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

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October 2010

Abstract

This study quantifies dynamic learning effects behind the tariff wall in the American pig iron industry during 1870-1940. First, we provide evidence that if pig iron duty was removed in 1870, the market share of imported pig iron would increase by 50 percent. Next, we provide evidence for dynamic learning effects. Finally, we simulate the hypothetical free trade regime starting in 1870. Despite substantial learning at the early stage of development, without protection domestic pig iron industry would continue to lose market share in the 1870s. Free trade would have added an additional decade to the time taken by the domestic production to surpass the production by British producers.

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 using 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, which were found in other industries such as the steel rail (Head, 1994).\(^2\)

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

\(^1\)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 quite 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 provide evidence that protection was necessary for the survival of the pig iron industry in 1870. We rely on a counter-factual calculation of market share of import, assuming that pig iron duty was removed in 1870. The calculation is based on the demand side parameters, estimated from the same framework as Irwin (2000a) or a national product differentiation model (Armington, 1969). This framework assumes that imported and domestic pig irons are imperfect substitutes. Based on the estimated elasticity of substitution between imported and domestic pig iron, the market share of imported pig iron in 1870 would be as high as 62 percent under free trade. Such an impact would amount to roughly 50-percent increase in the market share of imported pig iron. This implies that protection was crucial for the survival of domestic industry. This finding is different from Irwin (2000a), because our elasticity of import demand is larger than his and the shipping cost declined from 1869 to 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 29 percent, which means that doubling output lowers price by 29 percent. This learning rate is much higher than the estimate for the semiconductor industry in Irwin and Klenow (1994). However, we do not find evidence for learning spillover from the U.K. producers.

Finally, we simulate the hypothetical free trade regime beginning in 1870, taking into account dynamic learning. From 1870 to 1875, imported pig iron would continue to occupy roughly 70 percent of market share despite substantial learning at the early stage of development. Given that the actual market share of import in this period was roughly 10 percent, this implies that imported pig iron would replace 60 percent of market share.
From 1876, learning would sharply lower price of domestic pig iron to the point where the market share of imported pig iron would be lower than 20 percent by 1880. The market share of imported pig iron varied between 20-40 percent until 1940.

Why did the market share of import not fall quickly in the 1870s? This striking result can be explained by declining transport costs. In the 1870s transport costs continued to decline by as much as 70 percent. In the absence of protection, these large and unfavorable shocks would have impaired competitiveness from the American pig iron industry in the 1870s. 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 the framework for estimation. In Section 3, we describe the data and characteristics of the American pig iron industry from 1870 to 1940 and estimate the demand side and dynamic learning effects. Section 4 simulates the hypothetical case in which pig iron duty was removed in 1869. Section 5 concludes the analysis.

2 Framework for estimation

2.1 The effect of protection on industry survival

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

$$
\ln M_t = \alpha + \eta_{MD} \ln \left( \frac{p_D}{p_{CPI}} \right) + \eta_M \ln \left( \frac{p_M(1 + \tau)}{p_{CPI}} \right) + \gamma \ln Y_t + \lambda \ln M_{t-1} + v_t \tag{1}
$$
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. $\eta_{MD}$ is the cross-price elasticity of demand for imported pig iron, and $\eta_M$ is the elasticity of imported pig iron with respect to domestic price. $\gamma$ is the elasticity of demand for imported pig iron with respect to total pig iron expenditures.

Note that Irwin (2000a) does not include shipping cost in the domestic price of imported pig iron, due to the lack of shipping cost data. However, our work attempts to examine the role of shipping cost, therefore we construct series to proxy shipping cost for pig iron from data on shipping cost for other goods. For that matter, we include the shipping cost in the measure of domestic price of imported pig iron. Let $f$ denote the ad valorem cost of shipping. Then the second explanatory variable in (1) becomes $\ln(p_M(1 + \tau)(1 + f)/p_{CPI})$.

Let $\sigma$ be the elasticity of substitution between imported and domestic pig iron. It can be calculated from the estimated parameters as:

$$\sigma = \frac{\eta_{MD}}{\theta_D} + \gamma$$

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

$$\eta_Q = \frac{\eta_M}{\theta_D} - \sigma$$

As for the elasticity of foreign supply, Irwin (2000a) 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 confirmed by our experiment. We also use the same number
for the year 1870. For later periods, we estimate the elasticity from our data. The reason is that according to Allen (1977) the British pig iron industry experienced productivity loss from the 1880s. Thus, it is likely that the supply elasticity of the British producers had fallen below 15 in later years.

2.2 The effect of protection on dynamic learning effects

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).

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.\footnote{The original name was the American Iron and Associates.} 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 industry. 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).

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:

\[
P_{t,d} = \mu MC_t = e^\alpha A_t^\alpha E_t^\alpha \phi_t^{\alpha_o} P_{t,o}^{\alpha_o} P_{t,c}^{\alpha_c} Q_t^{\alpha_q} e^{u_t},
\]

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. $A_t$ captures both the scale effect and the productivity improvement, which reduces the marginal cost of production. We proxy $A_t$ with the number of furnaces, since it is an important determinant for the scale of production at the industry level in the event that demand shocks occur. $E_t$ 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 $\alpha_e$, $\alpha_o$, $\alpha_c$ and $\alpha_q$, respectively. $u_t$ is the stochastic component. The estimation equation becomes:

$$lnP_{t,d} = \alpha + \alpha_A lnA_t + \alpha_e lnE_t + \alpha_o lnP_{t,o} + \alpha_c lnP_{t,c} + \alpha_q lnQ_t + u_t$$ \hspace{1cm} (5)$$

The most important parameter is the elasticity of price with respect to experience, or $\alpha_e$. 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 (5) using ordinary least squares and the instrument variable technique. The instruments used for output are GDP, price of imported coal, price of rail and domestic consumption of rail.

It is also plausible that there are spillovers of learning from the U.K. through migration of workers. Let $E^*_t$ be cumulative industry output in the U.K. up to the last period. Then, the estimation equation becomes:

$$lnP_{t,d} = \alpha + \alpha_A lnA_t + \alpha_e lnE_t + \alpha^*_e lnE^*_t + \alpha_o lnP_{t,o} + \alpha_c lnP_{t,c} + \alpha_q lnQ_t + v_t$$ \hspace{1cm} (6)$$
3 Estimation

3.1 Summary of data and characteristics of domestic pig iron industry

The data appendix provides the sources of data in details. Figure 2 depicts pig iron duty and per-unit shipping cost. Their sum measures the overall per-unit trade costs for pig iron trade. Their ad valorem equivalent are displayed in Figure 3.

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). The 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 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

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4Sundararajan (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.
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.

As for the shipping cost, we do not have data on shipping charge on pig iron, hence we construct the shipping 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.

The decline in shipping cost in the 1870s is notable particularly in the dollar unit. The per-unit reduction in this period was roughly 70 percent. Then it declined sharply after 1890. The subsequent spike from 1913 to 1920 simply reflected the disruption in international trade as a result of war. On the other hand, the ad valorem reduction in shipping cost was relatively even for the entire sample period except for the war time.

Figure 4 compares domestic prices of U.S. and U.K. pig iron. 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. The fact that the two price series in Figure 4 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. The imports of pig iron in this

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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 in the U.K. for 1870-85, and Cleveland Bessemer price for 1886-1940.

6See the Appendix for details.
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. The primary reason for this is the high costs of shipping pig iron from the inland furnaces to the coastal areas.

Figure 1 plots the annual pig iron output in the U.S. and the U.K. 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. The 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. By 1940, the domestic production had tripled its 1900 level. Note that domestic pig iron was produced mostly for domestic demand. The U.S. was a net importer almost all of the time, and Britain was the main source from the late nineteenth century.

3.2 Estimation results

3.2.1 Estimation results: demand equation

The demand equation in (1) is estimated with instrument variable (IV) technique. The instruments for price of pig iron are price of domestic coal, price of imported bituminous coal, prices of domestic steel rails, domestic consumption of steel rails and its one-period lag.

The parameters estimated are summarized in Table 3. For the purpose of comparison, the table also displays the estimates in Irwin (2000a). Out elasticity of substitution ($\sigma$) between imported and domestic pig iron is 4.45 and 6.6 in the short run and in the long run, respectively. Our estimates are not so different from 3 and 6.6 in Irwin (2000a). However, our elasticity of demand for imported pig iron with respect to domestic price ($\eta_M$) is much higher than his estimate. The elasticity of demand ($\eta_Q$) here is quite similar

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

8. We do not exclude the production of ferro-alloys because of limitation of the data.
to his.

3.2.2 Estimation results: dynamic learning

The results are tabulated in Table 1. Column 1 studies the role of cost shocks, using simple OLS regression. Column 2 includes both cost and demand shocks. Demand shocks are captured by output, which is instrumented by pig iron duty, price of imported coal, price of rail and domestic consumption of rail. These two specifications serve as consistency checks of the dataset. Both cost and demand shocks are found to be significant factors driving price.

The effect of learning is in Columns 3 and 4, in which the U.S. experience is measured by lagged cumulative output. We estimate learning by instrumenting output like before. Column 3 ignore the scale effect, but Column 4 takes into account the scale effect. The latter specification gives strong evidence for learning. Specifically, the learning coefficient is -0.37, and statistically significant. The implied learning rate is 29 percent. The estimated learning rate is larger than the 20-percent learning rate in the semiconductor industry in Irwin and Klenow (1994). Column 5 studies learning spillover by replacing the U.S. experience with the U.K. experience. That specification produces no evidence for learning spillover.

As robustness checks, we employ alternative instruments for output and report the estimation results in 2. Column 1 is the benchmark result in Column 4 in 1. The instruments in IV1 are GDP, price of imported coal, price of rail and domestic consumption of rail. The instruments in IV2 are GDP, price of imported coal, domestic consumption of rail. The instruments in IV3 are GDP and price of imported coal. The instruments in IV4 are GDP. Clearly, the learning coefficient is marginally influenced by the choice of instruments.
4 Simulation with dynamic learning

In this section, we rely on the result in Column 4 in Table 1 to simulate the hypothetical free trade regime starting in 1870. To do so, we also need the demand and supply elasticities in Table 3. The elasticity of domestic supply can be obtained as the inverse of elasticity of price with respect to output in Equation (5). The result from Column 4 in Table 1 implies that the supply elasticity is 5.88.

For the foreign supply elasticity, we obtain it by estimating the dynamic learning for the British producers. The specification is similar to the specification Column 3 in 1. The instruments for output of British pig iron are GDP in the U.K., expenditure on pig iron in the U.S., expenditure on steel rail in the U.S. and price of imported coal. The implied foreign supply elasticity is 3.70, and we use this number for the dynamic simulation from 1871. For the static simulation in 1870, we rely on the same foreign supply elasticity as Irwin (2000a). We adopt his estimate of elasticity of foreign supply for only 1870, because we aim to compare the influence of different demand conditions and the influence of shipping cost on the impact of hypothetical free trade regime in the same year as his study.

As consistency checks, Figure 5 presents the relative price of domestic pig iron and that of imported pig iron, together with the simulated relative price under free trade. The gap between the free-trade series and actual series is quite in line with the pig iron duty data.

The main results are in Figure 6. There are three findings as follows. First, if the U.S. moved to free trade in 1870, the import market share in 1870 would become 62 percent. This implies that protection was critical for survival of the industry in 1870. The corresponding market share in Irwin (2000a) is 30 percent. The 32-percent difference arises from the fact that our estimate of elasticity of demand for imported pig iron is much larger than his estimate, and from falling shipping costs.

Second, the import market share would gradually rose in the early 1870s, and fall later
in the late 1870s, despite the presence of dynamic learning effects. The reason for this is that there had been persistent and large shocks on shipping costs in the 1870s. In the 1870s transport costs had declined by as much as 70 percent. The negative shocks on transport costs would offset the effect of learning on price until the late 1870s. As Figure 5 indicates, the relative price of domestic pig iron and imported pig iron would rose in the early 1870s. This implies that the hypothetical fall in price of imported pig iron is larger than the hypothetical fall in price of domestic pig iron. This results follow from a reduction of trade costs in the 1870s.

Third, from the mid 1870s learning would sharply lower price of domestic pig iron to the point where the market share of imported pig iron dropped below 20 percent by 1880. After that the market share of imported pig iron remained fairly stable at that level until the late 1930s. This 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.

Alternatively, Figure 7 displays the simulated output under free trade and the actual output. Note that the year that actual output of the American pig iron industry surpassed that of Britain was 1890. Under free trade, the year that simulated output of the American pig iron industry would surpassed that of Britain would be 1899. This implies that protection had saved the U.S. 9 years in its attempt to catch up with Great Britain.

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 exploit time series variations of output, price of domestic and imported pig iron, pig iron duty and transport costs to estimate the import demand schedule and 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. However, we find no evidence for learning spillover from the U.K. 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 lost 60 percent of market share by 1875. Our findings support the hypothesis that protection was necessary for the survival and 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 before the U.S. output surpassed the U.K. output.

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.

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. 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 failure of Latin American import substitution policies.

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 Shipping cost data

There are no data on pig iron shipping costs. For this reason, we construct the shipping 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


References


Irwin, D. A. (2000a). Could the united states iron industry have survived free trade after the civil war? *Explorations in Economic History* 37, 278–299.


Table 1: Estimation of dynamic learning effects

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<th>Variables</th>
<th>(1) Cost shocks</th>
<th>(2) Demand shocks</th>
<th>(3) Learning</th>
<th>(4) Learning and scale effect</th>
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<td>$R^2$ adjusted</td>
<td>0.71</td>
<td>0.67</td>
<td>0.77</td>
<td>0.82</td>
<td>0.82</td>
</tr>
<tr>
<td>F-statistics</td>
<td>58***</td>
<td>19***</td>
<td>24***</td>
<td>27***</td>
<td>28***</td>
</tr>
<tr>
<td>Implied learning rate</td>
<td></td>
<td></td>
<td>0.16***</td>
<td>0.29***</td>
<td>0.48</td>
</tr>
</tbody>
</table>

Note: All specifications include the constant term, although its coefficient is not reported. *, **, and *** denote statistical significance at 10 percent, 5 percent and 1 percent, respectively. The instruments for output are GDP, price of imported coal, price of rail and domestic consumption of rail. Standard errors are in the bracket and they are heteroskedasticity robust. Serial correlation in errors is rejected at 1 percent.
Table 2: Estimation of dynamic learning effects with various instruments for output

<table>
<thead>
<tr>
<th>Variables</th>
<th>IV1</th>
<th>IV2</th>
<th>IV3</th>
<th>IV4</th>
</tr>
</thead>
<tbody>
<tr>
<td>U.S. experience</td>
<td>-0.37***</td>
<td>-0.37***</td>
<td>-0.37***</td>
<td>-0.11**</td>
</tr>
<tr>
<td></td>
<td>(0.08)</td>
<td>(0.08)</td>
<td>(0.08)</td>
<td>(0.05)</td>
</tr>
<tr>
<td>Iron ore price</td>
<td>0.74***</td>
<td>0.74***</td>
<td>0.74***</td>
<td>0.53***</td>
</tr>
<tr>
<td></td>
<td>(0.18)</td>
<td>(0.18)</td>
<td>(0.18)</td>
<td>(0.20)</td>
</tr>
<tr>
<td>Coal price</td>
<td>0.57***</td>
<td>0.57***</td>
<td>0.57***</td>
<td>0.41**</td>
</tr>
<tr>
<td></td>
<td>(0.17)</td>
<td>(0.17)</td>
<td>(0.17)</td>
<td>(0.16)</td>
</tr>
<tr>
<td>Output</td>
<td>0.17***</td>
<td>0.15***</td>
<td>0.15***</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>(0.05)</td>
<td>(0.05)</td>
<td>(0.05)</td>
<td>(0.09)</td>
</tr>
<tr>
<td># furnaces</td>
<td>-0.31**</td>
<td>-0.30**</td>
<td>-0.30**</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>(0.03)</td>
<td>(0.03)</td>
<td>(0.03)</td>
<td>(0.15)</td>
</tr>
<tr>
<td>R² adjusted</td>
<td>0.82</td>
<td>0.82</td>
<td>0.82</td>
<td>0.82</td>
</tr>
<tr>
<td>F-statistics</td>
<td>27***</td>
<td>25***</td>
<td>25***</td>
<td>62***</td>
</tr>
<tr>
<td>Implied learning rate</td>
<td>0.29***</td>
<td>0.29***</td>
<td>0.29***</td>
<td>0.08**</td>
</tr>
</tbody>
</table>

Note: All specifications include the constant term, although its coefficient is not reported. *, **, and *** denote statistical significance at 10 percent, 5 percent and 1 percent, respectively. The instruments for output in each specifications are as follows. IV1 are GDP, price of imported coal, price of rail and domestic consumption of rail. IV2 are GDP, price of imported coal, domestic consumption of rail. IV3 are GDP, price of imported coal. IV4 are GDP. Standard errors are in the bracket and they are heteroskedasticity robust. Serial correlation in errors is rejected at 1 percent.
Table 3: Estimation of elasticity parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Irwin (2000a)</th>
<th>Naknoi</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma$</td>
<td>3, 6.7</td>
<td>4.45, 6.6</td>
</tr>
<tr>
<td>$\eta_M$</td>
<td>2.24</td>
<td>3.87</td>
</tr>
<tr>
<td>$\eta_Q$</td>
<td>-0.6, -1.4</td>
<td>-0.52, -0.78</td>
</tr>
<tr>
<td>$\epsilon_s^*$</td>
<td>15</td>
<td>15 (in 1870), 3.70 (from 1871)</td>
</tr>
<tr>
<td>$\epsilon_s$</td>
<td>1.1, 3</td>
<td>5.88</td>
</tr>
</tbody>
</table>

Notes:
(1) $\sigma$ is the elasticity of substitution. The first number is the short run elasticity and the second one is the long run elasticity.
(2) $\eta_M$ is the elasticity of demand for imported pig iron with respect to its domestic price.
(3) $\eta_Q$ is the elasticity of total demand. The first number is the short run elasticity and the second one is the long run elasticity.
(4) $\epsilon_s^*$ is the elasticity of foreign supply.
(5) $\epsilon_s$ is the elasticity of domestic supply. The first number is the short run elasticity and the second one is the long run elasticity.
Figure 1: Annual output of pig iron in the U.S. and the U.K. (gross tons)
Figure 2: Pig iron duty and shipping cost (dollar per gross ton)
Figure 3: Pig iron duty and shipping cost (ad valorem equivalent)
Figure 4: Domestic price of domestic and U.K. pig iron (dollar)
Figure 5: Actual and simulated paths of price of domestic pig iron relative to that of imports
Figure 6: Actual and simulated paths of market share of imported pig iron
Figure 7: Actual and simulated paths of domestic output