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EARLY 20TH CENTURY AMERICAN EXCEPTIONALISM: PRODUCTION, TRADE AND DIFFUSION OF THE AUTOMOBILE

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Early 20th Century American Exceptionalism: Production, Trade and Diffusion of the Automobile
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ABSTRACT

The early twentieth century provides a unique opportunity to explore the interaction of rapid technological progress and international trade barriers in shaping the worldwide diffusion of a new, highly traded good: the automobile. We scrape historical data from 1913 to 1940 on the quantity and value of passenger vehicles exported from the United States to 23 destination countries and measure five unique international frictions that prevented the both the pass-through of US automobile price declines from reaching foreign markets as well as much higher user costs (tariffs and excise taxes on fuel). We estimate a price and income elasticity of the demand for automobiles relative to an outside good. The price elasticity is between the macro and trade Armington elasticities reported in the contemporary literature. The estimated model captures both the vastly diverse *levels* of automobile adoption per capita across countries and the broad secular time *trends*. Relative price declines due to US technological innovation in assembly-line production and generally high international economic growth during the 1920s are reinforcing in the diffusion phase. The relative price decline abates during the 1930s while output generally collapses (through asymmetrically across nations), leading to large but heterogeneous reversals of the stocks of automobiles in most countries.

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1. Introduction

This paper tells the coming-of-age-story of the automobile. Our narrative begins in 1913, one year prior to Henry Ford's introduction of full assembly-line production of the Model T chassis. This process innovation has been credited with reducing labor input requirements for chassis production from 12.5 to 1.5 (hours), a factor of more than 8 (Baldwin et al. (1987)). Shortly thereafter, the average US domestic sales price of the automobile plummeted from $1,227 in 1913 to $659 in 1917 (in 1940 USD).[1]

Figure 1 presents a complete history of the average US domestic wholesale price alongside the median and inter-quartile ranges of US export unit values across 23 destination markets from 1913 to 1940.[2] All prices are in US dollars and are normalized by the US CPI index set to 100 in 1940 (as such 1940 is the actual US dollar nominal price distribution).

Aside from significant disruptions at the outset and one year after the conclusion of World War I, we see a highly collinear path of automobile prices in the US market (solid blue line) and the median price across the foreign destination markets (dashed red line). The interquartile range of export unit values is also quite stable, again, with the exception of World War I.

Notice also, that the rate of decline of the relative price of the automobile is decelerating over time. The fall is precipitous in the first decade and then the relative price of the automobile settles into what looks like a stationary price distribution relative to the broader US consumption basket as measured by the US CPI. The distinctive convex shape of the time-path of the relative automobile price is characteristic of a new product diffusion.[3]

Turning to quantities, **Figure 2** presents estimates of the US automobile stock and the median and inter-quartile range of foreign automobile stocks for the same destination markets as displayed in **Figure 1**. As one would expect, as the relative price of the automobiles falls, adoption levels rise in a highly correlated fashion across countries and when relative prices stop falling, adoption rates tend to stabilize.

Once a durable good reaches its steady state adoption level, neoclassical theory predicts that the stock of automobiles will be driven by cyclical variation characteristic of business cycle models of durable goods.[4] Qualitatively, at least, this diffusion story is largely born out by the

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[1] By US sales price, we mean the total value of passenger vehicles sales in the US wholesale market divided by the quantity sold domestically. Automobile industry census of manufacturing data in 1929, 1931, 1933 and 1935 allow benchmark comparisons of these prices to average prices of automobiles at the factory gate. All are within 9% of the annual average wholesale price from the Statistical Abstract of the United States.

[2] The 23 countries used to construct **Figure 1** and throughout the paper are: Argentina, Australia, Brazil, Canada, Chile, Colombia, Denmark, France, Greece, Italy, Japan, Mexico, New Zealand, Norway, Peru, Philippine Islands, Portugal, Spain, Sweden, Switzerland, the United Kingdom, Uruguay, and Venezuela.

[3] For more examples, see Jovanovic and McDonald (1994) on automobile tires, Olmstead and Rhode (2001) and Manuelli and Seshardi (2014) on farm tractors.

[4] See for examples, Baxter (1996) and Romer (1992), for studies of business cycles in the presence of durable goods during the post-World War II and interwar periods, respectively.

evidence: the stock of automobiles per capita rises rapidly from a near zero base. The growth of adoption is interrupted by a large negative business cycle shock, the Great Depression. This is very pronounced in the US and in the upper-quartile of adoption (the red dashed line). This is not entirely unexpected as the Great Depression is quite asymmetric across the nations in our sample.

The most striking and puzzling feature of **Figure 2** is the fact that the US automobile stock per capita is consistently 50 times higher than the median foreign country and more than 10 times higher than even the upper-quartile of foreign adopters, who themselves are below the rarefied category of foreign automobile producers. Simply put, while the time series movements of the relative prices and automobile stocks are highly collinear, the levels of adoption are remarkably diverse. Accounting for the cross-sectional distribution requires careful attention to level differences in real income and destination-specific trade frictions and the structural elasticities that translate those variables into different purchasing patterns of the automobile.

Figure 3 helps to illustrate the challenges that arise in accounting for the level of automobile adoption in the cross-section. Each line shows the loci of trade friction (y-axis) and substitution elasticity (x-axis) pairs that predict the same ratio of adoption in foreign countries relative to the US. The three loci displayed roughly match the median ratio (solid line) in the data and the inter-quartile range (dashed lines). The x-axis spans much of the range of price elasticities estimated in the contemporary trade literature, from a low of about 2 (the lower bound reported in Simonovska and Waugh (2014)) to a high of about 12 (the upper bound of estimates in Romalis (2007)).[5]

Notice that as the elasticity of substitution rises falls right-to-left on the x-axis of the graphic, the median and across-country dispersion of trade frictions necessary to account for the same distribution of adoption both rise. At an elasticity of 15, the implied friction at the median adoption level is 35%, and the lower and upper bounds are 19% and 43%, respectively. As the elasticity is lowered by moving from right to left, the median international friction rises dramatically as does the cross-country variation. At an elasticity of 3, the implied trade friction to account for the median adoption level is 268%, and lower and upper bounds are 115% and 365%, respectively. Intuitively, the lower the elasticity of substitution, the larger the relative price difference needed to induce a given demand change.

Our first and most novel contribution is to measure a comprehensive menu of trade frictions in an attempt to reconcile US and foreign adoption levels while restricting the price elasticity to equal the point estimate of 3.8. This requires novel historical archival work to span the four trade frictions that have been the focus of different segments of the recent trade and macroeconomics literature: 1) an export markup; 2) a traditional trade cost friction (shipping

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[5] Recent studies have begun to report what is referred to as the trade elasticity, the elasticity of the value of imports rather than the physical quantity and thus is the demand elasticity that we estimate (σ) plus 1.

and insurance); 3) custom duties; 4) retail and distribution margin and markups. In addition, a novel friction not previously investigated is found to be important: foreign import and excise taxes on gasoline. Since these were (and currently are) much higher in foreign destinations than in the US they drive a wedge between the US and foreign user cost and thus further contributing to lower foreign automobile adoption rates above and beyond the four traditional trade frictions.

Our second contribution to the literature is to estimate both a price elasticity and relative income elasticity for a highly durable good during the period of its introduction and international diffusion. The exercise is made feasible by three intriguing features of this historical period. First, the US is far and away the dominant source of the automobile. This fact implies a well defined one-way direction of automobile trade for most country pairs. Moreover, it allows the construction of foreign stocks of automobiles from US export data. Second, the US is a much larger economy than most of countries that relied upon it as a source of imports. This allows us to treat the destinations as small open economies who take the US price of the automobile as exogenous to their own purchasing decision. Third, this period featured both high and heterogeneous (across destination markets) levels of trade frictions on automobiles and as well as user costs (gasoline). This allows us to identify the Armington elasticity from both time series (US relative price declines) and cross-sectional (distortions) variation.

When estimated country-by-country, the price elasticity ranges from a low of 0.7 in the Philippine Islands to a high of about 7 in Switzerland. The range, perhaps coincidentally covers almost the entire span of estimates in the contemporary literature. These two countries however, are outliers. There exists considerable tendency toward a mean elasticity across the US and 23 foreign countries in the panel data. Pooling the cross-section produces an estimate of 3.8, which is close to the lower bound of values estimated by Simonovska and Waugh (2014) using recent data.

Trade elasticity estimates for the interwar period are few and far between. The most comprehensive study of import elasticities using sector-level interwar trade data is Irwin and Soderbery (2021), who report a median (mean) elasticity across sectors of 2.86 (5.95). Since the US did not import automobiles, there are no comparable interwar estimates among sectors in their study on which to base an exact comparison, but the magnitude of our automobile price elasticity is quite consistent with products in the US import basket. Interestingly, Soderbery (2015) estimates an average elasticity of US imports using data from 1993 to 2017 equal to 5.2. Thus there appears to be a remarkable amount of uniformity in these substitution parameters, both across long historical periods and across products.

Our third contribution is to use the estimated substitution and income elasticities to conduct an extensive set of counterfactuals that isolate the role of policy-related variables from other endogenous sources of variation in accounting for the much lower levels of foreign adoption of the automobile relative to the US. This is done both for the time series and cross-sectional variation in the stock of automobiles.

Beginning with the generally rising time series adoption characteristic of all countries, the US relative price accounts for 64.3% of the time series variation for the median country. The contribution of real income variation in the destination market is 21.6%. Time series variation in the export markup adds another 6.4%. The non-markup components of the trade frictions play almost no role in the time series variation of the automobile stock because they vary mostly across locations and not across time.

Turning to the cross-sectional variation of adoption the focus is on the level of the automobile stock averaged across the two years associated with the apex of global adoption, 1928 and 1929. These two years are chosen because they are late enough to allow the earlier relative price declines to build into the accumulated stocks and earlier enough to avoid conflation with the business cycle declines brought about by the Great Depression.

The adoption level of automobiles in the US is 46 (120/2.59) times higher than the median export destination. Our estimated benchmark model explains this well both at the median and across countries. It predicts the ratio to be 42 with all wedges and income differences allowed for. Elimination of income differences across nations reduces the gap to a factor of 7.1. Among the wedges, the user costs (fuel) is the most impactful. Elimination of fuel cost differences reduces the gap to a factor of 2.83. Complete elimination of the remaining four trade frictions reduces the gap to a factor of 2.3. Thus our model explains almost all of the gap in adoption despite its enormity and could account for the entire gap when using the upper bound of predicted adoption. However, we interpret the missing gap as due to complementary infrastructure which are beyond the scope of our empirical investigation: roads, gas stations and repair shops, among the most obvious.

2. The Model

We treat each destination market for US automobiles as a small open economy. From a general equilibrium perspective, the only theoretically relevant facet of *small* in our context is with regard to the demand and supply of automobiles. Evidence on this point is included in the section 3. As elaborated in that section, in the automobile sector, the US is the large open economy and foreign destinations are the small open economies because the US produces and consumes about 90% of the world flow of automobiles.

2.1. The Consumers Problem

In each of these small open economies, then, a representative consumer chooses an optimal mix of the stock of automobiles and a composite of other goods in their aggregate consumption bundle in each year, taking as given the relative price of automobiles and their real income. The preference parameters governing this decision are: a substitution elasticity between the automobile and other goods (i.e., the consumption bundle excluding automobiles), an income elasticity of automobiles relative to other goods, and a taste bias parameter.[6]

The extensive literature at the intersection of trade and macroeconomics has considered both homothetic and non-homothetic CES preferences. We follow Comin et al. (2021) in terms of the functional form of the non-homotheticity. Specifically, the aggregate consumption index for county j, $C_{j,t}$, is implicitly defined via the constraint,

$$(\Omega_j^A C_{j,t}^{\epsilon_A})^{\frac{1}{\sigma}}(A_{j,t})^{\frac{\sigma-1}{\sigma}} + ((1-\Omega_j^A)C_{j,t}^{\epsilon_O})^{\frac{1}{\sigma}}(O_{j,t})^{\frac{\sigma-1}{\sigma}} = 1, \tag{1}$$

where the automobile is denoted by $A_{j,t}$, and the bundle of all other goods is denoted by $O_{j,t}$. The parameter $\Omega_j^A > 0$ is a taste parameter for the automobile. For countries at the same level of income (and thus aggregate consumption) and when the relative price of the automobile is the same across borders, this parameter exclusively determines the consumption expenditure share of the automobile.

Using the CES demand functions that arise from these preference structures, the ratio of the demand for automobiles to a real index of other consumption goods for the more familiar homothetic case is,

$$\omega_{j,t} = \frac{A_{j,t}}{O_{j,t}} = \phi_j \left(RP_{j,t}^A\right)^{-\sigma}. \tag{2}$$

where, $RP_{j,t}^A \equiv P_{j,t}^A / P_{j,t}^O$ and $\phi_j \equiv \Omega_j^A/(1-\Omega_j^A)$.

The corresponding relative demand curve for non-homothetic CES preferences is:

$$\omega_{j,t} = \frac{A_{j,t}}{O_{j,t}} = \phi_j \left(RP_{j,t}^A\right)^{-\sigma} C_{j,t}^{(\epsilon_A-\epsilon_O)}. \tag{3}$$

It is important to keep in mind that since this is a representative consumer, both the number of automobiles and the real consumption index of other goods are in per capita terms. To work with more convenient units, the automobile data are presented as the number of passenger cars per 1,000 adults (i.e., the Census population counts are adults in each nation). As such, a 100 per 1,000 count, means one in ten adults own a passenger vehicle. For the median country in the cross-section the value would be 2.5 per 1,000 or one in 400 adults.

We turn, now, to the archival work involved in constructing estimates of the national stocks of automobiles.

3. Automobile Production, Trade and Diffusion

This section provides historical perspective on the quantity side of our empirical investigation, the production, consumption and trade of automobiles. Central to the model is the construction

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[6] The technical appendix provides the detailed derivation of these optimal choices, subject to a period-by-period budget constraint. The maintained assumption is that the representative consumer's intra-period Euler equation holds at each date.

of the stock of automobiles which appears in the representative agent's utility function.

3.1. The Data

The US automobile export data by destination were collected from annual reports filed by the Director of the Bureau of Foreign and Domestic Commerce to the Secretary of Commerce. The full reports are published as an annual serial volume called the Foreign Commerce and Navigation of the United States (FCNUS).[7]

The data pulled from the FCNUS are: the dollar value of exports and number of passenger vehicles exported to each destination country as reported in Table No. 3, Exports of Domestic Merchandise From the United States, by Articles and Countries, During the Calendar Year. The resulting unbalanced panel spans 81 nations from 1913 to 1940. Due to the empirical demands of our elasticity estimation, this paper focuses on a balanced panel of 23 countries for which macroeconomic and tariff friction data are also available.

The international automobile production data come from the trade magazine, *The Automotive Industries*, published by the Chilton Company. Curated from this source is an unbalanced panel of 16 countries over the period 1922-1939. Nine of these 16 countries overlap with our sample of 23 countries. Ranked by the level of automobile production in 1928, these countries are: Canada (242,382), UK (232,200) France (200,000), Italy (47,000), Sweden (2,000), Switzerland (1,600), Spain (700), Japan (371, in 1930), and Denmark (200).

3.2. Construction of Automobile Stocks

The first data requirement of the theory is a measure of each nation's stock of automobiles per capita, as this is what appears in the representative agent's utility function. As far as we know, there exist no estimates of the stock of automobiles by country for the interwar period, one of our contributions is to fill this void in the literature.

Flow data needed to construct the automobile investment series, in the form of automobile sales, are available for only a handful of nations, most of whom are also producers of automobiles.[8] In order to achieve something close to an international census of the stock of automobiles by country, some creativity is called for.

Consider the following stock-flow equation that describes the per capita automobile stock of country j, year t, $A_{j,t}$, using the stock-flow method:

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[7] The FCNUS has also been used to create a number of novel microeconomic panels on the import side of interwar US trade flows, see Crucini (1994), Bond et al. (2013) and Irwin and Soderbery (2021).

[8] The technical appendix compares our automobile stock estimates to registration data and explains the reasons to strictly prefer our constructs.

$$A_{j,t} = (1-\delta)A_{j,t-1} + (Y_{j,t} + M_{j,t}) - X_{j,t}$$

Notice that additions to the domestic automobile stock may include domestic production, $Y_{j,t}$ and imports, $M_{j,t}$ minus outflows via exports, $X_{j,t}$.

In contemporary data, there are numerous producers of automobiles (and parts) and, as a result, there is a considerable amount of what is called intra-industry trade in the automotive industry. The implication of this is that both domestic production and bilateral trade flows between dominant producers and various non-producers are important contributors to the investment flows into the automobile stock accumulation in most countries.

During the period of this study, when the automobile was just being introduced into product markets, the structure of production, trade and consumption was starkly different from today. Specifically, the dominance of the US in production and exports of automobiles implies that for virtually all foreign nations, the stock of automobiles can be accurately estimated as:[9]

$$A_{j,t} = (1-\delta)A_{j,t-1} + Y_{j,t} + M_{j,t},$$

In fact, in all but a handful of nations, domestic production is either absent or trivial relative to consumption and imports are sourced only from the US. For these reasons, the US export panel by destination is instrumental in the construction of the foreign stocks of automobiles and in understanding the global structure of the industry more generally.

3.3. Quantity Facts

We turn, now, to documenting the historical facts. In doing so we need to first consider the facts as they bear on the accuracy of our method of constructing the automobile stocks from data on flows. We then turn to the facts regarding the constructed stocks themselves such as the differences in levels across nations and their time series profiles.

Fact 1: During the interwar period, the US dominated world production.

Over the period 1923-1928, cumulative world production of the automobile was about 27,774,299 units, of which the US produced 23,963,401 (86.3%), compared to 1,069,817 (3.85%) in the next largest producing nation, Canada. The largest producing nations in Europe were (in descending order of production) the UK, France, Germany and Italy. In total, these four nations produced 2,630,879 automobiles (9.47%). Nine other European nations produced the remaining 0.5%.[10]

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[9] The annual depreciation rate of the automobile, δ is set to 20%, as estimated for the 1950s and 1970s by Wykoff (1970) and Ohta and Griliches (1976). There are no contemporary estimates for the interwar period.

[10] Note that foreign subsidiaries of US companies are included in the foreign production numbers, so these numbers are actually conservative estimates of US production dominance.

The data appendix provides a time series plot of world automobile production by country from 1922 to 1939. Up until the onset of the Great Depression, the US share of world production was consistently above 80%. During the Great Depression the United Kingdom and France increased their production shares, though this is mostly due to the much larger durable demand contraction in the US relative to Europe from 1929 to 1933. The world production share of the US rebounds to about 75% as the US recovers from the Great Depression. That said, there is, perhaps not surprisingly, a general erosion of US dominance over time as foreign countries start to adapt US assembly line production techniques and compete more directly with the US in the lower priced, mass market that the Ford company had historically dominated. The sustained US dominance in world production is truly staggering during this period of history.[11]

Fact 2: US dominated export markets.

Table 1 presents data on automobile production, bilateral import flows and total export flows averaged over the period 1923 to 1928. The first column is production plus net imports. The remaining columns are ratios of the flow indicated at the column head relative to the flow of gross additions to the automobile stock. This gross investment flow is defined as production plus imports minus exports. For most countries, domestic production and exports are both zero in which case the gross automobile investment flow is simply total automobile imports, most of which are from the United States. Countries that produce automobiles and have production shares of the gross investment flow greater than 100 are net exporters. Canada, for example, has an export share of 38.1% and an import share (from the US) of 14% and thus on average the trade balance in automobiles is 24.1% of gross automobile investment.

Due to the international concentration of production practically all of the bilateral trade flows are accounted for by the four nations listed in order of their production levels: the US, Canada, the U.K. and France.

The US is by far the dominant source accounting for 90% or more of the gross automobile investment in 9 countries. The US is also the majority source in all the remaining countries except New Zealand, the UK and Switzerland. Canada is an important secondary source for 8 countries. Notably, the more significant market shares are related to colonial ties to the U.K. which Canada shares with Australia and New Zealand. Canada accounts for 43.6% of New Zealand's gross investment in automobiles, compared to 21.7% for Australia. Canada also has a significant presence in the markets of Argentina, Chie, Columbia, Japan, Norway and Venezuela. France plays a secondary role of particular importance in Switzerland (62.7%), Spain (42.7%) and Japan (7.6%). The United Kingdom plays a more moderate role in supplying New Zealand (9.9%) and Portugal (9.3%).

Fact 3: Countries that produced automobiles were largely self-sufficient.

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[11] See the VoxEU column by Cheng et al. (2019) for a comparison of the industry structure as foreign multinationals expand their production into US markets after World War II.

Figure 4 presents estimates of the stock of automobiles per 1,000 population for 10 of the 23 countries in our panel. These countries are chosen to highlight features that compare or contrast production, adoption or importing characteristics.

Focusing on the left-hand panel of **Figure 4**, we see Canada, the UK, France, Italy and Japan (five of the six non-US members of the G-7). The first observation to make is that while the volume of automobile production by these countries was dramatically lower than that of the United States, it was sufficient to supply most of domestic demand. This fact is evident in the proximity between the red dashed lines and the red dotted lines, which represents the contribution of domestic production to the evolution of the stock.[12]

The right-hand panel presents automobile stock constructs for Australia, New Zealand, Switzerland, Spain and the Philippines. The significant contributions by imports from countries other than the US is evidence in the fact that the dashed line is significantly above the solid black line in all cases except the Philippine Islands. The Philippine Islands is typical of most nations of the world in its exclusive dependence on US imports for augmentation of the domestic automobile stock.

4. Automobile Prices and International Trade Frictions

As was self-evident in the comparison of adoption levels and export unit values, it is impossible to reconcile the two in the absence of both sizable and heterogeneous trade frictions. This leads to the second archival contribution of our work, the construction of a comprehensive panel of natural and official barriers to trade that drive destination prices above their US counterpart.

4.1. Taxonomy of International Trade Frictions

To better understand the point at which an individual wedges enter into the downstream supply chain on the trip from the US manufacturer to the final consumer in destination country j, **Table 1** provides the full taxonomy of relative prices and the wedges between each pair.

Chart 1. Definitions of prices in relation to each international friction

Equation and notation			Description of the wedge
P_{jt}^{EUV}	=	$(1+q_{j,t})P_{ut}^{A}$	Export markup relative to the US wholesale price
P_{jt}^{CIF}	=	$(1+s_j)P_{jt}^{EUV}$	Trade costs (ocean freight and marine insurance)
P_{jt}^{TIP}	=	$(1+t_{j,t})P_{jt}^{CIF}$	Customs duties in ad-valorem terms
P_{jt}^{R}	=	$(1+\mu_{j,t})P_{jt}^{TIP}$	Destination retail distribution cost and markup
P_{jt}^{A}	=	$(1+\kappa_j)P_{jt}^{R}$	User costs (the cost of fuel)

Notes: Price is unit value, value imported (not shown) divided by quantity imported.

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[12] The reader is cautioned to the fact that we lack production data before 1922.

The first price in the chain is the US wholesale price, denoted P_{ut}^{A}. It is computed as the ratio of nominal sales to physical quantity sold which are both found in Table No. 489 of the 1941 Statistical Abstract of the United States. The first wedge is an export markup defined as the ratio of the export unit value ($P_{j,t}^{EUV}$) in USD from our archival data, relative to the USD domestic wholesale price ($P_{u,t}^{A}$). This markup varies across countries and over time. The second wedge is a trade cost representing ocean freight and marine insurance, it varies modestly across countries. Following the existing trade literature this wedge is constant as a proportion of the export unit value. The trade cost wedge applied to the export unit value price gives the price to the importer inclusive of cost, insurance and freight (CIF, denoted as $P_{j,t}^{CIF}$). The third wedge is the customs duty applied to the importers purchase invoice. This duty is determined by the importer nation's tariff policies. This wedge may be time-varying as discussed further below. Adding this friction gives the tariff inclusive import price (TIP, denoted as $P_{j,t}^{TIP}$). The fourth wedge reflects the fact the consumers purchase final goods not a the customs house, but from retailers and this wedge must cover retailer's real costs as well as any markup they may be able to charge at the point of sale. The fifth and final wedge is a user cost wedge to reflect the role of tariffs and excise taxes on the cost of gasoline.

Collapsing these pairwise wedges, we arrive at a relationship between the US wholesale price and the price in a particular destination (both in US dollar terms):

$$\begin{aligned} P_{j,t}^{A} &= (1+\kappa_j)(1+\mu_{j,t})(1+t_{j,t})(1+s_j)(1+q_{j,t})P_{u,t}^{A} \\ &= (1+\hat{\tau}_{j,t}^{*})P_{u,t}^{A} \end{aligned}$$

The $\hat{}$ symbol is used to distinguish the estimated wedge in the data from the theoretical wedge in the Euler equation. Dividing both sides by the US CPI defines the relationship between the US relative price of the automobile and its foreign counterpart.[13]

$$RP_{j,t}^{A} = (1+\kappa_j)(1+\mu_{j,t})(1+t_{j,t})(1+s_j)(1+q_{j,t})RP_{u,t}^{A} = (1+\hat{\tau}_{j,t}^{*})RP_{u,t}^{A}$$

Note that the use of the US CPI as the deflator in constructing both the US relative price and the foreign relative price is due to a lack of such deflators in many countries of the panel. The implication is to assume complete pass-through of nominal price changes in the US into foreign prices. Given our focus on annual and longer term evolution of the stock of automobiles, this seems reasonable given the highly volatile nature of interwar price levels in general. However, if pass-through is incomplete the price elasticity may be downward biased.

We turn, now, to a careful discussion of the construction of each individual trade friction.

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[13] As we define in Section 3, the relative price, RP_{j}^{A} is the ratio of automobile price to the price of all other goods. Since automobiles only account for a small share of the consumption basket during the early twentieth century, replacing the price of all other goods with CPI is innocuous.

4.2. Construction of Trade Frictions: Sources and Methods

This section discusses the historical data sources and methods used to construct empirical measures of trade frictions.

4.2.1. Export Markups

To understand the role of export markups in the determination of the relative levels of automobile adoption, it is necessary to use absolute export prices, not indices.

Following the existing trade literature, export prices are computed by dividing the dollar value of exports to a particular destination by the number of units exported to that destination. In the trade literature, these average prices are called 'export unit values', which is the phrase used throughout this paper.

To be precise, as stated on page v. of FCNUS (1928):

"Articles of domestic production when exported shall be valued at their actual cost or the values which they may truly bear at the time of exportation in the ports of the United States from which they are exported."

Thus the export unit values are indeed the free-on-board (f.o.b.) price necessary to construct our first wedge, the export markup. Specifically, the export markup, denoted as $(1+q_{j,t})$, is constructed as the ratio of export unit value to the US wholesale price, where export unit value is export value (from the US) divided by quantity exported (from the US): $1+q_{j,t} = P^{EUV}_{jt}/P^{A}_{ut}$.

The definition and measurement of the markup used in this paper is precisely the one used in Alessandria and Kaboski (2011) who employed highly disaggregated US export unit values from 1989 to 2000 to assess the relationship between good-specific export markups and the real income of the destination country. They find an elasticity of the destination markup with respect to destination real GDP of about 0.20 when all exported goods are pooled. AK attribute this correlation to the fact that producers recognize that richer consumers may be willing to pay a higher markup to avoid search costs which are modeled as wage opportunity costs. While not the focus of this paper, it is notable that the corresponding correlation is statistically significant and economically small, but negative (-0.11) for automobiles.

4.2.2. Trade Costs

The next trade friction captures the cost of transporting the automobile from the US port to the destination port. These costs are obtained from the longest running US trade magazine, *Automobile Industries*. Specifically, the 1929 issue contains a table showing the nominal US dollar charges for ocean freight, marine insurance and destination port charges for Australia, Brazil, Germany, India, Italy, Japan and Poland.[14]

The ocean freight charges are the lion's share of the trade costs, averaging 90% of the total with very little variation across countries. These cost data are cross-tabulated with our panel data based upon a nearest neighbor method. The average cost for Germany, Italy and Poland (\$151.76) is used for our European destinations, the cost for Brazil (\$155.34) is used for Mexico and the 5 other (non-Brazilian) South American countries and the cost for Australia (\$182.19) is used for the Philippines and New Zealand. The trade cost to Canada is assumed to add a comparable wedge to that associated with rail transport of automobiles within the US (\$50).

To convert these nominal charges to their corresponding ad-valorem-equivalents, they must be normalized by export unit values. To provide a robust estimate of the ad-valorem shipping cost, $(1+s_j)$, a two-step procedure is used. First, as noted above, we obtain nominal trade/shipping cost (in current US dollars) in 1929 from the Automotive Industries and denote it as S_j. Second, the ad-valorem equivalent trade/shipping cost is computed as $1+s_j = S_j/\bar{P}_j^{EUV}$, where $\bar{P}_j^{EUV}$ is the average of the export unit value over the period 1928-31. Averaging is intended to mitigate measurement error in the export unit value data.

To place these numbers into historical perspective, it is instructive to compare the ad-valorem-equivalent shipping cost to estimates found in the seminal work of Hummels (2001). The nominal average trade cost in 1929 across all countries is \$160, which is 16% of the US factor gate price. Remarkably, this wedge is almost identical to the 15% trade cost wedge estimated by Hummels (2001) for the modern era.

4.2.3. Tariffs

The third trade friction has been the focus of much of the academic work during this historical period, which is understandable due to the tumult of interwar international commercial policy.

And yet, the classic historical narratives of US tariff legislation and foreign retaliation by Taussig (1931) and Jones (1934) cover only a small subset of the countries in our panel. Fortunately, extensive coverage of foreign tariffs on automobiles is found in *Automobile Industries* magazine for two benchmark years, 1920 and 1921.[15]

During the interwar period, the US and other countries employed both ad-valorem tariffs, assessed as a percentage of the customs value reported on the invoice and what are called specific duties, assessed as a nominal tax per unit of the physical quantity of imports. In the US, some items, such as textiles had both, a combined duty. Thus, in general, the ad-valorem equivalent duty is:

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[14] Automobile Industries: The Automobile, June 1929, page 828.

[15] The 1920 tariff data is from the January issue (page 192) while the 1921 tariff data are from April issue (pages 868-869).

$$\tau_{j,t} = \tau_j^a + \frac{\omega_j}{P_{j,t}^{CIF}} \tag{4}$$

Notice that a pure ad-valorem component, τ_j^a, is by definition a constant percent of the value and thus of the price. In contrast, a specific duty, ω_j, gives rise to an ad-valorem-equivalent rate that increases as the nominal price of the good falls. Effectively, this type of duty reduces the pass-through of nominal declines in US automobile prices into destination prices.

The legislated ad-valorem and nominal specific duties are averaged over the two years of observation (1920 and 1921) to arrive at the values, t_j^a and w_j, respectively. Then, the composite duty is computed using the equation above for all years, from 1913 to 1940.

4.2.4. The Relative Penn Effect

The fourth trade friction captures an important facet of trade emphasized in the contemporary literature (see, for example, Burstein et al. (2005) and Crucini et al. (2005)). Namely that consumers do not purchase goods directly from firms and have the goods shipped to their home as traditional trade models assume, nor do they acquire them at the dock or from wholesalers. Consumers purchase goods from retailers close to their point of consumption and retailers serve as intermediaries between final consumers and domestic and foreign producers. As such, a potentially large proportion of the retail price constitutes a real friction, the value added of the retail and distribution sector.

The distribution friction is intimately related to the more well-known Penn Effect: that richer countries pay more for the same consumption basket than do poorer countries. Estimates place the Penn Effect at about 50%: a doubling of income or the wage level is associated with about a 50% increase in the common currency cost of the consumption basket.

In order to calibrate the microeconomic implications of distribution margins on the price of the automobile relative to an aggregate of other goods and services in the consumption basket (i.e., the relative Penn Effect), we draw upon the work of Crucini and Yilmazkuday (2014). They estimate the distribution share of automobiles to be approximately 0.25 while the consumption expenditure weighted distribution share is 0.55. Thus, the distribution margin on automobiles relative to the overall consumption basket is 0.25-0.55=-0.30.

To understand this effect, consider two goods, automobile and another good which has a more typical (i.e., higher) distribution share such as clothing. If both goods satisfied the Law-of-One-Price at the dock, the relative retail price of the automobile to clothing would – after including the retail distribution markup – be about 20% higher in a country with per capita income half the level of the US.

Analytically, then, the distribution wedge, denoted as $(1+\mu_{j,t})$, is constructed as $1+\mu_{j,t} =$

$exp(0.30 ln(y_{u,t}/y_{j,t}))$. The retail price is thus: $P^{R}_{jt} = (1+\mu_{j,t})P^{TIP}_{jt}$.

4.2.5. The User Cost

The fifth trade friction reflects international differences in the excise taxes and import duties on fuel. This is an international wedge in the user cost of the automobile. International frictions associated with user costs have mostly been overlooked in the trade literature because they are typically associated with excise and sales taxes rather than tariffs or quotas. Be that as it may, these distortions have potentially large effects on durable goods because the flow expenditure attributable to them is often large relative to the amortized cost (rental price plus depreciation allowance) of the durable good purchase itself. And, it turns out, the US was also a dominant producer of oil and gas during this period of history. The combination of tariffs and excise taxes added a large wedge between the user costs of foreign consumers relative to their US counterparts.

With substantial variation in gasoline prices, it is natural to ask why we treat the wedge as time-invariant. The first reason is that the elasticity of gasoline demand is inelastic with respect to variation in gasoline price variation. The second is that marginal decision to purchase a large durable good is more likely to depend on permanent factors than transitory factors and with high-pass-through commodities prices internationally, taxation is the most obvious difference in the long-run user cost across countries.

On the question of demand elasticity, Hughes et al. (2006) study the price elasticity of demand for gasoline in two periods of tumult in energy markets, 1975 to 1980 and 2001 to 2006. They find the price elasticity ranges from -0.034 to -0.077 during 2001 to 2006, versus -0.21 to -0.34 for 1975 to 1980 period.[16] As these values are numerically close to zero, we treat fuel as a Leontief input in the service flow of utility from the automobile. This allows us to consider the gasoline tax wedge as an additional proportional international friction associated with the purchase decision.

On the question of the importance of user costs relative to purchase prices, recent US consumption expenditure survey data indicates that the consumption expenditure share is about 4% for gas and oil compare to 5.4% for new cars. Treating the flow expenditure on new cars as the flow equivalent of the non-fuel user cost (rent plus depreciation) puts the fuel and oil component of the user costs at about 75% of the total expenditure related to automobiles. It turns out to be comparable to this historically as well.

Specifically, to construct our user cost, we use the retail price of gasoline for the period 1928-1931 comes from the archive, Facts and Figures of the Automotive Industry, published by the National Automobile Chamber of Commerce, Inc., New York City. Originally, the data

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[16] The estimated income elasticity is also very low, ranging from 0.21 to 0.75 and when estimated with the same models are not significantly different between the two periods

were compiled by the Minerals and Transportation Divisions, Department of Commerce. The gasoline price is presented in the archive in US cents per gallon, where the gallon is the US gallon. We also collect US annual fuel consumption in gallons per motor vehicle for the same period, 1928-1931, from the Facts and Figures of the Automotive Industry. Comparing this to the rental equivalent of the wholesale purchase price in the US provides the scale variable to convert user cost wedges into ad-valorem equivalent wedges in the final purchase.

Turning to the notation of the wedges, the ad-valorem equivalent user cost, denoted as ($\kappa_{j,t}$), is constructed in three steps. First, we obtain nominal US dollar retail gasoline prices by country (including the US) for the years 1928 and 1931 from the Facts and Figures of the Automotive Industry. The combined tariff and excise tax distortions are estimated by taking the ratio of US dollar price of gas in the destination market relative to the US: $(1+\tau_j^G) = P_j^G/P_{US}^G$. The absence of a time subscript indicates that we use the average of available foreign gasoline prices over the period 1928-31. Second, to measure the wedge in relation to the cost of the automobile, the gasoline tax wedge must be adjusted by the ratio of US annual fuel expenditure per automobile (E_u^g) to the annual rent-equivalent plus depreciation cost of a US automobile: $\eta \equiv E_u^g/(r+\delta)P_u^A = 0.765$. Again, both the numerator and denominator are the averages of data over the period 1928 to 1931. Third, to arrive at the user cost wedge, we multiply the expenditure ratio, η by the estimated distortion to international fuel prices to arrive at $\kappa_j = \eta(1+\tau_j^G)$. The relationship between the user-cost inclusive price and the purchase price is thus: $P_{jt}^{RUC} = (1+\kappa_j)P_{jt}^R$.

4.3. Price Facts and Frictions

To anticipate the sources of elasticity identification and contributions of different wedges to cross-sectional and time series movements in the national stocks of automobiles, it is instructive to consider sources of variation in the destination relative prices.

One key advantage of our panel data is that the price and quantity data are not index numbers. As such, there is economically meaningful variation both in the cross-sectional dimension and the time series dimension. To fully understand the sources of microeconomic variation in our panel, we follow the variance decomposition method employed by Crucini and Telmer (2020) who study international and intranational LOP deviations from 1990 to 2015:

$$\underbrace{var(\ln(RP_{j,t}^A))}_{\text{Total Variance (V)}} = \underbrace{var_j[E_t(\ln(RP_{j,t}^A))]}_{\text{Cross-sectional Variance (C)}} + \underbrace{E_j[var_t(\ln(RP_{j,t}^A))]}_{\text{Time-series Variance (T)}}. \tag{5}$$

In words: the total variance of automobile relative prices across time and location, denoted V, may be decomposed into the cross-country variance of the time averaged relative prices, denoted by C, and the cross-country average of the time series variance around to these long-run means, denoted by T.

Table 2 reports the decomposition. In terms of total variation in destination prices, the time series component account for 57% of the total (0.1065/0.1883). The sources of time series variance is about equally divided between movements in the US relative price (0.0506) and time variation in the trade frictions (0.0575). Note that almost all the time series variation in the trade friction term arises from variability in the export markups. The other distinguishing feature relating to the time series components is that the US price is common to all destinations and thus represents a common stochastic trend in automobile demand across countries.

Table 3 reports the time-averages of the wedges. As in the earlier discussion of the estimation of the wedges, they are ordered from left-to-right as the automobile advances from the factory gate to the final consumer in destination country j.

The first observation to make is that all of the wedges are economically significant. Of the 115 wedges 49 are greater than 30% ad-valorem while only 18 are less than 10%. This clearly points to the necessity of constructing a comprehensive menu of wedges to gauge their cumulative impact. Broadly speaking – as measured by the median across countries – the export markup, tariffs, and shipping costs are roughly 20% ad-valorem-equivalent distortions, the retail distribution wedge are about 30%. The user cost wedge is the dominant wedge, consistently above 100%.

In terms of the heterogeneity of individual wedges across countries, the retail distribution wedge stands out. This is due to the enormous income and wealth differences across the nations in our panel. The wedge that is most uniform across destinations is shipping costs. This is due to the very similar distances between the US market and the destinations in the panel.

Not surprisingly, the dominant automobile producing countries (Canada, France, Italy and the UK) have higher tariffs, with a group median of 1.36 compared to 1.15 when they are excluded. One might ask why countries with little or no domestic industry would impose significant duties on the importation of automobiles. The historical narrative has two main threads. The first is that custom duties were a key source of revenue during this period of history. The second is the infant-industry argument: some nations were keenly interested in moving from agriculturally based economies to manufactures and starting a domestic automobile and parts industry seemed within reach. Increasingly so, as the world become aware of the success of US companies such as the Ford Motor Company. In particular, the workers across the world became aware of the high wages for skilled labor that arose from the emerging automotive industries. The tangible evidence of this advance of industrialization was the arrival of the US automobile at ports around the world.

Notice that the wedges sometimes interact in subtle ways: since major automobile producers tend to be technologically advanced and have much higher income than agriculturally dependent nations, the retail distribution wedge works to mitigate the relative distorting impact of the tariff. The most obvious manifestation of the distribution wedge is in South America where, due to the very low income relative to the US, the median retail distribution wedge is 1.62.

5. Results

Recall that the model's Euler equation, in natural logarithms is given by:

$$ln(A_{j,t}) - ln(O_{j,t}) = ln(\phi_j) - \sigma ln(1+\tau^*_{j,t}) - \sigma ln(RP^A_{u,t}) + (\epsilon_A - \epsilon_O) ln(C_{j,t}) \tag{6}$$

where the presence of possibly time-varying trade frictions are included.

As a practical matter, aggregate real consumption data is available in only a few countries and for those for which measures are available they tend not be be as reliable as GDP measures. For this reason, we use output (GDP) as a proxy for aggregate consumption and other (non-automobile) consumption.

Thus, the log-transformed Euler equation becomes:

$$ln(A_{j,t}) = ln(\phi_j) - \sigma ln(1+\tau^*_{j,t}) - \sigma ln(RP^A_{u,t}) + (1 + \epsilon_A - \epsilon_O) ln(Y_{j,t}) \tag{7}$$

Reading from left-to-right the four determinants of relative demand are: 1) a time-invariant parameter arising from a potentially country-specific taste parameter for automobiles relative to other goods (ϕ_j); 2) a potentially time-varying country specific component due to the composite trade friction $(1+\tau_{j,t})$; 3) a time series component common to all countries, arising from the movement of the US wholesale price of automobiles relative to the US CPI ($RP^A_{u,t}$); and 4) a real income effect which may be larger or smaller than unity depending on the relative income elasticity of the automobile and the outside good (i.e., $\epsilon_A \neq \epsilon_O$). Unlike the case of the US relative price component which induces perfect time series collinearity across all destination markets including the US, the time series component of the income effect will depend upon how correlated GDP is across countries.

The distinction between time series and cross-sectional variation of the import demand function is central to the ongoing debate revolving around the magnitude of the Armington elasticity. As first pointed out by Ruhl (2008), the international business cycle literature, which focuses on time series variation, relies on a very low Armington elasticity to match the joint volatility of the terms of trade and trade balance (see, for example, the seminal work by Backus et al. (1994)). In contrast, the trade literature relies on higher Armington elasticities to match the long-run cross-sectional variance of bilateral trade flows based upon the gravity equations of trade. Estimation of the gravity equation typically relies upon proxies for trade frictions, most robust among them is the greater circle distance. That is, the volume of trade falls as the distance between bilateral trading partners rises. Our work measures the absolute size of five different frictions directly.

One distinguishing feature of our archival work is the use of absolute prices and the physical number of units of purchased as opposed to index number data used in most of the existing literature. As such, it is possible to consider the independent role of time invariant trade frictions and time-varying relative price movements in accounting for level differences in physical quantities as well as their dynamics using the Armington trade model.

5.1. Elasticity Estimation

Our benchmark specification eliminates to trade frictions. This means the elasticity of substitution is identified from common time series movements in the US relative price,

$$ln(A_{j,t}) = \alpha_j - \sigma ln(RP_{u,t}) + \left(1 + \epsilon_A - \epsilon_O\right) ln(Y_{j,t}) \ , \tag{8}$$

where $\alpha_j \equiv ln(\phi_j)$.

The use of the US relative price in the estimating equation is a preferred choice for two reasons. First, the use of the US relative price is consistent with the small open economy assumption whereby the destination relative prices are driven by the declining relative price of automobiles in the dominant producing nation, the US, and reverse causality is not an issue. This contrasts with the cases of tariffs, excise taxes and destination-specific export markups which may be endogenous to foreign economic conditions.

Second, the lack of retail prices of automobiles in destination countries required that we build up proxies for them from the US factory gate price using both measured and estimated wedges. This introduces measurement error into the destination relative price. For example, export unit values, are known to be subject to measurement error. The measurement error is likely to be significant because errors in valuation and in the quantity counts of exports are independent sources of measurement error entering into the computation of the unit value, which is the ratio of the two.

For these reasons, the US relative price is used for our benchmark elasticity estimates and counterfactual analysis is employed to gauge the impacts of the wedges on the levels of automobile adoption. However, estimates using export unit values and export unit values instrumented with US prices are also reported to convey a concrete sense of the issues raised above. Consistent with priors, serious attenuation bias in the price elasticity estimate occurs when the export unit values are used.

Table 4 presents a comprehensive set of estimation results. The columns labelled BM refer to the benchmark model using the US relative price to estimate the price elasticity of demand. The column labelled IV regresses the export unit values on the US relative price in the first stage. In the second stage the fitted value is used to estimate the price elasticity. The column labelled, EUV, uses the raw export unit values directly in the demand equation.

Beginning with the price elasticity, the BM and IV estimates by country are quite consistent with the existing trade literature with only 9 of the 23 estimates outside of the 3 to 5 range. The estimates using EUV price are lower in all but one case. The average EUV elasticity is 2.23 compared to 3.76 for the BM estimates. The pooled estimates tell basically the same story with the BM at 3.8, the IV at 3.45 and the EUV at 2.13.

In summary, the price elasticity estimates using the BM small open economy approach for each destination market is cross-validated when the EUV are instrumented with the US relative price. It is worth noting that the coefficients on the US relative price in the first-stage of the IV is consistent with full pass-through of US prices into destination EUV over time. The EUV estimates are consistent with the initial premise of substantial measurement error and significant attenuation bias of the substitution elasticity estimates.

Turning to the income elasticity, while income is not instrumented, the income elasticity estimates change modestly across the IV and EUV specifications due to mild changes in the covariance between the two regressors as different price measures are employed across the three specifications. The estimates for the income elasticities are very consistent across specifications, both at the country level and the pooled case.

The benchmark specification produces an income elasticity coefficient of 3.09 compared to 3.26 for the IV case and 3.08 for the EUV case. Thus automobile demand is expected to be about twice as responsive to changes in aggregate demand compared to non-automobile demand. This interwar US income elasticity for automobiles is comparable to McCarthy (1996) who obtains an estimate of 1.7 using household survey of new vehicle purchasers in 1989.

5.2. Simulation of Automobile Adoption

The ability to estimate the price and income elasticity with precision (low standard errors) and consistency across countries, does not guarantee a high within sample fit. However, the adjusted R^2 values ranging from a low of 0.71 for Italy and France to a high of 0.94 in Columbia and Venezuela is suggestive, as is the pooled R^2 value of 0.86. This suggests that the estimated Euler equation does indeed provide an excellent fit of the contemporaneous relationship between the stock of automobiles, their relative price and real income.

To further convey the fit of the model, **Figure 5** presents the stock of automobiles in the data (solid lines) and the predictions from the log-linear model inclusive of all empirical wedges and with the price and income elasticity set to the pooled estimates of **Table 4**. The shaded region is the 95% prediction confidence interval.

The figures are sorted by column with the leading producers on the left and import-dependent countries on the right. Japan is intermediate in the sense that the domestic production surge is very late in time. The rows are ordered based on the height of automobile adoption from high to low.

The model tracks the low frequency variation in the data reasonably well given the simplicity of the model. Notable exceptions are countries that experience late surges in domestic production such as the UK, France and Japan. These late surges may be partly due to preparations for World War II by national governments.

In general the simulation paths are more volatile year-to-year than the data. This reflects the assumption that each country's representative agents chooses the optimal stock based on the current spot price. Better fit to the higher frequency movements would be possible using a complete DGSE model with stock-flow dynamics over the business cycle, an aggregate irreversabilty constraint on the automobile stock and attention to production capacity constraints of US automobile producers. These are beyond the scope of the current paper, but are extensions currently underway in a companion paper.

5.3. Sources of Variation in Automobile Stocks

Given that the model tracks the time series at medium to low frequencies with some success, it is productive to ask what variables are driving these adjustments. To accomplish this we conduct a beta-decomposition of the variance of the log-level of the automobile stocks into the contributions of all the variables of the empirical model: the US wholesale price, real income, the export markup, the Penn effect and the tariff. Note that neither shipping cost nor user costs are time-varying frictions and those play no role in accounting for time series variability. And, as a practical matter, the export unit values and Penn Effect while time varying, account for trivial fractions and are thus also excluded from the table.

The time series variance of the predicted (fitted) automobile stock in country j is computed using the β variance decomposition method:

$$1 = -\hat{\sigma}\beta_{RP_u} + \hat{\upsilon}\beta_{y_j} - \sigma \sum_{j=1}^{5} \beta_{\tau_j} \tag{9}$$

where the substitution and income elasticities, $\hat{\sigma}$ and $\hat{\upsilon}$ are set at their estimated values using the pooled panel of 3.80 and 3.09, respectively. The β's are the coefficients from a regression of each predictor on the stock of automobiles. For example, β_{RP_u} is the covariance between the logarithm of the US relative price of automobiles and the logarithm of destination j's accumulated stock of automobiles divided by the variance of the predicted stock of automobiles.

Table 5 shows the results of this variance decomposition. The drivers of the automobile stock are ordered in the columns from most influential to least influential in an average sense across countries. The countries are grouped into panels to be consistent with earlier tables.

As is obvious from these results, it is the common movement in the US wholesale price that is driving the common trends in automobile stocks in virtually every country. On average, the US relative price accounts for 71.4% of the fitted time series of the simulated automobile stock. In 20 of the 23 countries, the variance contribution exceeds 50%.

The next most important drives is real income. Given the fact that the income elasticity for the automobile is about twice that of other goods and the dramatic variation due to the Great Depression, this is not surprising. One average, destination income accounts for 25.6% of the variation in the stock of automobile. The contribution of income varies more across countries due to the very different business cycle variation across them. The highest contribution to automobile stock accumulation is 58% (France) while the lowest is 8.1% (New Zealand).

The export markup is the third most important driver on average. In the beta-decomposition, the markup will a negative coefficient ($-\sigma$) multiplied by the partial correlation between the markup and the automobile stock. The markup covariance is negative at the mean and median consistent with higher markups driving lowering demand. There are however, small marginal positive covariances in some cases, which may be due to factors in the destination that raise demand for automobiles and also the markup (i.e., endogenous markups).

5.4. Counterfactuals

Our paper was motivated by the puzzle that foreign nations adopted the automobile at an astoundingly low rate relative to the US. Given the success of the model in matching the time serious properties of the data, it is natural to consider counterfactual analysis to explore economic explanations for the adoption gap. The counterfactuals focus on the cross-sectional levels of automobile stocks averaged across 1928 and 1929. These years are chosen late enough in the diffusion process for much of the transitional dynamics to have been complete and early enough to avoid the confounding effects of demand shifts due to the Great Depression.

Recall that the adoption level of automobiles in the US is 46 (120/2.59) times higher than the median export destination. Our estimated benchmark model explains this well both at the median and across countries. It predicts the ratio to be 42 with all wedges and income differences allowed for. Elimination of income differences across nations reduces the gap to a factor of 7.1. Among the wedges, the user costs (fuel) has the greatest impact. Elimination of fuel cost differences reduces the gap to a factor of 2.83. Complete elimination of the remaining four trade frictions reduces the gap to a factor of 2.3. Thus our model explains almost all of the gap in adoption despite its enormity.[17]

These results should be qualified by the fact that complementary infrastructure is excluded from the model: roads, gas stations and repair shops, among the most obvious. It is worth noting, however, that one snippet of archival data, road miles per person correlates strongly with the residuals of our counterfactual analysis, which seems promising for future work that incorporates these dynamic features.

6. Conclusion

At the turn of the twentieth century, the automobile advanced from a luxury item of the wealthy to near widespread adoption. The automobile transformed both the mode of com-

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[17] As shown in the appendix, using the upper bound price elasticity estimate the diffusion gap is fully accounted for.

muting and the decision of where to live and work. Toward the end of the 1920s most US states had adoption rates in excess of 120 per 1,000 population.[18] In stark contrast the median foreign adoption level failed to surpass 4 per 1,000 population.

The evidence suggests a dominant role for the declining relative price of the automobile originating from the dominant source, the US, in accounting for the temporal diffusion of the automobile. The differences in adoption levels, however, is driven by a combination of income differences and trade frictions.

The complementary role of infrastructure both across locations within the US and worldwide remains an important research topic for future exploration.

Much remains to be done.

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[18] For correlates of adoption levels across US states, see Eli et al. (2022).

References

[1] **Alessandria George and Joseph P. Kaboski** 2011. "Pricing-to-Market and the Failure of Absolute PPP," American Economic Journal: Macroeconomics, 3(1): 91-127.

[2] **Anderson, James E. and Eric van Wincoop** 2003. "Gravity with Gravitas: A Solution to the Border Puzzle," American Economic Review, 93(1): 170-192.

[3] **Backus, David K., Patrick J. Kehoe, and Finn E. Kydland** 2013. "International Real Business Cycles," Journal of Political Economy, 100(4): 745-775.

[4] **Baldwin, Nick, G. N. Georgano, Michael Sedgwick, and Brian Laban**. 1987. The World Guide to Automobile Manufacturers. Facts on File Publications.

[5] **Baxter, Marianne.** 1996. "Are Consumer Durables Important for Business Cycles?" Review of Economics and Statistics, 78(1): 147-155.

[6] **Burstein, Ariel, Martin Eichenbaum, and Sergio Rebelo**. 2005. "Large Devaluations and the Real Exchange Rate," Journal of Political Economy, 113(4): 742-784.

[7] **Bond, Eric W., Mario J. Crucini, Tristan Potter, and Joel Rodrigue**. 2013. "Misallocation and Productivity Effects of the Smoot-Hawley Tariff," Review of Economic Dynamics, 16: 120-134.

[8] **Cabral, Luís, Zhu Wang, Daniel Yi Xu** 2018. "Competitors, complementors, parents and places: Explaining regional agglomeration in the U.S. auto industry," Review of Economic Dynamics, 30: 1-29.

[9] **Cheng, Dong, Mario J. Crucini, Hyunseung Oh, and Hakan Yilmazkuday**. 2019. "Early 20th Century American Exceptionalism: Production, Trade and Diffusion of the Automobile," VoxEU.org, 08 November.

[10] **Comin, Diego, Danial Lashkari and Marti Mestieri**. 2021. "Structural Change with Long-run Income and Price Effects," Econometrica, 89(1): 311-374.

[11] **Crucini, Mario J.**. 1994. "Sources of Variation in Real Tariff Rates: The United States, 1900-1940," American Economic Review, 84(3): 732-743.

[12] **Crucini, Mario J. and Christopher I. Telmer**. 2020. "Microeconomics Sources of Real Exchange Rate Variation," Review of Economic Dynamics, 38: 22-40.

[13] **Crucini, Mario J., Chris I. Telmer, and Marios Zachariadis.** 2005. "Understanding European Real Exchange Rates," American Economic Review, 95(3): 724-738.

[14] **Crucini, Mario J. and Hakan Yilmazkuday.** 2014. "Understanding Long-run Price Dispersion," Journal of Monetary Economics, 66: 226-240.

[15] **Eli, Shari, Joshua K. Hausman and Paul W. Rhode**. 2022. "Transportation Revolution: The Car in the 1920s," American Economic Association Papers and Proceedings, 112: 219-223.

[16] **Haberler, Gottfried**. 1976. The World Economy, Money, and the Great Depression, 1919-1939. Washington, DC: American Enterprise Institute.

[17] **Hughes, Jonathan E. Christopher R. Knittel and Daniel Sperling**. 2006. "Evidence of a Shift in the Short-Run Price Elasticity of Gasoline," NBER Working Paper No. 12530.

[18] **Hummels, David**. 2001. "Toward a Geography of Trade Costs," mimeo, Purdue University.

[19] **Irwin, Doug and Anson Soderbery**. 2021. "Optimal Tariffs and Trade Policy Formation: U.S. Evidence from the Smoot-Hawley Era," mimeo, Purdue University.

[20] **Jones, Joseph M, Jr.** 1934. Tariff Retaliation: Repercussions of the Hawley-Smoot Bill. Philadelphia: University of Pennsylvania Press.

[21] **Jovanovic, Boyan and Glenn M. MacDonald.** 1994. "The Life Cycle of a Competitive Industry," Journal of Political Economy, 102(2): 322-347.

[22] **Ruhl, Kim**. 2008. "The international elasticity puzzle," mimeo.

[23] **McCarthy, Patrick S**. 1996. "Market Price and Income Elasticities of New Vehicle Demands," The Review of Economics and Statistics, 78(3): 543-547.

[24] **Manuelli, Rodolfo and Ananth Seshadri.** 2014. "Frictionless Technology Diffusion: The Case of Tractors," American Economic Review, 104(4): 1368–1391.

[25] **Ohta, Makoto and Zvi Griliches**. 1976. "Automobile Prices Revisited: Extensions of the Hedonic Hypothesis," NBER Chapters, in Household Production and Consumption: 325-398.

[26] **Olmstead, Alan L. and Paul W. Rhode.** 2001. "Reshaping the Landscape: The Impact and Diffusion of the Tractor in American Agriculture, 1910-1960," The Journal of Economic History, 61(3): 663-698.

[27] **Romalis, John.** 2007. "NAFTA's and CUSFTA's Impact on International Trade," Review of Economics and Statistics, 89(3): 416-435.

[28] **Romer, Christina D.** 1992. "What Ended the Great Depression?" Journal of Economic History , 52(4): 757-784.

[29] **Simonovska, Ina and Michael E. Waugh.** 2014. "The Elasticity of Trade: Estimates and Evidence," Journal of International Economics, 92(1): 34-50.

[30] **Soderbery, Anson** 2015. "Estimating Import Supply and Demand Elasticities: Analysis and Implications," Journal of International Economics, 96(1): 1-17.

[31] **Taussig, Frank W.** 1931. ,"The Tariff History of the United States," New York: G.P. Putnam's and Sons, 1931.

[32] **Wykoff, Frank C.** 1970. "Capital Depreciation in the Postwar Period: Automobiles," Review of Economics and Statistics, 52(2): 168-172.

Table 1. Production and trade in automobiles (averages, 1923-1928)

	Production	Shares of Gross Automobile Investment					
	plus net		Imports from:				
Country	imports	Production	US	Canada	France	UK	Exports
		Panel A: Automobile producing countries					
United States	3,760,311	106.3	0.0	0.0	0.0	0.0	-6.3
Canada	149,465	124.1	14.0	0.0	0.0	0.0	-38.1
France	127,401	135.2	0.8	0.0	0.0	0.1	-36.2
United Kingdom	176,875	93.6	5.7	4.0	4.0	0.0	-7.2
Italy	48,541	91.2	7.5	0.0	1.3	0.0	0.0
		Panel B: European countries					
Greece	760	0.0	100.0	0.0	0.0	0.0	0.0
Denmark	7,708	0.6	92.8	4.9	0.0	1.7	0.0
Portugal	964	0.0	90.7	0.0	0.0	9.3	0.0
Sweden	7,591	4.5	88.9	6.4	0.0	0.2	0.0
Norway	1,536	0.0	81.8	12.2	3.6	2.5	0.0
Spain	12,653	2.7	52.7	0.9	42.7	1.0	0.0
Switzerland	4,403	8.8	27.7	0.0	62.7	0.8	0.0
		Panel C: South American countries					
Peru	1,166	0.0	100.0	0.0	0.0	0.0	0.0
Mexico	9,678	0.0	98.9	1.1	0.0	0.0	0.0
Brazil	13,515	0.0	92.0	6.9	0.9	0.1	0.0
Uruguay	4,822	0.0	90.2	9.8	0.0	0.0	0.0
Argentina	28,005	0.0	87.0	11.5	1.3	0.2	0.0
Columbia	1,602	0.0	86.9	13.1	0.0	0.0	0.0
Venezuela	2,067	0.0	86.6	13.4	0.0	0.0	0.0
Chile	2,433	0.0	85.7	14.3	0.0	0.0	0.0
		Panel D: Other countries					
Philippine Islands	3,086	0.0	100.0	0.0	0.0	0.0	0.0
Australia	52,799	0.0	75.9	21.7	0.0	2.4	0.0
Japan[1]	4,453	0.0	74.8	14.7	7.6	2.9	0.0
New Zealand	14,917	0.0	46.5	43.6	0.0	9.9	0.0

Notes. The sample period is 1923-1928 for every country. We take time average over the sample period. See the technical appendix for details of original data sources. Within each group, countries are ordered from most to least dependent on the US as an import source.

[1] Japan produces automobiles during the period of 1913-1940, but the production data available start in 1931.

Table 2. Variance Decomposition of Destination Relative Prices

Component	Destination Relative Price	US Relative Price	International Trade Frictions
Total variance (V)	0.1883	0.0506	0.1393
Time series variance (T)	0.1065	0.0506	0.0575
Cross-sectional variance (C)	0.0818	0.0000	0.0818

Notes. The decomposition of variance into cross-sectional and time series components follows equation (6) of the paper. The entire panel is used over the sample 1913 to 1940.

Table 3. International Trade Frictions (sample averages)

	Individual wedges				
	Export Markup	Shipping Cost	Customs Duty	Retail Distribution	Fuel Tax
Country	$(1+q_j)$	$(1+s_j)$	$(1+\tau_j)$	$(1+\mu_j)$	$(1+\kappa_j)$
Panel A: Automobile producing countries					
Canada	1.29	1.06	1.39	1.07	1.90
France	1.54	1.14	1.45	1.19	2.39
Italy	1.12	1.19	1.31	1.44	2.60
United Kingdom	1.24	1.22	1.33	1.08	2.09
Panel B: European countries					
Denmark	0.98	1.27	1.07	1.12	2.05
Greece	1.37	1.22	1.07	1.45	2.60
Norway	1.25	1.17	1.15	1.19	1.89
Portugal	1.40	1.17	1.36	1.58	2.25
Spain	1.40	1.17	1.26	1.21	2.25
Sweden	1.15	1.23	1.15	1.19	2.02
Switzerland	1.36	1.16	1.05	1.16	2.37
Panel C: South American countries					
Argentina	1.04	1.24	1.32	1.11	2.25
Brazil	1.05	1.22	1.21	1.99	2.59
Chile	1.25	1.18	1.16	1.34	2.70
Colombia	1.32	1.14	1.01	1.62	2.94
Mexico	1.14	1.24	1.12	1.62	2.13
Peru	1.23	1.21	1.18	1.77	2.27
Uruguay	0.98	1.27	1.27	1.28	2.15
Venezuela	1.14	1.20	1.01	1.81	2.53
Panel D: Other countries					
Australia	0.91	1.33	1.23	0.98	2.39
Japan	1.09	1.27	1.43	1.46	2.06
New Zealand	1.12	1.25	1.05	1.07	2.30
Philippine Islands	1.22	1.25	1.00	1.69	2.39

Notes. We take time averages of the wedges over the sample period, 1913-1940. By construction, the wedges of shipping cost and fuel tax are time-invariant. See the main text and technical appendix for details of wedge construction.

Table 4. Elasticity Estimates

	Price Elasticity			Income Elasticity			Adjusted R^2		
Country	BM	IV	EUV	BM	IV	EUV	BM	IV	EUV
US	2.09			1.74			0.90		
	(0.17)			(0.43)					
Pooled	3.80	3.45	2.13	3.09	3.26	3.08	0.86	0.85	0.80
	(0.17)	(0.17)	(0.15)	(0.21)	(0.22)	(0.26)			
Panel A: Automobile producing countries									
Canada	4.29	4.32	3.85	3.91	3.91	1.15	0.66	0.66	0.65
	(0.67)	(0.90)	(0.65)	(1.25)	(1.22)	(0.90)			
France	2.31	4.38	0.23	8.18	10.64	10.68	0.71	0.72	0.71
	(0.48)	(5.47)	(0.96)	(1.88)	(2.26)	(2.78)			
Italy	3.26	3.24	0.84	12.18	12.18	12.40	0.71	0.71	0.52
	(0.61)	(0.98)	(0.26)	(2.25)	(2.21)	(2.02)			
United Kingdom	2.67	2.76	2.25	7.94	7.94	7.21	0.77	0.77	0.85
	(0.78)	(0.93)	(0.37)	(0.79)	(0.79)	(1.01)			
Panel B: European countries									
Denmark	4.75	3.79	3.64	4.20	4.20	−1.66	0.82	0.82	0.73
	(0.63)	(0.60)	(0.89)	(0.81)	(0.82)	(1.93)			
Greece	5.40	5.57	2.04	1.07	1.07	2.31	0.89	0.89	0.62
	(0.63)	(0.97)	(0.72)	(0.28)	(0.39)	(0.90)			
Norway	4.54	4.61	2.00	1.64	1.64	−1.28	0.84	0.84	0.32
	(0.41)	(0.71)	(0.74)	(0.92)	(0.91)	(1.51)			
Portugal	2.84	3.12	1.81	3.96	3.96	3.51	0.82	0.82	0.71
	(0.50)	(0.77)	(0.79)	(0.79)	(0.86)	(1.30)			
Spain	5.31	9.02	2.64	2.08	2.08	4.32	0.88	0.88	0.48
	(0.46)	(0.96)	(0.84)	(0.71)	(1.07)	(1.37)			
Sweden	5.76	4.76	3.25	7.10	7.10	2.58	0.88	0.88	0.72
	(0.50)	(0.65)	(0.83)	(0.54)	(0.65)	(1.26)			
Switzerland	6.89	12.35	5.63	7.25	7.25	−1.21	0.83	0.83	0.52
	(0.63)	(1.49)	(1.08)	(1.25)	(1.20)	(2.64)			
Panel C: South American countries									
Argentina	3.45	3.25	2.42	3.95	3.95	4.04	0.76	0.76	0.79
	(0.59)	(0.73)	(0.41)	(1.04)	(1.09)	(1.32)			
Brazil	2.48	2.63	1.58	4.37	4.37	4.93	0.81	0.81	0.78
	(0.54)	(0.64)	(0.50)	(0.78)	(0.78)	(1.06)			
Chile	4.22	4.29	2.05	0.65	0.65	0.16	0.77	0.77	0.28
	(0.57)	(0.73)	(0.90)	(0.62)	(0.72)	(1.36)			
Colombia	1.32	1.97	0.12	3.73	3.73	4.44	0.94	0.94	0.90
	(0.20)	(0.42)	(0.39)	(0.20)	(0.23)	(0.26)			
Mexico	5.59	3.48	3.39	2.91	2.91	−0.30	0.87	0.87	0.73
	(0.51)	(0.43)	(0.50)	(1.44)	(1.77)	(2.51)			
Peru	2.84	3.42	0.32	3.22	3.22	5.04	0.86	0.86	0.72
	(0.37)	(0.69)	(0.81)	(0.56)	(0.52)	(0.99)			
Uruguay	4.43	3.51	2.00	1.79	1.79	2.67	0.87	0.87	0.57
	(0.25)	(0.26)	(0.64)	(0.65)	(0.63)	(1.32)			
Venezuela	3.38	3.92	3.32	2.41	2.41	2.46	0.94	0.94	0.89
	(0.24)	(0.35)	(0.32)	(0.17)	(0.19)	(0.21)			
Panel D: Other countries									
Australia	2.98	2.16	1.58	3.97	3.97	3.20	0.83	0.83	0.78
	(0.43)	(0.34)	(0.25)	(0.86)	(0.92)	(1.03)			
Japan	2.54	1.79	1.82	5.97	5.97	4.94	0.87	0.87	0.88
	(0.53)	(0.55)	(0.25)	(0.75)	(0.91)	(0.69)			
New Zealand	3.10	2.90	1.89	0.94	0.94	0.78	0.84	0.84	0.59
	(0.22)	(0.21)	(0.39)	(0.40)	(0.43)	(0.85)			
Philippine Islands	0.70	0.57	0.56	2.59	2.59	2.41	0.85	0.85	0.83
	(0.25)	(0.23)	(0.27)	(0.41)	(0.45)	(0.65)			

Notes. The sample period is 1913-1940 for every country (except for France in the cases of IV and EUV estimations, we use 1919-39 to avoid outliers from WWI and WWII). Robust standard errors are in parentheses.

Table 5. Variance Decomposition of Simulated Automobile Stocks

Country	US price	Income	Export markup	Penn effect	Tariff	Total
Mean	0.714	0.256	0.020	0.028	-0.018	1.000
Median	0.634	0.216	0.064	0.021	-0.001	
IQR	0.277	0.156	0.165	0.062	0.023	
Panel A: Automobile producing countries						
Canada	0.730	0.168	0.126	-0.024	0.000	1.000
France	1.907	0.580	-1.533	0.047	0.000	1.000
Italy	0.979	0.099	0.034	-0.053	-0.059	1.000
United Kingdom	0.774	0.188	0.043	-0.006	0.000	1.000
Panel B: European countries						
Denmark	0.502	0.177	0.318	0.024	-0.021	1.000
Greece	0.383	0.451	0.048	0.131	-0.013	1.000
Norway	0.882	0.055	0.120	-0.056	0.000	1.000
Portugal	0.684	0.289	0.082	0.055	-0.110	1.000
Spain	0.874	0.352	-0.309	0.086	-0.004	1.000
Sweden	0.570	0.125	0.312	-0.007	0.000	1.000
Switzerland	0.890	0.201	-0.063	-0.008	-0.020	1.000
Panel C: South American countries						
Argentina	0.710	0.203	0.080	0.007	0.000	1.000
Brazil	0.634	0.304	0.007	0.054	0.000	1.000
Chile	0.771	0.216	0.064	-0.017	-0.034	1.000
Colombia	0.548	0.490	-0.164	0.127	-0.001	1.000
Mexico	0.519	0.139	0.386	0.003	-0.048	1.000
Peru	0.558	0.389	-0.008	0.087	-0.025	1.000
Uruguay	0.595	0.221	0.162	0.021	0.000	1.000
Venezuela	0.440	0.483	-0.047	0.126	-0.002	1.000
Panel D: Other countries						
Australia	0.565	0.185	0.315	0.013	-0.077	1.000
Japan	0.435	0.245	0.271	0.048	0.000	1.000
New Zealand	0.936	0.081	0.051	-0.068	0.000	1.000
Philippine Islands	0.546	0.243	0.168	0.043	0.000	1.000

Notes. The sample period is 1913-1940 for every country. We implement variance decomposition for each country. The variance decomposition uses the β-method, taking the covariances of each right-hand variable with the logarithm of simulated automobiles divided by the variance of the logarithm of simulated automobiles times the estimated coefficient on that variable. Mathematically, $\beta_j^k = \frac{Cov(log(\hat{A}_{j,t}),log(\tau_{j,t}^k))}{Cov(log(\hat{A}_{j,t}),log(\hat{A}_{j,t}))}$ for any price wedge k, and $\beta_j^y = \frac{Cov(log(\hat{A}_{j,t}),log(y_{j,t}^k))}{Cov(log(\hat{A}_{j,t}),log(\hat{A}_{j,t}))}$ for income, where $\hat{A}$ is the simulated automobile adoption, τ refers to a specific price wedge, and y is real income per capita. Then the β's are multiplied with corresponding elasticity estimates: $\hat{\sigma}$ for price wedges, and $1\widehat{+\epsilon_A-\epsilon_O}$ for income. Notice that $\hat{\sigma}$ and $1\widehat{+\epsilon_A-\epsilon_O}$ are the elasticity estimates of pooled foreign data in **Table 4**. Since the ad-valorem wedges for the shipping cost and the fuel tax are time-invariant wedges, they do not contribute to the time component of variation.

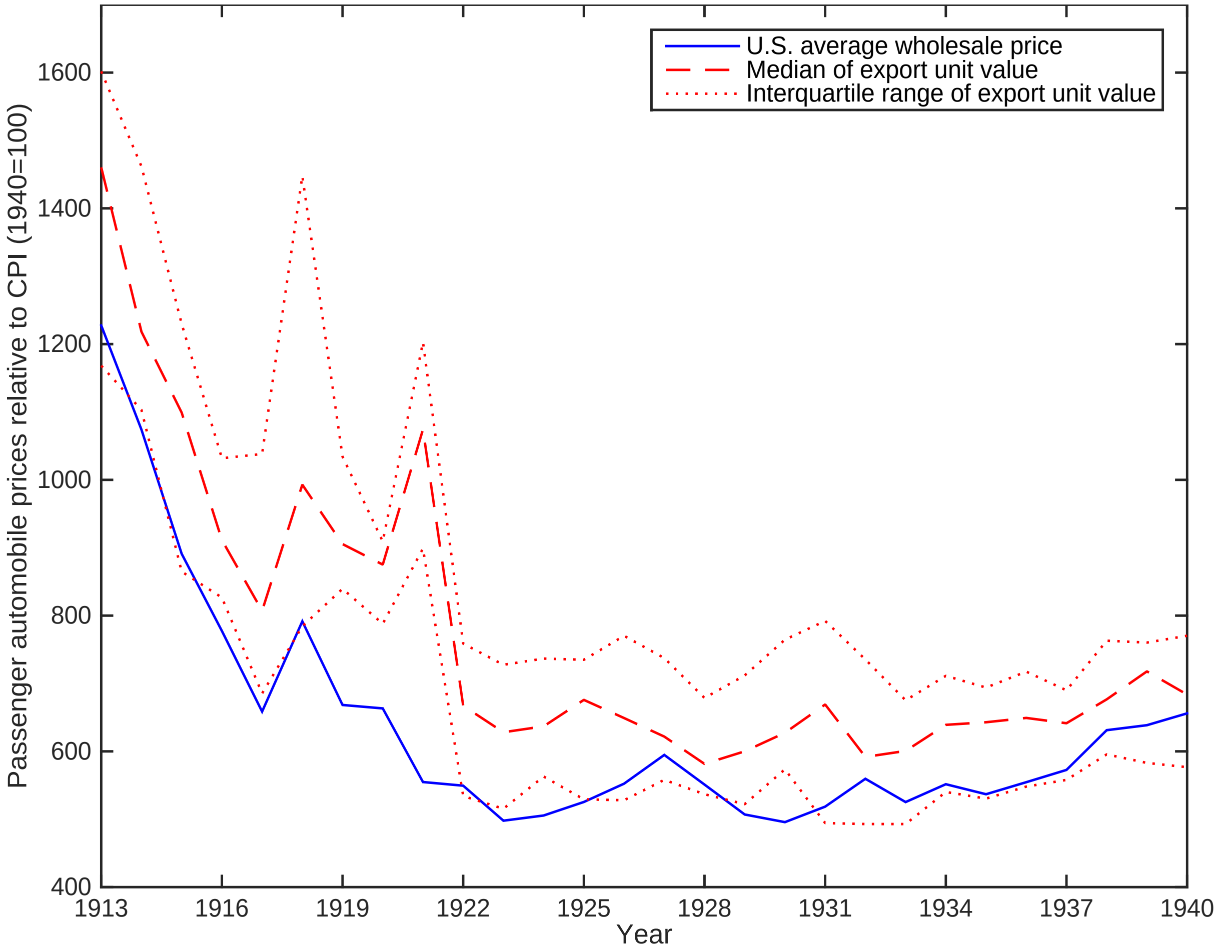

Figure 1. US Price and Export Unit Value (Value of sales divided by quantity sold).

Notes. US average wholesale price is the ratio of wholesale value to the quantity of automobiles produced at the US factory gates. Export unit value is the ratio of US export value to the quantity of automobiles exported from the US to the specific destination. For each destination, we compute export unit value for the period of 1913-1940. And then for each year, we calculate the following statistics across all the 23 destinations: 25th percentile, median, and 75th percentile. All prices are deflated using US CPI (1940=100).

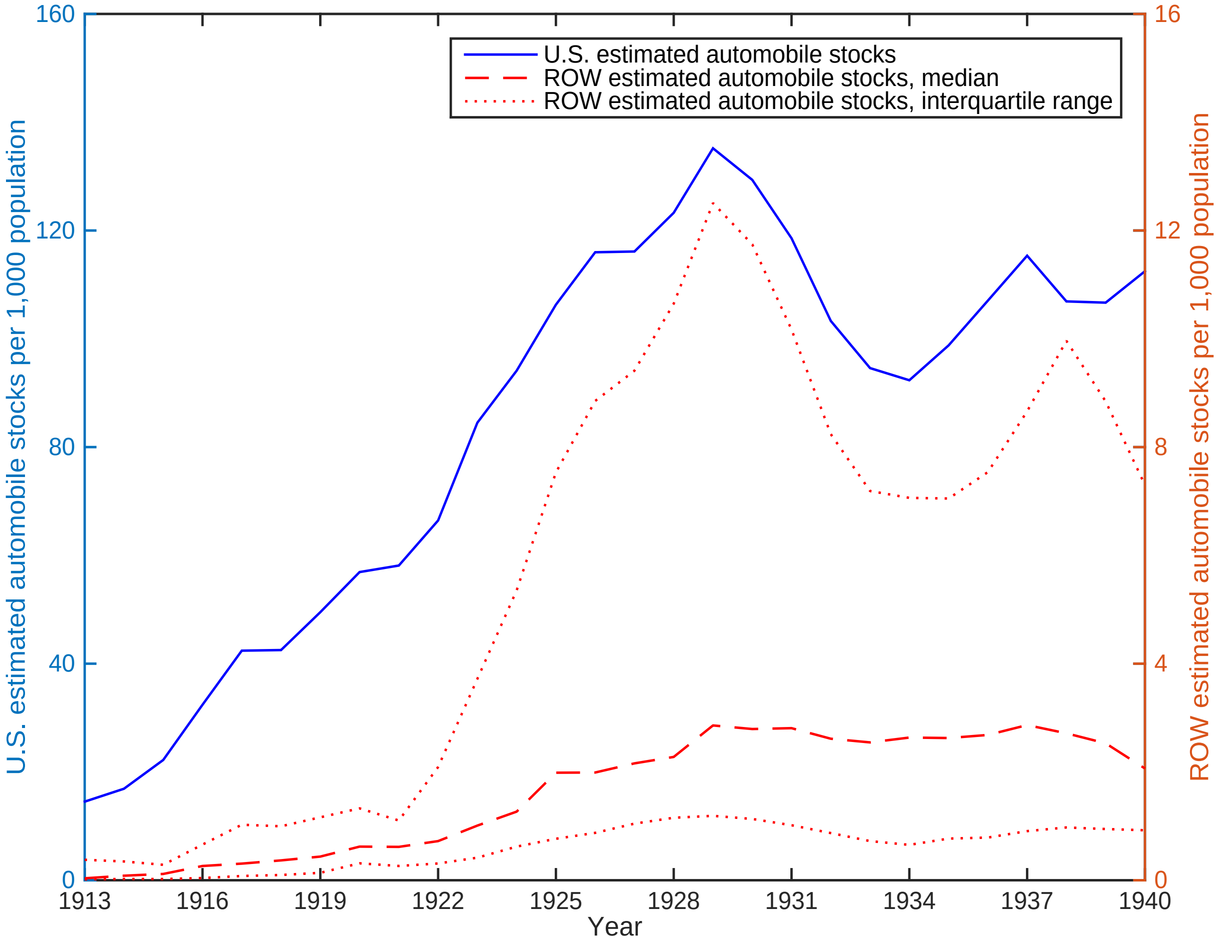

Figure 2. US and ROW Estimated Automobile Stocks per 1,000 Population.

Notes. For both the US and the rest-of-the-world (ROW), automobile stocks is estimated using the stock-flow equation. For each destination, we compute automobile stocks for the period of 1913-1940. And then for each year, we calculate the following statistics across all the 23 destinations: 25th percentile, median, and 75th percentile. Scales for the US are on the left vertical axis, while scales for the ROW are on the right vertical axis. The unit for automobile stocks is the number of automobiles per 1,000 population.

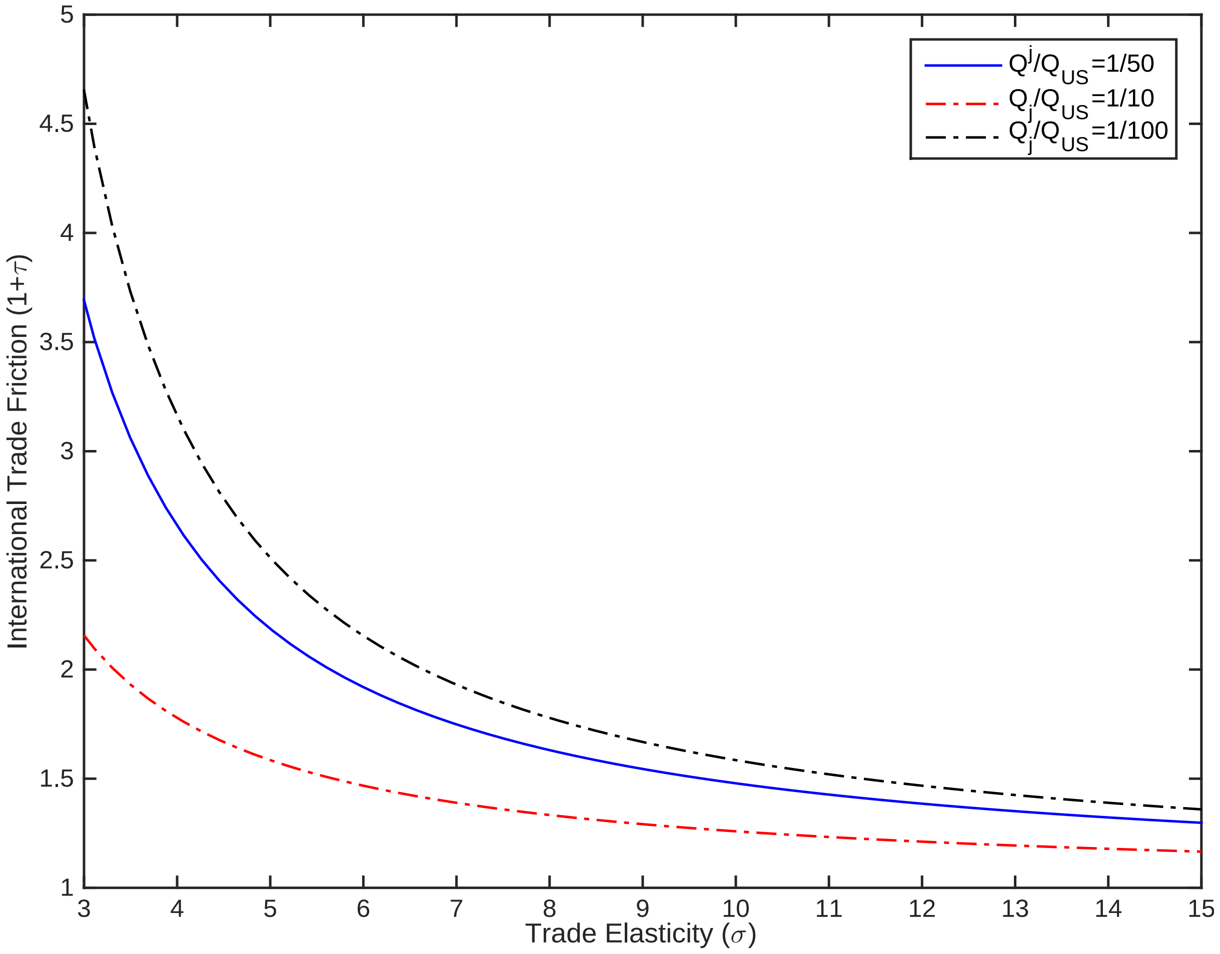

Figure 3. Identification: Trade Elasticities and Trade Frictions.

Notes. σ denotes the elasticity of substitution (alternatively, the trade elasticity), and τ denotes the international trade friction. Q^j/Q^{US} is the ratio of automobile per 1,000 population in destination j over that in the US. Equation (2) of the main text implies the following relationship: $1+\tau_j = (Q^j/Q^{US})^{-1/\sigma}$. We draw the relation ship between $1+\tau$ and σ for three cases of quantity ratio: Q^j/Q^{US}=1/50, Q^j/Q^{US}=1/10, and Q^j/Q^{US}=1/100.

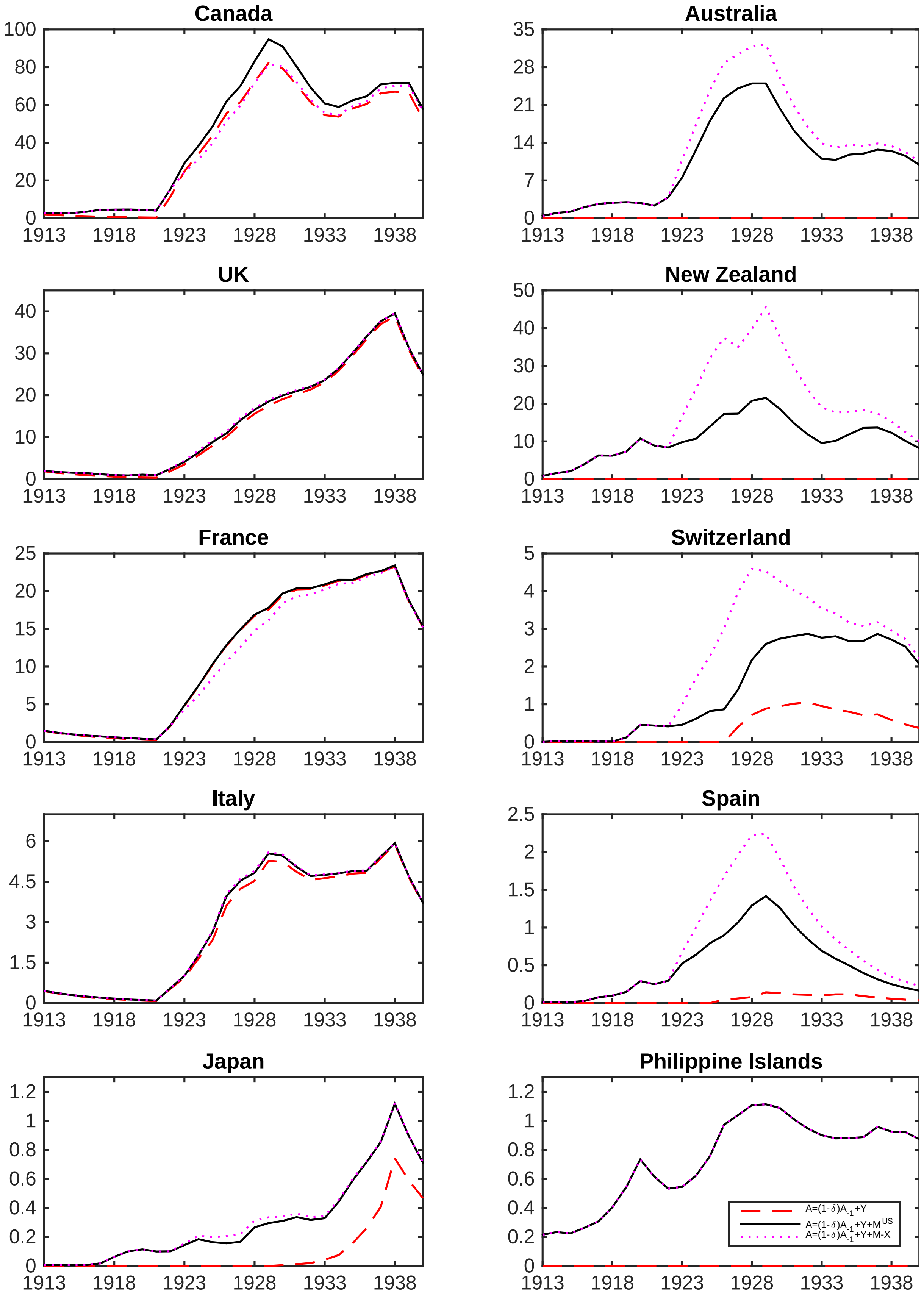

Figure 4. Stock-flow Estimates.

Notes. The sample period is 1913-1940 for every country. Numbers are estimated stocks of automobiles per 1,000 population. The total import (M) include imports from Canada, UK, France, and the United States (M^{US}). Production is the production of automobiles in the destination country and includes production by foreign multinationals. Solid line estimates stock using home production and imports from the U.S, while dashed line uses home production only, and dotted line uses home production and imports from all four sources.

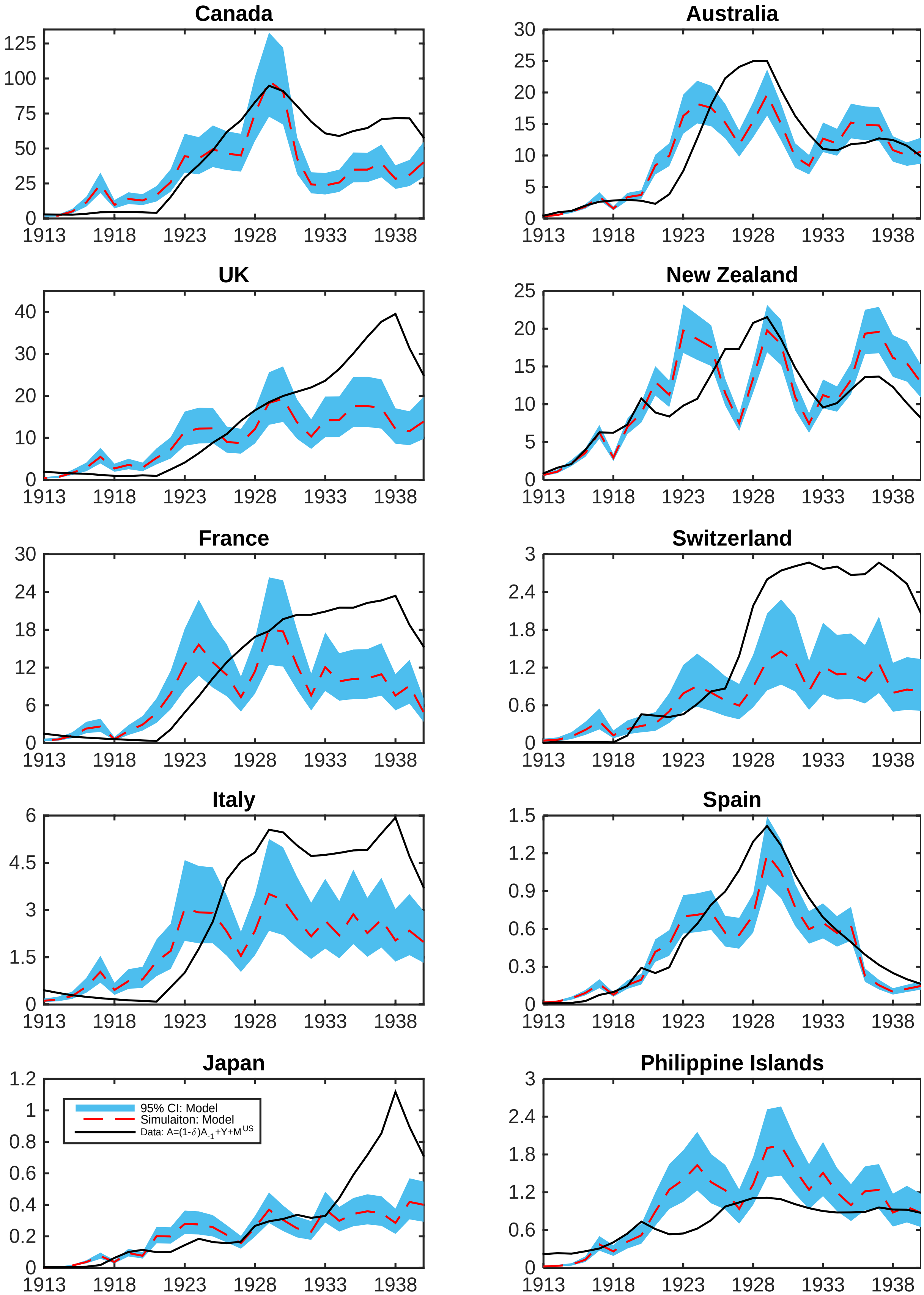

Figure 5. Simulated Automobile Adoption Path versus Data.

Notes. The sample period is 1913-1940 for every country. Data is the automobile adoption constructed using US export flows and domestic production. Simulation uses common price and income elasticity estimates from the pooled regression with US wholesale price and destination income present. 95% confidence interval is presented for the simulated adoption. Automobile adoption is measured as quantity levels, $A_{j,t}$, which means automobiles per 1,000 population.

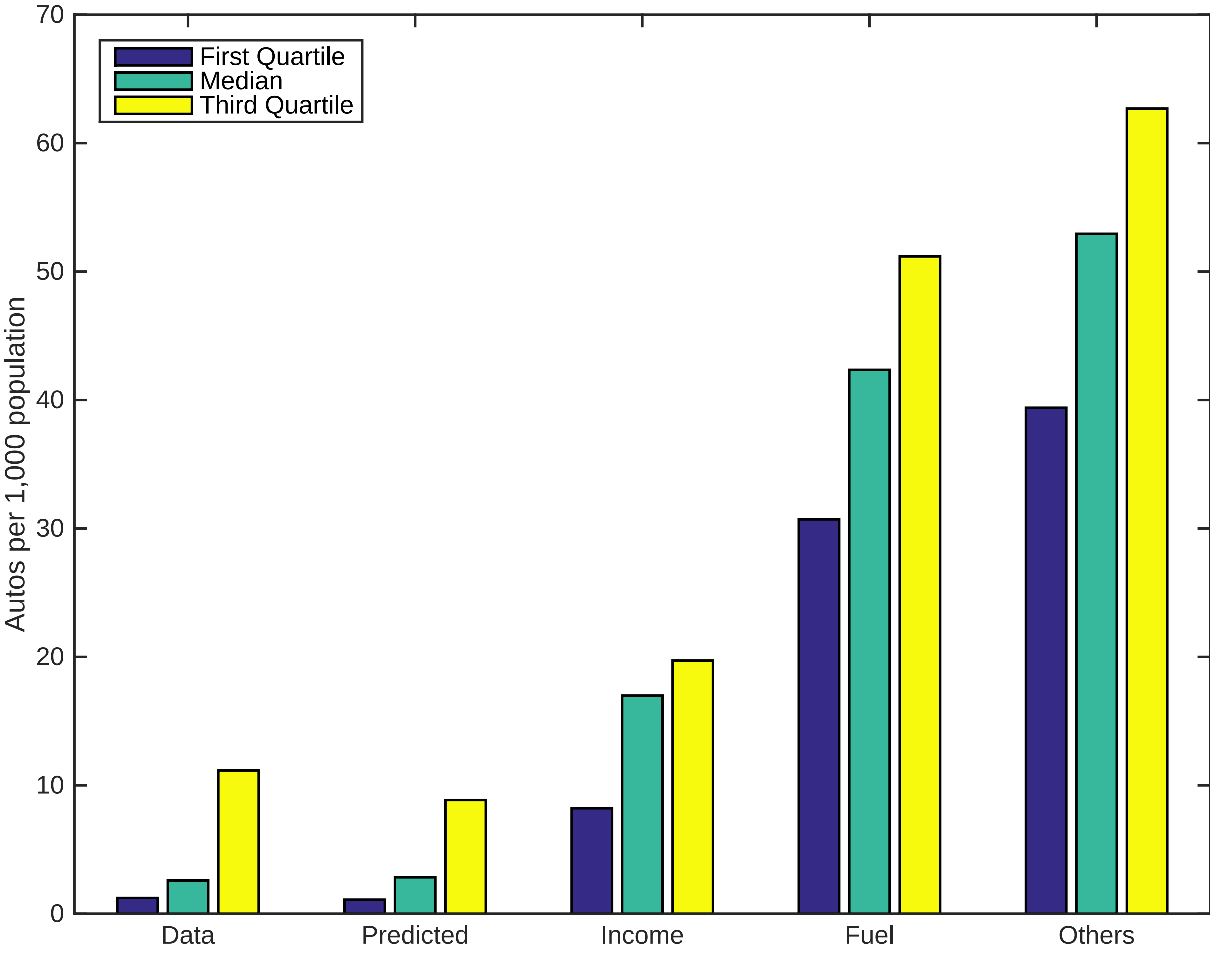

Figure 6. Distribution of Adoption as Policy and Economic Characteristics Converge.

Notes. Values are the adoption levels (in autos per 1,000 population) for the steady-state period of 1928-29. Three quartiles across 23 destinations are presented in the bar graph. From left to right, we plot adoption levels in the data (“Data”), in the case when we have all five frictions (“Predicted”), and in the cases we gradually remove a friction in a cumulative way (income differences between the destinations and the US, fuel tax, and the other four trade wedges including tariff, shipping cost, export markup, and Penn effect or distribution cost). In such a way, the category labeled “Income” corresponds to the case when the income differences between the destinations and the US are removed; and the category labeled “Others” corresponds to the case when all five trade frictions and the income differences are removed. More details about the counterfactual analysis are presented in the technical appendix.