron fell from an average value of 29.63 dollars per gross ton during the 1870s to 20.20 dollars per gross ton during the 1880s. The average price declined sharply to 13.78 dollars per gross ton during the 1890s. In the early twentieth century, the domestic price bounced back to its previous level on average. The average price in the 1900s was 18.21 dollars per gross ton. It subsequently rose to 23.19 dollars per gross ton in the 1910s and to 25.34 dollars per gross ton in the 1920s. In the 1930s, the price declined to 20.69 dollars per gross ton. The relatively high price in the twentieth century suggest a possibility of monopoly pricing scheme, which could have resulted from the formation of the United States Steel Corporation in 1901. Investigation of the effects of the emergence of the United States Steel Corporation on pricing and production of domestic pig iron in this period is crucial, but beyond the scope of this paper.

It is also evident from Table 4 that, on average, domestic pig iron was priced higher than imported British pig iron throughout the seven decades. The ratio of price of domestic pig iron to that of British counterpart of the same variety far exceeded unity. It should be noted that transport costs are not included in this comparison, because there is no consistent time series on pig iron transport costs. To get a better picture, Figure 3 gives an annual price comparison between domestic prices of pig iron, U.K. prices of pig iron and prices of U.K. pig iron in the U.S.⁵ It is clear that the price of imported pig iron in the U.S. was lower than the U.S. price until 1887. Then, it exceeded the price of domestic

⁵The U.S. prices are no.1 Foundry price at Philadelphia for 1870-85, and Bessemer price at Chicago for 1886-1940. The U.K. price of pig iron is no.1 Foundry price at Cleveland for 1870-85, and Cleveland Bessemer price for 1886-1940.

pig iron throughout the following 15 years, until 1902. From 1902 to the abolition of pig iron duty in 1913, the two prices were approximately equal despite the fluctuations. From 1913, the U.K. price and the price of U.K. pig iron in the U.S. remained slightly lower than the U.S. price almost all the time.

As indicated in Figure 3, the protective nature of pig iron duty against the British pig iron became the most apparent in 1888-1902. However, there were still imports of pig iron from Britain in this period. This does not necessarily imply that the substitution between domestic and imported pig iron was less than perfect. The imports of pig iron in this period were mainly for consumption in the Atlantic and Pacific coastal areas. Throughout the 1910s, the share of imports to Atlantic and Pacific ports accounted for more than 90 percent of the total imports⁶. The primary reason for this is the high costs of shipping pig iron from the inland furnaces to the coastal areas. This pattern of imports is consistent with the decline of production in New York-New Jersey area, as indicated in Table 2. Unlike inland producers, the seaboard area producers are not naturally protected by inland transport costs and faced tough foreign competition.

2.4 Protection of the Domestic Pig Iron Industry

A pig iron duty was in effect through the sample period except for from 1913 to 1921, when the duty was temporarily abolished. The duty was specific regardless of types or qualities until January 1, 1939.

The rate on pig iron was 7 dollars per gross ton from 1870 to 1872; then it was 6.30 dollars per gross ton from 1872 to 1875. From 1875 to 1883, the rate was increased back to 7.00 dollars per gross ton. It was again reduced to 6.72 dollars per gross ton from 1883 to 1894. Then it was 4 dollars per gross ton from 1894 to 1909. From 1909 to 1913 where the pig iron duties were removed, the rate was 2.50 dollars per gross ton. However, the duty of 0.75 dollars per gross ton was reintroduced in 1922. In 1927, it was raised

⁶The imports statistics by ports of entry are from *Foreign Commerce and Navigation of the United States*, Bureau of the Census.

to 1.125 dollars per gross ton. From 1939, the duty applied differently to different types, namely 1.125 dollars per gross ton for pig iron with over 0.04 percent of phosphorus and 0.75 dollars per gross ton for pig iron with 0.04 percent or lower of phosphorus.

The frequent adjustments of the tariff level in the 1880s and 1890s are more accurately seen as adjustments for price changes than as actual reductions in the rate. An equivalent ad valorem rate ⁷ is thus preferable to the duties as a measure of protectiveness because it reflects changes in effective tariffs without changes in tariff laws (Temin, 1964; and Sundararajan, 1970). ⁸ The movements of equivalent ad valorem rates are shown in Figure 4. The series are calculated using times series of price and collected duties. The ad valorem equivalent tariffs rose dramatically in the 1870s and 1880s because of the declines in prices of imported pig iron. The rate peaked at 84 percent in 1885 and declined slowly in the 1890s. Then it fluctuated around 25 percent in the early twentieth century until the removal of duties on pig iron in 1913.

Although the pig iron duty was reintroduced in 1922, it did not play a significant role in protection of the industry as a whole. The purpose of its re-introduction was to protect manufactures in seaboard areas. Seaboard areas such as New York and New Jersey were not naturally protected by high transport costs and thus faced tough foreign competition (Berglund and Wright, 1929; Sundararajan, 1970). The equivalent ad valorem rates remained below 10 percent from 1922 to 1940. The reason lies on the fact that the domestic pig iron producers had long replaced Britain as the main supplier for domestic pig iron market. Although domestic suppliers sometimes could not meet the entire domestic demand for pig iron, import market share in domestic consumption in net terms remained lower than 2 percent most of the time from 1889. In 1922, import market share became as low as 1.30 percent.

⁷As mentioned above, pig iron was subjected to specific duty, not tariffs. The term “equivalent ad valorem” rate applies to the ratio of collected duties to the value of imports. It is used to gauge the degree of protectiveness.

⁸Sundararajan (1970) suggests using “effective protection rate” as a proxy for protection. The correlation of his measured effective protection rate and ad valorem tariff is, however, as high as 0.93.

It should be noted that the cross section comparison in this section is based on a specific pair of varieties of pig iron at a specific point in time. Pig iron is actually a differentiated products industry. There are various grades of pig iron being categorized by chemical contents. The next section discusses about the composition of pig iron production in details.

3 Varieties, and Substitution between Foreign and Domestic Pig Iron

Pig iron is a form in which iron first appears when smelted from its ore. It varies in its chemical composition and utilized for different purposes based on these differences. Table 5 classifies various grades of pig iron by their chemical contents (Berglund and Wright, 1929).⁹ The major chemical contents determining quality of pig iron are carbon, silicon, manganese, phosphorus and sulphur. Carbon is the most important element that influences hardness, malleability, magnetism and electric conductivity. The carbon content for pig iron ranges from 3 to 4 percent. It is the high carbon content that makes pig iron non-malleable in any temperature. One method to make it malleable is to use high temperature without fusing. The pig iron produced by this particular method is called malleable iron. In general, there are no monotonic relationships between a single chemical content of pig iron and its quality except for silicon. The higher silicon content is, the worse the quality (Kirk, 1911).

The composition of pig iron production in the U.S. and Great Britain is shown in Figure 5 and 6.¹⁰ Until 1940, the major types of pig iron produced domestically were basic, Bessemer and low phosphorus, forge, foundry and malleable. The main characteristic of domestic production is the shift in the position of the dominant grade from Bessemer

⁹Classification of pig iron can be done by several standards, e.g. by fuel used, etc. (See Burglund and Wright (1929), or Kirk (1911) for details.) But those are irrelevant to the discussion in this paper.

¹⁰The Figures do not cover the entire sample period due to data limitations.

and low phosphorus to basic pig iron over the period 1900-1940. In 1900, Bessemer and low phosphorus pig iron accounted for almost 60 percent of total production, while basic pig iron accounted for only 8 percent. In contrast, the corresponding numbers in 1940 were 17 and 74 percent. The production of foundry pig iron was shrinking gradually and became less significant than the two major grades. The combined share of all other types remained less than 10 percent throughout the forty years.

Similar to the domestic pig iron industry in the twentieth century, British industry produced basic, hematite, forge and foundry pig iron during 1887-1906. Hematite pig iron is pig iron made from hematite ore by a Bessemer process. The primary purpose of using hematite ore is to lower phosphorus content in pig iron output (Carr and Taplin, 1962). For these reasons, British hematite pig iron is considered comparable to Bessemer and low phosphorus pig iron produced domestically. Evidently, hematite and Bessemer pig iron are used interchangeably in the discussion of British iron trade by Jeans (1906). Forge and foundry, and hematite pig iron remained the most important types throughout the period. The shares of forge and foundry, hematite and basic pig iron in 1887 were 49, 41 and 6 percent of total production, respectively. Their counterparts in 1906 were 44, 40 and 12 percent.

Based on the composition of pig iron production described above, it is reasonable to consider pig iron in the U.S. and Great Britain as an *identically differentiated products industry*. There is no reason to believe that varieties produced in one location were different from the same varieties in other locations, given the objectivity of the classification method. Our view is consistent with the observation that several authors consider imported and domestic pig iron homogeneous.¹¹ In contrast to the conventional approach, Irwin (2000a) treats American and British pig iron as two non-homogeneous goods. Without providing evidence for the heterogeneity, he applies a national product differentiation model by Armington (1969) and estimates elasticity of substitution between imported and

¹¹For instance, Allen (1979) draws on international competition among the U.S., Britain and German pig iron, and views pig iron as one homogeneous good. Or, see Sundararajan (1970)

domestic pig iron. Although he also uses a more flexible demand system, his results rest on the assumption of imperfect substitution. As a result, he underestimates the impacts of tariff on the expansion of domestic pig iron industry.

The key assumption in Armington (1969) model is that products are distinguished not only by their kind, but also by their place of production. The assumption is appropriate for some circumstance. It is plausible, if, for example, Steffan-Linder's home market effect is at force. In other words, when a country exports a good for which there is a strong domestic demand, the assumption is appropriate in explaining demand for its export. In addition, the Armington model predicts a decline in relative price when national output and export expands in equilibrium. The relative price and output data do not show such a trend and are at odds with the implication, as shown in Figure 7. Importantly, the Armington model was originally addressed to geographically differentiated varieties of a *final* good, not an intermediate input. It is very difficult to justify Irwin's argument for imperfect substitution between an intermediate input produced in the U.S. and Great Britain.

To illustrate this point, Table 6 gives some estimates of the elasticity of substitution between foreign and domestic goods in selected industries in the study by Shiell et al (1986). Clearly, the elasticity for intermediate goods industries varies from 7 to 14 percent. In contrast, the elasticity for final goods industries is approximately 2-3 percent. The pattern is consistent with our argument that pig iron, which is an intermediate input, is not differentiated by location of production. Lastly, the remaining dimension of locational differentiation in modern trade theory is the currency of denomination. However, the world was in a bimetallic and subsequently a metallic standard in his and our sample period. Therefore, importing pig iron to the U.S. did not involve currency risks. Overall, there was no differentiation between foreign and domestic pig iron of the same variety.

A better analysis on patterns of trade and tariff protection of the pig iron industry could be done by using a trade model embedded with production differentiation, economies

of scale and monopolistic competition, along the lines of Dixit and Stiglitz (1977) or Lancaster (1979). The two models predict that both countries will produce different varieties under free trade, and the gain from trade results from an opportunity to consume more varieties than in the autarky equilibrium. In the free trade equilibrium, each variety will be produced by only one country and the two countries will specialize on different varieties. Which country will produce what varieties depends on comparative advantage that is induced by differences in productivity of technology in each country (Helpman, 1984). In that framework, we will observe domestic production of pig iron under free trade if the U.S. has comparative advantage in varieties. In that case, the U.S. will also export the same set of varieties to other countries as well.¹²

Harley (2001) provides an excellent application along these lines. He investigates British cotton textiles exports to the U.S. and other markets, in order to assess comparative advantage of the U.S. and Great Britain in antebellum cotton textiles industry. Needless to say, cotton textiles industry is a differentiated products industry. The export data suggest that the U.S. imported high quality cotton products from Great Britain, while expanding domestic production of low quality cotton products. Great Britain, however, continued to export low quality cotton to other countries like India and Brazil. Such a trade pattern indicates that Great Britain had comparative advantage in both high and low quality products in international markets. Thus, the finding supports his hypothesis that antebellum U.S. cotton textiles industry depended substantially on tariff to survive.

In the context of pig iron, knowledge about the British exports of different varieties is sufficient to identify its comparative advantage relative to the U.S. This is because the American pig iron was produced for domestic use, not export, consistently throughout the sample period. In the late nineteenth century, the main trading partners importing pig iron from Great Britain were Canada, India, Australia, South Africa and Argentina.¹³

¹²Helpman (1983) constructs a model for intermediate input as a differentiated products industry. Nonetheless, the general prediction of pattern of trade is similar to what discussed here.

¹³The U.S. was also one of the main importers until the mid 1880s, and almost stopped importing pig iron from Great Britain in 1893-94.

Unfortunately, there are no bilateral data on quality breakdown of British pig iron exports. Nevertheless, the finding that British industry produces pig iron of the same varieties as domestic industry is sufficient to make the assumption of imperfect substitution between imported and domestic pig iron invalid. Next section will assume perfect substitution and give an estimate of the benefit of tariff protection on domestic pig iron industry.

4 The Impact of Tariff Structure

A partial equilibrium analysis provides a simple framework for assessing an impact of tariff protection on a particular industry. Besides the elasticity of substitution between domestic and imported pig iron, the impact of the tariff also depends on the elasticity of total domestic demand, the elasticity of domestic supply and the elasticity of foreign supply. Irwin (2000a) estimates the four elasticity parameters, estimates effects of a reduction in duty, and simulates some counterfactual scenarios by varying duty in ad valorem term in 1870.

In the following subsections, we discuss the methodology and the results in his paper. Finally, we re-estimate the elasticity parameters using the same method with different series and period, and then simulate a similar hypothetical scenario, in which the U.S. moves to a free trade regime in 1870.

4.1 Methodology

4.1.1 Estimation of Demand Side Elasticity Parameters

With an Armington assumption, Irwin (2000a) allows for more flexible demand system proposed by Shiells et al (1986). It results in estimating the equation:

$$\log M_t = \alpha + \eta_{MD} \log(p_D/p_{CPI}) + \eta_M \log(p_M(1 + \tau)/p_{CPI}) + \gamma \log Y_t + \lambda \log M_{t-1} + v_t \quad (1)$$

where M is the quantity of imported pig iron. Given the price of domestic pig iron denoted p_D , and the ad valorem tariff inclusive price of imported pig iron denoted $p_M(1 + \tau)$, p_{CPI} is a domestic consumption price index used to normalize the domestic price and tariff inclusive price of imported pig iron. Y_t is total domestic expenditure on pig iron. The lagged dependent variable is included to account for partial adjustment. η_{MD} is the cross-price elasticity of demand for imported pig iron, and η_M is the elasticity of imported pig iron with respect to domestic price. γ is the elasticity of demand for imported pig iron with respect to total pig iron expenditures. Let σ be the elasticity of substitution between imported and domestic pig iron. It can be calculated from the estimated parameters as:

$$\sigma = \frac{\eta_{MD}}{\theta_D} + \gamma \quad (2)$$

where θ_D is the share of total spending on pig iron devoted to domestic production. The elasticity of total demand (η_Q) can be computed by the following formula.

$$\eta_Q = \frac{\eta_{MD}}{\theta_D} - \sigma \quad (3)$$

Irwin (2000a) estimates Equation (1) with instrumental variable technique. Table 4 summarizes the implied parameter estimates. His estimates are reported in the first column. Ours are in the second column. Since our estimation is done merely as a sensitivity check, we employ the same technique. A more appropriate method of estimation is, however, to use a simultaneous equations model based on a structural model, because of the invalidity of the Armington assumption.¹⁴ Also, we use a different set of instrumental variables because Irwin's variables appear to be endogenous. The instrumental variables are prices of domestic and imported Bituminous coal, prices of domestic steel rails, domestic consumption of steel rails and its one-period lag. The IV estimates of Equation (1) do not perform well in terms of statistical significance. As a result, we use OLS estimates to

¹⁴See Fogel and Engerman (1969), for example

calculate the parameter estimates.

Irwin's estimate of the cross-price elasticity of demand for imports is 2.24. His estimates of the short run and the long run elasticity of substitution are 3 and 6.6, respectively. Ours are 1.52 and 2.15. His estimate of the elasticity of total demand is -0.6 for short run and -1.4 for long run. Ours are -0.29 and -0.41.

4.1.2 Estimation of Elasticity of Domestic and Foreign Supply

The elasticity of domestic supply initially estimated by Irwin (2000a) is as small as 0.98. He then uses a period in which there is an exogenous shock to identify the elasticity parameters. The so-called "iron famine" period was used. The "iron famine" was a large, unanticipated shock to U.S. demand, starting in the spring of 1879 and continuing through 1880. The elasticity of domestic supply can be obtained by measuring percentage changes of production with respect to one percentage change in domestic price in this period. The elasticity of foreign supply can be obtained in a similar way using changes in imports of pig iron and the foreign price. For the short run parameter, we can compute it using changes in a shorter time horizon, that is, 1878 to 1880. In contrast, the long run parameter can be computed using 1878 to 1881.

The estimates of the elasticity parameters are also in Table 4. Irwin's estimates of the short run and the long run elasticity of domestic supply are 1.1 and 3. Ours estimates are 1.2 and 1.69. As for the elasticity of foreign supply, he proposes using 15, although his estimate was so high as 40. His argument that the results do not change significantly for elasticity values above 10 was consistent with our experiment. We also use the same number.

4.2 Simulation results

Using the estimates of the elasticity parameters, it is possible to simulate hypothetical situations in which the U.S. reduced pig iron duty in 1870. In other words, the benchmark

year is 1869. In 1870, the U.S. actually reduced pig iron duty from 9 dollars to 7 dollars per gross ton. Besides estimating effects of the actual duty reduction in 1870, Irwin (2000a) simulates a few hypothetical scenarios including a removal of the 60 percent tariff in 1870. Although the building block assumption in his analysis is the assumption of imperfect substitutes, he provides results of the simulation with perfect substitutability as well. As a sensitivity check, we simulate with perfect substitutability using our estimates.

Table 5 tabulates the simulation results under free trade regime. Cases A and B show Irwin's results under the imperfect-substitutes assumption. Case C corresponds to his results under the perfect-substitutes assumption, Finally, Case D show the results based on my parameter estimates. The most important variables of interest here are percentage change in domestic shipments and import market share. Assuming perfect substitutability, moving to a free trade regime would have yielded 54 percent of reduction in domestic shipments. The import market share in 1870 would have been as high as 71 percent. Our calculation gives 37 percent for the former, and 66 percent for the latter.

Irwin (2000a) concludes based on Case C that the American pig iron industry in the post-civil war period would have survived if the U.S. had moved to a free trade regime in 1870. Given the invalidity of imperfect substitutability, the numbers in Case D, not Case C, form the basis of the conclusion. Irwin's results themselves, however, show that his entire argument relies on the one particular assumption, which we found no evidence to support. Indeed, a substantial part of domestic pig iron industry would have not survived in a free trade regime. Although our simulation results imply slightly smaller benefits from protection than Irwin (2000a), the conclusion still holds.

In fact, our finding above is consistent with the tariff-growth paradox documented by Clemens and Williamson (2001). In their study, protection was associated with fast growth before World War II, while it was associated with slow growth thereafter. In addition, the tariff-growth association was powerful and positive in the industrial Core and rich New World before the World War II. In this connection, Irwin (2002) warns that

the tariff-growth correlation does not necessarily imply causality by providing country evidence. For instance, he argues that Argentina and Canada, which are the high tariff countries, grew because capital imports stimulated export-led growth in agricultural products, not because of trade protection. This scenario would not apply to the U.S. case. Therefore, our study supports the view that American industrialization largely benefited from protection.

4.3 International Competition in Pig Iron

Irwin (2000a) overlooks another important aspect in the international trade of pig iron, namely he formulates the competition in a bilateral context. In fact, Great Britain did not maintain her status as the most advantageous pig iron exporter throughout 1889, which marks the end of his sample period. In a comparison done by Allen (1979), Germany surpassed Britain in terms of competitiveness, and presumably became the potential source of imports to the U.S., from the late 1870s to 1913. Evidently, the domestic price of the German pig iron had been consistently lower than that of American pig iron from 1880 to 1913. The average domestic price of the German pig iron in 1881-1890 was 57 shillings per metric ton, and that of the American pig iron was 85 and shillings. The corresponding prices in 1906-1913 were 74 and 78 shillings, respectively. The competitiveness of the German pig iron is viewed as a result of technological growth, cartel formations and tariff protection. In particular, the cartel system allowed export price of the German pig iron to be even lower than its domestic price (Webb, 1980).

Such a shift in the pattern of international competition has an important implication for empirical strategies. By using the British supply condition in his simulation, Irwin substantially underestimates the benefits from protection. Re-estimating the supply condition with German data will give a more accurate evaluation of the benefits from protection.

5 Dynamic Learning Effects

Since protection was proved critical to the survival of the American pig iron industry, the benefits of protection could cumulate over time through learning-by-doing. Besides the invention of pneumatic or Bessemer process by Williams Kelly and Henry Bessemer, “hard driving” has received considerable attentions as the major innovation raising productivity of the American pig iron producers (Allen, 1977; Temin 1964). Hard driving technique was pioneered by some American producers from 1870, and further improved in the 1880s and 1890s. It allows a large amount of hot air to flow into blast furnaces at high pressure, in order to fasten the smelting process. It helps increase output per furnace, but adding this hard driven feature to a furnace requires a large sum of capital (Berck, 1978).

According to Berck’s calculation, constructing a new hard-driven furnace at Chicago would cost from 180,000 to 250,000 dollars in 1887. However, it saves capital costs per ton of output and yields profits as high as 130,000 dollars in one year. The annual capacity of a hard-driven furnace is estimated to be 43,500-52,690 gross tons. Clearly, this is highly profitable but quite a risky business, because redeeming the initial fixed cost mainly depends on the demand side fluctuations. However, pig iron duty helped reducing the riskiness by restricting competition with inexpensive imports, and allowing producers to sell in domestic markets at high price to cover the fixed costs.

As a consequence, the American producers could produce up to their furnace capacity when a small positive demand shock occurred. The economies of scale at the plant level was, therefore, the direct benefit from protection. The indirect effect of protection is the spillovers of learning-by-doing at the industry level. That institutions for learning have been in place made spillovers possible. They are professional associations that published their reports and provided a place to exchange knowledges among engineers and ironmasters. The most notable one was the American Iron and Steel Association first organized in 1864.¹⁵ Other related organizations are American Institute of Mining

¹⁵The original name was American Iron and Associates.

Engineers and the United States Association of Charcoal Iron Workers. The *Transactions of the American Institute of Mining Engineers* was first published in 1871, and the United States Association of Charcoal Iron Workers' *Journal* in 1880 (Gordon, 1996). Through these institutions, spillovers of learning led to further cost-saving techniques and achievements of industry-wide economies to scale. Consequently, pig iron producers became price-setters in imperfectly competitive markets, and operated at a large scale, along the same line as the endogenous growth theory (Romer, 1986).

Such learning effects could also spread to related industries through as people respond to incentives (Romer, 1990). Economies of scale in pig iron production created incentives for an expansion of investment in its inputs, particularly iron ore industry. Exploring ore deposits and mining are capital-intensive ventures and they were begun with sponsorships from several Great Lakes and Southern state governments from the 1820s.¹⁶ Among others, the explorations undertaken by Minnesota state geologists in the 1870s successfully led to the discovery of rich Lake Superior deposits (Gordon, 1996). Encouraged by potential profits, some private entrepreneurs subsequently participated in the exploration business. Notably, the Merritt brothers made a discovery of a rich Mesabi Range ore deposit in 1890. The opening of the Mesabi iron ore range and the Mesabi ore rush in 1892 resulted led to a fall in the domestic price of iron ore by half during the 1890s (Irwin, 2003). Consequently, pig iron production began shifting away from coal sites to the Great Lake areas.

Although downward integration of the spillovers is beyond the scope of this paper, it is difficult to deny a possible link between pig iron duty and discoveries of important ore deposits. The protection on pig iron helped reduce the risk of investment in iron ore exploration, as it created a favorable demand condition for iron ore. However, tariff alone would not make economies of scale possible. As emphasized by David and Wright

¹⁶North Carolina began as early as 1821. Tennessee followed in 1831, Pennsylvania in 1836, and South Carolina in 1844. Michigan and Kentucky state geologists also undertook explorations by 1870. See Gordon (1996) for details.

(1997), the role of legal and institutional organizations that encouraged learning cannot be ignored. The American ironmasters expanded their production around the new ore range, simply because they responded to incentives. To be specific, the positive feedbacks between iron ore exploration and pig iron production were the key drive. The cheap ore helped expand pig iron production, and pig iron production helped expanding iron ore exploration. Such feedbacks eventually resulted in a large scale of investment in both pig iron and iron ore industry. The protection on pig iron then became effective, given the right set of incentives.

The best proxy for economies of scale or dynamic learning effects in pig iron production is probably *capacity of furnace*. This is because capacity of furnace and scale of investment are closely related, as explained above. There are two measures of capacity: gross annual capacity and average capacity per furnace. The former measures scale at the industry level, and the later at the plant level.¹⁷ These measures are more useful in reflecting different driving forces than accumulated output used by Head (1994). To be specific, the plant level capacity is almost entirely determined by technology or supply condition. But the industry level capacity has much to do with demand condition, as it is a result of entries or exits of plant owners.

Figure 8 illustrates the capacity of the American pig iron industry at the industry and plant levels.¹⁸ In Figures 8.A and 8.B, there was only single observation in the nineteenth century in 1873. Within 40 years, from 1873-1912, the industry capacity increased almost 11 folds from 4 to 43 million gross tons. It continued to grow and reach 50 million gross tons in 1919 and fluctuated around the level since then. At the plant level, from 1873 to 1912, the capacity increases nearly 16 folds from 6,000 to 93,000 tons. From 1912, it remarkably showed an uninterrupted upward trend. The upward trend of furnace

¹⁷A pig iron production site usually had 3-4 furnaces (Berck, 1978). However, one plant equals one furnace in our discussion. This is purely semantic.

¹⁸American ironmasters also produced pig iron from electric furnaces. However, majority of them continued to rely on blast furnaces. Therefore, excluding electric furnaces, due to data limitations, should not post a serious problem.

capacity is indeed a manifestation of learning-by-doing that took place behind tariff walls from the 1870s to 1940. In 1940, the American furnace capacity was on average as large as 220,000 tons. As far as the dynamic learning effects hypothesis are concerned, such a favorable supply condition must have contributed to efficiency gains and falls in prices of the American pig iron. The next subsection formally tests the hypothesis.

5.1 Estimating Dynamic Learning Effects

The direct way to estimate the dynamic learning effects is to estimate a relationship between cost curves and investment scales. However, such data are not available. An alternative is to indirectly estimate from price data, as suggested by Head (1994).

In imperfectly competitive markets, firms are price-setters and price is the product of mark-up and marginal cost:

$$P_d = \mu MC = \mu A^{\alpha_A} P_o^{\alpha_o} P_c^{\alpha_c} Q^{\alpha_q} \exp(u) \quad (4)$$

where P_d is the domestic price of pig iron, $\mu > 0$ is the mark-up, and MC is the marginal cost. The cost function is assumed to be Cobb-Douglas. The marginal cost is consisted of learning effects A , prices of main inputs, namely price of iron ore P_o , price of coal P_c , and capital and labor costs implicitly embodied in output Q . The elasticity of each component is α_A , α_o , α_c and α_q , respectively. u is the stochastic component. The resulting estimation equation becomes:

$$\log P_d = C + \alpha_A \log A + \alpha_o \log P_o + \alpha_c \log P_c + \alpha_q \log Q + u, \quad (5)$$

where $C = \log(\mu)$.

In fact, the mark-up term may be variable. With imperfect competition, profits could arise when there is a positive demand shock, because firms may respond by raising mark-up and increasing cost-saving investment altogether. To capture a possibility of time-

variant mark-ups, we use the increase in the number of furnaces, ΔF , built as a measure of positive demand shocks. Hence,

$$\log(\mu) = C + \alpha_F \Delta F,$$

and the estimating equation with variable mark-ups become:

$$\log P_d = C + \alpha_F \Delta F + \alpha_A \log A + \alpha_o \log P_o + \alpha_c \log P_c + \alpha_q \log Q + u. \quad (6)$$

The most important parameter here is the elasticity of price with respect to scale, or α_A . If there are dynamic learning effects, $\alpha_A < 0$ must hold. Although an increase in output puts an upward pressure on price, its economies of scale also pushes price down in the opposite direction. The canceling effect of economies of scale depends on the relationship between output and capacity, or output-capacity ratio. As a result, dynamic learning effects increase the elasticity of domestic supply. Suppose the output-capacity ratio is k . Then the elasticity of domestic supply ϵ_s can be computed from the following formula:

$$\epsilon_s = (\alpha_q + \alpha_A(1 - dk/k))^{-1}, \alpha_A < 0, \quad (7)$$

and dk/k is the percentage change in k .

5.2 Estimation Results

We estimate Equations (5) and (6) using ordinary least square. There was no statistically significant time trend in both equations. The results are tabulated in Table 9.

Column A and B correspond to the constant mark-up case. Those for variable mark-up are in Column C and D. In all cases, factor prices contribute to a rise in price of pig iron, as indicated by the positive and statistically significant coefficients of iron ore price

and output, as anticipated. The coefficient of coal price is positive, although not significant. The coefficient of industry capacity and plan capacity is negative and statistically significant at 1 percent level in all cases. Assuming constant mark-up, the elasticity of pig iron price with respect to the industry capacity is -0.23, and that with respect to the furnace capacity is -0.12. The elasticity values become slightly smaller when we assume variable mark-up. However, the coefficient of the number of new furnaces is not statistically significant. It seems Column A and B are better fits. The adjusted R-squares in these regression are quite high, and the zero-slope F-test is rejected in all cases.

The main problem in this calculation is that, the extremely crucial output-capacity data in the early periods (1870-1872 and 1874-1911) are missing. Without the data, we cannot precisely compute the gain from economies to scale and the elasticity of domestic supply for the pre-World War I period. The only available observation in the period is 1873, and the output-capacity ratio is 0.64. We assume that the ratio for 1870-1911 has the same value, then the resulting estimate of the elasticity of supply is 33. From 1912-1940, the output-capacity ratio varied from 0.17 to 0.86 and the estimate of the elasticity can be computed accordingly.

5.3 Simulation with Dynamic Learning Effects

In this section, We re-simulate a hypothetical scenario where the U.S. moved to a free trade regime in 1870, using the estimates for the elasticity of domestic supply in the previous subsection. The demand side and foreign parameters remain the same as before.

We use our previous simulation result as the initial condition under free trade. Figure 9 summarizes the result. If the U.S. moved to free trade in 1870, the import market share in 1870 would become 66 percent, as showed in Table 8. If the policy continued, the import market share in 1940 would be 42 percent. It began to decline from 1920, after a long period of knowledge accumulation. Evidently, a gap between the simulated import market share and the actual one, which indicates the benefits from protection, is quite

large. By 1940, the gap still remained as high as 44 percent. From the actual path, the U.S. became an exporter of pig iron in 1894. Such an event would not be realized without tariff protection.

Note that the reason that the simulated import market share remained stable for a long period is that we assumed constant output-capacity ratio. Without a change in the ratio, there is little progress in learning because the initial duty removal in 1870 triggers a contraction in investment. As a result, it took a long time to cancel out the initial diseconomies. This is in a sense the by-product of the assumption of constant capacity-output ratio. An alternative approach is to try to estimate the ratio. The output-capacity ratio usually fluctuates depending on demand condition. Its estimation would involve many upstream industries and that could be quite a complicated task.

6 Concluding Remarks

This paper attempts to reexamine the question of the degree to which the domestic pig iron industry benefited from tariff protection from 1870 to 1940. Our finding contradicts the recent work by Douglas Irwin: British and American pig irons are *identically* differentiated products and they are perfect substitutes, consequently the expansion of the domestic pig iron industry depended highly on protection. If the duty were removed in 1870, domestic pig iron shipments would have fallen as much as 37 percent and the import market share would have risen to 66 percent in 1870.

In the second part of the analysis, we confirm the presence of dynamic learning effects at both industry and plant level. To put differently, both demand and supply conditions contributed to the growth of the American pig iron industry. We then incorporate dynamic learning effects and simulate a free trade regime from 1870 to 1940. We find that, without protection, the import market share in 1940 would be as high as 42 percent. Our findings support the hypothesis that tariff was necessary for the growth of the American pig iron industry.

Certainly, such a *ceteris paribus* counterfactual analysis does not capture dynamic changes over the period. It, however, offers a simple way to evaluate the role of protection in American industrialization. A more complete analysis would require substantial knowledge about the pattern of international competition in pig iron. In our study, the estimate of foreign supply curve is based on British data throughout the period, although potential exporters to the U.S. shifted from Britain to Germany in the late nineteenth century. In the late 1920s, British India had dominated Britain as the main exporter, given the breakdown of import data. In the 1930s, the leading exporters were British India, Netherlands and Canada. Consequently, our current analysis underestimated the effect of protection for the most part, as Britain was not always competitive and did not maintain its status as the main exporter from the mid 1930s.

The simulation results should also be interpreted with caution. In our analysis, we ignore the geographical aspect of the American pig iron industry. Besides tariff protection, a large fraction of the industry was naturally protected by high inland transport costs. Even without protection, some inland producers would be able to continue their production and keep accumulating experience and knowledge. That could generate spillovers across regions and fasten the dynamic learning effects. Treating the U.S. pig iron industry as an integrated national market could therefore overestimate the importance of protection. In addition, both domestic prices and import prices of pig iron vary across regions, depending on regional demand and supply conditions. Thus, breaking the industry into regional markets will be a natural extension of this study.

Having concluded that the American pig iron industry expanded behind tariff wall, our study does not imply that developing countries today will surely enjoy the benefits from protection in the same way. The primary reason is that, the economic system today is far different from the past. For instance, international monetary arrangement is no more a metallic standard and importing foreign goods does incur currency risks. Such a change certainly reduces the substitutability of domestic goods and imports, and can

undermine the import substitution policy. This is just one possibility. If anything, the fall of transport costs have made countries prone to foreign competition, and a large-scale investment in import-competing industries have become riskier than in the past. These factors, among other things, may partially contribute to why Latin American import substitution policies did not lead to industrial successes.

**Table 1. The U.S. and U.K. Pig iron Production
(1,000 Gross Tons)**

Year	U.S.	U.K.
1870	1,665	5,963
1875	2,024	6,365
1880	3,835	7,749
1885	4,045	7,415
1890	9,203	7,875
1895	9,446	7,703
1900	13,789	8,960
1905	22,992	9,608
1910	27,304	10,012
1915	29,916	8,724
1920	36,926	8,035
1925	36,701	6,262
1930	31,752	6,192
1935	21,373	6,424
1940	42,320	8,204

Sources:

(1) U.S. series are from the *Annual Statistical Report*, American Iron and Steel Association, various issues

(2) U.K. series are from Carr, J. C. and W. Taplin (1962).

**Table 2. Geographical Distribution of the U.S. Pig
Iron Production**

Year	New York New Jersey	Pennsylvania	Illinois	Ohio	Indiana Michigan	Wisconsin Minnesota	Alabama
1872	0.14	0.49	0.14	0.03	0.05	0.02	0.00
1880	0.08	0.48	0.15	0.03	0.04	0.02	0.02
1890	0.05	0.48	0.13	0.08	0.03	0.02	0.09
1900	0.03	0.46	0.18	0.10	0.01	0.01	0.09
1910	0.08	0.41	0.21	0.10	0.05	0.01	0.07
1920	0.07	0.38	0.23	0.09	0.08	0.02	0.06
1930	0.07	0.32	0.21	0.11	0.12	0.03	0.08
1940	0.07	0.17	0.22	0.09	0.15	0.02	0.07

Sources:

- (1) The *Annual Statistical Report*, American Iron and Steel Association, various issues.
- (2) The *Annual Report of the Secretary*, American Iron and Steel Association, 1875.

Table 3. Country Share in Net Imports of Pig Iron

Year	Britain	Belgium	Germany	Netherlands	British India	Canada
1895	1.09	0	0.02	0	0	-2.40
1900	0.13	-0.13	-0.18	-0.20	0	-0.15
1905	1.47	0.05	0.10	0	0	-0.66
1910	1.22	0.01	0.02	0.01	0	-0.42
1913	0.84	-0.01	0.07	0	0	-1.65
1915	1.46	0.01	0.25	0	0.13	-0.92
1917	-0.09	0	0	-0.03	0	-0.14
1920	1.85	-0.93	-0.46	-0.66	0.06	1.46
1923	0.57	0.04	0.06	0	0.05	0.10
1925	0.28	-0.01	0.06	n.a.	0.39	-0.01
1927	0.19	-0.02	0.08	n.a.	0.56	-0.11
1930	0.11	0	0	0.05	0.88	-0.07
1933	0.04	0	0	0.44	0.44	0.08
1935	0.11	0	0.04	0.38	0.29	0.10
1937	-0.35	-0.02	0	0.04	0.10	0
1940	-0.84	-0.01	0	0	0.01	-0.04

Sources:

(1) *Foreign Commerce and Navigation of the United States*, Bureau of the Census, various issues.

(2) *The Annual Statistical Report*, American Iron and Steel Association, various issues.

Note: A negative sign implies an export share.

Table 4. Average Ad Valorem Rate and Prices of Pig Iron

Decade	Ad valorem rate (%)	U.S. price (\$)	U.K. price (\$)	U.S. price/U.K. price
1870s	50.67	29.63	15.15	1.95
1880s	66.56	20.20	10.41	1.94
1890s	41.35	13.78	12.53	1.10
1900s	25.64	18.21	15.19	1.20
1910s	4.61	23.19	19.69	1.18
1920s	3.96	25.34	21.32	1.19
1930s	6.41	20.69	17.80	1.16

Notes:

- (1) All averages are simple means.
- (2) The ad valorem rate is defined as the ratio of collected duties to the value of imports.
- (3) U.S. prices are no. 1 foundry price at Philadelphia for 1870-85, and Bessemerprice at Chicago for 1886-1940.
- (4) U.K. prices are no. 1 foundry price at Cleveland for 1870-85, and Bessemer price at Cleveland for 1886-1940.

**Table 5. Non-Ferrous Content of Various Grades of
Pig Iron
(Percentage of Total Content)**

Name	Carbon	Silicon	Manganese	Phosphorus	Sulphur
Foundry, <i>no.1</i>	3-4	2.75	0.2-1.6	0.3-1.5	0.035
Foundry, <i>no.2</i>	3-4	2.25	0.2-1.6	0.3-1.5	0.045
Foundry, <i>no.3</i>	3-4	1.75	0.2-1.6	0.3-1.5	0.055
Foundry, <i>no.4</i>	3-4	1.25	0.2-1.6	0.3-1.5	0.065
Forge iron	3-4	0.75-1.75	0.2-1.5	0.3-3.0	0.05-0.3
Bessemer, <i>acid</i>	3.5-4	0.8-2.0	0.3-0.5	Less than 0.1	0.03-0.8
Bessemer, <i>basic</i>	3.5-4	Less than 1.0	1.0-2.0	1.75-3.5	Less than 0.1
Open hearth, <i>acid</i>	3.5-4	0.75-2.5	0.3-0.5	Less than 0.05	Less than 0.5
Open hearth, <i>basic</i>	3.5-4	Less than 1.0	1.0-2.0	0.1-2.0	Less than 0.1

Source: Stoughton, Bradley. (1913) *The Metallurgy of Iron and Steel*, p. 8.

**Table 6. Estimates of the Elasticity of Substitution
between Imports and Home Goods for the U.S.,
1962-1978**

Industry	Estimate
<i>Intermediate goods</i>	
Chemicals	14.0
Industrial chemicals	9.9
Plastics	6.5
<i>Final goods</i>	
Iron and steel products	3.1
Rubber products	2.7
Finished leather	1.6

Source: Shiells, Stern and Deardorff (1986)

Table 7. Estimates of the Elasticity Parameters

Parameter	Irwin (2000a)	Naknoi
σ	3, 6.6	1.52, 2.15
η_{MD}	2.24	1.24
η_Q	-0.6, -1.4	-0.29, -0.41
ϵ_s	1.1, 3	1.2, 1.69
ϵ_s^*	15	15

Notes:

(1) σ is the elasticity of substitution. When two numbers are reported, the first is to the short run value and the second is the long run value. This is true for other parameter estimates as well.

(2) η_{MD} is the cross-price elasticity of demand for imported pig iron.

(3) η_Q is the elasticity of total demand.

(4) ϵ_s is the elasticity of domestic supply.

(5) ϵ_s^* is the elasticity of foreign supply.

Table 8. Simulated Effects of Duty Removal

Change (Percent)	Imperfect Substitution		Imperfect Substitution	
	A.	B.	C.	D.
	Irwin (2000a) Short run	Irwin (2000a) Long run	Irwin (2000a)	Naknoi
Domestic price	-5.7	-5.5	-25.1	-22.0
Domestic production	-5.5	-15.8	-53.9	-37.1
Border price of imports	6.9	12.6	19.3	14.3
Internal price of imports	-33.2	-29.7	-25.1	-22.0
Imports value	171.7	489.1	1323.8	1420.7
1870 Import market share	13.9	29.4	70.5	65.7

Notes:

- (1) The benchmark equivalent ad valorem rate in 1869 is 60 percent in Irwin (2000a), and 59 percent in my calculation.
- (2) The value of domestic output in 1869 is 58.9 million dollars and the value of import is 4.7 million dollars.
- (3) The import market share in 1869 is 7.4 percent.
- (4) The "Perfect Substitution" case uses the long run elasticity estimates.

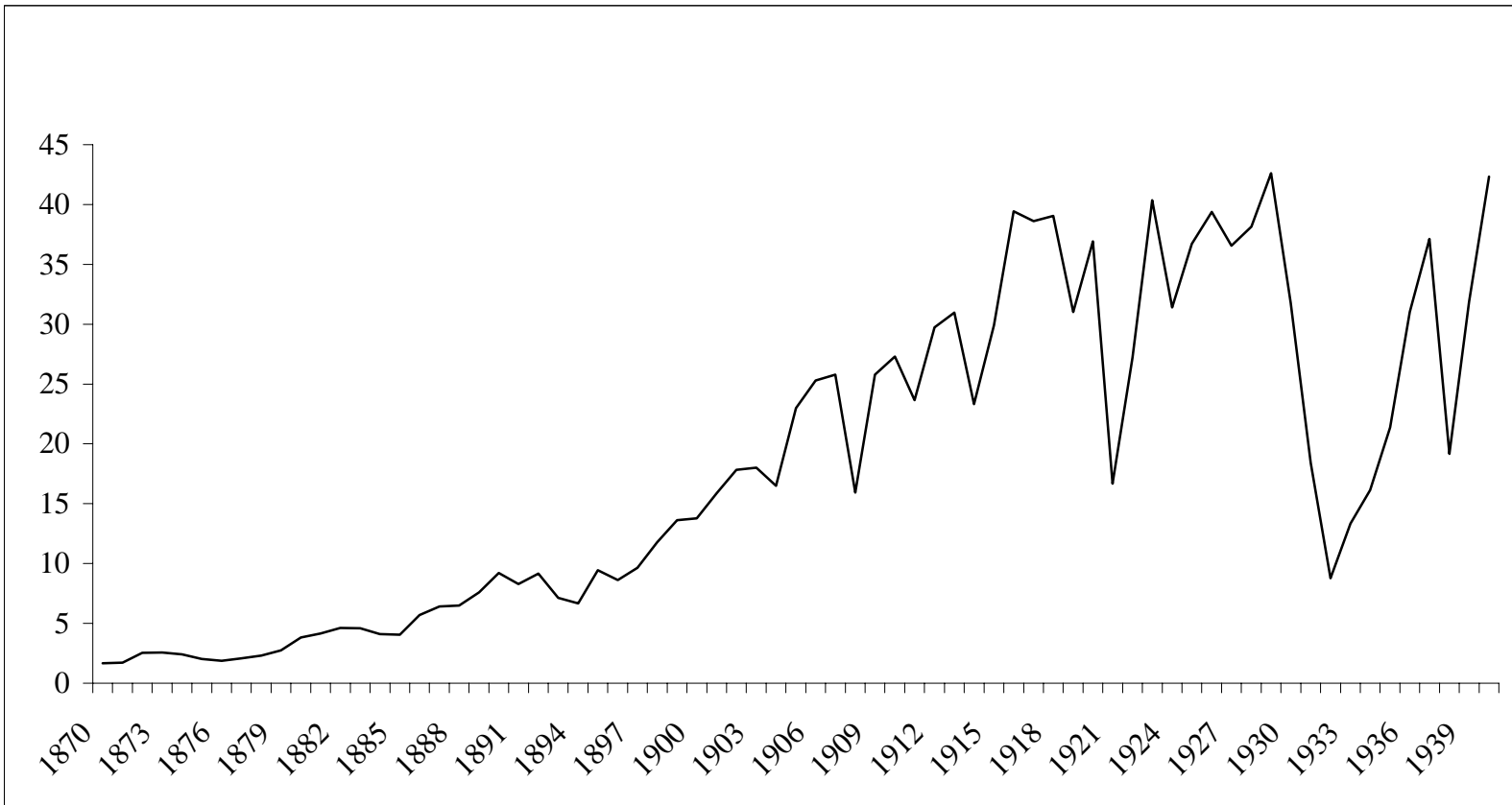
Table 9. Dynamic Learning Effects in Pig Iron Industry

Variables	Constant mark-up		Variable mark-up	
	A. Industry	B. Plant	C. Industry	D. Plant
Constant	0.59 (0.54)	-1.10 (1.41)	0.07 (0.07)	-1.43 (1.45)
Iron ore price	1.20*** (8.24)	1.21*** (10.18)	1.05*** (6.15)	1.09*** (6.83)
Coal price	0.14 (1.23)	0.14 (1.10)	0.23 (1.61)	0.21 (1.31)
Output	0.26*** (5.13)	0.21*** (4.66)	0.26*** (4.90)	0.21*** (4.66)
Industry capacity	-0.23*** (3.55)		-0.19*** (2.87)	
Plant capacity		-0.12*** (3.17)		-0.09* (1.89)
New furnaces			1.83 (1.60)	1.75 (1.48)
R^2	0.88	0.88	0.90	0.89
F-statistics	58.69	54.72	53.39	48.01
Sample size	31	31	31	31

Notes:

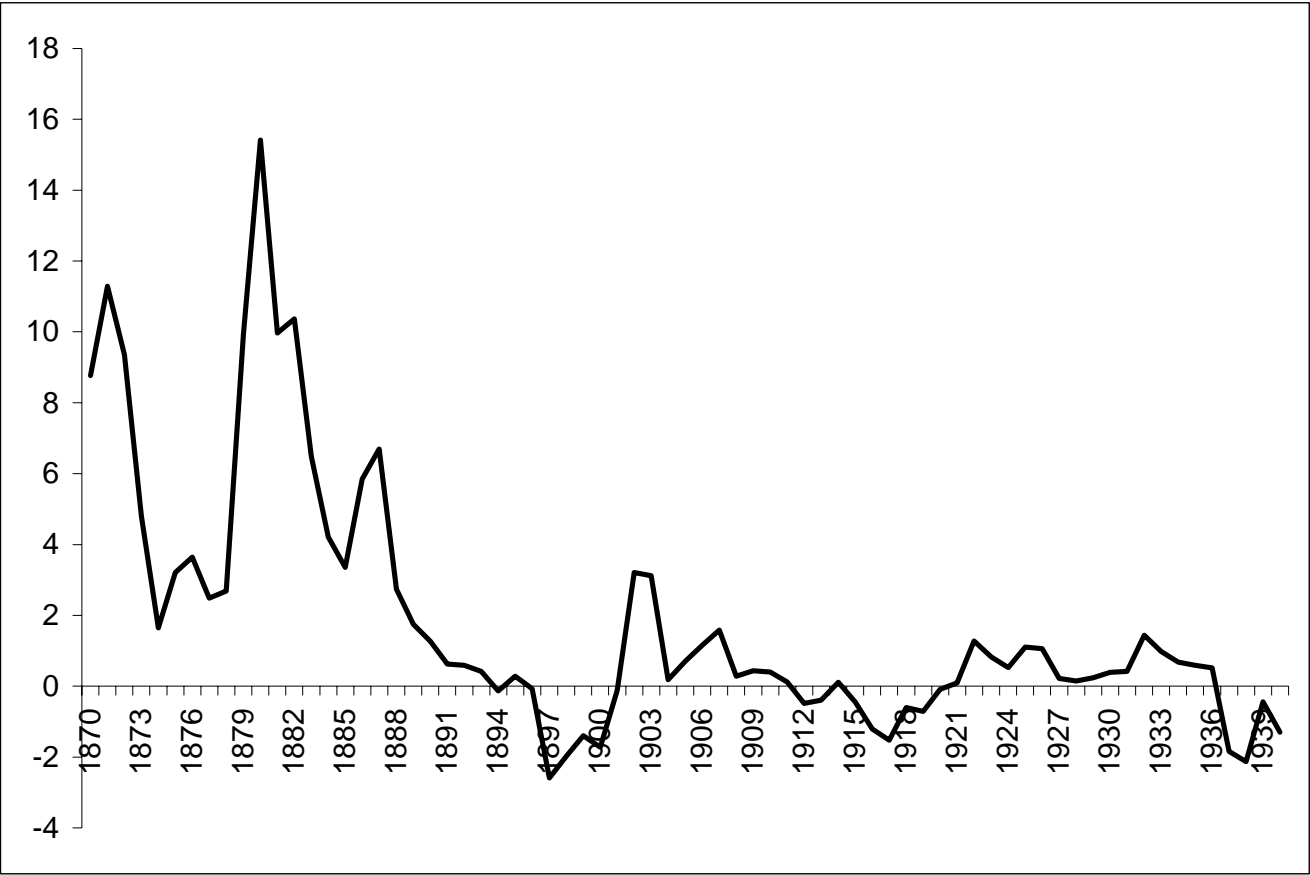
- (1) Method of estimation is ordinary least square. Standard errors are adjusted for heteroskedasticity.
- (2) Numbers in parentheses are t-ratios.
- (3) *** and * indicate statistical significance at 1 and 10 percent level, respectively.

**Figure 1. Annual Production of U.S. Pig Iron
(Million Gross Tons)**



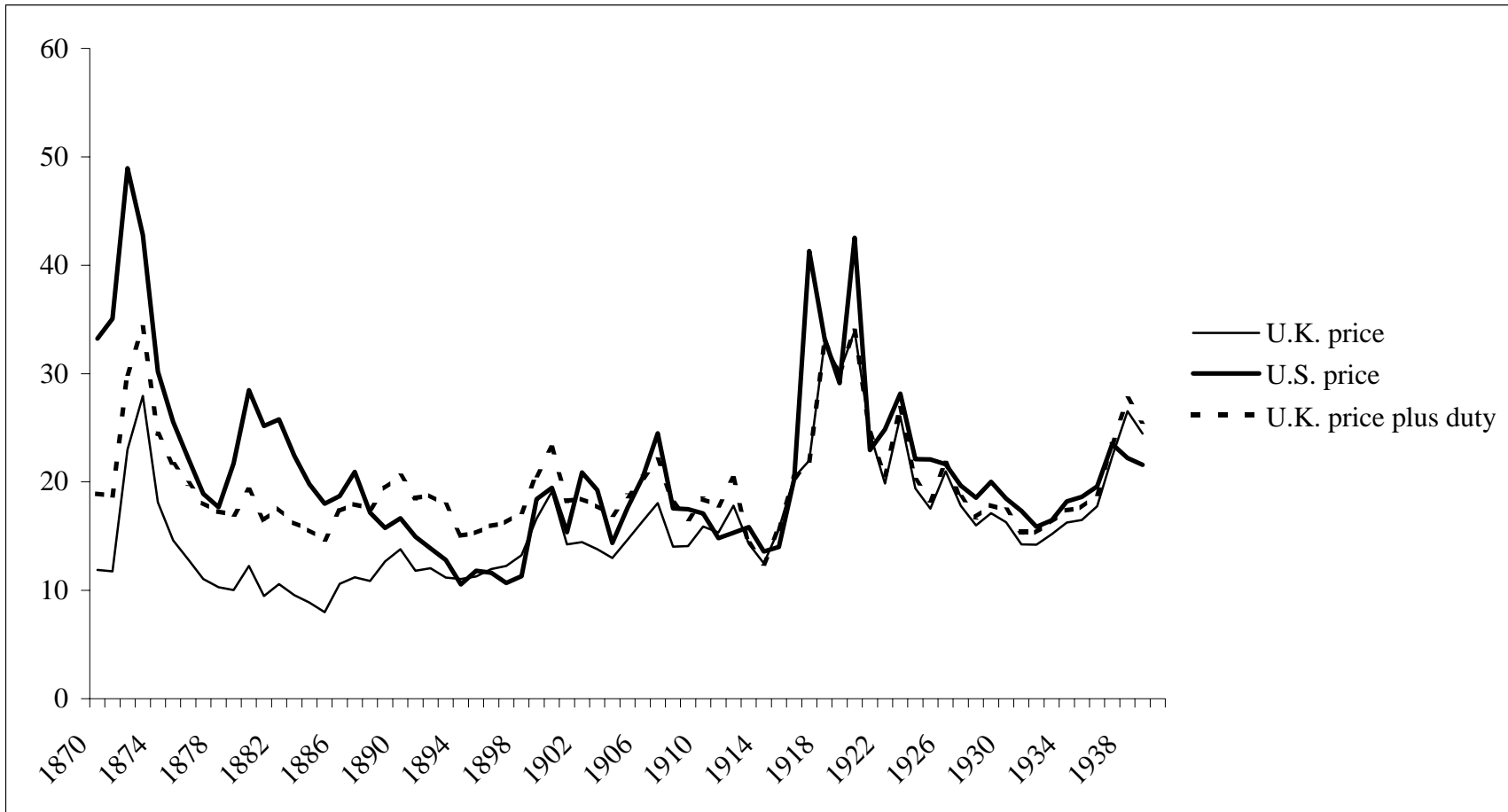
Source: See sources for Table 1.

**Figure 2. Import Market Share by Volume
(Percent)**



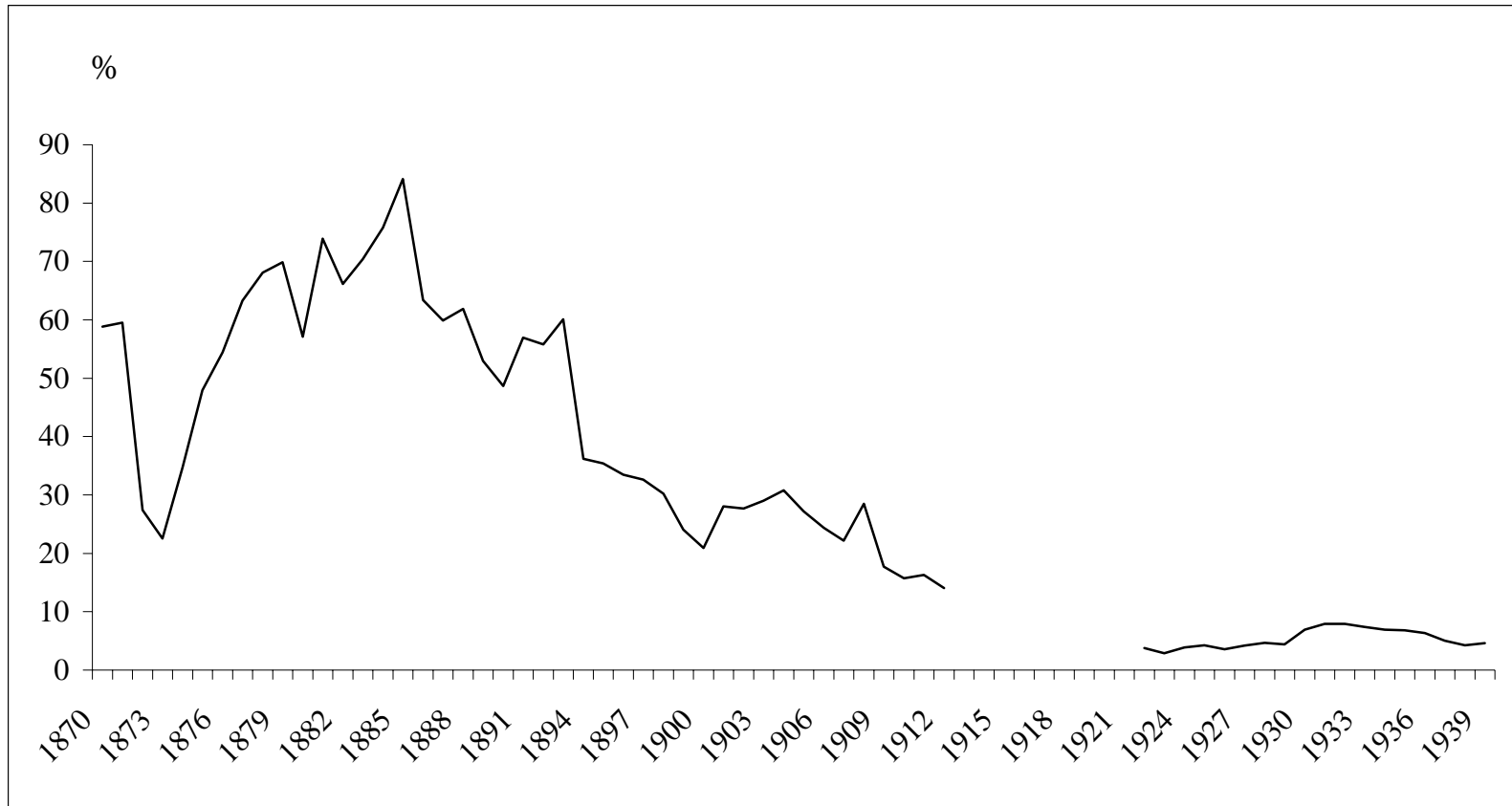
Source: *Statistical Abstract of the U.S.*, various issues.

**Figure 3. Average Price of Domestic and British Pig Iron
(US\$ per Gross Ton)**



Source: *Annual Statistical Report*, American Iron and Steel Association, various issues.

**Figure 4. Equivalent Ad Valorem Rate of Imported Pig Iron
(Percent)**



Sources: Taussig (1915), Berglund and Wright (1929), and *Metal Statistics*, American Metal Market Daily Iron and Steel Report, various issues.

Figure 5. Composition of U.S. Pig Iron Production

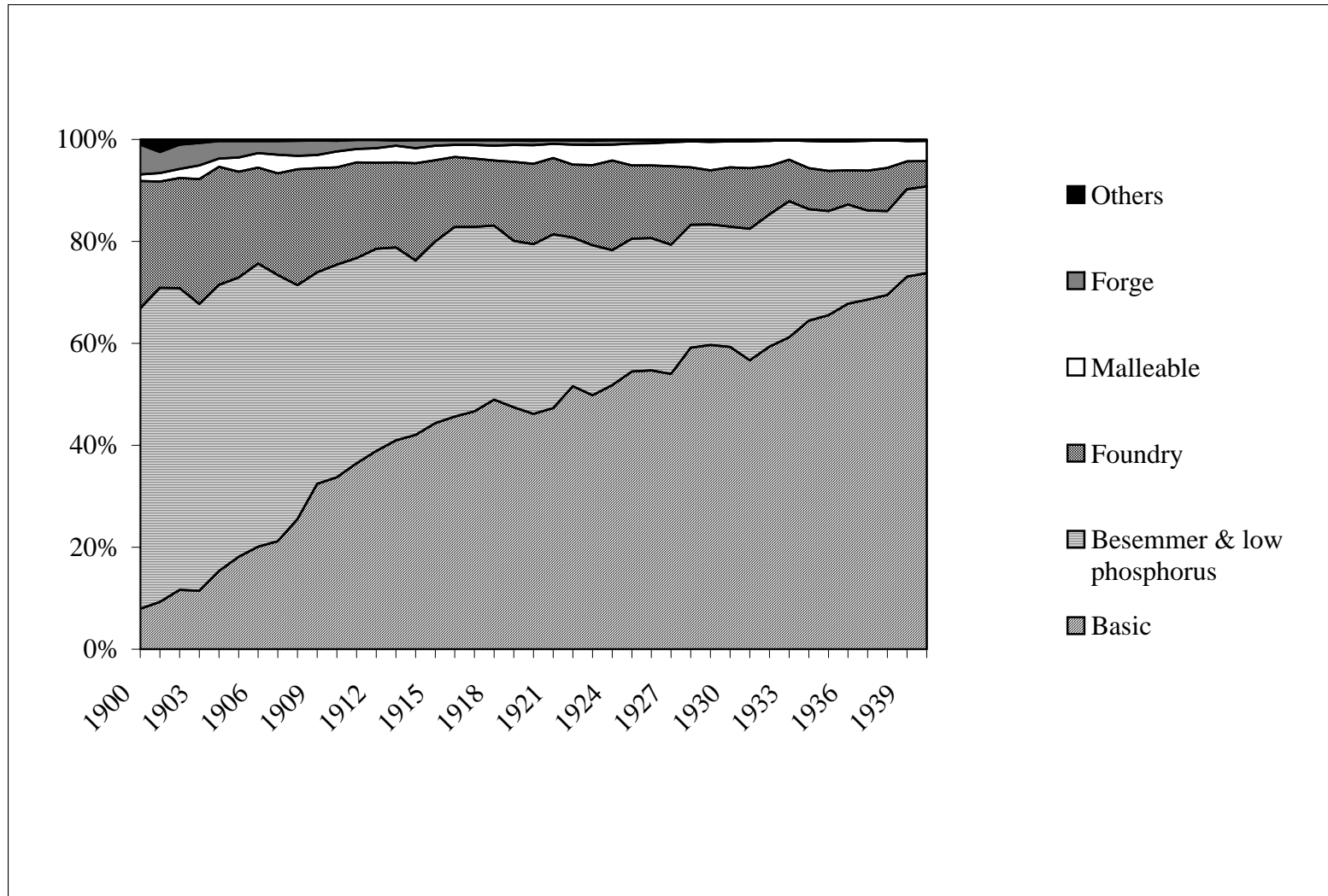


Figure 6. Composition of U.K. Pig Iron Production

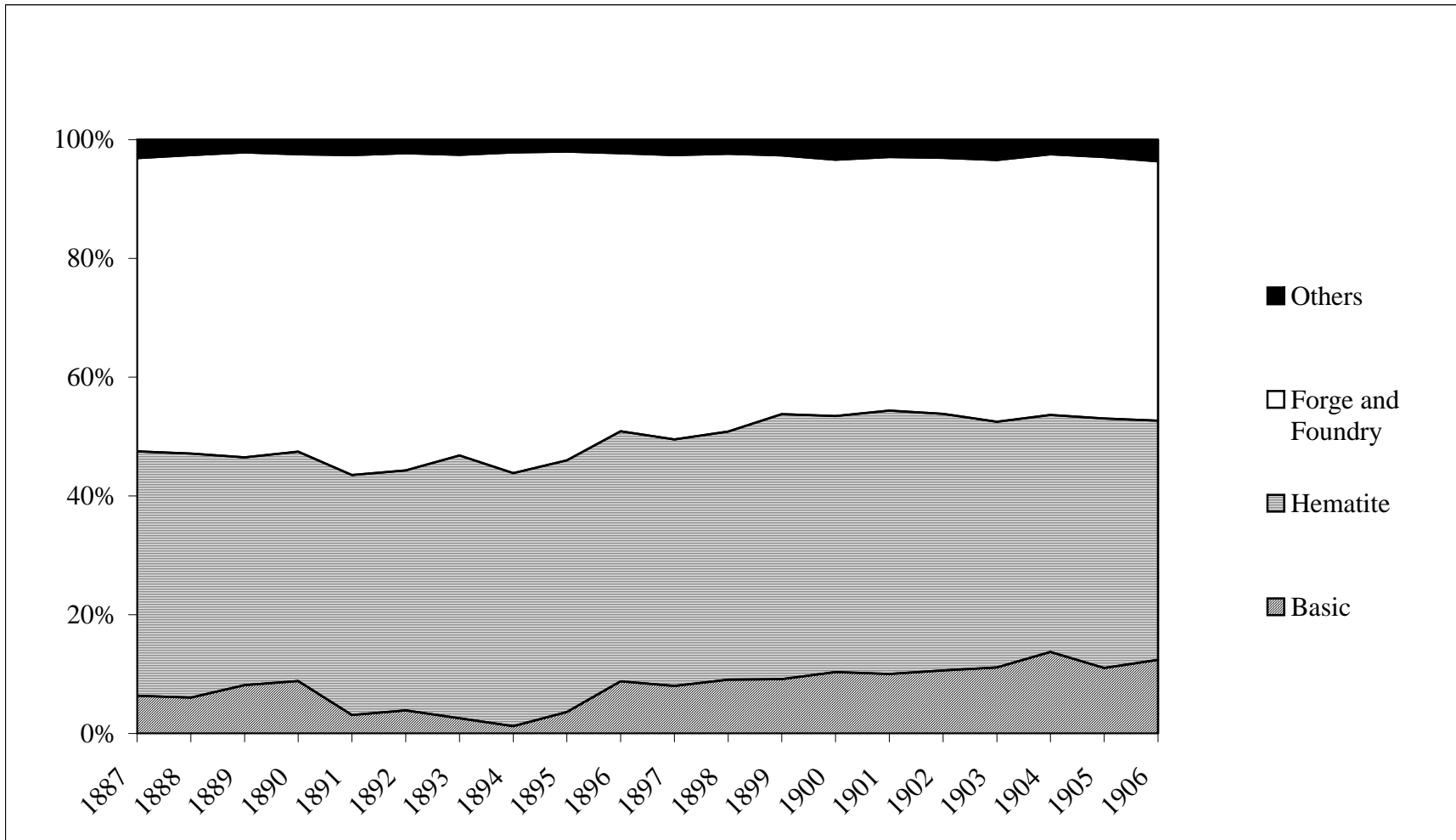
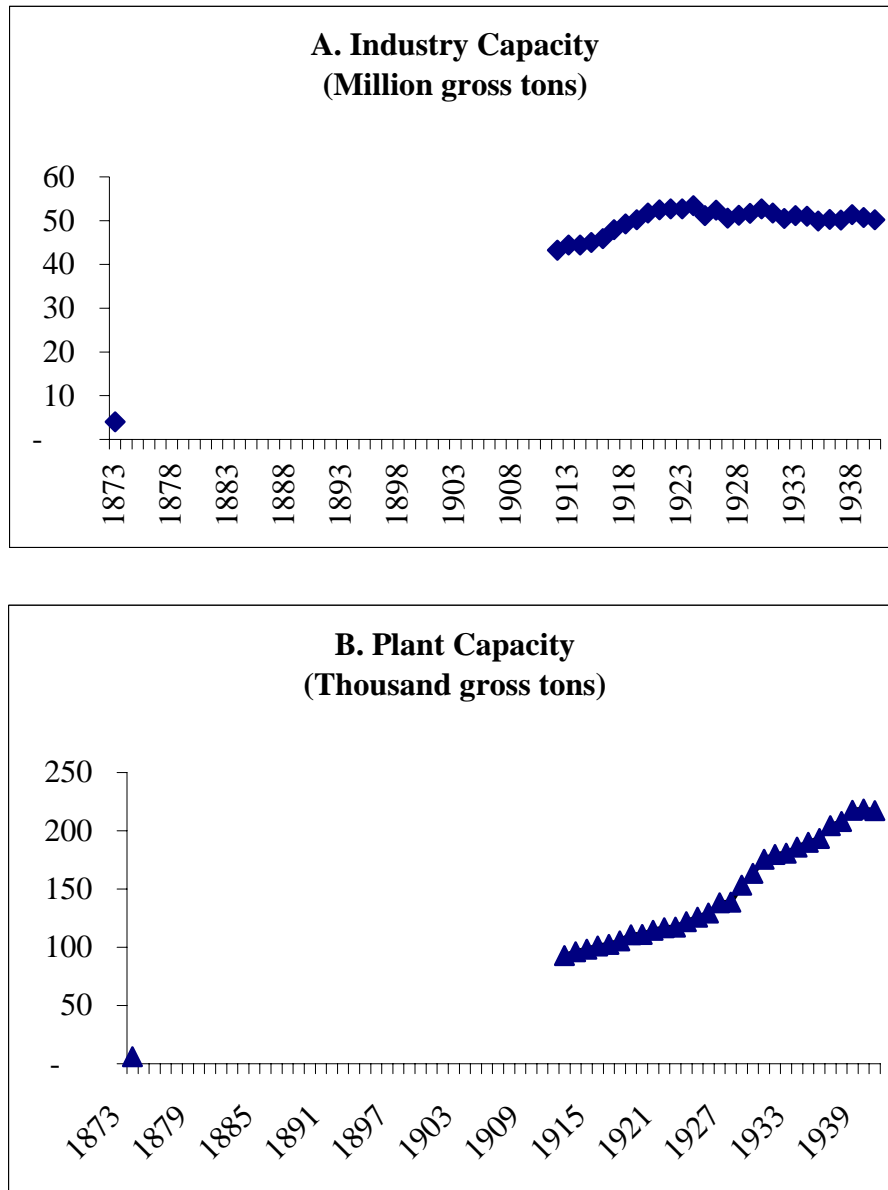


Figure 7. Capacity of the American Pig Iron Industry

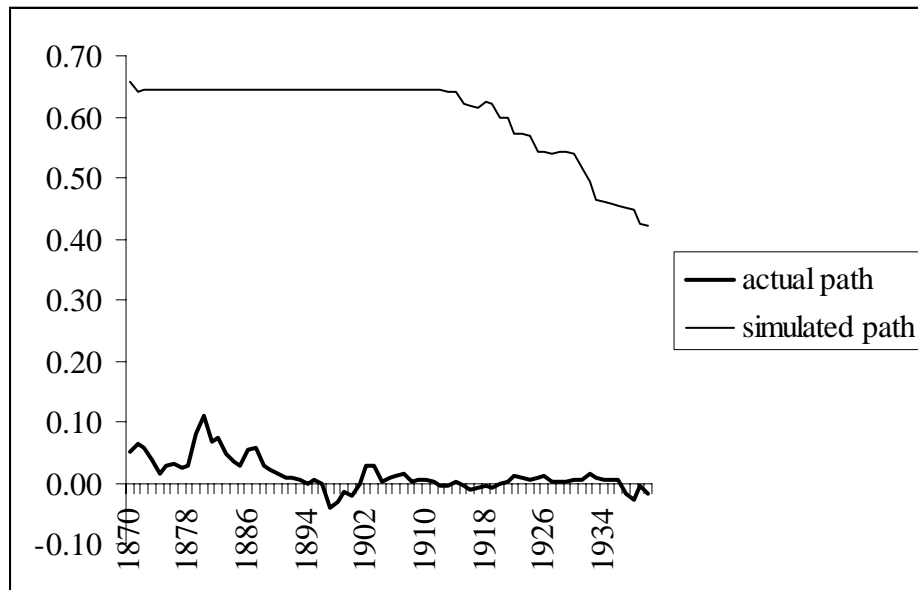


Source: American Iron and Steel Association, *Annual Statistical Report and Bulletin*, various issues.

Notes:

- (1) Industry capacity is the annual furnace capacity.
- (2) Plant capacity is the average capacity per furnace.

Figure 8. Simulated Path of Import Market Share by Value



Notes:

- (1) The initial condition in 1870 is from the simulation result from Table 8.
- (2) Output-capacity ratio is assumed to be constant at 0.64 (at 1873 level) when data are missing, namely, during 1870-1911.

A Data Appendix

A.1 Pig Iron Data

The annual time series of pig iron production (imports and exports) includes Ferro-alloys production (imports and exports). U.S. figures and the composition by grades are from Taussig (1915), *Some Aspects of the Tariff Question*, and the *Annual Statistical Report*, American Iron and Steel Association, various issues. The composition does not include ferro-alloys. British figures, the composition by grades, and world total are from Carr, J. C. and W. Taplin (1962), *History of the British Steel Industry*.

Prices of domestic pig iron are taken from the Statistical Abstract of the U.S. and the *Annual Statistical Report*, American Iron and Steel Association, various issues. They are no. 1 Foundry price at Philadelphia for 1870-85, and Bessemer price at Chicago for 1886-1940. The U.K. price of pig iron from Taussig (1915) and the *Annual Statistical Report*, American Iron and Steel Association. They are no. 1 Foundry price at Cleveland for 1870-85, and Bessemer price at Cleveland for 1886-1940.

Blast furnace data, capacity and furnace consumption of ore, fuel and limestones, are from the *Annual Statistical Report*, American Iron and Steel Association, and the *Bulletin*, American Iron and Steel Association, various issues.

Volume of exports and imports of pig iron are from the *Statistical Abstract of the U.S.*, various issues. Trading partner countries are from the *Annual Statistical Report*, American Iron and Steel Association, various issues. Pig iron duty is from Taussig (1915), Berglund and Wright (1929), and *Metal Statistics*, American Metal Market Daily Iron and Steel Report, various issues.

A.2 Other Data

Mesabi Bessemer ore price, bituminous coal domestic price and its import price, domestic price of steel rails and domestic consumption of steel rails are from the Statistical Abstract

of the U.S. The consumer price index is taken from the *Historical Statistics of the United States: Colonial Times to 1970*, Bicentennial Edition, U.S. Department of Commerce, Bureau of the Census.

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