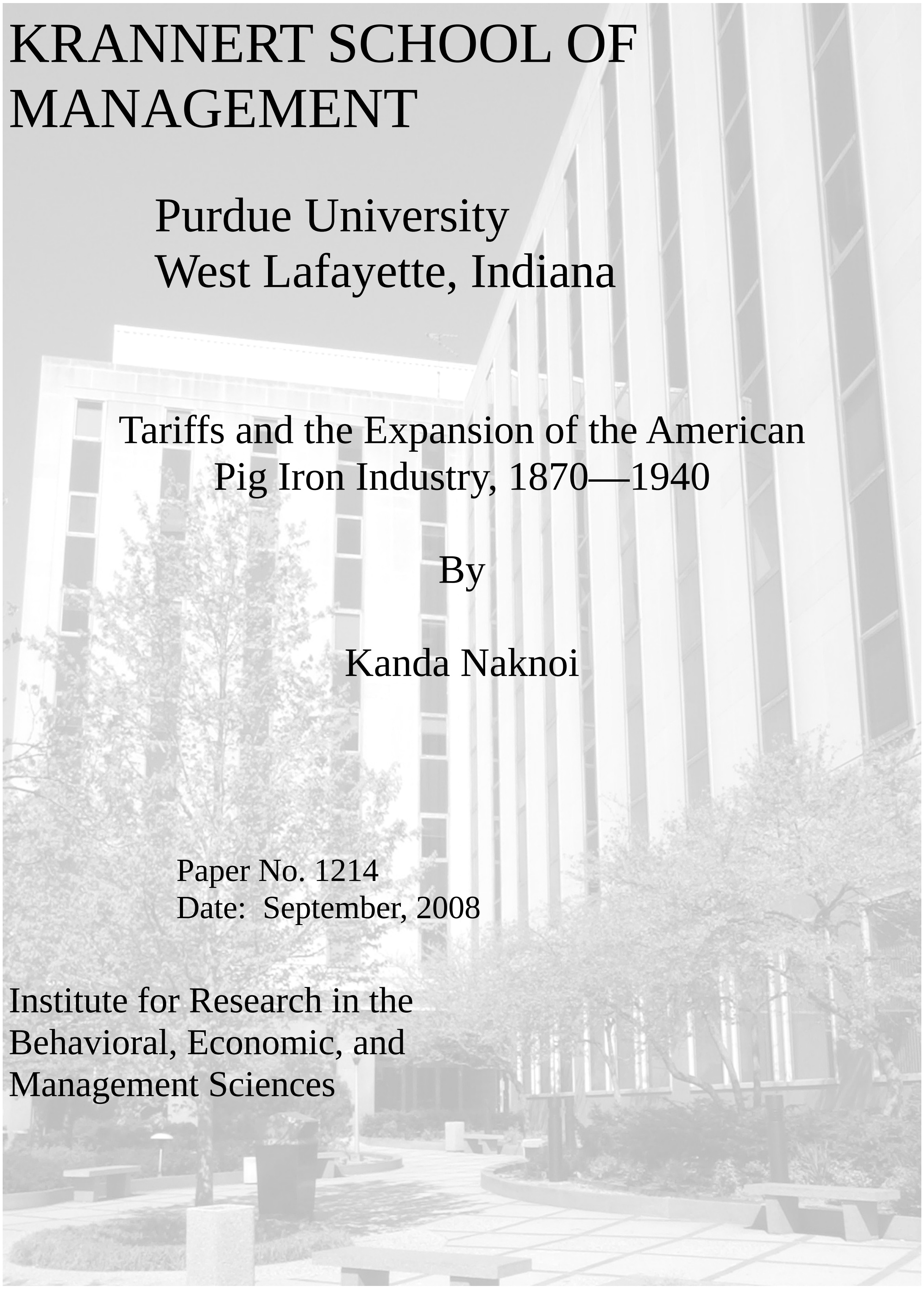

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Tariffs and the Expansion of the American Pig Iron Industry, 1870—1940

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Paper No. 1214
Date: September, 2008

Institute for Research in the
Behavioral, Economic, and
Management Sciences

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

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First draft: December 2003

This draft: August 2008

Abstract

This study quantifies dynamic learning effects behind the tariff wall in the American pig iron industry in 1870-1940. First, we present new datasets to argue that imported and domestic pig iron were close substitutes. Next, we provide evidence for dynamic learning effects. Finally, we use the estimated learning rate to simulate the hypothetical free trade regime starting in 1870. Despite substantial learning at the early stage of development, free trade would have wiped out the domestic industry by 1881. This would be caused by unfavorable shocks on demand, input costs and transport costs.

Key words: Pig iron trade, protection, dynamic learning effects

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1 Introduction

Pig iron is the 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; Irwin, 2003). By 1890, American pig iron production surpassed that of Great Britain, and subsequently the U.S. emerged as the leading producer of pig iron. Pig iron received substantial protection as early as the 1820s and by 1870 the ad valorem equivalent rate of protection was almost 50 percent. The duty on pig iron had been in place long before the invention of the 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.

The exploration of the so-called infant-industry hypothesis has two questions. One is whether the industry required protection to survive on such a large scale that learning could take place. The other is whether dynamic learning was subsequently realized. The recent study by Irwin (2000a) focuses only on the first question. He estimates the elasticity of substitution between domestic and imported pig iron in 1867-1889 based on the national product differentiation model by Armington (1969).[1] Irwin (2000a) uses the estimated elasticity to simulate a hypothetical free trade regime and concludes that the domestic industry would have sustained approximately 70 percent of market share, even if the U.S. had moved to free trade in 1869. Based on this result, he proceeds to dismiss the importance of dynamic learning effects. Evidence for dynamic learning behind the tariff wall is presented by Head (1994) in the case of steel rails industry.[2]

This study examines dynamic learning behind the tariff wall in the domestic pig iron industry over the period 1870-1940. We extend the analysis up to 1940 because the time

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[1] Irwin (2000a) uses a similar specification to Fogel and Engerman (1969), who study pig iron industry in the ante-bellum period.

[2] An 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 wall, such as Irwin (2000b)

series of domestic pig iron output displays large fluctuations after 1900. The price and shipping costs series are also volatile over this sample period. Such time series variations are highly useful for investigating the dynamic properties of the industry. We make the following contributions to the literature. First, we argue that despite being differentiated products, imported and domestic pig iron of the same variety are close substitutes. This is because pig iron is an intermediate input, the varieties of which are classified objectively by chemical contents. The degree of product differentiation is likely to be much lower than final goods such as steel rails. We provide evidence that the U.S. and the U.K. produced the same set of varieties. Based on Irwin's (2000a) own calculation, a high degree of substitution between imported and domestic pig iron would cause the domestic market share to drop to 30 percent. In this case, there could have been large learning effects from 1870.

Next, we estimate the size of dynamic learning effects from 1870 to 1940, using cumulative industry output as the measure of experience. We find strong evidence for learning. The implied learning rate is 16 percent, which is close to the estimate for the semiconductor industry in Irwin and Klenow (1994). We also find strong evidence for learning spillover from the U.K. producers. The learning rate in this case is 38 percent. Such a high learning rate indicates that the growth of the U.K. pig iron industry actually benefited the American producers.

Finally, we use the estimated learning rate to simulate the hypothetical free trade regime. Learning effects are found to be large at the early stage of development. However, in the simulation free trade would have wiped out the domestic industry by 1881. This striking result can be explained by unfavorable shocks as follows. First, the "iron famine" or large positive demand shocks from 1879 to 1880 put upward pressure on price of domestic pig iron. Second, from 1879 to 1880 the cost of coal rose as much as 34 percent, and remained at that level until 1882. Third, from 1872 to 1881 transport costs continued to decline by as much as 350 percent. In the absence of protection, these large and unfavorable shocks would have removed competitiveness from the American pig iron industry in 1881. Our result is consistent with the finding by Allen (1977), that the productivity of the American pig iron industry began to rise substantially in the 1880s.

Our findings contrast with early work by Taussig (1915) and Temin (1964) on the post-bellum period, which viewed the effects of tariffs on the industry as marginal. 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. The latter two studies also argue that domestic and imported pig iron were perfect substitutes.

The next section describes characteristics of the American pig iron industry from 1870 to 1940 and provides evidence for a high degree of substitution between imported and domestic pig iron. In Section 3 we estimate dynamic learning effects. Section 4 simulates the hypothetical case in which pig iron duty was removed in 1870. Section 5 concludes the analysis.

2 Characteristics of the American pig iron industry

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

2.1 Production

Figure 1 plots the annual pig iron output in the U.S. and the U.K.[3] The domestic production doubled in every decade from 1870 to 1890. The U.S. surpassed the U.K. and became the world leading producer in 1890. At this point, the U.S. share in world production was 34.4 percent while the U.K. share was 29.4 percent. U.S. output slowed down during the depression in the 1890s but resumed its growth by the end of the century.

Starting in 1900 the U.S. pig iron output was quite volatile. It expanded with periodic

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[3] We do not exclude the production of ferro-alloys because of limitation of the data.

contractions in 1908, 1911 and 1914. When the pig iron duty was temporarily removed in 1913, the U.S. accounted for 40 percent of world production. The U.S. share reached its peak at 60 percent in 1918. By 1932, the U.S. output was over 4 times of the U.K. output. After the sharp drop in 1933 during the Great Depression, the domestic output returned to the pre-depression level in 1937. By 1940, the domestic production had tripled its 1900 level.

In terms of geographical distribution, the main locations of production moved away from coal deposits toward iron ore deposits in the late 1870s. The reasons for this are rising fuel economy, a fall in coal transport costs and the discovery of rich ore deposits in the Great Lakes area, and subsequently in the South (Isard, 1948; Wright, 1986). Table 1 gives the share of major iron-producing states. In the late nineteenth century, almost 50 percent of pig iron was produced in Pennsylvania. There was a downward trend in New York, New Jersey and Pennsylvania. On the contrary, the Great Lakes states and Alabama showed an upward trend. Still, Pennsylvania was by far the most important state by the end of the nineteenth century. By 1920, the combined share of the Great Lakes states was 42 percent and surpassed Pennsylvania's share. Ohio was the fastest growing state among the Great Lakes. Alabama's share continued to grow but remained at 7 percent in 1940.

2.2 International trade

Domestic pig iron was produced mostly for domestic demand. The U.S. was a net importer almost all of the time and exports remained below 3 percent of output. The U.S. was one of the U.K. most important importers until the mid 1880s. In 1894, the U.S. became a net exporter of pig iron for the first time. The domestic producers produced for domestic demand throughout 1895-1940, although the U.S. sporadically became a net exporter. By any standard, the pig iron import substitution for the U.S. experience was a great success.

Table 2 gives the breakdown of source countries. The U.K. was the main source from the late nineteenth century. Although Belgium, Germany and Netherlands became net exporters to the U.S. by 1910, their shares were far smaller than that of the U.K. British India rose as a new source in the mid 1910s. However, the U.S. became a net exporter to these trading partners temporarily in 1917. In the 1920s, the main sources were British India, Great Britain and Germany. In the 1930s, the Netherlands led British India and Canada, while the U.K. turned to import pig iron from the U.S. through the second half of the decade.

2.3 Protection

Figure 3 depicts pig iron duty and its ad valorem equivalent. 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. From 1939, the duty applied differently to different types. The frequent adjustments of the duty in the 1880s and 1890s are more accurately seen as adjustments for price changes than as actual reductions in the duty. Thus, an equivalent ad valorem equivalent is preferable to the duty as a measure of protectiveness because it reflects changes in effective tariffs without changes in tariff laws (Temin, 1964; and Sundararajan, 1970). [4] The equivalent ad valorem equivalent is calculated using series of price, collected duty and transport costs. Note that the construction of transport costs series is discussed in the next subsection. The ad valorem equivalent rose dramatically in the 1870s and 1880s due to the declines in import price, peaked at 70 percent in 1883 and slowly declined in the 1890s. Then it fluctuated around 25 percent in the early twentieth century until the removal of pig iron duty 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. Its role was to protect the seaboard-area producers, who were not naturally protected by high transport costs and thus faced tough

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[4] Sundararajan (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.

foreign competition (Berglund and Wright, 1929: Sundararajan, 1970). The equivalent ad valorem rate remained below 10 percent from 1922 to 1940. The reason is that domestic producers had replaced the U.K. as the main supplier for the domestic market long before 1922. Although domestic suppliers sometimes could not meet the entire domestic demand, import market share in domestic consumption in net terms remained lower than 2 percent most of the time during 1889-1940.

2.4 Price

Figure 2 compares domestic prices of U.S. and U.K. pig iron.[5] Domestic price of U.K. pig iron is the sum of U.K. price adjusted by exchange rate, duty and transport costs. The transport costs series are constructed from the shipping cost index in Mohammad and Williamson (2004), and coal freight charge in Harley (1989), because the data on pig iron freight charge are not available.[6] The fact that the two price series in Figure 2 tracked each other closely with an 84 percent correlation after the duty was removed in 1913 indicates that the constructed transport costs series is strongly correlated with the unobserved cost of shipping pig iron.

The protective nature of the pig iron duty was apparent from 1870 to 1885, since domestic pig iron was more expensive than imported pig iron for the most part. However, there were still imports of U.K. pig iron 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 imports [7]. The primary reason for this

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[5] The 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.

[6] See the Appendix for details.

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

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 the New York and New Jersey area, as indicated in Table 1.

It should be noted that the cross-country price comparison is based on a specific pair of the same variety at one point in time. Pig iron is a differentiated products industry, and there are various grades of pig iron being categorized by chemical contents. The next section discusses the composition of pig iron production in detail.

2.5 Varieties, and substitution between foreign and domestic pig iron

Pig iron is the form in which iron first appears when smelted from its ore. It varies in its chemical composition and is utilized for different purposes based on these differences. Table 3 classifies various grades of pig iron by their chemical contents (Berglund and Wright, 1929). [8] The major chemical contents determining the quality of pig iron are carbon, silicon, manganese, phosphorus and sulphur. Carbon is the most important element and 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 at 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. A higher silicon content indicates worse quality (Kirk, 1911).

The composition of pig iron production in the U.S. and the U.K. is depicted in Figures 4 and 5. The figures do not cover the entire sample period due to data limitations. Until 1940, the major types of pig iron produced domestically were basic, Bessemer and low

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[8] Classification 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.

phosphorus, forge, foundry and malleable. The main characteristic of domestic production is the shift in the position of the dominant grade from Bessemer 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.

Similarly, the British producers 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 production described above and the objectivity of the classification method, it is reasonable to consider pig iron in the two countries as an almost-identically differentiated products industry. Our view is in line with the studies that consider pig iron a homogeneous product, such as Allen (1979) and Sundararajan (1970).

In contrast, the Armington (1969) model in Irwin (2000a) assumes that products are distinguished by locations of production. The assumption is appropriate for some circumstances, for example, when Steffan-Linder's home market effect is present. In addition, the Armington model predicts a decline in relative prices when output and export expand. In our dataset, the correlation between relative output and relative price is virtually zero and thus rejects the Armington assumption.

The Armington model was originally addressed to geographically differentiated varieties of final goods, not to intermediate inputs. The estimate of elasticity of substitution between domestic and imported products by Shills, et al. (1986) confirmed that the elasticity is much higher among final products than intermediate products. Another aspect of locational differentiation is the currency of denomination. However, the world was in a bimetallic and subsequently a metallic standard in Irwin's (2000a) and our sample period. Therefore, importing pig iron involved lower currency risks than today. Overall, we could possibly argue that the degree of product differentiation between foreign and domestic pig iron of the same variety is low.

Based on trade models with production differentiation, economies of scale and monopolistic competition along the lines of Dixit and Stiglitz (1977) or Lancaster (1979), under free trade countries specialize in different varieties. Which country produces what varieties depends on comparative advantage or differences in productivity (Helpman, 1984). Harley (2001) provides an excellent example. He investigates British cotton textiles exports to the U.S. and other markets, to assess the comparative advantage of the U.S. and the U.K. in the antebellum cotton textiles industry. The export data suggest that the U.S. imported high quality cotton products from the U.K., while expanding domestic production of low quality cotton products. The U.K., however, continued to export low quality cotton to other countries. The trade pattern indicates that the U.K. had comparative advantage in both high and low quality products. Thus, the finding supports his hypothesis that the antebellum U.S. cotton textiles industry depended substantially on tariffs to survive.

In the context of pig iron, knowledge about British exports of different varieties is sufficient to identify the U.K. comparative advantage relative to the U.S. This is because the American pig iron was produced only for domestic use consistently throughout the sample period. In the late nineteenth century, the main trading partners importing pig iron from the U.K. were Canada, India, Australia, South Africa and Argentina. [9] Unfortunately, there are no bilateral data on the variety breakdown of British pig iron exports. Nevertheless, the finding that the British industry produced pig iron of the same varieties as the domestic industry supports the notion that imported and domestic pig iron were close substitutes.

The assumption concerning the degree of substitutability is crucial to the impact of protection. Irwin (2000a) shows using a simulation that when the degree of substitutability is low, the market share of imports right after switching to a free trade regime would be 30 percent. In the same study, the corresponding number would become 70 percent if the degree of substitutability is high. Thus, our dataset on variety-specific output in the U.S. and the U.K. suggests that the the latter case in Irwin (2000a) presents an accurate picture of the essential role of protection.

3 Estimating dynamic learning effects

Since protection was 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 the pneumatic or Bessemer process by Williams Kelly and Henry Bessemer, "hard driving" has received considerable attention as the major innovation increasing the productivity of the American pig iron producers (Allen, 1977; Temin, 1964). The hard driving technique was pioneered by some American producers starting in 1870, and further improved in the 1880s and 1890s. This technique allows a large amount of hot air to flow into blast furnaces at high pressure, in order to speed up the smelting process. It helps increase output per furnace, but adding this hard driving feature to a furnace requires a large sum of capital (Berck, 1978).

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[9] The U.S. was also a main trading partner until the mid 1880s, and eventually almost stopped importing pig iron from the U.K. in 1893-94.

According to Berck (1978), constructing a new hard-driven furnace in Chicago in 1887 would have incurred the fixed cost ranging from 180,000 to 250,000 dollars. However, that would have saved the variable cost and yielded profits as high as 130,000 dollars in one year. Given that the estimated annual capacity of a hard-driven furnace was 43,500-52,690 gross tons, this was highly profitable but risky business, because redeeming the fixed cost depended on fluctuations of demand. However, pig iron duty reduced the riskiness by restricting competition with imports and allowing the domestic producers to sell at a high price to recover the fixed cost.

As a consequence, the domestic producers could produce up to their furnace capacity when a positive demand shock occurred. The economies of scale at the plant level were, therefore, a direct benefit from protection. Indirect effects of protection are the spillovers of learning-by-doing at the industry level. Spillovers were made possible by the institutions for learning, namely the professional associations that published their reports and provided places to exchange knowledge among engineers and iron masters. The most notable of these was the American Iron and Steel Association established in 1864.[10] Other related organizations were the American Institute of Mining 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* was published in 1880 (Gordon, 1996). Through these institutions, spillovers of learning led to further cost-saving techniques and achievements of industry-wide economies of 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 can also spread to related industries as people respond to incentives (Romer, 1990). Specifically, economies of scale in pig iron production created incentives for an expansion of investment in its inputs, particularly in the iron ore in-

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[10] The original name was the American Iron and Associates.

dustry. Since the capacity of the furnace and the scale of investment are closely related, the capacity of the furnace can serve as a measure of economies of scale. However, it is not possible to estimate dynamic learning effects using capacity, because we do not have investment data. For this reason, we employ the most common measure of economies of scale in the literature, namely the cumulative industry output (Irwin and Klenow, 1994).

3.1 Estimating strategy

The direct way to estimate dynamic learning effects is to estimate a relationship between the cost curve and cumulative output. However, cost data are not available, so we must indirectly estimate this from price data, as in Head (1994).

Assume that firms are price-setters. Hence, price is the product of mark-up and marginal cost:

$$P_{t,d} = \mu MC_t = e^{\alpha} E_t^{\alpha_e} P_{t,o}^{\alpha_o} P_{t,c}^{\alpha_c} Q_t^{\alpha_q} e^{u_t}, \tag{1}$$

where $P_{t,d}$ is the price of domestic pig iron, $\mu > 0$ is the mark-up and MC_t is marginal cost. The cost function is assumed to be Cobb-Douglas. E_t is cumulative industry output up to the last period. The marginal cost consists of learning effects E_t, prices of main inputs, namely price of iron ore $P_{t,o}$, price of coal $P_{t,c}$, and costs of capital and labor implicitly embodied in output Q_t. The elasticity of each component is α_e, α_o, α_c and α_q, respectively. u_t is the stochastic component. The estimation equation becomes:

$$lnP_{t,d} = \alpha + \alpha_e lnE_t + \alpha_o lnP_{t,o} + \alpha_c lnP_{t,c} + \alpha_q lnQ_t + u_t \tag{2}$$

The most important parameter is the elasticity of price with respect to experience, or α_e. If there are dynamic learning effects, $\alpha_e < 0$. Although an increase in output puts an upward pressure on price, the economies of scale pushes price down in the opposite direction. In the literature on learning, one commonly used concept is the so-called "learning rate." It is the rate at which the marginal cost drops following doubling cumulative output. Formally, learning rate is calculated as $1 - 2^{\alpha_e}$. We estimate Equation (2) using ordinary least squares and the instrument variable technique. The instruments used for output are duty, price of imported coal, price of rail and domestic consumption of rail.

3.2 Estimation results

The results are tabulated in Table 4. Column 1 studies the role of cost shocks, and Column 2 includes both cost and demand shocks. Both cost and demand shocks are found to be significant factors driving price. In Column 3, we include the U.S. experience in the regression. This specification gives strong evidence for learning, and the implied learning rate is 16 percent. The estimated learning rate is close to the 20 percent learning rate in the semiconductor industry in Irwin and Klenow (1994). Column 4 studies learning spillover by replacing the U.S. experience with the U.K. experience. That specification produces strong evidence for learning spillover with 38 percent learning rate.

4 Simulation with dynamic learning

In this section, we rely on the result in Column 3 in Table 4 to simulate the hypothetical free trade regime starting in 1870. To do so, we also need the demand and supply elasticities. The elasticity of domestic supply can be obtained as the inverse of elasticity of price with respect to output in Equation (2). The result from Column 3 in Table 4 implies that the supply elasticity is 5.88. We set the demand elasticity to 10, to generate the case in which protection is critical for survival of the domestic pig iron industry in Irwin (2000a). For other elasticity parameters, we follow Irwin (2000a) as well. As for the elasticity of foreign supply, he proposes using 15, although his estimate was 40. Irwin's (2000a) argument that the results do not change significantly for elasticity values above 10 was consistent with our experiment.

As consistency checks, Figure 6 presents the actual price of domestic pig iron and the simulated prices in two cases: (1) protection with actual duty; and (2) free trade. The simulated series with protection consistently track the actual series. In addition, the simulated series with free trade are consistently below the actual series.

The main results are in Figure 7. If the U.S. moved to free trade in 1870, the import market share in 1870 would become 70 percent as in Irwin (2000a), assuming a high degree of substitutability between domestic and imported pig iron. Then the import market share would sharply drop in 1870 due to strong dynamic learning effects. However, the pattern would be reversed shortly before 1880, and the domestic pig iron industry would be completely wiped out in 1881.

There are three reasons for this striking finding. First, there were large, unanticipated shocks to U.S. demand, or the so-called "iron famine" from the spring of 1879 until the end of 1880. Second, the price of coal in Figure 8 jumped from 2.79 dollars per gross ton in 1879 to 3.75 dollars per gross ton in 1880. The cost shock was as large as 34 percent and persisted until 1882. Finally, there had been persistent and large shocks on transport costs since 1872. In Figure 8, from 1872 to 1881 transport costs had declined by as much as 350 percent. Overall, the positive demand shocks, the positive cost shocks and the negative shocks on transport costs would eliminate competitiveness of the American producers in 1880 in the absence of protection.

Our result is also consistent with the finding by Allen (1977). He finds that the productivity of the domestic pig iron industry began to rise substantially in the 1880s. Until then protection helped isolate domestic pig iron producers from the large and unfavorable shocks described above.

5 Concluding remarks

This paper attempts to quantify the degree to which the domestic pig iron industry benefited from protection from 1870 to 1940. We argue that the U.K. and the U.S. pig iron of the same variety are close substitutes, using a new dataset on variety-specific output and classification of varieties. That argument, together with recent work by Irwin (2000a) suggests that a large fraction of domestic producers would not have survived free trade, and there could be large dynamic learning effects behind the tariff wall.

We exploit time series variations of output, price of domestic and imported pig iron, pig iron duty and transport costs to estimate dynamic learning effects. Using cumulative output as the measure of experience, we confirm the significance of dynamic learning effects together with demand and supply shocks. Moreover, there is also strong evidence for learning spillover from the U.K. experience. In fact, the learning rate from the U.K. experience is more than double the learning rate from the U.S. experience.

Finally, we incorporate dynamic learning effects to simulate the hypothetical free trade regime from 1870. Without protection the American pig iron industry would have vanished by 1880. Our findings support the hypothesis that protection was necessary for the growth of the American pig iron industry. Transport costs played a significant role because their persistent and large declines would have reduced competitiveness of domestic producers.

Certainly, such a ceteris paribus counterfactual analysis does not capture other dynamic changes over this period. The exercise treats conditions in the U.K. as given. This is not true since Allen (1979) provides evidence that by 1913 productivity of the U.K. producers had declined significantly. Nevertheless, the exercise offers a simple way to evaluate the role of protection in the 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 the U.K. data throughout the period, although potential exporters to the U.S. shifted from the U.K. to Germany in the late nineteenth century. In the late 1920s, British India had dominated the U.K. as the main exporter. In the 1930s, the leading exporters were British India, Netherlands and Canada. Consequently, our current analysis underestimates the effect of protection for the most part, as the U.K. was not always competitive and was not the main exporter starting in the mid 1930s.

The simulation results should also be interpreted with caution, since we ignore the geographical aspect of the American pig iron industry. Besides protection, a 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 in the absence of unfavorable shocks. Still, the learning process was national and a function of the scale of the national industry. Thus if large and unfavorable shocks could wipe out most producers, learning would be not possible. To evaluate whether treating the U.S. pig iron industry as an integrated national market overestimates the importance of protection by breaking the industry into regional markets will be a natural extension of this study.

Having concluded that the American pig iron industry expanded behind the 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 longer a metallic standard and importing foreign goods incurs higher currency risks as compared to 100 years ago. 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 has become riskier than in the past. These factors may partially contribute to the reason why Latin American import substitution policies did not lead to industrial successes.

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 their 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. prices of pig iron are 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 Transport cost data

There are no data on pig iron shipping costs. For this reason, we construct the transport cost series from (1) the index of grain shipping cost in Mohammad and Williamson (2004);

and (2) the coal shipping cost in pounds in Harley (1989). The former series is the shipping charge applied to grain shipped on Atlantic routes from the U.S. to the U.K. Hence, we implicitly assume a symmetric shipping charge for both outbound and inbound trips.

We calculate the shipping charge in two steps. First, we use the shipping cost index in Mohammad and Williamson (2004) as the measure of shipping-cost inflation, to rescale the cost of shipping coal in Harley (1989), given the pound-sterling cost in the initial year. We do so because the series in Harley (1989) does not cover the entire sample period. Next, we use the pound-dollar exchange rate to convert the shipping cost to dollars. The exchange rate data are from Economic History Services (EH.net).

A.3 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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Table 1: Geographical distribution of the U.S. pig iron production

Year	New York and 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.

Figure 1: Annual output of pig iron in the U.S. and the U.K. (1,000 Gross Tons)

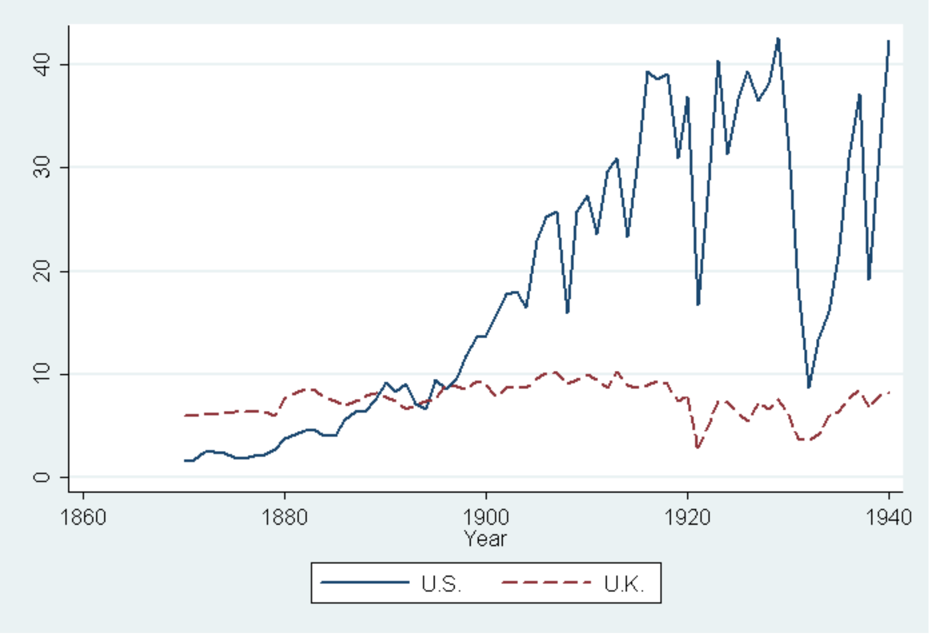


Table 2: Country share in net imports of pig iron

Year	U.K.	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 3: Non-ferrous content of various grades of pig iron (percentage of total content)

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

Figure 2: Domestic price of U.S. and U.K. pig iron (dollar)

Table 4: Estimation of dynamic learning effects

Variables	Cost shocks	Demand shocks (IV)	Learning (IV)	Learning spillover(IV)
U.S. experience			-0.22***	
U.K. experience				-0.46***
Constant	1.59***	-1.67	3.67*	7.17**
Iron ore price	0.88***	0.62**	0.61***	0.63***
Coal price	0.07	0.07	0.50***	0.46***
Output		0.21**	0.17***	7.17**
Learning rate			0.16***	0.38***
R^2 adjusted	0.71	0.67	0.78	0.77
F-statistics	58***	19***	21***	21***

Note: *, **, and *** denote statistical significance at 10 percent, 5 percent and 1 percent, respectively. IV corresponds to the instrument variable technique. The instruments for output are duty, price of imported coal, price of rail and domestic consumption of rail. Standard errors are heteroskedasticity robust. Serial correlation in errors is rejected at 1 percent.

Figure 3: Pig iron duty and its ad valorem equivalent

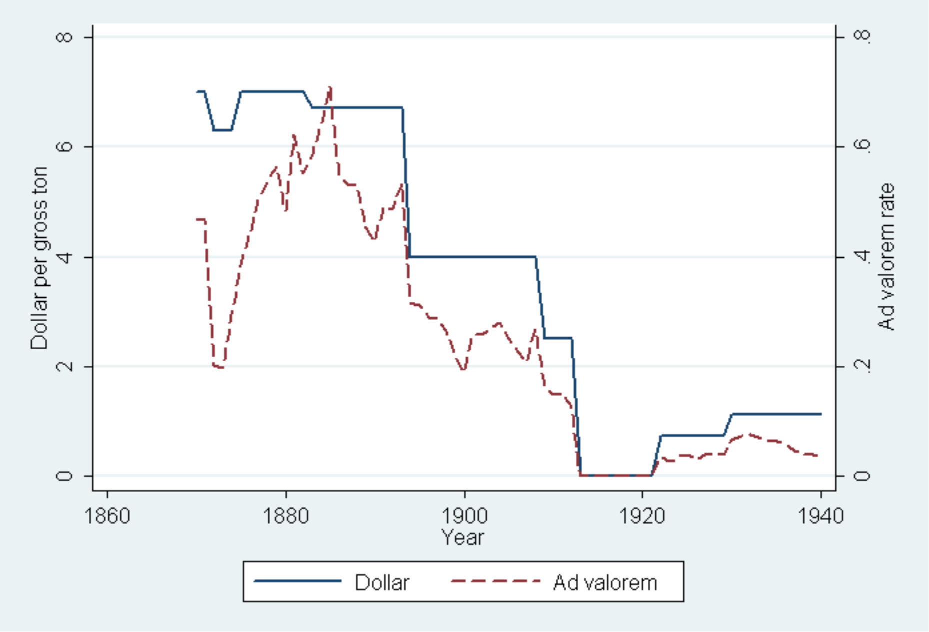


Figure 4: Composition of U.S. pig iron output

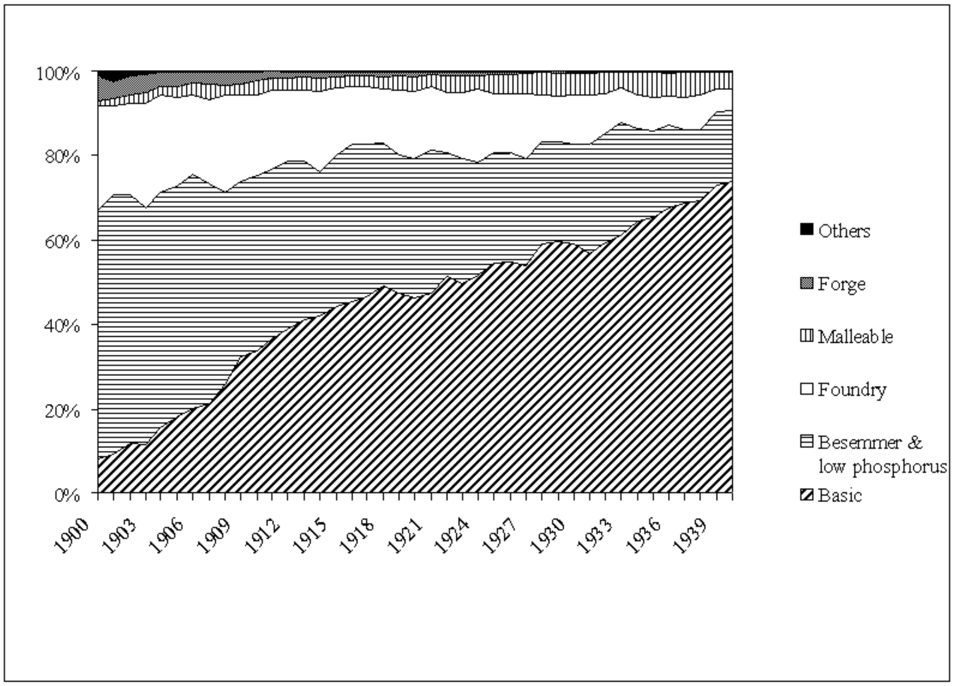


Figure 5: Composition of U.K. pig iron output

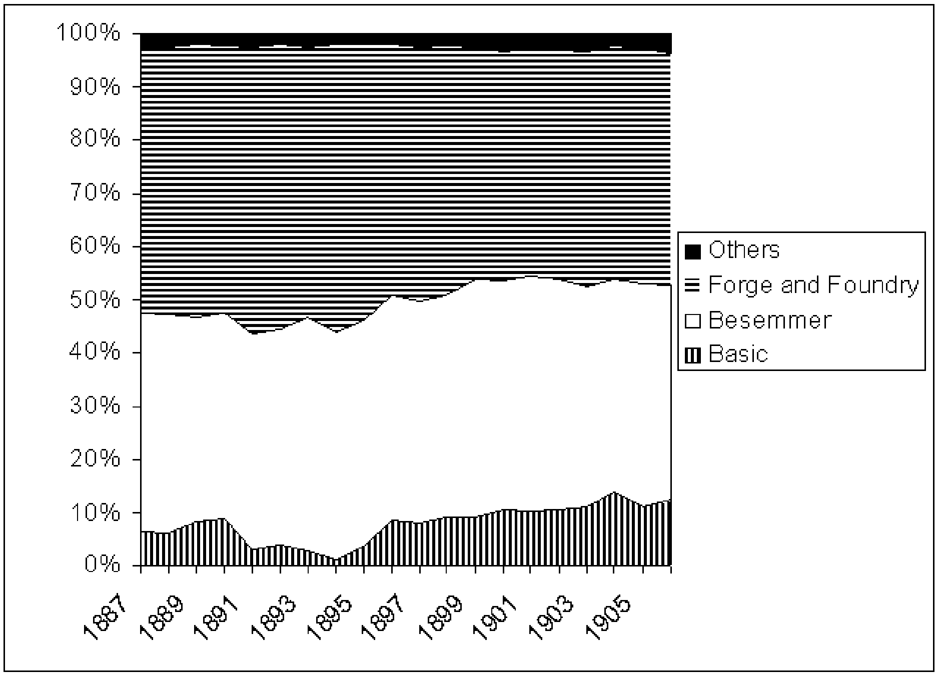


Figure 6: Actual and simulated price series

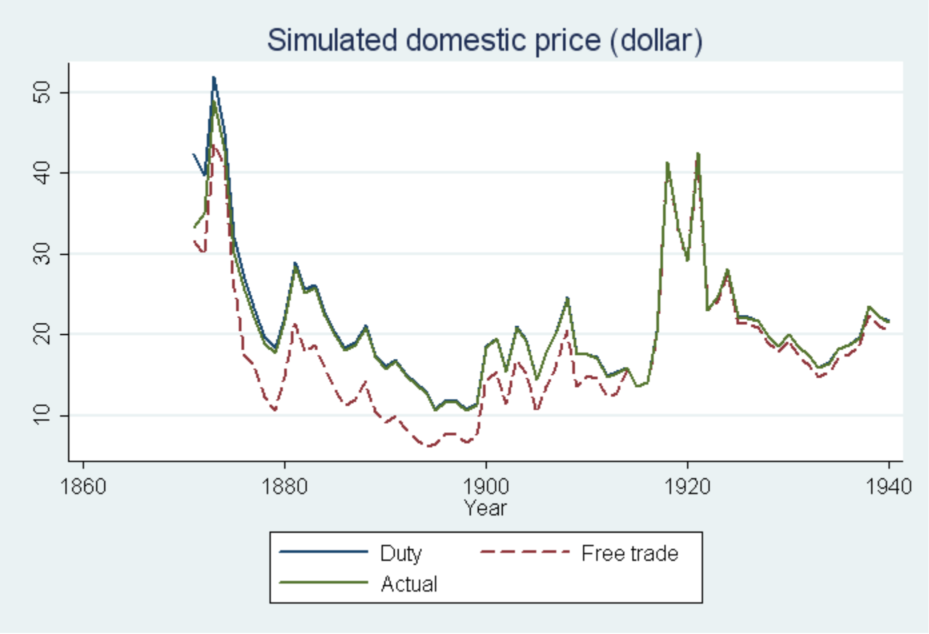


Figure 7: Actual and simulated import market share

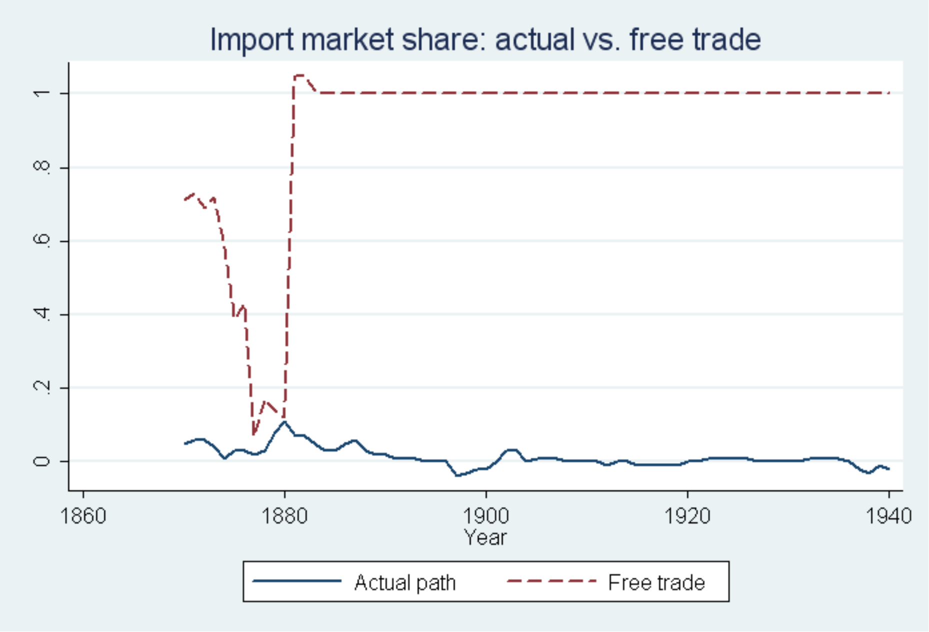
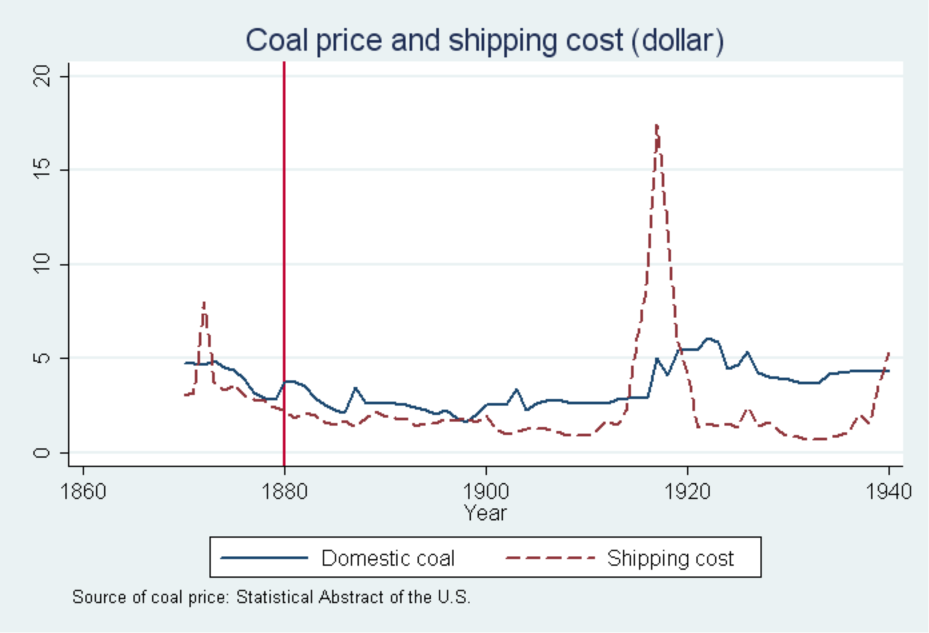


Figure 8: Coal price and transport costs



Source of coal price: Statistical Abstract of the U.S.