Transport Costs and Trade Volumes: Evidence from the Trans-Atlantic Iron Trade, 1870-1913†

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May 2014

† The authors would like to thank Ann Carlos, Tim Guinnane, Noam Yuchtman, and participants at the Yale Economic History Workshop, 2012 Canadian Economics Association Annual Meeting, 2012 Rimini Conference and 2012 Economic History Association Annual Meeting for helpful comments. Robert C. Allen and David Jacks generously provided data and documentation. All errors and omissions remain the responsibility of the authors.
Abstract

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We use newly compiled evidence on inter- and intra-continental shipping costs to investigate the relationship between transport costs and trade volumes for the trans-Atlantic iron trade from 1870-1913. Although we find a surprisingly weak connection linking ocean freight rates to British export volumes, when we control for endogeneity, and measure the full range of transport costs - including overland rail charges, insurance, wharfage and brokerage fees - for the inter-continental shipment of pig iron and the intra-continental assembly of raw materials, the importance of transportation strongly asserts itself. During the late-nineteenth and early-twentieth centuries, the cost to transport pig iron across the Atlantic ocean, and the cost to move iron ore and coking coal to North American blast furnaces, were important determinants of the volume of British iron shipments to North America.
1. Introduction

It seems self-evident that a sharp decline in transport costs should contribute to an expansion in trade volumes, and this relationship should be strongest, *ceteris paribus*, if transport costs account for a large share of a good's final market price. Falling ocean freight rates and the late nineteenth-century global trade boom represent a commonly cited example of this transport-trade relationship. O'Rourke and Williamson (1999: 35) argue that, "...the decline in transport costs after mid-[nineteenth] century was enormous, and it ushered in a new era [of globalization]." Echoing this conclusion, Estevadeordal, Frantz and Taylor (2003: 362) report that, "[t]ransport costs on maritime routes played a big role in both [trade] boom and bust: they fell dramatically before 1914...[and] rose steeply up to 1939." And, based on estimates of falling distance effects within a gravity model specification, Jacks (2009: 232) writes, "...[after 1870]...the spread of communication [and] transport networks lowered trade costs, and thus, stimulated trade flows." Despite the widely accepted belief that cheaper ocean shipping must have contributed to higher trade volumes between 1870-1913, there is surprisingly little direct evidence that can confirm this view.1

In this paper we argue that transport costs did play an important role in the determination of late-nineteenth and early-twentieth trade volumes, but the nature of the relationship was complex. At least for some products, we can only uncover the connection between transport and trade if we recognize that falling transport costs simultaneously affect the inter-continental shipment of final goods, and the intra-continental shipment of raw materials. Our evidence ultimately supports the traditional narrative of late-nineteenth century globalization, but this support is conditional on an understanding that ocean freight rates alone are often inadequate to fully capture the impact of transport costs on trade.

Our conclusions are based on a detailed route and product-specific case study of one of the more important, and widely studied trade relationships in economic history:

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1 Looking at aggregate British trade, Jacks and Pendakar (2010: 745) find, "...little systematic evidence suggesting that the maritime transport revolution was a primary driver of the late-nineteenth century global trade boom." The contemporary empirical trade literature (Anderson and van Wincoop (2004); Levinson (2006); and Didier and Head (2008)), unlike much of the globalization literature, is more ambiguous about the importance of shipping costs. The decline in late-nineteenth century ocean shipping costs is discussed in North (1968); Harley (1988); Lew and Cater (2006); and Mohammed and Williamson (2004).
the late nineteenth- and early twentieth-century trans-Atlantic iron trade.\(^2\) Using newly compiled information on west-bound trans-Atlantic ocean freight rates for pig iron, and British and North American railway charges, wharfage costs, brokerage fees and insurance fees, we calculate the total cost to transport pig iron from British blast furnaces (through Liverpool) to Pittsburgh, Pennsylvania (through New York City), and to Hamilton, Ontario (through Montreal), for each year from 1870-1913. We also calculate the total cost to move iron ore from Michigan and coking coal from Pennsylvania to the North American blast furnaces in Pittsburgh and Hamilton. We include these inter- and intra-continental transport cost measures in import demand functions, with additional controls for nation-specific pig iron, iron ore and coal tariffs, adherence to the gold standard, technological discontinuities, domestic demand determinants, British and North American pig iron prices, and lagged trade volumes. An instrumental variables (IV) approach controls for the endogenous nature of the relationship linking transport costs, tariffs and pig iron prices, to trade volumes.

Some of the estimated import demand elasticities are unexpected. If we naively estimate an import demand function that includes trans-Atlantic ocean freight rates as the only transport influence on British pig iron shipments, we find a weak and statistically insignificant connection between transportation and trade. When we broaden our measure of transport costs to include overland rail charges, wharfage, brokerage fees and insurance, the impact of transportation on British exports becomes stronger and statistical significance improves. However, it is only with the inclusion of costs associated with the intra-continental assembly of iron ore and coking coal by American and Canadian iron and steel producers, that we can identify a considerably more elastic and statistically robust link between transportation and trans-Atlantic trade. Controlling for potential endogeneity in the transport-trade relationship only strengthens this result.

Our case study reveals the complexity of the relationship between transport costs and trade. It is not only ocean freight rates that influence the incentive to engage in

\(^2\) The need to use a route and product-specific case study is illustrated by the diversity in commonly referenced average freight rate indexes: North’s (1958) US export freight rate index declines by 84% between 1870-1910; Harley’s (1989) westbound trans-Atlantic shipping costs for coal fall by 54%; Isserlis (1938) average British shipping cost index declines by 34%; Mohammed and Williamson’s (2004) global rate declines by 69%; and Jacks and Pendakar’s (2010) semi-parametric, partner-specific British shipping cost index falls by 45%.
international trade because, as it becomes cheaper to assemble raw materials or intermediate inputs in import competing nations, trade may be suppressed even as ocean freight rates fall. This result is unlikely to be unique to the trans-Atlantic iron trade. We might reasonably expect falling transport costs to have affected the prices for imported final goods and raw material assembly costs in other European (Russian, German) or Asian iron markets, and for a wide range of other trans-Atlantic trade goods, including processed food (flour, cheese, pork), paper products, or refined mineral products.

Does an appreciation of the complexity of the transport-trade relationship really matter from an economic or historical perspective? In our case study, the elasticities derived from the import demand functions reveal the extent to which transport costs contributed to the collapse in Britain's iron trade after 1870. A series of simple counterfactual experiments indicate that the decline in inter- and intra-continental transport costs were very nearly as important as falling relative prices in the determination of British export volumes into North American iron markets between 1870-1913. In contrast, the impact of falling ocean freight rates alone was inconsequential relative to these price movements.

2. Pig Iron Production and Trans-Atlantic Trade

A nation's ability to produce pig iron at competitive prices has often been taken as an indicator of an advanced stage of industrial development. Pig iron is an intermediate input produced by smelting iron ore with high carbon content fuels such as charcoal or coking coal. The molten metal that results from this process can be poured into moulds to form bars or slabs, which can then be further refined to oxidize a range of impurities, producing either wrought iron or steel. The production of pig iron relies on techniques that make intensive use of both human and physical capital. By 1913 efficient blast furnaces, foundries and rolling mills were technologically advanced, organizationally complex, and they were characterized by significant scale economies.

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3 Among the key contributors to the debate surrounding the causes of British export failure in pig iron, neither Temin (1966), McCloskey (1973), nor Allen (1979) even mention trans-Atlantic freight rates. Irwin (2000) and Davis and Irwin's (2008) more recent work on the US pig iron industry emphasizes the role played by tariffs, again largely ignoring transport costs.

4 For more on British and North American technological characteristics and their economic implications see Allen (1977), Donald (1915) or Inwood (1986).
Figure 1 depicts the total quantity of pig iron produced by US, Canadian and British blast furnaces annually from 1870-1913. By the early 1890s US production matched British levels at approximately 9 million net tons. By 1913 the US produced more pig iron than any other nation, smelting just over 30 million net tons during that year. Although production levels in Canada were low relative to the US and Britain, the Canadian market was not inconsequential. Shipments to Canada were important to British blast furnaces, particularly during the second half of our period, and Canadian and US markets were viewed as close substitutes by British exporters. From a macroeconomic perspective, pig iron was an increasingly important industrial product. Canadian pig iron production was growing 12% faster than real GDP between 1870-1913 and US production was growing 7% faster, while British production was shrinking by 0.5% relative to GDP. By 1913 Canadian blast furnaces were producing 293 lbs of pig iron per capita - an increase of nearly 290 lbs per person since 1870. US pig iron production increased from 76 lbs per person to 567 lbs over the same interval, and the British industry produced 561 lbs per capita in 1913 - an increase of just 31 lbs since 1870. This growth in the trans-Atlantic industries occurred during a period of rapidly increasing North American demand for pig iron. Between 1870-1913 real GDP per capita grew at an average annual rate of 2.1% in Canada and 1.8% in the US, urbanization grew by 4.2% and 2.1% respectively, railway mileage expanded by 5.6% and 3.7% in the two countries, and real gross fixed capital investment increased by 5.6% per year in Canada and 4.9% in the US.

The total quantity of British pig iron exported to the United States and Canada in

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5 Broadberry (1997: Chapter 10) reviews the large literature on the stagnation of the British industry during the late nineteenth century. The key explanatory variables in much of this work, which focuses on technological choice and input market conditions, are relative pig iron prices. We are not trying to explain British stagnation, although our results do reveal the underappreciated impact of transport.

6 All quantities used in this paper have been converted to 2,000 lbs net tons.

7 Although the US and Canadian markets appear to have been substitutes (see Other NA Price elasticities reported in Table 2), they were not identical. Production patterns, technological decisions, chronological patterns in demand, tariff policies and transport costs all differed substantially. Our single product-dual trade route case study may limit our ability to draw conclusions about global trade, but the inclusion of Canada and the diversity in North American market conditions supports a considerably more comprehensive investigation than would be possible with a bilateral study.

8 See Appendix Figure A1.
each year between 1870-1913 is shown in Figure 2a. Figure 2b shows the share of North American pig iron consumption supplied by these British shipments. Over the post-1870 period, British iron exports into Canada increased slightly, tonnage to the US dropped, and Britain's share of the Canadian and American iron markets fell steeply. In 1913 Britain shipped just 118,700 tons of pig iron to the United States - a 16,000 ton decrease from the total tonnage shipped in 1870. These imports accounted for less than one half of one percent of US consumption. In Canada nearly 79,000 tons of British pig iron entered the market in 1913, but this represented only slightly more than 5% of domestic consumption, down from 30% in 1870 and nearly 90% in 1874.9

Why did the trans-Atlantic trade in pig iron collapse just as North American demand was expanding sharply? Plausible import demand elasticity estimates imply that any answer to this question must involve fairly dramatic movements in trade determinants that include (but not necessarily confined to) ocean freight rates and intra-continental raw material transport costs.10

3. Trade Determinants

Pig iron is dirty, heavy, awkward to handle and cheap to produce. This implies that, as a share of its final market price, transport costs for pig iron are likely to be substantial - the ocean freight rate alone accounted for one-fifth of the price of British pig iron in Montreal in 1870. Figure 3a shows the cost to ship a 2,000 lbs net ton of pig iron from Liverpool to New York City and Montreal in each year between 1870-1913. These freight rates have been collected from a wide range of sources, and they are specific to the westbound trans-Atlantic shipment of pig iron.11 Although there is considerable volatility from year-to-year, in general trans-Atlantic pig iron freight rates were trending sharply downwards. The Liverpool-Montreal rate peaked in 1880 at $4.53, then fell to a

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9 US producers exported small quantities of pig iron into Canada, rising from approximately 1.5% of the Canadian market in 1870 to just under 10% in 1913.

10 For example, based on the US market for pig iron between 1867-1889, Irwin (2000: Table 1) reports import elasticities with respect to domestic demand that range from 1.1 to 0.6, implying that, ceterus paribus, rising North American demand should have triggered a rapid expansion in British trade.

11 Sources include Angier's (1920) Fifty Years of Freights; the periodical Iron Age; British Board of Trade reports; and the 1914 British Dominions Royal Commission. The data appendix includes information on sources and construction for all series used in this paper.
low of $1.81, settling at $3.02 in 1913 - a 33% decline since 1870.\textsuperscript{12} Liverpool to New York freight rates were lower than the Montreal rates in virtually every year, they fell from $4.13 per net ton in 1870 (16% of the Philadelphia price) to a minimum of $0.37 in 1895, ending our period of study at $0.83 - an 80% decline since 1870.

Of course, the total cost to ship pig iron from British blast furnaces to North American foundries and steel mills is not fully captured by ocean freights. A full accounting must include the cost to move the iron to and from port facilities, wharfage charges, brokerage fees and insurance.\textsuperscript{13} Accordingly, we include wharfage for the Montreal and New York ports, brokerage and insurance for the trans-Atlantic shipment of pig iron, and the cost to load and move pig iron by rail from British blast furnaces in Lancashire to British port facilities in Liverpool, and from the New York and Montreal port facilities to Pittsburgh and Hamilton.\textsuperscript{14}

Insert Figure 3a, 3b and 3c

A comparison of the freight rate series depicted in Figure 3a and the total transport cost series depicted in Figure 3b illustrates the importance of overland and supplementary charges in the total cost to move pig iron. On average between 1870-1913 rail, wharfage, brokerage and insurance costs exceeded the cost to ship pig iron port-to-port across the Atlantic by more than 27% on the Montreal route and by nearly 80% on the New York City route. In 1890, for example, it cost $4.55 per net ton to ship pig iron from British blast furnaces to Pittsburgh steel mills, of which the ocean freight accounts for only $2.08. In the same year it cost $6.39 to ship British iron to Hamilton's steel mills, but the trans-Atlantic part of the trip cost only $3.02. Total transport costs fell by 47% between 1870-1913 on the Canadian route and 65% on the US.

\textsuperscript{12} All values are reported in CAD, but after 1879 the Canadian and US dollars were valued at par.

\textsuperscript{13} Persson (2004: 137-39) discusses the challenges involved in the measurement of port charges and insurance rates for the nineteenth century grain trade. His estimate of the size of these charges relative to port-to-port freight rates is similar to our findings for the iron trade.

\textsuperscript{14} We assume that British trans-Atlantic exports originated in Lancashire blast furnaces. To the extent that other production locations participated in the trans-Atlantic iron trade, our claims about the substitutability of the US and Canadian markets is weakened. Rail charges specific to pig iron are derived from the periodical \textit{Iron Age}, with interpolation across missing years based on freight revenue per ton-mile for British, American and Canadian rail systems. Brokerage fees and insurance rates for pig iron are again taken from \textit{Iron Age}, with exponential decay assumed for insurance rates and a fixed percentage of unit value assumed for brokerage. Wharfage for the Montreal docks is taken from reports in the \textit{Montreal Times}, while New York wharfage is determined on the basis of average registered tonnage (as reported in various newspapers for vessels involved in the pig iron trade) and the official per ton wharfage rates legislated by New York State.
Falling transport costs affected the cost of British iron in North American markets, but they also affected raw material prices, and hence the cost to produce iron domestically. Both inter- and intra-continental transport costs influenced North American blast furnaces' ability to compete with British imports. Throughout our period of study North American blast furnaces used approximately 1.75 tons of iron ore and 1.25 tons of coke to produce one ton of pig iron. These two inputs alone accounted for approximately two-thirds of the value of a ton of pig iron. With few exceptions, Canadian and US blast furnaces acquired their raw materials from geographically proximate sources - iron ore came from the upper Great Lakes, including Marquette, Michigan, and coking coal came from Connellsville, Pennsylvania. Iron ore transport costs include a fresh-water freight rate from ports in the upper Great Lakes to ports in the lower Great Lakes, insurance, brokerage fees and rail charges for the shipment of ore from the mine head to the upper lake ports and from the lower lake ports to Hamilton and Pittsburgh. Coke transport costs include rail charges from the Connellsville kilns to Pittsburgh and, through Buffalo, to Hamilton.

Figure 3c depicts total transport costs for the assembly of 1.75 tons of ore and 1.25 tons of coking coal in Pittsburgh and Hamilton for each year between 1870-1913. Comparing Figure 3b and 3c, we can see that (per net ton of pig iron), raw material transport costs consistently exceeded trans-Atlantic transport costs, and intra-continental shipping costs were falling faster than inter-continental shipping costs. In 1870 the cost to move the ore and coke required to produce one net ton of pig iron from their US extraction points to Hamilton's blast furnaces, exceeded the cost to move one ton of iron from Britain to Hamilton by $6.55. This differential shrank over the next 44 years, such

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15 Raw material input intensities (= average tonnage iron ore or coke consumed per ton pig iron produced) are derived from the US Census of Manufacturing: Blast Furnaces, Materials Used (census dates 1880-1910). They correspond closely to raw material "yields" reported for US blast furnaces in Allen (1978, notes to Appendix Table 2) and input elasticities estimated for nation-specific three-factor Cobb-Douglas production functions (Inwood and Keay, 2013). Because the production of pig iron allowed for very little substitution among raw material inputs, we assume constant raw material intensities. All raw material quantities, prices, transport costs and tariffs are weighted by these intensities.

16 Not all iron ore used in North American blast furnaces came from Marquette, and not all fuel came from Connellsville, but a substantial and increasing proportion did come from these sources, or very near to them. See Donald (1915) or Inwood (1983) for Canada, and Allen (1977: Notes to Appendix Table 1 and 2) for the US. The Lake Carriers' Association publication, The Iron Ores of Lake Superior, provides much of the iron ore transport cost information.

17 O'Rourke and Williamson (1999: 41) anticipate the relative change in over-land versus over-water shipment costs.
that by 1913 trans-Atlantic shipping costs were $0.16 higher than the intra-continental raw material transport costs faced by Canadian furnaces. The US experience was similar - in 1870 intra-continental raw material assembly costs per net ton of pig iron were $4.16 higher than inter-continental shipping costs, and this transport cost differential fell by 1.4% per year, to just $0.89 in 1913.18

Transport costs are just one of the determinants of trade costs. They may be offset (or augmented) by other determinants. In the nineteenth century it was not unusual, for example, for interested parties to petition governments for changes in tariff protection in response to perceived changes in transport costs.19 Governments impose tariffs on output products and/or raw material inputs in an effort to alter aggregate trade costs in a politically or economically advantageous manner. In the United States, the imposition of pig iron tariffs motivated a long and heated political battle during the years following the Civil War.20 This battle culminated in substantial reductions in the pig iron tariff in 1883, 1894 and 1912. In 1882 the US pig iron tariff peaked at $6.25 per net ton, but by 1894 the tariff had dropped $3.57, and by 1913 the US was admitting pig iron imports free of duty.21 US tariffs on raw materials were low throughout the period, with US iron ore tariffs reaching a maximum of $1.17 per net ton of pig iron between 1883-1893 and US coal tariffs reaching a maximum of $1.40 in 1871.22 By 1913 iron ore was entering the US at a rate of just $0.23 per net ton of pig iron, and coal was entering at just $0.50 per net ton.

Tariff protection followed a very different trajectory in Canada. While American tariffs on pig iron moved steadily towards free trade from initially high levels, there were

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18 The difference between Canadian and US raw material transport costs was proportionately larger than the difference in trans-Atlantic shipping costs, reflecting the relatively favourable geographic location of US steel production, with Pittsburgh located less than 50 miles from Connellsville.


20 Irwin (2000: 280-83) describes the US Government's slow move towards free trade in pig iron.

21 US pig iron and coal tariffs were quoted at specific rates per ton between 1870-1913. US iron ore tariffs were quoted at specific rates from 1883-1913. \textit{Ad valorem} tariff rates on iron ore have been converted to $/ton using UK iron ore export prices. US tariff rates are taken from Taussig (1931). Appendix Figure A2 shows Canadian and US "effective" tariff protection for pig iron (= pig iron duty per net ton - (1.75 x iron ore duty) - (1.25 x coal duty)).

22 US blast furnaces relied heavily on domestic raw material supplies. In aggregate, coal and iron ore imports were small compared to domestic consumption, and according to Taussig (1931: 231-232) ore tariffs in particular were paid by only a few firms located close to the Atlantic coast. Sensitivity tests have been performed dropping US raw material tariffs. See Appendix Table A2, Panel A: Test 1.
no Canadian tariffs on pig iron (or the raw materials used in its production) until the imposition of a $2.00 per net ton duty following Canada's adoption of a protection-based trade policy in 1879. An additional $0.50 increase in 1884 was followed by a doubling of the pig iron tariff to $5.00 in 1888, and a final increase to $6.00 in 1893. By 1913 pig iron entering Canada faced a tariff rate that averaged $2.13 per ton, with a slight preference offered to British imports. Throughout the 1870-1913 period coal entered Canada duty free, and iron ore faced only a small $0.63 tariff per net ton of pig iron between 1879-1893.²³

Exchange rate fluctuations also influence trade costs.²⁴ For the trans-Atlantic iron trade we expect the impact of exchange rate volatility to have been small, at least relative to transport and tariff effects, because all three trade partners were strong proponents of the late nineteenth century fixed exchange rate regime. Canada and Britain maintained bilateral fixed exchange rates, tied to gold, throughout the 1870-1913 period. This resulted in very low exchange rate volatility between Canada and Britain. Although slightly more volatile than the Canada-UK exchange rate, aside from the immediate post-Civil War reconstruction period when the US was off gold, the value of the US dollar was also remarkably stable.

Trade costs associated with transport, tariffs and exchange rates are not the only factors that affect trade volumes. Because imported pig iron may have been an imperfect substitute for domestically produced pig iron, North American and British pig iron prices may have differentially affected the volume of British shipments.²⁵ Rising Canadian and US prices provided an incentive to trade, while rising British prices suppressed trade. We also expect that price movements in the neighbouring North American market may have diverted trade, with high US prices suppressing shipments into Canada, and in turn, high

²³ We can calculate ad valorem net protection for Canadian and American blast furnaces (= (pig iron transport costs - raw material transport costs + pig iron tariff - raw material tariffs)/pig iron price). Net protection for Canadian producers was negative from 1870 until 1884, but it rose to a maximum of +25% in 1898. US ad valorem net protection was consistently higher than Canadian protection up to 1893, after which it was consistently lower, ending the period at -11%. See Appendix Figure A3.


²⁵ Irwin (2000: 285-86) reports that US and foreign pig iron were not perfect substitutes during the late-nineteenth century. For a depiction of British, American and Canadian pig iron prices from 1870-1913, see Appendix Figure A4.
Canadian prices suppressing shipments into the US. From Table 1 we can see that average Summerlee No. 2 pig iron prices in Montreal were higher than No. 1 foundry pig iron prices in Philadelphia, which were considerably higher than Cleveland No. 3 pig iron prices in Britain. However, British domestic prices rose gradually after 1870, while prices in Canada fell and US prices dropped even more sharply. The ratio of pig iron prices in Philadelphia relative to Britain fell from 2.5 in 1870 to just 1.2 in 1913, while the Montreal / UK price differential fell from 2.1 to 1.6 over the same period.

Insert Table 1

The size of the North American iron markets may also have influenced trans-Atlantic trade. Because most iron and steel products are purchased by firms and governments as investment goods, rather than by individuals as consumption goods, demand for pig iron is not well represented by typical measures of market size, such as population, GDP per capita or real wages. Real gross fixed capital investment is a better measure of domestic demand for the machinery, equipment and construction materials produced with pig iron. The summary statistics in Table 1 reveal that the US accumulated gross fixed capital steadily through our period of study, increasing at an average annual rate of nearly 5%. In contrast, Canadian investment was discontinuous, growing by only 1.6% per year over the 1870-1895 period, before expanding in dramatic fashion (by more than 11% per year) during the post-1896 "wheat boom" era.

Finally, trade volumes may also have been affected by production technologies. Pig iron has been the subject of much scholarly interest not only because of its importance in the process of industrial development, but also because of the discontinuous nature of the technological changes that were transforming late-nineteenth century iron and steel production. Two important technological discontinuities had the potential to influence trans-Atlantic trade volumes. First, the move away from charcoal and the adoption of coking coal dramatically altered the cost structure and optimal locations for North American blast furnaces, which in turn affected the incentive to trade iron across international borders. The proportion of coke burning furnaces in the United States began to grow well before 1870, and the transition away from charcoal was relatively smooth. In contrast, the adoption of coke as a primary fuel source in Canada
was slightly delayed, but very abrupt. Second, the rise to competitive dominance of fully integrated steel mills employing open hearth processes facilitated the use of molten pig iron in the production of steel. This switch to "hot-metal" affected trade incentives by introducing significant cost savings when firms integrated blast furnaces, steel furnaces and rolling mills into large, organizationally complex plants that used tightly coordinated physical and human capital.

If the data were available from a broad panel of countries, we could assess the relative strength of each of these trade determinants using a gravity model framework, including distance, GDP and lagged trade volumes (to allow for delayed export responses) as additional explanatory variables. Unfortunately, detailed information about route and product-specific transport costs for final goods and raw materials is rare, and the standard gravity model approach is inappropriate for an analysis of a single product traded along two trans-Atlantic trade routes. The uni-directional trade of a specific product between two sets of bilateral partners can be modeled more usefully with import demand functions.

4. Import Demand and the Impact of Transport Costs

Our empirical specifications borrow heavily from the Shiells, Stern and Deardorff (1986) approach employed by Irwin (2000) to estimate late nineteenth century elasticities of substitution for US iron products. We focus narrowly on the relationship between British trans-Atlantic pig iron exports and transport costs, controlling for other trade

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26 Temin (1964: Table C3) reports that only 20% of US pig iron was produced using charcoal as a primary fuel source in 1870. This proportion fell to 7% in 1890 and just 1% in 1910. In Canada, charcoal burning furnaces in Quebec went from producing over 90% of Canadian pig iron during the mid-1870s to less than 15% by the mid-1880s (Inwood 1986).

27 Bridge (1903: 149) describes the use of hot-metal in the open hearth process and the transition to open hearth techniques in the US through the 1890s. Temin (1964: 157-63) chronicles the reduction in investment in stand-alone blast furnaces following the introduction of fully integrated open-hearth steel mills. He argues (1964: 164) that the use of hot-metal, "...had spread throughout the industry by 1900." Early Canadian examples of fully integrated mills include the Steel Company of Canada in Hamilton ON (1899) and the Dominion Iron and Steel Company in Sydney NS (1901). The dominant US examples include Carnegie Steel (1892) and US Steel (1902) in Pittsburgh.

costs, import demand determinants and technological discontinuities. The models we estimate take the form:

\[
\text{British Exports}_{it} = f(\text{Trade Costs}_{it}, \text{Import Demand Determinants}_{it}, \text{Technology}_{it}, \text{Fixed Effects}_{i})
\]

Where: \(\text{British Exports} = 000s\) net tons of pig iron; \(i = \text{Canada and US}\); \(t = 1870-1913\); \(\text{Trade Costs} = \text{gold standard dummy}^{29}\), pig iron and raw material tariffs, and pig iron and raw material transport costs; \(\text{Import Demand Determinants} = \text{domestic final market price, British price, other North American price, real gross fixed investment, and lagged exports}^{30}\); \(\text{Technology} = \text{charcoal dummy and hot-metal dummy}^{31}\); \(\text{Fixed Effect} = \text{Canada dummy}\).

We estimate four models based on this general empirical framework. The first model naively captures the unconditional correlation between ocean freight rates and trade volumes. The second model incorporates controls for standard import demand determinants, including: changes in British, American and Canadian pig iron prices; exchange rate effects; technological discontinuities; and pig iron and raw material tariffs. However, in Model 2 we still measure transport costs with only westbound trans-Atlantic ocean freight rates. In our third model we identify the impact of all other transport charges, including rail costs to-and-from port, brokerage, wharfage and insurance, on the transport-trade relationship, but we still ignore intra-continental raw material transport costs. The fourth model includes all transport charges for the assembly of iron ore and coking coal in Pittsburgh and Hamilton as the final dimension in our assessment of the impact of transport on trade.

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29 The gold standard dummy takes the value 1 during adherence to fixed exchange rates, 0 otherwise: Canada = 1 from 1870-1913; US = 0 from 1870-1878 and 1 from 1879-1913.

30 Following Jacks and Pendakur (2010: 750), sensitivity tests have been performed including an additional trade cost variable (exchange rate volatility = 5 year centred standard deviation of bilateral exchange rates) and an additional import demand variable (GDP similarity = \(\ln \left( \frac{\text{GDP}_{UK}}{\text{GDP}_{UK}+\text{GDP}_{i}} \times \frac{\text{GDP}_{i}}{\text{GDP}_{UK}+\text{GDP}_{i}} \right) \)). See Appendix Table A1, Panel A: Test 2.

31 The charcoal dummy takes the value 1 during intensive use of charcoal as a primary fuel input, 0 otherwise: Canada = 1 from 1870-1878 and 0 from 1879-1913; US = 0 from 1870-1913. The hot-metal dummy takes the value 1 when integrated steel mills dominate, 0 otherwise: Canada = 0 from 1870-1895 and 1 from 1896-1913; US = 0 from 1870-1902 and 1 from 1903-1913. Sensitivity tests have been performed using two hot-metal dummies for the US - one for early integration (1892) and a second for later integration (1902). See Appendix Table A1, Panel A: Test 3. Parameter stability tests reject the possibility that the tariff and transport cost elasticities differ before and after 1879, 1896 or 1902.
Model 4:

\[
\text{British Exports}_{it} = \alpha_0 + \beta_1 \text{Total Iron Transport}_{it} + \beta_2 \text{Total Raw Material Transport}_{it} + \beta_3 \text{Iron Tariff}_{it} + \beta_4 \text{Raw Material Tariff}_{it} + \beta_5 \text{Gold Standard}_{it} + \gamma_1 \text{Own Price}_{it} + \gamma_2 \text{British Price}_{it} + \gamma_3 \text{Other NA Price}_{it} + \gamma_4 \text{Gross Investment}_{it} + \gamma_5 \text{British Exports}_{it-1} + \alpha_1 \text{Canada}_i + \delta_1 \text{Charcoal}_{it} + \delta_2 \text{Hot-Metal}_{it} + \varepsilon_{it}
\]

All continuous variables are measured as natural logarithms, which implies that parameter estimates represent contemporaneous elasticities.\(^{32}\) In each model the \(\alpha\) parameters include the constant and a fixed effect for time invariant, but nation-specific import demand determinants that are otherwise absent from the equations. The \(\beta\) parameters reflect the responsiveness of British trans-Atlantic pig iron exports to changes in trade costs, including transport costs, tariffs and exchange rate effects. The \(\gamma\) parameters reflect the responsiveness of British exports to changes in import demand determinants, including domestic prices, British prices, prices in the neighbouring North American market, gross investment, and lagged exports. The \(\delta\) parameters reflect technological discontinuities associated with the switch from charcoal to coke, and the move from stand-alone blast furnaces to fully-integrated steel mills (that used molten pig iron, rather than re-heating cold iron).

We estimate all four models by ordinary least squares (OLS). Table 2 reports the results, including parameter estimates for each model, robust standard errors (corrected for serial correlation in the error terms and within and across panel heteroskedasticity), and an indicator of statistical significance. From Model 1 we can see that the unconditional correlation linking late-nineteenth and early-twentieth century trans-Atlantic freight rates to pig iron exports was small, statistically indistinguishable from zero, and positive.\(^{33}\) This positive parameter estimate implies that if we ignore all other influences on the transport-trade relationship, cheaper ocean freight rates after 1870 were

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\(^{32}\) We follow Sinha and Sinha (2000) and the minimization of Akaike Information Criteria in our adoption of the log-log specification. Indexes have been created with minimum observed values set equal to 1.00 for the transport and tariff variables. Nation-specific Phillips-Perron unit root tests have been performed to test for stationarity in the key variables. Only British exports into Canada show any evidence of non-stationarity (Phillips-Perron test p-value = 0.098). Sensitivity tests have been performed using levels and first differenced data. See Appendix Table A1, Panel A: Test 4 and Test 5.

\(^{33}\) As described in the data appendix, the ocean freight rate series interpolates over missing years using other westbound trans-Atlantic freight rates. Up to 28 observations are lost if we use our narrowest definition for "observed" pig iron freight rates. Sensitivity tests have been performed using no interpolation in the freight rate series (see Appendix Table A1, Panel A: Test 6).
correlated with falling trade volumes. Of course, the results from our remaining models indicate that other influences on this relationship should not be ignored, so this most naive approach is misspecified.

The estimates from Model 2 indicate that after controlling for standard import demand determinants, the OLS estimate of the relationship linking ocean freight rates to trade volumes remains weak and statistically indistinguishable from zero, but the conditional correlation now has the expected negative sign. Model 2 also reveals that both pig iron and raw material tariff rates were important trade determinants. A 1% increase in North American pig iron tariffs was associated with a strongly statistically significant 0.7% reduction in British export volumes, while a 1% increase in iron ore and coal tariffs triggered a 0.6% expansion in British shipments. The results from this model support the British failure literature's focus on productivity differences, technological choice and input quality, insofar as these effects manifest themselves in changes in relative output prices. The estimates reported in Table 2 indicate that a 1% increase in each destination country's own pig iron prices was associated with a 3.1% increase in British shipments, while a 1% increase in Britain's pig iron prices was associated with a 1.6% decrease in shipments, and a 1% increase in the neighbouring country's pig iron prices lead to a 1.1% decrease in shipments to your own market. Clearly, relative prices mattered. We can also see that increases in domestic gross investment encouraged British trade, trade volumes were persistent over time, and trade was suppressed by the shift from charcoal to coke and from cold-metal to hot-metal. One surprising result from Model 2 is the statistically significant negative impact that adherence to the gold standard appears to have had on trade volumes. Given that Canada

34 In Model 2-4b we aggregate iron ore and coke transport costs and tariffs into single (per net ton of pig iron) Raw Material Transport and Raw Material Tariff measures, using US blast furnace input intensities as weights. The results are not sensitive to the inclusion of ore and coke transport costs and tariffs separately, although the ore tariff elasticity is small and statistically insignificant. See Appendix Table A1: Model 5b. We cannot reject the hypothesis that ore and coke transport and tariff elasticities are statistically indistinguishable. Inwood and Keay (2013) investigate the role of tariff policy in the development of the Canadian industry, including evidence on entry-exit, investments in new technology and location decisions.

35 The negative correlation between other North American prices and trade volumes indicates that North American markets were substitute destinations for British pig iron. For the US iron industry from 1867-1889, Irwin (2000, Table 1) reports import elasticities with respect to domestic and foreign prices of 1.67 and -2.09, respectively.

36 Sensitivity tests have been performed using an industrial output index to capture domestic demand (see Appendix Table A1, Panel A: Test 7).
was on gold throughout our period of study, and the US was only off gold during the years immediately following the end of the Civil War, this result may be capturing the reduction in British exports that followed from the winding down of America's reconstruction efforts.

**Insert Table 2**

In *Model 3* we add all costs involved in the movement of pig iron from British blast furnaces to North American consumption points, to ocean freight rates. Following the inclusion of a more complete accounting of all trans-Atlantic transport costs, the OLS estimate of the transport elasticity rises (becomes more negative), but remains statistically indistinguishable from zero. Transportation's impact on trade volumes still appears small relative to the impact of final good and raw material tariffs, and very small relative to the estimated price elasticities. The other import demand elasticity estimates remain largely unchanged in the move from *Model 2* to *Model 3*. Including all costs associated with the trans-Atlantic export of British iron, therefore, increases the estimated sensitivity of trade volumes to transport costs, but the transport-trade relationship still appears inconsequential relative to the impact of prices and tariffs.

The import demand function in *Model 4* embodies an understanding of the multi-dimensional role of transport costs in the trans-Atlantic iron trade. All costs associated with the shipment pig iron, and the overland rail charges and Great Lakes shipping costs associated with moving ore from Marquette and coal from Connellsville are included in this specification. Recognition that falling transport costs affect the import price of final goods and the cost to assemble raw materials, reveals a considerably more robust relationship between trade and transport. The elasticity estimates from *Model 4* indicate that a 1% increase in the cost to ship pig iron from Britain to North America was associated with a strongly statistically significant 0.96% reduction in trade volumes, while a 1% increase in the cost to assemble iron ore and coking coal in North American production facilities was associated with a marginally (\(p\) value = 0.064) significant 1.3%

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37 We allow price, tariff and transport cost elasticities to differ in *Model 2-4b*. Irwin (2000) and Davis and Irwin (2008) assume common elasticities across output prices and all forms of protection. Statistical tests strongly reject the hypothesis that British, domestic and neighbouring output price elasticities are equal, and that price, tariff and transport cost elasticities are equal. However, we cannot reject the hypothesis that pig iron and raw material tariff and transport cost elasticities are equal. Sensitivity tests have been performed that combine tariffs and transport costs into a single protection variable (see Appendix Table A1: *Model 6b*).
increase in British exports. The OLS estimates of these transport cost elasticities imply that trans-Atlantic iron shipments were almost as sensitive to transport charges as they were to domestic demand, neighbouring pig iron prices and British pig iron prices. Even the domestic price elasticity estimate in Model 4 is only just over twice the size of the transport cost elasticities. In this specification, British trade volumes do, in fact, appear to have been very sensitive to movements in both inter- and intra-continental transport costs. After 1870, cheaper trans-Atlantic shipping costs encouraged British iron exports, while cheaper North American raw material shipping costs suppressed British exports.

The OLS estimates reported in Table 2 for Models 2-4 indicate that final market prices, transport costs, and tariffs were strongly correlated with the quantity of British iron shipped to North America between 1870-1913. However, as described by Irwin (2000), Jacks and Pendakar (2010), and Inwood and Keay (2013), the OLS import demand elasticities for these determinants may be biased due to the presence of endogeneity. For example, while increases in US and Canadian prices for pig iron may encourage trans-Atlantic trade, the resulting increase in British imports could shift domestic supply curves, subsequently driving down these same prices. This source of endogeneity implies a potential downward bias (closer to zero) in the OLS elasticity estimates associated with pig iron prices in the destination markets. Similarly, the OLS transport cost elasticities may be biased downward because an increase in the cost to ship pig iron may suppress trade volumes, but lower trade volumes also reduce the demand for shipping services, potentially driving down transport costs. Another possibility is that rising North American tariffs could reduce British exports, but weakening British competition could induce either higher tariffs, because the policy has been so successful

38 One could also argue that endogeneity might affect the OLS elasticity estimates for British iron prices, neighbouring market iron prices, input transport costs (particularly for iron ore), and input tariffs. In Model 4, Hausman exogeneity tests cannot reject the exogeneity of British prices, neighbouring market prices, input transport costs or input tariffs. However, in some specifications our inability to reject exogeneity for British prices and input transport costs and tariffs is marginal. Sensitivity tests allowing for potential endogeneity in these three variables have been performed (see Appendix Table A2, Panel B: Test 8 and 9).

39 Trans-Atlantic shipments of pig iron were not so large that we might expect them to affect the global demand for transport services, but they did represent a sizable share of the total British trade flowing through Montreal and New York. For example, on average between 1870-1913 pig iron accounted for over 10% of all British freight unloaded at the port of Montreal (by weight), reaching a peak in 1909 at over 25% of all British traffic. If the human and physical capital involved in the trans-Atlantic iron trade had product or route specific attributes, endogeneity must remain a concern for our OLS transport elasticities.
and therefore politically popular, or lower tariffs because the policy has succeeded in its initial protection objectives and/or failed in its revenue objectives.

To account for potentially endogenous relationships linking trade volumes to destination market prices, transport costs and tariffs, we re-estimate Model 4 using a fixed effects - two stage - generalized method of moments (GMM) instrumental variables approach. Excluded instruments for North American pig iron prices include domestic coal prices and domestic manufacturing productivity.\(^40\) For trans-Atlantic transport costs, excluded instruments include Harley's (1989) westbound coal freight rate index, a domestic railroad productivity index, and domestic fish prices.\(^41\) The excluded instruments for North American tariff rates, including electoral support for protectionist parties in the neighbouring North American nation, and a dummy variable that takes the value 1 during the period in which the Canadian federal government was committed to broad nation-building policy objectives under the "National Policy", reflect factors typically used in political economy models to explain late nineteenth and early twentieth century trade policies.\(^42\)

The IV results for Model 4b reported in Table 2 include an indication that the model has passed a Durbin-Wu-Hausman specification test confirming the presence of endogeneity among the Own Price, Ocean + Other Freight, and Pig Iron Tariff variables, a weak instrument F test confirming the statistical strength of the excluded instruments, and a Hansen over-identification test confirming that the excluded instruments are, in fact, exogenous. A comparison of the OLS estimates from Model 4 and the IV estimates from Model 4b reveals that, although the trade responses are slightly more elastic for raw material transport costs, raw material tariffs, domestic demand, prices in Britain, and

\(^{40}\) Iron ore prices are not used as an excluded instrument because, in most specifications, they fail tests for instrument exogeneity. Labour productivity in iron ore mining passes instrument exogeneity tests, but is only available for Canadian mines after 1886. Sensitivity tests using labour productivity in metallic mineral mining as an additional instrument for pig iron prices have been performed (see Appendix Table A2, Panel B: Test 10).

\(^{41}\) In most specifications other general freight rate indexes (Mohammed and Williamson (2004), for example) fail tests for instrument exogeneity. Because British rail charges from blast furnace-to-port are relatively small, British railroad productivity instruments are relatively weak. Sensitivity tests using British railroad productivity from Crafts, Mills and Mulatu (2007) as an additional instrument for transport costs have been performed (see Appendix Table A2, Panel B: Test 10).

\(^{42}\) A more detailed discussion of our IV estimation approach, instrument choice, first stage results and diagnostic testing is provided in the appendix. Appendix Table A3 reports parameter estimates and robust standard errors for the relevant excluded instruments from the first stage OLS regressions for Model 4b, and diagnostic test results for the first and second stage regressions.
prices in the neighbouring North American market, the sign and significance of the
elasticity estimates on all of the exogenous continuous variables are unaffected by the
introduction of controls for endogeneity. There is, therefore, no qualitative impact on our
conclusions with respect to these variables following the move to an IV approach.

The same is true for destination market prices - as expected, a small downward
bias in the OLS estimates is revealed by a comparison with the IV estimates, but the sign
and significance of the Own Price elasticities are unaffected. Even after controlling for
endogeneity, falling domestic prices in the Canadian and US iron markets remain
strongly and significantly correlated with falling British pig iron exports.

Because a reduction in British import competition could have encouraged either
an increase or decrease in the political rewards associated with tariff protection, a priori
we can not predict the direction of any potential bias in the OLS estimates due to
endogenously determined tariffs. A comparison of Model 4 and Model 4b reveals that
any bias must be fairly small, because although the IV estimates do appear more elastic
(more negative) than the OLS estimates, the tariff elasticities derived from both
approaches (and their standard errors) are qualitatively very similar. Falling North
American tariffs on pig iron remain strongly and significantly correlated with rising
British pig iron shipments.

In contrast to the Own Price and Pig Iron Tariff elasticity estimates, the OLS
estimates for trans-Atlantic transport costs appear to suffer from a more substantial
downward bias. After using Harley's westbound coal freight rate index, a domestic
railroad productivity index, and domestic fish prices as excluded instruments to control
for the possibility that higher trans-Atlantic transport costs may suppress trade, while
simultaneously, lower trade volumes may reduce the demand for transport services, we
find that trade volumes become considerably more sensitive to changes in trans-Atlantic
transport costs. In Model 4b the IV pig iron and raw material transport cost elasticities
are larger (more negative) and have more statistical influence than the OLS estimates,

43 Because the IV elasticity estimate on transport costs is substantially larger than the OLS estimate, there
may be some question about the importance of endogeneity controls relative to the inclusion of raw
material transport costs in our effort to fully articulate the transport-trade relationship. If we control for
endogeneity in Model 3, which does not include Raw Material Transport, the elasticity estimate on
transport costs does increase, but it remains small relative to the price and tariff elasticities, and it is just
marginally significant. See Appendix Table A1: Model 3b.
and only final market iron prices appear to have had a stronger connection to trade volumes than transport costs. After controlling for endogeneity, a 1% decrease in the cost to move iron across the Atlantic was associated with a 2.6% increase in British pig iron shipments into North America, while a 1% decrease in the cost to assemble iron ore and coking coal in Pittsburgh and Hamilton was associated with a 2.0% drop in shipments.

In general, both the OLS and IV elasticity estimates point to a strong connection linking the cost of moving products between distant markets and the volume of trade exchanged between these markets. However, the strength of this connection can only be fully uncovered after measuring all contributions to transport costs (not just ocean freight rates), accounting for the potential endogeneity in the transport-trade relationship, and perhaps most importantly, recognizing that transport costs affect raw material costs as well as the price of imported final goods. These results, therefore, confirm the importance of transport costs in the determination of late-nineteenth and early-twentieth century trade volumes, and they reveal the complex nature of this relationship. This conclusion leaves us with one final question to consider: how important were these effects for the trans-Atlantic iron trade?

5. Transport Costs and the Collapse of the Iron Trade

A series of simple counterfactual experiments provide some context for the econometric evidence reported in Table 2. In these experiments we use the IV elasticity estimates from Model 2 and Model 4 to execute iterative calculations that allow us to determine counterfactual levels of British trans-Atlantic pig iron exports in each year between 1870-1913. We consider four counterfactual scenarios: in Counterfactual # 1 we ask what British export volumes would have been if there had been no changes in North American tariff policies after 1870; in Counterfactual # 2 we do not allow any changes in North American prices relative to British prices after 1870; in Counterfactual

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44 In our approach we control for domestic and foreign prices that embody tariffs and transport costs. An alternate approach would be to remove tariffs and transport costs from prices before their inclusion in our import demand functions. The elasticity estimates associated with prices would then reflect the impact of price determinants that were unrelated to protection (see Appendix Table A1, Panel B: Test 11).

45 The trade-transport relationship remains strong even if we expand our panel to include US exports into Canada, which are only affected by changes in intra-continental transport costs (see Appendix Table A1, Panel B: Test 12).
# 3 we do not allow westbound ocean freight rates to fall after 1870; and finally, in 
*Counterfactual # 4* we do not allow pig iron or raw material total transport costs to fall 
after 1870.

Britain exported 8.9 million net tons of pig iron into North American between 
1870-1913. There was a 327% increase in shipments into Canada and a 13% decrease in 
shipments into the US over this period, resulting in a 31% increase in aggregate trans-
Atlantic trade. In our first counterfactual we derive British export volumes in each year 
holding US and Canadian effective tariff rates fixed at their 1870 levels. We iterate the 
model forward through time using counterfactual rather than observed $t-1$ export 
quantities. The results from this experiment are depicted in Figure 4. We find that if 
Canadian effective tariff rates had not risen above their 1870 levels and US tariff rates 
had not fallen, cumulative British exports would have totalled 11.7 million net tons, 
representing a 30% increase over observed cumulative exports. As this result suggests, 
the volume of trade generated by the maintenance of low pig iron tariffs in Canada would 
have just slightly exceeded the volume of trade suppressed by the maintenance of high 
pig iron tariffs in the US.

*Insert Figure 4*

In our second counterfactual we derive British export volumes while maintaining 
the log-difference between British pig iron prices and US and Canadian pig iron prices at 
their 1870 levels. British prices are allowed to evolve over our period of study as we 
actually observe them, but US and Canadian prices are not allowed to fall relative to the 
British price. The results from *Counterfactual # 2* indicate that cumulative British pig 
iron exports into North America would have totalled 56.0 million net tons if British 
producers had not lost their relative price advantage in the US and Canadian markets - an 
increase over observed shipments of more than 47 million net tons. This estimate once 
again illustrates the importance of relative price movements in the determination of 
British exports.

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46 By maintaining relative pig iron prices at their 1870 levels, we are imposing counterfactual *Own Prices* 
and *Other NA Prices* in our experiment. Therefore, for example, British exports into Canada would have 
grown faster than observed if Canada's relative pig iron prices had not fallen, but if US prices also did not 
fall, then Canada would have looked like a less desirable market, so there would have been a counteracting 
downward pressure on British exports into Canada. The trade volumes predicted by *Counterfactual # 2* 
reflect the impact of both relative output price effects.
In our third and fourth counterfactual experiments we derive British export volumes holding ocean freight rates fixed at their 1870 levels (Counterfactual # 3), and holding all pig iron and raw material transport costs fixed at their 1870 levels (Counterfactual # 4). If westbound trans-Atlantic freight rates had not fallen during the 44 years after 1870, cumulative British pig iron exports would have dropped to just 2.6 million net tons, a decrease of more than 70%. Clearly, falling ocean freight rates stimulated trade. However, when we hold all transport costs, including intra-continental raw material shipping costs, constant after 1870, the counterfactual trade effects are even more dramatic, nearly matching those we derived in Counterfactual # 2 when we maintained constant relative output prices. In Counterfactual # 4 we do not allow inter- or intra-continental freight rates, railway charges, brokerage fees, wharfage, or insurance to vary from their 1870 levels. Under this scenario, British exports into the US and Canada would have been more than five times higher than what we actually observe - a counterfactual increase in trans-Atlantic shipments of approximately 38 million net tons.

There is, of course, an important caveat we must keep in mind when assessing the results from these experiments. Each counterfactual varies only one determinant, while holding all else constant. For example, in Counterfactual # 4 British and North American pig iron prices are not allowed to adjust to the dramatic restructuring of the trans-Atlantic iron markets implied by the results. If we were to take the predictions of this experiment at face value, we would be implicitly assuming perfectly elastic supply curves in the US, Canada and Britain, at each point in time throughout the 1870-1913 period. Clearly, this assumption does not reflect the economic realities of late nineteenth and early twentieth century markets. Despite this limitation, the experiment is still useful because it clearly illustrates the relative economic and historical importance of the trade effects implied by our transport cost, tariff, and output price elasticity estimates.

6. Conclusions

The relationship between transport costs and trade volumes is complex and multidimensional. It is not ocean freight rates alone that affect the incentive to trade between geographically distant markets. A full analysis of transportation's effects must include other transport costs, including those paid during the assembly of raw material inputs. A
scarcity of detailed evidence on transport costs and trade volumes from the late nineteenth and early twentieth century globalization period necessitates the adoption of a detailed product and route-specific case study to identify the presence and strength of the transport-trade connection. In this paper we use newly compiled evidence on westbound trans-Atlantic transport costs for pig iron and intra-continental transport costs for iron ore and coking coal, to estimate elasticities derived from import demand functions. These estimates explicitly control for endogeneity in the transport, tariff and destination market price connections to trade. We find that changes in relative output prices, tariff rates and domestic demand were important determinants of the volume of British pig iron shipments to North America between 1870-1913, and inter- and intra-continental transport costs also had a large and strongly statistically significant effect. Our elasticity estimates reveal that the full range of transport costs associated with the shipment of final goods across international borders and the assembly of raw material inputs in import competing production facilities, were important determinants of trade volumes. Counterfactual experiments illustrate the underappreciated impact of falling intra-continental iron ore and coke transport costs on the collapse of the British trans-Atlantic iron trade after 1870. Changing transport costs affect trade volumes, but all dimensions of these costs must be considered, and the endogeneity inherent in the transport-trade relationship must be recognized if we are to empirically identify and assess the strength of the connection.
7. Bibliography


Fremdling, R. (2005), "Industrialization and Scientific and Technological Progress", in The Nineteenth Century, P. Mathias and N. Todorov (Eds.), Abingdon, UK: UNESCO.


8. Figures and Tables

Figure 1: Pig Iron Production

Figure 2a: UK Pig Iron Exports into North America
Figure 2b: UK Share of North American Pig Iron Markets

Figure 3a: Westbound Pig Iron Ocean Freight Rates (Montreal - NYC Comparison)
Figure 3b: Westbound Pig Iron Total Transport Costs
(Hamilton - Pittsburgh Comparison)

Figure 3c: Intra-Continental Raw Material Total Transport Costs
(Hamilton - Pittsburgh Comparison)
Figure 4: Counterfactual British Pig Iron Exports into North America

- Observed British Exports
- CF #1: No Change in Tariff Policy
- CF #2: No Change in Relative Prices
- CF #3: No Change in Ocean Freight Rates
- CF #4: No Change in Transport Costs

Observed Cumulative Imports: 8.9 m Net Tons
CF #1: + 2.8 m Net Tons
CF #2: + 47.1 m Net Tons
CF #3: - 6.3 m Net Tons
CF #4: + 37.9 m Net Tons
Table 1: Summary Statistics, 1870-1913

<table>
<thead>
<tr>
<th></th>
<th>Canada Mean</th>
<th>Canada Std Dev</th>
<th>% Δ</th>
<th>US Mean</th>
<th>US Std Dev</th>
<th>% Δ</th>
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<td>Domestic Production</td>
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<td>147.1</td>
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<td>Ocean Freight Rate - Pig Iron</td>
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<td>4.26</td>
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<td>-0.031</td>
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<td>2.13</td>
<td>0.002</td>
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<td>1.53</td>
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<td>Net Protection</td>
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<td>1.09</td>
<td>1.35</td>
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<tr>
<td>Own Price</td>
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<td>British Price</td>
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<td>11.21</td>
<td>2.99</td>
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<td>Gross Investment</td>
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<td>1609.8</td>
<td>0.056</td>
<td>6138.6</td>
<td>3579.4</td>
<td>0.049</td>
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Note: Quantities = 000s net tons; prices, rates, tariffs = CAD/net ton pig iron; aggregate values = 000s CAD; raw materials are measured per net ton pig iron = 1.75 net tons iron ore + 1.25 net tons coking coal; net protection = (pig iron total transport + tariff) - (raw material total transport + tariff) per net ton pig iron; % Δ = average annual log difference, 1870-1913. Additional detail on sources and construction provided in data appendix.
Table 2: North American Import Demand Functions

<table>
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<tr>
<th></th>
<th>Independent Variable = British Pig Iron Exports to North America (Net Tons)</th>
<th>OLS</th>
<th>IV</th>
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<tr>
<td></td>
<td>Model 1</td>
<td>Model 2</td>
<td>Model 3</td>
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<tr>
<td>Transport:</td>
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<tr>
<td>Ocean</td>
<td>0.248 (0.198)</td>
<td>-0.210 (0.137)</td>
<td>-0.473 (0.361)</td>
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<td>Ocean + Other Freight</td>
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<tr>
<td>Input Transport</td>
<td>0.640** (0.300)</td>
<td>0.673** (0.303)</td>
<td>0.617** (0.285)</td>
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<td>Tariff:</td>
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<tr>
<td>Pig Iron Tariff</td>
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<td>-0.664*** (0.149)</td>
<td>-0.620*** (0.143)</td>
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<tr>
<td>Input Tariff</td>
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<td>0.673** (0.303)</td>
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<td>Gold Standard</td>
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<td>-0.723** (0.323)</td>
<td>-0.339 (0.453)</td>
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<td>Import Demand:</td>
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<tr>
<td>Own Price</td>
<td>3.116*** (0.528)</td>
<td>3.151*** (0.563)</td>
<td>2.786*** (0.671)</td>
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<td>UK Price</td>
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<td>-1.582*** (0.564)</td>
<td>-1.312* (0.678)</td>
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<tr>
<td>Other N. Amer. Price</td>
<td>-1.111* (0.564)</td>
<td>-1.074* (0.577)</td>
<td>-1.504** (0.626)</td>
</tr>
<tr>
<td>Gross Investment</td>
<td>0.989*** (0.183)</td>
<td>0.947*** (0.181)</td>
<td>1.201*** (0.206)</td>
</tr>
<tr>
<td>Lagged Trade Volume</td>
<td>0.486*** (0.085)</td>
<td>0.493*** (0.084)</td>
<td>0.442*** (0.081)</td>
</tr>
<tr>
<td>Technology:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Charcoal-to-Coke</td>
<td>-0.544* (0.282)</td>
<td>-0.449 (0.285)</td>
<td>-0.799** (0.354)</td>
</tr>
<tr>
<td>Cold-to-Hot Metal</td>
<td>-0.607*** (0.206)</td>
<td>-0.599*** (0.211)</td>
<td>-0.648*** (0.201)</td>
</tr>
<tr>
<td>Fixed Effects:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canada</td>
<td>-1.638*** (0.238)</td>
<td>0.612 (0.453)</td>
<td>0.613 (0.456)</td>
</tr>
<tr>
<td>Constant</td>
<td>2.668*** (0.258)</td>
<td>0.727 (1.699)</td>
<td>0.294 (1.825)</td>
</tr>
<tr>
<td>N</td>
<td>88</td>
<td>86</td>
<td>86</td>
</tr>
<tr>
<td>R²</td>
<td>0.369</td>
<td>0.865</td>
<td>0.865</td>
</tr>
<tr>
<td>Durbin-Wu-Hausman</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Weak Instrument</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sargan-Hansen</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Annual data for Canada and US, 1870-1913; all continuous variables measured in natural logarithms; ***, **, * indicate statistical significance with 99%, 95%, 90% confidence; robust standard errors reported in parentheses. IV estimation with GMM/fixed effects (Stata Command `xtivreg2`); Durbin-Wu-Hausman specification tests identify the presence of endogeneity; weak instrument partial F-tests identify jointly insignificant excluded instruments; Sargan-Hansen over-identification tests identify instrument exogeneity. Excluded instruments in Model 4b: Transport = British ocean freight rate index from Harle (1989), domestic railroad TFP index, domestic fish price index; Tariff = electoral support for protectionist party in other North American nation, National Policy dummy (= 1 in Canada from 1879-1913); Own Price = domestic coal prices, domestic non-iron and steel manufacturing TFP. First stage estimation results and a full set diagnostic test results reported in Appendix Table A2. Additional detail on sources and construction provided in data appendix.