GLOBAL TRADE AND THE MARITIME TRANSPORT REVOLUTION

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Abstract—What is the role of transport improvements in globalization? We argue that the nineteenth century is the ideal testing ground: maritime freight rates fell on average by 50% while global trade increased 400% from 1870 to 1913. We estimate the first indices of bilateral freight rates and directly incorporate these into a standard gravity model. We also take the endogeneity of bilateral trade and freight rates seriously and propose an instrumental variables approach. The results are striking: we find no evidence that the maritime transport revolution was the primary driver of the late-nineteenth-century global trade boom.

I. Introduction

IN 1995, Krugman noted that the question of why world trade has grown was then an open issue. The most commonly held perception was that this growth was strongly associated with relentless technological improvement in the communication and transport sectors—roughly, computers, containers, and supertankers. However, academics and policymakers were prone to associate the explosion of global trade in the post–World War II period to the decline in protectionist commercial policies. Particularly dramatic in this sense was the succession of GATT negotiations, which achieved a reduction of average tariffs in industrialized countries from roughly 40% in 1950 to less than 5% in 1995 (Irwin, 1995).

More than ten years later, the issue has still not been conclusively resolved. In one of the main contributions to the literature, Baier and Bergstrand (2001) argue that a general equilibrium gravity model of international trade implies that roughly two-thirds of the growth of world trade since 1950 can be explained by income growth, one-fourth by tariff reductions, and less than one-tenth by transport cost reductions. Given that there are few sources for consistent data on the cost of international freight for the postwar period (Hummels, 2001; Levinson, 2006), their general equilibrium approach allows the economics of supply and demand to fill in the holes.

An alternative approach is to use data on the actual cost of international shipping to determine whether declining freight costs drive increasing international trade. In this paper, we use data on over 5,000 maritime shipping transactions in the period from 1870 to 1913 to address this question. We argue that the late nineteenth century is an ideal testing ground: from 1870 to 1913, maritime freight rates fell on average by 50% as a result of productivity growth in the shipping industry (Mohammed & Williamson, 2004), while global trade increased by roughly 400% (Cameron & Neal, 2003). In contrast, during the post–World War II period, the joint trajectory of freight rates and bilateral trade is less clear, and the data, at least for freight rates, are sparse. Thus, if maritime transport revolutions matter, the nineteenth century is the place to start looking.

This paper addresses some of the issues raised by the recent work of Estevadeordal, Frantz, and Taylor (2003). They use a gravity model of bilateral trade for the years 1913, 1928, and 1938 to indirectly decompose the forces driving the change in country-level aggregate trade volumes between 1870 and 1939. However, in contrast to Estevadeordal et al. (2003), we focus only on the initial upsurge of trade from 1870 to 1913 and accordingly bring new, direct panel data to bear on the issue. More specifically, we are able to provide the first indices of country-pair-specific freight rates for this earlier period and incorporate these into a standard gravity equation of bilateral trade. That these indices are country-pair-specific is important, as it is well-known that technological innovation in the maritime shipping industry reduced long-haul freight rates more than short-haul ones.

We also address a major and previously unnoticed identification issue: maritime freight rates are endogenous to bilateral trade. This is due to the fact that freight rates are the price for shipping services and are thus partially determined by import demand. Although one would expect that lower maritime freight rates would stimulate higher volumes of trade, this simultaneity may generate a spurious positive correlation between two variables of interest. In the short run, increases in import demand could interact with capacity constraints in the shipping industry to create higher freight rates. Disentangling these two forces using standard IV panel methods is one of the paper's main contributions.

In our empirical work, we are able to document such correlations. OLS estimates generate a positive coefficient on freight rates in a standard gravity equation. But by using a plausible set of instruments ranging from shipping input prices to weather conditions on major shipping routes, we are able to identify a negative but statistically insignificant relationship between the two variables. In sum, the results are striking: we find little systematic evidence suggesting that the maritime transport revolution was a primary driver of the late-nineteenth-century global trade boom. Rather, the most powerful forces driving the boom were those of income growth and convergence. Finally, we suggest that a significant portion of the observed decline in maritime transport costs may have been generated by the trade boom itself. In this view of the world, the key innovations in the shipping industry were induced technological responses to the heightened trading potential of the period.

Received for publication September 11, 2007. Revision accepted for publication October 27, 2008.

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We thank Rui Esteves, Douglas Irwin, Chris Meissner, Alan Taylor, William Hutchinson, and the paper's two referees for comments. We also appreciate the feedback from presentations at the 2007 Allied Social Sciences meetings; the 2007 All-UC Group in Economic History conference; the 2007 Economic History Association meetings; the 2007 European Historical Economics Society meetings; the Long-term Perspectives for Business, Finance, and Institutions conference; CU Boulder; Dalhousie; and Harvard. Finally, we gratefully acknowledge the Social Sciences and Humanities Research Council of Canada for research support.

In the following section, we explore the relationship between freight costs and trade flows more fully. In the third section, we discuss our data and introduce the means by which the bilateral freight indices are constructed. The fourth section presents our main empirical results, while the fifth section presents a decomposition exercise in the spirit of Baier and Bergstrand (2001). The sixth section concludes with a discussion of several important caveats to our results, including the role of contemporaneous technological improvement in the nonmaritime transport sector and the possibility that the period prior to 1870 might have been the true locus of the maritime transport revolution.

II. Transportation Costs and Trade Flows

There is a strong impression in both popular and professional opinion that the late twentieth century—just like the late nineteenth century—witnessed drastic improvements in transport technology, which are assumed to have necessarily spilled over into international trade flows. Lundgren (1996, p. 7) writes, "During the last 30 years merchant shipping has actually undergone a revolution comparable to what happened in the late nineteenth century." In these accounts, identifying the sources of such improvements is relatively straightforward and is seen in the movement toward containerization and increased port efficiency. Thus, "the clearest conclusion is that new technologies that reduce the costs of transportation and communication have been a major factor supporting global economic integration" (Bernanke, 2006).

However, this view has not gone unchallenged. Hummels (1999) strongly argues against a twentieth-century maritime transport revolution and accompanying declines in shipping costs. In reviewing the limited data on maritime freight rates dating from 1947, Hummels concludes that "there is remarkably little systematic evidence documenting [such a] decline" (p. 1). Yet he does find considerable evidence of changes in the composition of transport medium and in the trade-off between transport cost and transit time. The most marked development in this regard has been the increasing reliance on air shipments in international trade. As of 2000, these shipments had grown from negligible levels in the 1940s to roughly one-third (by value) of all U.S. trade. This points to the fact that the late nineteenth century offers a much simpler context in which to study the effect of rapidly declining maritime freight rates on global trade.

As to the most widely held view of the nineteenth century, it is generally supposed that the railroad and telegraph take pride of place in promoting economic integration within countries, while the wholesale adoption of steam propulsion in the maritime industry plays a similar role in spurring trade between countries (cf. Frieden, 2007; James, 2001). While analytically sound, this interpretation overlooks many critical elements of the late nineteenth century. The first would be the development of a host of commercial and monetary institutions, chief among them the classical gold standard. More important, this view fails to condition on the economic environment in which this global trade boom occurred: this was a period of both significant income growth and convergence (Taylor & Williamson, 1997).

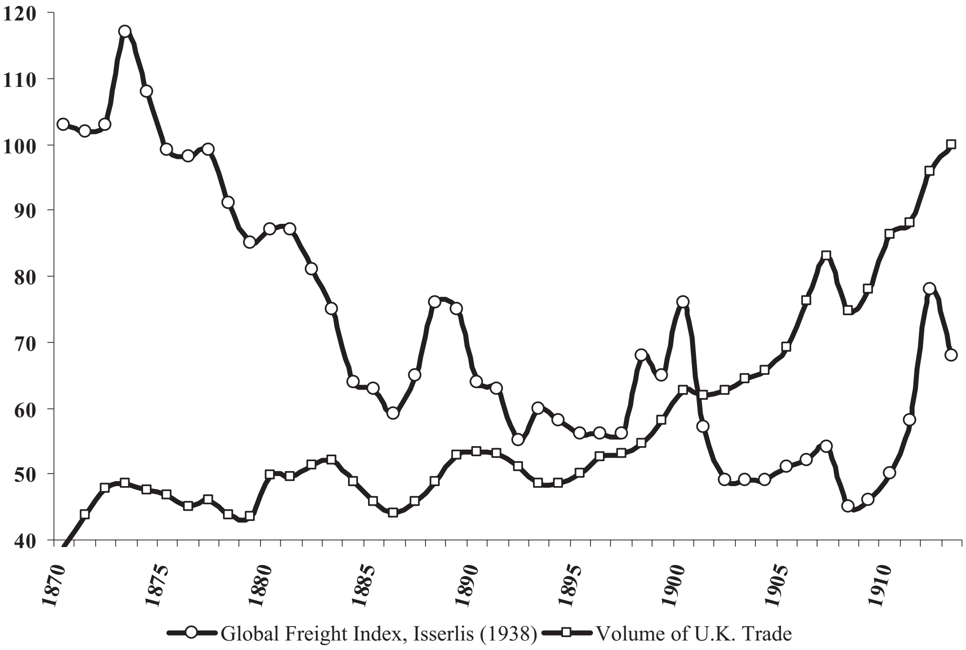
What is needed, then, is evidence on the relationship between transport costs and trade flows. Of course, this is traditionally proxied within the context of gravity models of trade as the mapping of distance into bilateral trade flows. Almost always this is formulated as a log-linear equation that allows potential fixed costs in shipping and a concave relationship between distance and transport costs. This seems to be a reasonable procedure, especially in the cross-section. But this approach suffers from the fact that distance between countries is a time-invariant variable, so this means that to gauge the contribution of changes in transport costs to changes in trade flows is decidedly blunt.

This paper makes contribution on several fronts. First, it provides economists with a different testing ground for assessing the interaction between transport costs and trade flows. Second, and much more important, it is the first study for any period to tackle this question with the aid of direct information on country-pair-specific freight rates rather than proxies such as the ratio of declared cost-insurance-freight to free-on-board prices as in Baier and Bergstrand (2001) or a country-invariant index of global freight rates as in Estevadeordal et al. (2003). Finally, freight rates are almost certainly endogenous to trade flows. Freight rates are the price of shipping services and thus are determined by supply and demand in the shipping industry, where demand obviously depends on international trade flows. The identification strategy employed in this paper is to isolate the supply curve of shipping services from changes in demand with a wide-ranging set of instrumental variables. This approach yields a small, negative, but statistically insignificant relationship between freight rates and trade volumes, leaving little independent role for the maritime transport revolution in explaining the late-nineteenth-century trade boom.

III. Data

The first issue is how to separate out the effects of changes in maritime transport from changes in other modes of transport. Our approach is to identify a country that might be thought of as representative and for which all trade was maritime by definition. The choice here is obvious. The United Kingdom loomed large in developments in the global economy of the time and is conveniently separated from all of its trading partners by water. Thus, we will explore the evolution of maritime freight rates and trade flows through the lens of the United Kingdom's experience during the late nineteenth century. Figure 1 gives a rough sense of the changes. The trends in the two variables are clear: freight rates decline appreciably while trade volumes explode, suggesting a negative correlation between these variables. At the same time, figure 1 also demonstrates that trade volumes take off only after 1895, by which time the maritime transport revolution had essentially played itself out.

FIGURE 1.—GLOBAL FREIGHTS AND U.K. TRADE



Our data are an unbalanced panel on 21 countries (U.K. trading partners) for the period 1870 to 1913. Table 1 provides the share of our sample in total trade with the United Kingdom, the share of the United Kingdom in global trade, and the share of our sample in global trade during the period. Here we see that although the sample's share of U.K. trade is slightly rising through time, the U.K. share in global trade is effectively halved over this period from 30% to 15%. Consequently, our sample falls from 21% to 11% of global trade in the period. However, the United Kingdom was the primary trading partner of not only the fastest-growing economies of the time (Germany, Japan, and the United States) but also those economies experiencing the most rapid decline in maritime freight rates (Australasia, India, and Japan). Table 2 summarizes the coverage of matched bilateral trade, freight, and GDP data. It should be noted that in general, the limiting variable here is GDP. By comparison, the bilateral trade data are complete, and the freight data have only a few breaks in coverage.

Our underlying gravity equation of bilateral trade flows is

$$Trade_{UK,i,t} = \alpha f_{UK,i,t} + X_{UK,i,t}\beta + \delta_t + \theta_i + \varepsilon_{i,t}, \qquad (1)$$

where i indexes countries; t indexes years; *Trade* is the trade flow between the United Kingdom and country i in year t and is equal to $(\ln(\text{Exports}_{UK,i,t}) + \ln(\text{Imports}_{UK,i,t}))/2$; f is the freight cost index to ship 1 ton of a generic commodity from Great Britain to country i in year t; and X is a vector of covariates suitable to a gravity model of trade. The third-to-last term is a decade fixed effect to control for secular changes in world GDP and other variables. The second-to-last term is a country fixed effect to control for time-invariant multilateral barriers or price effects, or both,

TABLE 1.—TRADE RATIOS

	Sample-to-U.K. Trade Ratio	U.K.-to-Global Trade Ratio	Sample-to-Global Trade Ratio
1870–1875	0.7116	0.2969	0.2111
1875–1880	0.7264	0.2629	0.1909
1880–1885	0.7369	0.2310	0.1703
1885–1890	0.7456	0.2193	0.1635
1890–1895	0.7508	0.2098	0.1575
1895–1900	0.7607	0.2013	0.1532
1900–1905	0.7657	0.1940	0.1486
1905–1910	0.7539	0.1692	0.1276
1910–1913	0.7412	0.1514	0.1122

Source: Estevadeordal et al. (2003); *Statistical Abstract for the United Kingdom.*

TABLE 2.—SAMPLE COUNTRIES AND COVERAGE

Countries with a Full Panel of GDP and Freight Data from 1870	
Brazil	Japan
Canada (ends 1907)	Portugal
Ceylon	Russia
Dutch East Indies	Spain
France	United States
Germany	Uruguay (ends 1907)
Italy	
Countries with a Full Panel of GDP and Freight Data from 1884	
Australasia	India
Denmark	Norway and Sweden
Countries with a Full Panel of GDP and Freight Data from 1900	
Argentina	Colombia
Chile	Philippines

Note: Australia and New Zealand do not enter as separate trade entities before 1887; Norway and Sweden do not enter separately until 1891.

which capture the average trade barrier facing countries (Anderson & van Wincoop, 2003).[1] In addition, these country fixed effects absorb all other time-invariant factors that affect international trade volumes, including the geographical distance between trading partners, membership in the British Empire, use of the English language, and other cultural factors.

The freight cost index used in equation (1) constitutes a primary contribution of this paper and varies across countries and over time. All freight cost indices are either commodity and city specific, as in Mohammed and Williamson (2004), or invariant across countries, as in Isserlis (1938). We use information on 5,247 shipments of forty different commodities during the period 1870 to 1913 between the United Kingdom and our sample of 21 countries. These shipping data were collected from a number of sources, detailed in Jacks and Pendakur (2008).

We model the freight index as $f_{UK,i,t} = f_{UK,i}(t)$, where $f_{UK,i}(t)$, $i = 1, \ldots, 21$ are country-specific freight rate indices, each of which is estimated as part of the function:

$$\ln F_{UK,i,s,t} = \delta_i + f_{UK,i}(t) + \phi_{i,s} + u_{UK,i,s,t}. \quad (2)$$

Here, $F_{UK,i,s,t}$ is the shipment cost in Great Britain pounds per ton, i indexes shipments between a give country i and the United Kingdom in a given year t for a given commodity s, and δ_i is (the log of) a country fixed effect capturing the 1870 freight cost separating Great Britain and country i. In addition, $f_{UK,i}(t)$ are commodity-independent smooth functions of time normalized to have a mean of 0 (that is, the log of 1), and $\phi_{i,s}$, $s = 1, \ldots, 40$ are commodity fixed effects, which vary across countries. The function is estimated separately for each country i and is implemented as a semiparametric model, using a penalized B-spline smoother for $f_{UK,i}(t)$ with partially linear effects for commodities.

The motivation for using semiparametric estimation is to let the data determine the shape of $f_{UK,i}(t)$ rather than imposing a parametric structure a priori. The penalized spline approach uses polynomial functions of t over separate "windows" covering different time periods (the spline functions) to approximate the unrestricted function $f_{UK,i}(t)$, with additive commodity effects in this case. We implement quadratic B-splines: quadratic splines for the curvature within windows and B-splines that optimize the spacing and placement of the windows to minimize the collinearity of spline functions across windows. To maintain degrees of freedom, a roughness penalty is added to restrict the change in curvature from window to window, resulting in greater smoothness. The spline functions are cross-validated to achieve the semiparametrically optimal smoothness. We use quadratic splines with a cross-validated roughness (λ) of 2 and implement the model in S-Plus using the GLASS routines of Eilers and Marx. (See Eilers & Marx, 1996, for a description of the software and Ruppert, Wand, & Carroll, 2003, for a survey of semiparametric spline methods.)

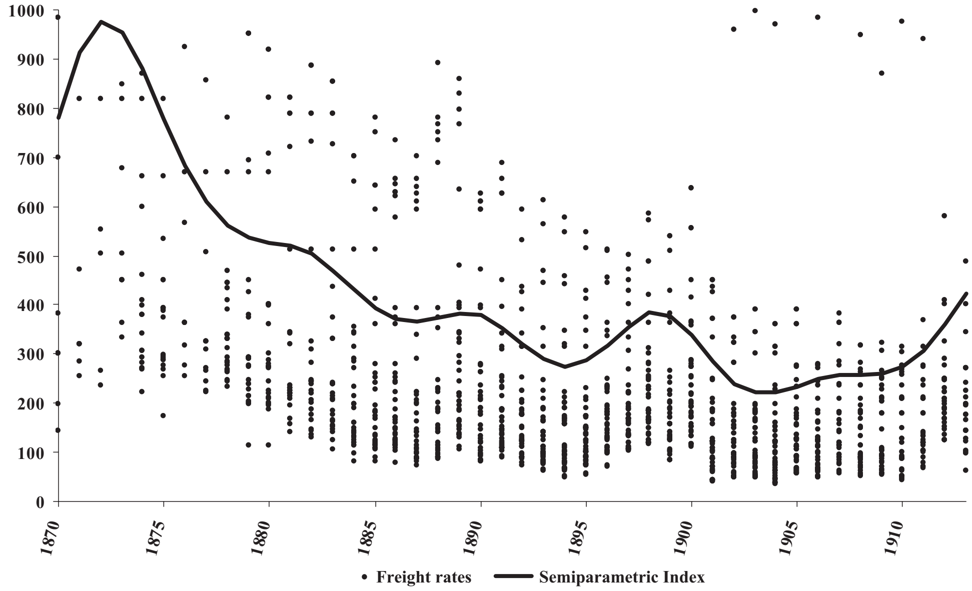
Three crucial assumptions are embodied in our semiparametric estimation of freight rate indices. First, we use country-specific but time-invariant coefficients for the forty commodities we observe in our sample. This implies that in any given country, the prices for shipping different commodities must be related by the same proportionate differences over the entire period. Historically, this restriction may be justified by considering freight rates in the North Atlantic, the most heavily traveled route. In 1870, grain could be transported between Britain and the United States at 30% of the cost per ton of cotton, and wheat could be transported at 20% of the cost. In 1913, the respective figures were 25% and 16%. Given that the overall maritime freight rate index for this route fell by 45% between 1870 and 1913, the changes on the order of 5% are relatively small and likely of second-order importance. Second, the penalized splines employ a small number of windows and a roughness penalty that delivers a freight index that varies smoothly over time and does not allow discrete jumps or falls in freight costs. Both assumptions are imposed to deliver a tractable empirical model. If either is relaxed, the resulting model has too many parameters to feasibly estimate.

Finally, since we are interested in the total volume of trade between country i and the United Kingdom, that is, imports plus exports, we estimate equation (2) using information on both U.K.-bound and -originated freight rates. In this sense, the $f_{UK,i}(t)$ term can be thought of as the commodity-independent average freight rate separating country i and the United Kingdom. This method also avoids the problem that indices derived from freight rates in only one direction, for example, from the United States to the United Kingdom, are likely to be biased as back-haulage rates were vitally affected by both outward-bound rates and the composition of trade between two countries.

Figure 2 gives a rough sense of this approach by plotting all available per ton freight rates between the United States and the United Kingdom against our U.K.-U.S. freight rate index as estimated from equation (2). The results are reassuring, as the main trends in the data seem to be captured well. From 1870 to 1913, the index registers a 45% decline for the U.K.-U.S. as compared to the 34% decline reported in the standard source on freight rates for this period (Isserlis, 1938). Again, we emphasize that this Isserlis series, which Estevadeordal et al. (2003) used, among others is simply a chained, unweighted average of a large number of disparate freight rate series with no controls for commodities or routes and is thus country invariant. We believe that explicitly modeling the structure of freight rates as in equation (2), as well as allowing cross-country differences in the evolution of freight rates, is an important step in the right direction.

[1] The appendix considers other formulations of the gravity equation that address the identification problem highlighted by Baldwin and Taglioni (2006). Specifically, they incorporate country-specific year dummies. The results presented in the following section remain qualitatively unaltered by the addition of country-specific decade dummies. In the body of this paper, we present results with country fixed effects and decade fixed effects, but without their interaction as these diminish the identifying power of the *freight* variable.

FIGURE 2.—FREIGHT RATES AND FREIGHT INDICES
PENCE-PER-TON FREIGHT RATES FOR THE UNITED KINGDOM AND UNITED STATES AND THE SEMIPARAMETRIC INDEX



Next, we incorporate the country-specific freight indices into the vector of covariates X of equation (1), which includes standard gravity model variables: GDP, income similarity, average tariff intensities, and exchange rate volatility for the United Kingdom and the 21 sample countries, plus an indicator for gold standard adherence by each trading partner.[2] The data are summarized in table 3, and the sources are detailed in Jacks and Pendakur (2008).

IV. Results

Our first exercise is to run a very naive regression of bilateral trade flows on nothing more than a constant and our measure of bilateral freight rates. These results are reported in column A of table 4 and strongly confirm the traditional story of the role of the maritime transport revolution in the nineteenth-century global trade boom. The estimated elasticity between the two variables is precise, large, and negative. A 10% drop in freight rates is associated with an increase in trade volumes of over 4%. Thus, the drop in average freight rates between 1870–1875 and 1908–1913 is predicted to explain approximately 25% of the change in U.K. trade volumes in the same period.

Of course, this is the wrong exercise for evaluating the relationship of interest in light of the considerable body of research into gravity models of international trade flows. Thus, we include standard gravity variables: GDP, income similarity, tariff intensity, the gold standard, and nominal

[2] The United Kingdom was, of course, on the gold standard for the entire period from 1870 to 1913.

TABLE 3.—DATA SUMMARY

	Description	N	Mean	s.d.	Minimum	Maximum
Volume of trade	Average of bilateral imports (log of) plus exports (log of)	671	20.38	1.206	17.22	22.58
Freight	Semiparametric index of country-specific freight rates (log of)	671	4.28	0.368	3.11	5.19
GDP	Sum of U.K. and partner GDP (log of)	671	12.32	0.334	11.69	13.53
Income similarity	Product of U.K.- and partner-shares of combined GDP (log of)	671	−2.31	0.860	−4.71	−1.39
Average tariffs	Average of partner and U.K. tariffs (log of)	671	2.30	0.511	1.25	3.46
Gold standard	Indicator variable for partner adherence to gold standard	671	0.56	0.497	0.00	1.00
Exchange rate volatility	Standard deviation of change in logged nominal exchange rate	671	0.01	0.014	0.00	0.10
Growth of trade	Decadal difference in volume of trade	463	0.1565	0.3108	−0.9414	1.7904
Change in freight	Decadal difference in freight	463	−0.2327	0.1814	−0.7567	0.4213
Growth in GDP	Decadal difference in GDP	463	0.1894	0.0532	0.0638	0.4133
Convergence of GDP	Decadal difference in income similarity	463	0.0300	0.0939	−0.1863	0.5062
Change in average tariffs	Decadal difference in average tariffs	463	0.0112	0.2444	−0.7258	0.8139
Change in gold standard adherence	Decadal difference in gold standard	463	0.1102	0.4349	−1.0000	1.0000
Change in exchange rate volatility	Decadal difference in exchange rate volatility	463	−0.0018	0.0167	−0.0771	0.0930

TABLE 4.—GRAVITY REGRESSIONS
DEPENDENT VARIABLE: AVERAGE BILATERAL VOLUME OF TRADE

	A: OLS Estimates			B: OLS Estimates			C: IV Estimates		
	Estimate	s.e.	p-Value	Estimate	s.e.	p-Value	Estimate	s.e.	p-Value
Freight	**−0.4457**	**0.0590**	**0.000**	**0.2463**	**0.1047**	**0.019**	−0.0146	0.1754	0.934
GDP				**0.7549**	**0.1650**	**0.000**	**0.5470**	**0.1532**	**0.000**
Income similarity				**0.9095**	**0.1556**	**0.000**	**0.8498**	**0.1529**	**0.000**
Average tariffs				**−0.1556**	**0.0645**	**0.016**	**−0.2211**	**0.0618**	**0.000**
Gold standard				**0.2019**	**0.0396**	**0.000**	**0.2178**	**0.0358**	**0.000**
Exchange rate volatility				**−1.7926**	**0.8069**	**0.026**	**−1.5656**	**0.8346**	**0.061**
Decade fixed effects?		*No*			*Yes*			*Yes*	
Number of observations		671			671			671	
R^2		0.1937			0.4789			0.4837	
Davidson-Mackinnon panel exogeneity test, p-value								0.0470	
First-stage (uncentered R^2								0.8423	
Shea partial R^2								0.2145	
F-statistic (p-value)								7.44 (0.000)	
Robust F-statistic (p-value)								5.49 (0.000)	
Weak ID critical value: 20% relative bias								6.24	
Weak ID critical value: 30% relative bias								4.43	
Hansen J test of overidentification (p-value)								29.87 (0.095)	
Moreira LIML estimate (s.e.)								−0.1959 (0.1708)	
Conditional IV 95% coverage set								(−0.5815, 0.1464)	
Conditional likelihood ratio test p-value								0.269	

Note: All estimation with first-order autoregressive and heteroskedastic robust standard errors. Fixed effects not reported. Freight instrumented with sailors' wages, coal and fish prices, average sail and team tonnages, lagged sail and steam net tonnages, and barometric means and standard deviations.

exchange rate volatility. GDP is defined as (log GDP_{UK} + log GDP_i), while income similarity is measured by

$$\log\left(\frac{GDP_{UK}}{GDP_{UK}+GDP_i}\times\frac{GDP_i}{GDP_{UK}+GDP_i}\right).$$

Tariff intensities are defined as

$$\log\left(\text{average}\left[\frac{\text{Tariff revenue}}{\text{Imports}}\right]_{UK,i}\right).$$

We note that we lack country-pair-specific information on tariff barriers—that is, these measures capture the general level of protection afforded in the U.K. and U.S. markets, for example, but not the protection afforded against British goods in U.S. markets and vice versa. At the same time, these same measures have been shown to correlate in sensible ways with such things as trade costs and flows (Jacks, Meissner, & Novy, 2006). Likewise, adherence to fixed exchange rate regimes as a stimulus to bilateral trade has a fairly long provenance in the literature (Rose, 2000), especially in the context of the gold standard of the late nineteenth century (López-Córdova & Meissner, 2003).

When we incorporate these variables, the picture changes radically. Column B of table 4 reports the results of OLS estimation of the gravity equation. Conforming to our priors, we find significant positive coefficients for GDP, income similarity, and the gold standard, as well as significant negative coefficients for average tariffs and exchange rate volatility. But by far the most striking result is that for the freight rate term. Whereas in column A, the relationship was decidedly negative, here in column B the relationship is decidedly positive.[3]

What explains this divergence from the previous results and, more pointedly, the traditional narrative of the nineteenth century? In this take, the relationship should be a negative one as lower freight rates drive down the costs of international trade and thus stimulate an increase in observed trade volumes. Such a result would be consistent with the findings of Baier and Bergstrand (2001) in company with Estevadeordal et al. (2003), both of which invoke the exogeneity of transportation costs in explaining the growth of world trade.

We believe there is another explanation: freight rates are not exogenous. One of our key arguments is that there has been insufficient appreciation of the two following facts. First, freight rates are nothing but the prices for transport services and as such are a function of the supply of shipping and the volume of trade demanded. And second, the volume of trade is a function of traded prices and the quantity of goods shipped. In other words, the two variables—trade volumes and freight rates—are simultaneously determined.

In the next battery of regressions, we address this endogeneity by instrumenting for the freight price indices $f_i(t)$ using a vector of instruments that includes the log of Norwegian sailors' wages, log of the prices of coal and fish, the log of the average tonnages of sail and steamships registered in the United Kingdom, the log of the (once- and

[3] We note that this finding is not affected by the inclusion of time-variant fixed effects or other freight indices. The appendix reports the results of this sensitivity analysis.

twice-lagged) net tonnage of British sail and steamships, and the annual mean and variance of barometric pressures in four quadrants around the United Kingdom (the Baltic and North Seas, the Mediterranean Sea, and the North and South Atlantic). The basic idea here is to isolate the supply curve of shipping services from changes in demand, and we can motivate our instruments as follows.

Wage bills constituted a significant portion of variable costs in shipping. However, using British sailors' wages might be inappropriate, as these wages are likely correlated with the British business cycle and, thus, import demand. We exploit a different source of exogenous variation in sailors' wages. Hiring Norwegian sailors was common on merchant ships of all flags throughout this period, so their wages are likely to be highly correlated with, but not wholly dependent on, those prevailing in the British shipping industry as their labor was, in effect, an internationally traded commodity (Grytten, 2005). Such wages are likely to be a suitable instrument in that they should be correlated with freight rates but not with the error term, that is, they affect only trade volumes indirectly through freights. Likewise, coal was a major input to the production of shipping services during the period, but the share of coal consumed by the industry was relatively small, with 1.3% and 1.2% of British coal output in 1869 and 1903, respectively, being allocated to coaling stations which acted as the depositories for coal consumed in maritime transport (Griffin, 1977).

The measures of fish prices and route-specific barometric pressures are intended to capture climatic effects on the supply of shipping, with the idea being that inclement weather over a year should have an adverse effect on the level of freight rates. The average tonnage of sail and steamships is intended to capture exogenous technological change in the shipping industry. As refinements in steamship technology were adopted and the physical size of steamships ballooned, the cost advantages of steam versus sail mounted and shifted out the supply curve of shipping over the long run. And as these average tonnages enter logarithmically, these variables capture the ratio of the average steamship size to that of the average sail ship, which should not be contemporaneously correlated with prevailing freight rates. We have measures of the stock of net tonnage in the sail and steam fleets of the United Kingdom at our disposal. Capacity constraints should vitally affect freight rates. However, we include only lagged values of these measures to avoid the simultaneity between the quantity supplied (net tonnages) and price (freight rates) of shipping service. Finally, as the proportionate decline in freight rates is dependent on the distance separating ports, we also interact all instruments with the distance between country i's chief port and London.

The use of instrumental variables may also correct for the endogeneity of freight rates due to correlated missing variables. One such correlated missing variable is unobserved declines in overland shipping costs within countries, particularly the introduction and extension of railroad networks. These costs bear on one of the alternatives to maritime trade with the United Kingdom, that is, domestic trade. Again, our instruments are based on the weather, sail and steam tonnages, sailors' wages, fish prices, and U.K. coal prices. Coal is a relatively small input to rail and other overland transport, so these instruments are plausibly uncorrelated with overland freight costs. Consequently, our IV regressions can be thought of as also dealing with unobserved declines in overland freight costs.

The results of the instrumental-variables exercise are reported in column C of table 4. The coefficient on freight is now small, negative, and statistically indistinguishable from 0.[4] The bottom rows of table 4 give an alternative IV estimator and test for the coefficient on freight: the Moreira (2003) conditional IV estimator and the Andrews, Moreira, and Stock (2006) conditional likelihood ratio test. These also show a coefficient that is negative and statistically indistinguishable from 0.

The passage above gave our rhetorical case for the validity and exogeneity of our instruments. The econometric case is given in the bottom rows of column C of table 4. First, we note that freight is endogenous: the Davidson-Mackinnon panel test for exogeneity fails with a p-value of 4.7%. Of course, the validity of this test hinges on the validity of our instruments, which are reasonably well correlated with our endogenous variables of interest. In our baseline model, the R^2 of the first-stage regression is 0.84, and the Shea partial R^2 of excluded instruments is 0.21. The F-statistic for the first stage is 7.44 (or 5.49, using the heteroskedasticity-robust covariance matrix), which implies that the instruments are relevant. The instruments also marginally pass the Hansen J-test for exogeneity with a p-value of 9.5%. This means that if at least one of the instruments is exogenous, there is a 9.5% chance that all of the others are exogenous.

Although with relevant instruments, IV regression is asymptotically unbiased, Moreira (2003) and Stock and Yogo (2005) have recently emphasized that when instruments are relevant but weak—that is, they have low but nonzero explanatory power—IV may have substantial small-sample bias. Stock and Yogo allow us to put a limit on how large the small-sample bias of IV relative to OLS estimates can be based on the size of the first-stage F-statistic. In our case, we see that the relative bias of the IV estimate is below an upper bound somewhere between 20% and 30%. So our estimated IV coefficients may be polluted with, say, one-fourth as much bias as the OLS estimates.

Taken together, these results suggest that we are correctly identifying the relationship between trade flows and freight

[4] The z-test statistic on an exclusion restriction for a constructed, endogenous regressor is asymptotically normally distributed. This is because the semiparametric estimate of our constructed regressor is consistent under the model and because the constructed regressor is not in the model under the null hypothesis. See section 6.2 of Newey and McFadden (1994).

TABLE 5.—DIFFERENCED REGRESSION
DEPENDENT VARIABLE: CHANGE IN AVERAGE BILATERAL VOLUME OF TRADE

	Coefficient on Regressor	s.e.	p-Value	Average Change in Regressor	Predicted Effect	As a Percentage of Average Trade Growth
	A			B	$C = A \times B$	$D = (C/.1565) \times 100$
Change in freight	−0.2010	0.2348	0.392	−0.2327	0.047	29.89
Growth in GDP	**0.6311**	**0.2320**	**0.007**	**0.1894**	**0.120**	**76.36**
Convergence of GDP	**0.9583**	**0.1836**	**0.000**	**0.0300**	**0.029**	**18.38**
Change in average tariffs	**−0.1958**	**0.0851**	**0.021**	**0.0112**	**−0.002**	**−1.40**
Change in gold standard adherence	**0.0854**	**0.0453**	**0.060**	**0.1102**	**0.009**	**6.23**
Change in exchange rate volatility	**−1.9396**	**0.9580**	**0.043**	**−0.0018**	**0.003**	**2.26**
Number of observations	463					
R^2	0.3161					
Durbin-Wu-Hausman exogeneity test, p-value	0.0370					
First-stage (uncentered) R^2	0.6863					
Shea partial R^2	0.1934					
F-statistic (p-value)	11.95 (0.000)					
Robust F-statistic (p-value)	4.45 (0.000)					
Weak ID critical value: 20% relative bias	6.65					
Weak ID critical value: 30% relative bias	4.9200					
Hansen J test of overidentification (p-value)	12.74 (0.121)					
Moreira LIML estimate (s.e.)	−0.3209 (0.1931)					
Conditional IV 95% coverage set	(−0.7463, 0.0513)					
Conditional likelihood ratio test p-value	0.092					

Note: All variables are differenced over ten-year periods in the estimation above. The change in freight is instrumented with changes in sailors' wages, coal and fish prices, average sail and steam tonnages, lagged sail and steam net tonnages, and barometric means and standard deviations.

rates: that freight rates are partially determined by the volume of trade—or, more broadly, the degree of economic integration—demanded by nations. However, once these demand-induced changes in freight rates are accounted for, freight rates seem to have little independent bearing on the volume of trade as the coefficient on *freight* in column C is effectively 0.

V. What Drove the Nineteenth-Century Trade Boom?

We have presented the evidence on the relationship linking trade flows and freight rates with the view of determining the sources of globalization in both the past and the present. As of yet, we have reached a seemingly negative conclusion: there is little evidence suggesting that the maritime transport revolution was a primary driver of the late-nineteenth-century global trade boom.[5]

If this conclusion is warranted, it raises the issue of what might be the true drivers. In order to provide an answer, we turn to the work of Baier and Bergstrand (2001), who argue that a general equilibrium gravity model of international trade implies that roughly two-thirds of the growth of world trade after 1950 can be explained by income growth, one-fourth by tariff reductions, and less than one-tenth by transport cost reductions, while virtually none of the growth in trade can be explained by income convergence. In the following, we suggest implicitly invoking their underlying model of world trade and explicitly following their lead by estimating the following equation:

$$\begin{aligned}\Delta(Trade_{UK,i}) &= \beta_1\Delta \log (Freight_{UK,i}) \\ &+ \beta_2\Delta(\log GDP_{UK} + \log GDP_i) \\ &+ \beta_3\Delta \log\left(\frac{GDP_{UK}}{GDP_{UK}+GDP_i}\times\frac{GDP_i}{GDP_{UK}+GDP_i}\right) \\ &+ \beta_4\Delta \log\left(\text{average}\left[\frac{\text{Tariff revenue}}{\text{Imports}}\right]_{UK,i}\right) \\ &+ \beta_5\Delta Gold_i + \beta_6\Delta(Exchange\ rate\ volatility_{UKi}) + \varepsilon_i,\end{aligned} \tag{3}$$

where Δ denotes the change in a variable over a ten-year period. What we are trying to achieve here is comparability of results for the nineteenth and twentieth centuries as well as provide another test of the independent role of freight rates in determining the volume of trade.

The results of this exercise are presented in table 5. Once again, the instrumented *freight* variable fails to register in a manner consistent with prevailing narratives of a transport-led global trade boom in the late nineteenth century. However, the variables capturing changes in income growth, convergence, tariffs, gold standard adherence, and exchange rate volatility are all highly statistically significant and signed consistently with the results of table 4.

Coupled with the sample means of the variables reported in table 3, the point estimates allow us to decompose the

[5] At the same time, there is a voluminous body of work on commodity price convergence throughout the nineteenth century (O'Rourke & Williamson, 1994; Jacks, 2005). In the most influential contribution to this literature, O'Rourke and Williamson write that the "impressive increase in commodity market integration in the Atlantic economy [of] the late nineteenth century" was a consequence of "sharply declining transport costs" (1999, p. 33). However, O'Rourke and Williamson (1999) are quick to point out that a host of other factors could also be responsible for the dramatic boom in international trade during the period, chief among them being increases in GDP and import demand.

relative contribution of these variables. Clearly, the overwhelming majority (76%) of the change in trade volumes is explained by the growth of economies in this period—a result that compares well with the 65% figure from O'Rourke and Williamson (2002) for 1500 to 1800, the 67% figure from Baier and Bergstrand (2001) for 1958 to 1988, and the 76% figure from Whalley and Xin (2007) for 1975 to 2004. Unlike Baier and Bergstrand (2001), we are also able to associate income convergence with the growth of trade volumes as this variable explains 18% of the variation of the dependent variable—a result that might be explained by the greater convergence forces in effect for the pre–World War I era (O'Rourke, Taylor, & Williamson, 1996). Finally, we find significant but relatively mild trade-enhancing effects for the gold standard (6.23%) and the decline in nominal exchange rate volatility (2.26%) as well as trade-diminishing effects for average tariffs (−1.40%).

VI. Discussion

This paper has established two important facets of global trade that are likely to be just as applicable to the post–World War II trade boom as the pre–World War I one. First, greater care must be taken in future work in considering the relationship between maritime transportation costs and trade volumes as they are simultaneously determined. Second, and more fundamental, once this endogeneity is dealt with in an appropriate fashion, there is potentially little room for maritime transport revolutions to be the primary drivers of the two global trade booms of the nineteenth and twentieth centuries. Rather, the most powerful forces driving the booms were those of income growth and convergence—a finding established here and congruent with a mounting body of research on the sources of trade growth spanning not only the late twentieth century but all the way back to the beginning of the global trading system in 1500.

In balance, these results allow a potential revision of the first wave of globalization—one in which the maritime transport revolution is substituted by the general progression and convergence of incomes and in which freight rates are driven by the demand for globalization. In this view of the world, the key innovations in the shipping industry, such as iron hulls and the screw propeller, were induced technological responses to the heightened trading potential of the period (see Peet, 1969, for an earlier statement of this view). Analogously, the movement toward containerization of the world mercantile fleet was strongly conditioned on agents' expectations of commercial policy in light of attempts to reestablish the prewar international economic order (Levinson, 2006). In short, exploring this potential causal connection between technological innovation and the diplomatic and political environment surrounding world trade remains an important task for future research.

Another possibility that our results suggest is that focusing solely on the secular decline in freight rates across the nineteenth century may be misleading. Aggregate trade costs of the countries in our sample fell on average by around 15% from 1870 to 1913 (Jacks et al., 2006). How can such a finding be reconciled with the well-documented decline in maritime freight rates in the period? First, transportation costs are only one input into trade costs, as Anderson and van Wincoop (2004) emphasized. A broader look at the factors contributing to declines in trade costs should include overall shipping and freight rates, the rise of the classical gold standard and the financial stability it implied, and improved communication technology. There were also countervailing effects of tariffs. These rose on average by 50% between 1870 and 1913 (Williamson, 2006). In addition, new nontariff barriers were erected (Saul, 1967).

At the same time, the results also warrant some caution. First, it could be argued that the United Kingdom might well be a peculiar unit of observation. Given the heavy share of raw materials and especially foodstuffs in its imports, it may have found itself on an inelastic section of its demand curve, that is, the level of freight rates would not affect the decisions of importers. However, given that separate gravity equations estimated for imports and exports (not reported) yield symmetric results, it seems unlikely that this is generating our findings.

Second, more work needs to be done in documenting and testing the complementary decline in overland freight rates during this period. In some instances, the introduction of the railroad and the telegraph led to declines in transportation costs on the order of 90%. This point can be seen in the example of the grain trade between the United Kingdom and United States after 1850. Much of the decrease in price differentials between the U.K. and U.S. markets came through a narrowing of price gaps separating the Midwest and the East Coast of the United States (O'Rourke & Williamson, 1994). The ever-expanding networks of railroads and telegraphs lowered transportation costs between the Midwest and the Atlantic ports at a faster rate than the observed decline in maritime freight rates. Jacks (2005) documents a similar pattern based on commodity price data for a large set of countries, which shows much faster within-country integration than cross-border integration over the period from 1800 to 1913. Thus, the differential decline in overland and maritime freight rates across countries might tell a different story, and we encourage others to follow our lead. Yet as we have argued before, to the extent that within-country freight costs are uncorrelated with the supply-side instruments we use, our instrumental variables strategy corrects for such excluded changes in overland transportation costs.

Finally, recent research has suggested that the period prior to 1870 might have, in fact, been the "big bang" period for the maritime transport revolution. Again, Jacks (2006) documents a decline in the price gap for wheat separating London and New York City from 1830 to 1913 of 88%. Yet this decline was highly concentrated. Of that 88%, the period from 1830 to

1870 witnessed a 74% decline, with the remaining 14% decline being contributed in the period from 1870 to 1913. It stands to reason that if maritime transport revolutions matter, we should also be looking at the early nineteenth century for clues. Unfortunately, systematic freight, output, and trade data are all lacking for this earlier period. But there are some fragments at our disposal: real U.S. trade with ten European countries and Canada grew 449% between 1870 and 1913 but only 412% between 1830 and 1870 (U.S. Treasury Department, 1893). Of course, one needs to condition on standard gravity variables as argued above, but this suggests that if anything, the response of trade in the face of an even steeper decline in freight rates from 1830 to 1870 was more muted. Only ongoing work by economic historians piecing together the trade history of the early nineteenth century will allow us to test this hypothesis directly.

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APPENDIX

Sensitivity Analysis

The following tables present the results of some sensitivity analysis. The inclusion of decadal country fixed effects (there are five separate fixed effects for each of the 21 sample countries) in the second column of table A.1 is intended to capture any remaining unexplained variation coming from time-varying country attributes. The specification preserves the sign of the *freight* variable while decreasing its magnitude and significance. This does little to change our basic story. This specification also destroys most of the explanatory power of the remaining variables, but the GDP and GDP shares remain large and highly significant. Additionally, this specification comes closest to addressing the identification and problems highlighted in Baldwin and Taglioni (2006). The results are much the same for the IV specification.

Table A.2 shows that the results presented in the text are robust to the inclusion of other freight rate indices, whether they be variants of our preferred index or the Isserlis (1938) index. Across the board, the coefficients on the *freight* variable are statistically indistinguishable from the results discussed above.

TABLE A.1.—REGRESSIONS WITH TIME-VARYING COUNTRY FIXED EFFECTS
DEPENDENT VARIABLE: AVERAGE BILATERAL VOLUME OF TRADE

	Country and Decade Fixed Effects			Decadal Country Fixed Effects		
	Estimate	s.e.	*p*-Value	Estimate	s.e.	*p*-Value
OLS with fixed effects						
Freight	**0.2463**	**0.1047**	**0.019**	0.0692	0.0674	0.305
GDP	**0.7549**	**0.1650**	**0.000**	**0.8308**	**0.1250**	**0.000**
Income similarity	**0.9095**	**0.1556**	**0.000**	**0.7300**	**0.1973**	**0.000**
Average tariffs	**−0.1556**	**0.0645**	**0.016**	−0.0306	0.0755	0.686
Gold standard	**0.2019**	**0.0396**	**0.000**	0.0633	0.0447	0.157
Exchange rate volatility	**−1.7926**	**0.8069**	**0.026**	−0.1466	0.6822	0.830
Number of observations		671			671	
R^2		0.4789			0.7800	
IV with fixed effects						
Freight	−0.0146	0.1754	0.934	0.0572	0.1546	0.712
GDP	**0.5470**	**0.1532**	**0.000**	**0.7357**	**0.1421**	**0.000**
Income similarity	**0.8498**	**0.1529**	**0.000**	**0.5185**	**0.1984**	**0.009**
Average tariffs	**−0.2211**	**0.0618**	**0.000**	−0.0812	0.0561	0.148
Gold standard	**0.2178**	**0.0358**	**0.000**	**0.1037**	**0.0304**	**0.001**
Exchange rate volatility	**−1.5656**	**0.8346**	**0.061**	−0.0431	0.6535	0.947
IV relevance (*p*-value)		152.185 (0.000)			226.696 (0.000)	
IV overidentification test (*p*-value)		29.871 (0.095)			45.324 (0.002)	
Number of observations		671			671	
R^2		0.4837			0.7801	

Note: All estimation with first-order autoregressive and heteroskedastic robust standard errors. Fixed effects not reported.

TABLE A.2.—REGRESSIONS WITH ALTERNATE FREIGHT INDICES
DEPENDENT VARIABLE: AVERAGE BILATERAL VOLUME OF TRADE

	Estimate	s.e.	*p*-Value	Estimate	s.e.	*p*-Value	Estimate	s.e.	*p*-Value	Estimate	s.e.	*p*-Value
OLS with countries fixed effects												
Freight (λ = 2)	**−0.4457**	**0.0590**	**0.000**									
Isserlis index				**−0.5020**	**0.0676**	**0.000**						
Alternate freight (λ = 1)							**−0.4363**	**0.0587**	**0.000**			
Alternate freight (λ = 3)										**−0.4513**	**0.0592**	**0.000**
Number of observations		671			671			671			671	
R^2		0.1937			0.1856			0.1878			0.1976	
OLS with country and decade fixed effects												
Freight (λ = 2)	**0.2463**	**0.1047**	**0.019**									
Isserlis index				**0.1904**	**0.0821**	**0.020**						
Alternate freight (λ = 1)							**0.2397**	**0.0942**	**0.011**			
Alternate freight (λ = 3)										**0.2486**	**0.1121**	**0.027**
GDP	**0.7549**	**0.1650**	**0.000**	**0.6447**	**0.1446**	**0.000**	**0.7499**	**0.1606**	**0.000**	**0.7572**	**0.1681**	**0.000**
Income similarity	**0.9095**	**0.1556**	**0.000**	**1.0133**	**0.1665**	**0.000**	**0.9092**	**0.1568**	**0.000**	**0.9100**	**0.1549**	**0.000**
Average tariffs	**−0.1556**	**0.0645**	**0.016**	**−0.1854**	**0.0649**	**0.004**	**−0.1576**	**0.0644**	**0.014**	**−0.1548**	**0.0646**	**0.017**
Gold standard	**0.2019**	**0.0396**	**0.000**	**0.1878**	**0.0389**	**0.000**	**0.2002**	**0.0396**	**0.000**	**0.2027**	**0.0395**	**0.000**
Exchange rate volatility	**−1.7926**	**0.8069**	**0.026**	**−1.7378**	**0.8002**	**0.030**	**−1.8173**	**0.8051**	**0.024**	**−1.7802**	**0.8080**	**0.028**
Number of observations		671			671			671			671	
R^2		0.4789			0.4810			0.4791			0.4786	
IV with country and decade fixed effects												
Freight (λ = 2)	−0.0146	0.1754	0.934									
Isserlis index				0.1653	0.1151	0.151						
Alternate freight (λ = 1)							−0.0195	0.1838	0.915			
Alternate freight (λ = 3)										−0.0734	0.1913	0.701
GDP	**0.5470**	**0.1532**	**0.000**	**0.5703**	**0.1314**	**0.000**	**0.5301**	**0.1522**	**0.000**	**0.4993**	**0.1587**	**0.002**
Income similarity	**0.8498**	**0.1529**	**0.000**	**0.8833**	**0.1477**	**0.000**	**0.8479**	**0.1716**	**0.000**	**0.8591**	**0.1700**	**0.000**
Average tariffs	**−0.2211**	**0.0618**	**0.000**	**−0.1943**	**0.0622**	**0.002**	**−0.2062**	**0.0636**	**0.001**	**−0.2151**	**0.0634**	**0.001**
Gold standard	**0.2178**	**0.0358**	**0.000**	**0.2323**	**0.0368**	**0.000**	**0.2317**	**0.0369**	**0.000**	**0.2288**	**0.0371**	**0.000**
Exchange rate volatility	**−1.5656**	**0.8346**	**0.061**	−1.3195	0.8458	0.119	−1.3140	0.8588	0.126	−1.3105	0.8549	0.125
IV relevance (*p*-value)		152.185 (0.000)			468.905 (0.000)			137.162 (0.000)			135.872 (0.000)	
IV overidentification test (*p*-value)		29.871 (0.095)			22.952 (0.347)			29.030 (0.113)			29.659 (0.099)	
Number of observations		671			671			671			671	
R^2		0.4837			0.4846			0.4767			0.4717	

Note: All estimation with first-order autoregressive and heteroskedastic robust standard errors. Fixed effects not reported.