Dry Bulk Shipping and the Evolution of Maritime Transport Costs, 1850-2020

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Abstract

We provide evidence on the dynamic effects of fuel price shocks, shipping demand shocks, and shipping supply shocks on real dry bulk freight rates in the long run. We first analyze a new and large dataset on dry bulk freight rates for the period from 1850 to 2020, finding that they followed a downward but undulating path with a cumulative decline of 79%. Next, we turn to understanding the drivers of booms and busts in the dry bulk shipping industry, finding that shipping demand shocks strongly dominate all others as drivers of real dry bulk freight rates in the long run. Furthermore, while shipping demand shocks have increased in importance over time, shipping supply shocks in particular have become less relevant.

JEL classifications: E30, N70, R40

Keywords: Dry bulk, maritime freight rates, structural VAR

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1. Introduction

A long-standing body of research in economic history centers on documenting the radical decline in transportation costs from the 18th and 19th centuries as well as identifying the fundamental drivers of this transport revolution. In a key contribution to this literature, Mohammad and Williamson (2004) offer up the most comprehensive analysis of maritime transport costs in the critical period from 1869 to 1950. They collect tramp freight rates for a larger and more representative sample of routes than in previous research, identify significant but varying rates of productivity growth in the shipping sector over these 80 years, and find that this productivity growth is most strongly associated with dramatic changes in ship cargo capacities/sizes and turnaround times in ports. In O'Rourke and Williamson's related and seminal work on the pre-World War I global economy (1994, 1999), the associated decline in maritime transport costs along with the diffusion of railways takes pride of place in explaining the emergence of the first wave of globalization from 1870.

Alongside such considerations of slowly evolving trends in freight rates, professional sentiment has long argued for the existence of alternating booms and busts in the maritime shipping industry (Metaxas, 1971; Cufley, 1972; Stopford, 2009). What is more, a burgeoning academic literature in behavioural finance and industrial organization has taken these claims to heart, finding that such boom/bust activity goes a long way in understanding the dynamics of ship building, ship earnings, and ship prices in the dry bulk sector. The key underlying mechanism in these papers is the role of unanticipated positive shipping demand shocks and their propagation over time. In the wake of such shocks, the attendant booms in maritime freight rates generate over-investment in shipping supply either due to time-to-build constraints as in Kalouptsidi (2014) or firms being simultaneously too optimistic in their projections of future freight rates and too pessimistic in their projections of their competitors' responses as in Greenwood and Hansen (2015). Kilian, Nomikos and Zhou (2020) provide a comprehensive empirical evaluation of the oil tanker shipping market in the Arabian Gulf.

Here, we seek to — at least partially – integrate these two perspectives on maritime transport costs in the short- and long-run. Building on new and more encompassing data on global shipping activity, we first present evidence on the evolution of real dry bulk freight rates for the entire period from 1850 to 2020.[1] To our knowledge, this is the longest consistently-measured and continuous series on the costs of shipping goods in the literature. A similar approach has been taken by Kilian (2009) who

[1] All figures for 2020 are only for January through July.

constructed a monthly real freight rate index based on bulk dry cargo ocean shipping rates starting in January 1968.

We document the following important facts. First, real dry bulk freight rates are estimated to have followed a downward but undulating path over time: thus, they fell from 1850 to 1910, rose from 1910 to 1950, and fell once again from 1950 with a cumulative decline of 79% between 1850 and 2020. Second, behind these slowly evolving trends, there were also often abrupt movements with real dry bulk freight rates in some instances nearly tripling on a year-to-year basis.

Abstracting away from this long-run trend and its potential productivity-related determinants, we then narrow our focus to understanding the drivers of booms and busts in the dry bulk shipping industry which occur at a higher frequency. That is, is it possible to rationalize the often large inter-annual changes we observe in dry bulk freight rates by considering fundamentals in the sector? We build on a canonical structural vector auto-regressive model with sign restrictions to set-identify shocks in the market for maritime dry bulk shipping services. Based on assumptions related to basic supply-and-demand analysis, we specify four orthogonal shocks to real maritime freight rates which we interpret as a shipping demand shock, a shipping supply shock, a fuel price shock, and a residual shock.[2]

In particular, we assume that a positive aggregate demand shock, representing an unexpected expansion in global economic activity as in periods of rapid industrialization and urbanization, leads to higher global real GDP, global shipping tonnage, real fuel prices and real freight rates within the same year. The second shock corresponds to a classic shipping supply shock. An unexpected inward shift of the supply curve negatively affects global real GDP, global ship production and the fuel price, but increases real freight rates within a year. We interpret the third shock as a fuel price shock based on the assumption that a positive fuel price shock negatively impacts global real GDP and tonnage, while it positively affects the fuel price index and the real freight rate index within a year.

Finally, the residual term captures all remaining uncorrelated shocks, including changes in expectation. For our purpose, it can also – at least partially –be interpreted as a utilization shock. Higher utilization of ships may occur, for example, as trading routes are affected by the risk of storms, piracy or military attack, forcing vessel owners to take detours or to sit idle until the risk has passed (see Kilian, Nomikos, and Zhou, 2020). We postulate that the residual shock has a negative effect on global real GDP, a positive effect on the supply of shipping services, an ambiguous effect on real fuel prices, and a positive effect on real maritime freight rates.

[2] We emphasize that these shocks are specifically related to the market for dry-bulk shipping services and should not be confused with the aggregate demand and aggregate supply shocks used in the macroeconomic literature.

Based on the sign-restricted VAR model, we compute structural impulse response functions and historical decompositions for real dry bulk freight rates. The historical decomposition shows the cumulative contribution at each point in time of each of the four structural shocks in driving booms and busts in real dry bulk freight rates. It serves to quantify the independent contribution of the four shocks to the deviation of our new series from its base projection after accounting for long-run trends in real dry bulk freight rates.

Our results indicate that shipping demand shocks strongly dominate all others as drivers of real dry bulk freight rates over the long run. Over the period from 1880 to 2020, the average share of shipping demand shocks in explaining variation in real dry bulk freight rates is 49% while the average share of shipping supply shocks is 22% and the average share of fuel price shocks is 11%. Residual shocks absorb the remaining 18% of variation in the real dry bulk index. Additionally, we consider the contribution of these shocks across three sub-periods: the pre-World War I era from 1880 to 1913, the interwar years from 1919 to 1939, and the post-World War II era from 1949 to 2020. We find that the contribution of shipping demand shocks to variation in real dry bulk freight rates increased substantially in the interwar years and remained elevated in the post-World War II era. Likewise, the contribution of shipping supply shocks decreased substantially in the interwar years and remained suppressed in the post-World War II era. Finally, the contribution of both fuel price shocks and residual shocks remained roughly constant through the three sub-periods.

The rest of the paper proceeds as follows. Section 2 describes the new dry bulk freight rate series constructed for this paper while Section 3 outlines the methodology related to structural vector auto-regressions. Section 4 quantifies the contribution of various shocks on freight rate dynamics. Section 5 concludes.

2. A new series of dry bulk freight rates and other data

One of the chief outputs of this paper comes in the form of a new and comprehensive dataset on global dry bulk freight rates from 1850 to 2020.[3] The primary sources of the data are a mixture of an abundant academic literature (both contemporary and historical), government reports, and official/trade publications along with standards in the literature like Angier (1920) and Isserlis (1938). Appendix A details the sources in full.

[3] From 2017, our index of real dry bulk freight rates is extended by using the annual changes in the real value of the Baltic Dry Index. This approach mirrors that described in Kilian (2019). In future work, we hope to supplement the underlying dataset with raw observations on dry bulk freight rates for the years of 2018, 2019, and 2020.

We narrow our attention to activity in the dry bulk sector — that is, commodity cargo like coal, grains, and ore which is shipped in large, unpackaged parcels — for two principal reasons. For one, this sector represents roughly 50% of world trade by volume in the present day (UNCTAD, 2015). Historically, this share would have only been higher, given that the composition of trade by value only began to favor manufactured goods from the late 1950s (Jacks and Tang, 2018). Thus, developments in the dry bulk sector loom large in our understanding of the global economy and its evolution (see Kilian, 2009).

For another, dry bulk markets are decentralized spot markets whereby exporters/importers/traders must engage in a search process in order to hire a ship for a specific itinerary. Thus, Brancaccio, Kalouptsidi, and Papageorgiou (2020) and others characterize dry bulk ships as the "taxis of the oceans", and so, their hire rates — that is, dry bulk freight rates — reflect real-time conditions in the supply of and demand for their services. This is in contrast to some other means of maritime transport like containerships or liners which operate in between fixed ports on fixed schedules and which sometimes can be bound to long-term contracts among exporters, importers, and shippers.

All told, there are 10,448 observations on maritime freight rates underlying the real dry bulk index presented below. Table 1 summarizes the principal currencies, destinations, goods, and origins in the raw freight rate data. The sample is split roughly 85/15 between observations in Great British pounds (which predominate up to the 1960s) and US dollars (which predominate after the 1960s) and is heavily weighted towards coal and grains. European countries and their offshoots are also heavily represented in terms of destinations and origins, given their outsized role in global trade flows throughout the 19th and 20th centuries (Jacks and Tang, 2018).

Our method of annually aggregating the individual observations comes in using the following general estimating equation:

$$(1)\quad ln(f_{i,t}) - ln(f_{i,t-j}) = \gamma_1 D_{i1} + \gamma_2 D_{i2} + ... + \gamma_T D_{iT} + \varepsilon_{it}$$

where $f_{i,t,}$ is the real freight rate between a particular origin and destination (e.g. New York City to London) for a particular good (e.g. wheat) at time *t*; *D* represents a set of indicator variables that are equal to 1 at time *t*, equal to -1 at time *t-j* when the last observation of this particular origin/destination/good combination was observed, and equal to 0 otherwise; and ε is an error term. This procedure has strong intuitive appeal in that it roughly amounts to calculating an unweighted average of changes in real freight rates in any given year. This procedure has also been used to good effect by Klovland (2009, 2017) in a set of papers which explore the trajectory of freight rates at a higher (monthly) frequency and which will form a good basis of comparison as they draw on different samples of freight rates than those used here. Finally, we employ the most conservative selection of the data and only use real freight rate observations which are observed on a year-to-year basis, thereby excluding any observations which include gaps which are two or more years in length.

Figure 1 depicts the resulting index for real dry bulk freight rates from 1850 to 2020 as the solid black series. At first glance, the series matches up well with many of our priors, but how does it compare with existing estimates in the literature? Mohammed and Williamson (2004) draw on the original sources underlying Isserlis (1938) in an attempt to correct his index for issues related to aggregation, deflation, and sample selection. They report a global real freight rate index for successive five-year periods from 1870-1874 to 1995-1999. Evaluating these values at their midpoints generates a correlation in between Mohammed and Williamson's series and ours of 0.85. We can make this association even tighter if we only consider the period of their primary focus which is from 1870 to 1939: in this case, the correlation climbs to a value of 0.94 over these 70 years.[4] Likewise, we find: a correlation of 0.98 in between our series and that reported in Klovland (2009) for the period from 1850 to 1861; a correlation of 0.89 in between our series and that reported in Klovland (2017) for the period from 1912-1920; and a correlation of 0.98 in between our series and the annual Baltic Dry Index for the period from 1999-2017. By all accounts then, our index of real dry bulk freight rates appears to be highly representative of developments in the general market for shipping services.

In Figure 1, our series is also overlayed by an estimate of its very long-run trend. The now-familiar story of a radical decline in real maritime freight rates for the period before the first World War is reproduced in the dotted black series with dry bulk rates estimated to have declined by 55% in between 1850 and 1910. This decline was then partially reversed with the index estimated to have risen 62% between 1910 and 1950 and finally resumed with the index estimated to have fallen 71% between 1950 and 2020. Cumulatively, the index is estimated to have fallen 79% in between 1850 and 2020. Underpinning the secular declines from 1850 to 1910 and from 1950 to 2020 has been significant productivity growth as changes in naval architecture occurred enabling large increases in ship cargo capacities/sizes, shipping transitioned from sail to steam and from steam to the internal combustion engine, and equally dramatic improvements in goods handling and storage in ports were achieved (Harley, 1988; Mohammed and Williamson, 2004; Tenold, 2019).

[4] The primary reason for any divergence in between Mohammed and Williamson's series and ours stems from the fact that after 1950 they tie their series to the Norwegian Shipping News global freight rate index for tramp charters. Likely due to the time-varying but unknown set of weights it uses, the Norwegian Shipping News index demonstrates a somewhat larger decline from 1950 to 2000 but substantially less variation in real freight rates than we document here.

Of course, behind the smooth arcs and slow transitions depicted in Figure 1 are often abrupt movements of real dry bulk freight rates on a year-to-year basis. Figure 2 depicts the de-trended version of the real dry bulk index to get a better sense of the inherent variation in the series. Prior to 1970, positive spikes in the real dry bulk index occur in and around 1854, 1917, 1943, 1951, and 1956. And all of these spikes can be associated with the outbreak of interstate conflict (respectively, the Crimean War, World War I, World War II, the Korean War, and the Suez Crisis). After 1970, there are spikes around the time of the oil crisis of1974 and 1980 and the economic rise of China in the period from 2004 to 2008. And while there are some sharp reversals in the index (most significantly after World War I and during the Great Depression), there is also a degree of asymmetry across the relative strength of its booms versus busts.

Apart from documenting long-run trends in maritime transport costs, the other purpose of this paper then comes in explaining this inter-annual variation in the real dry bulk index by considering the roles of global economic activity, real fuel prices for shipping, and worldwide shipping capacity. The other data needed for our analysis relate to these measures in the following fashion:

(a) Global real output

Our benchmark measure of global economic activity is world real GDP data based on Maddison (2010) with extensions from Jacks and Stuermer (2020).[5] This measure is far from ideal in that GDP contains many elements which are not likely to be bearing on the demand for shipping services and which may be growing over time (in particular, the domestic component of the service sector). As sensitivity analysis, we also consider an index of US industrial production spanning the period from 1850 to 2020. This measure is limited in its geographic scope and, therefore, its representativeness. It may also be a inadequate measure during the earlier period of our sample when agricultural goods fy far dominated shipped goods. Finally, we also consider an OECD index of world industrial production, which was extended by Baumeister and Hamilton (2019) from 2011 to 2020. The index covers the OECD plus Brazil, China, India, Indonesia, Russia, and South Africa representing roughly 75% of world GDP but which is only available from 1958.

Panels A through C of Figure 3 respectively document changes in world real GDP, US industrial production, and industrial production for the OECD+6 in percentage terms from 1850 to 2020. The

[5] For further discussion of the trade-offs between alternative measures of global real activity see Kilian and Zhou (2018).

pairwise correlation for changes in world real GDP and US industrial production from 1850 to 2020 is 0.95 while the pairwise correlation for changes in world real GDP and industrial production for the OECD+6 from 1958 to 2020 is 0.99. Appendix A details the sources for the individual series.

(b) Real fuel prices for shipping

In our framework, fuel price shocks emerge from unanticipated changes in supply and demand conditions in global energy markets. In principle, fuel prices are one of the most important variable costs in the shipping industry and have obvious implications for the determination of real dry bulk freight rates. In practice, we need to be conscious of important changes in the primary fuels used in the shipping industry as Panel A of Figure 4 makes clear. It depicts the share of world mercantile gross tonnage by fuel type from 1879 (when consistent records on world mercantile gross tonnage first become available). There, we see the well-known decline of sail (with coal achieving dominance in 1885 but with sail lingering around until 1957) and the less well-studied decline of coal-driven propulsion (with fuel oil achieving dominance in 1937 but with coal lingering around until 1989).

We then combine these tonnage shares with data on real energy prices from Wegerich (2016) and Jacks (2019). There are two important considerations in this regard. First, we lack long-run data on fuel oil prices and instead use petroleum prices. We rationalize this choice by noting that, while fuel oil and other distillate prices can indeed diverge from petroleum prices in the short run due to differential supply and demand, the two series are very highly correlated on an annual basis (r = 0.98 for the period from 1983 to 2019). Second, we need to contend with the fact that for at least part of our period, a not-insignificant share of world tonnage was still under sail and, therefore, remained relatively unaffected by changes in real fuel prices.

To this end, we construct two real fuel price indices. Our benchmark series depicted in Panel B of Figure 4 considers the respective shares of coal, fuel oil, and sail in all tonnage (irrespective of the type of propulsion)[6] and combines these with real prices for coal and petroleum. An alternative series depicted in Panel C of Figure 4 only considers the respective shares of coal and fuel oil in tonnage with propulsion via mechanical means and combines these with the same real price data for coal and petroleum. Not surprisingly, the correlation between the two series is very high at 0.98 as they are virtually the same from 1900, the point at which the share of sail dips below 25% and steadily declines

[6] We make this distinction for the fact that ships which used fuel oil for boilers — that is, the generation of steam — dominated those which used fuel oil for internal combustion until 1963.

to zero. Regardless of the series considered, large and positive fuel price shocks can easily be discerned for years with known disruptions in global energy markets (e.g., 1973 and 1979).

(c) Worldwide shipping capacity

The final component needed for our analysis is a measure of changes in the quantity supplied of shipping services in the dry bulk market. We rely on a newly constructed series on changes in world mercantile gross tonnage from 1879 to 2020 which is depicted in Figure 5 (again, Appendix A details the sources of this new series). Building of new ships increases the fleet size while scraping reduces it.

In Figure 5, changes in the dry bulk fleet size are tracked on an annual basis back to 1880 when consistent records on world mercantile gross tonnage first become available. We see ample variation over this period with lower volatility in the annual growth rate of shipping in the post-1950 period (σ = 2.8) than in the pre-1950 period (σ = 4.1). Some of this volatility is naturally attributable to the pronounced destruction of and subsequent recovery in the size of the fleet surrounding the World Wars (including a tremendous 16.8% increase in 1943). But the pre-1950 period was also marked with more frequent (and sizeable) downward adjustments in world mercantile gross tonnage during peacetime: indeed, the largest annual decline in the fleet (-6.5%) came in the year 1892. In contrast, the only period of any decline in the post-1950 period was from 1982 to 1987 when the fleet cumulatively shrank by a relatively modest 5.0%.

Given the sweeping span of time under consideration, we should acknowledge some important caveats associated with the use of this particular measure of shipping quantity. For one, even a statistically accurate measure of physical tonnage of worldwide mercantile shipping worldwide will fail to capture the effective increases in shipping capacity which marked the transitions from sail to steam and from steam to the internal combustion engine. These transitions were marked by increasing speeds of shipping service: one ton under steam was initially reckoned to be roughly as effective as one ton under sail in 1850 but subsequently reckoned to be roughly as effective as four tons under sail in 1910 (Sturmey, 1962, pp. 13-14). However, in our series on world mercantile gross tonnage, we choose to take the data at face value rather than impose arbitrary corrections for effective shipping supply, given uncertainty over the exact timing and magnitude of these transitions.

There has also been a remarkable revolution in naval architecture which has – somewhat lamentably – been overshadowed in the academic literature by the aforementioned changes in propulsion. In particular, the post-1950 era gave way to a marked transition from general cargo carriers to ships which were not only much larger in size but also much more specialized in the types of goods they carried (Beaver, 1967; Lundgren, 1996; Tenold, 2019). Much of the impetus for this increasing specialization in shipping came from the needs of the petroleum industry in which the main sites of consumption and production were generally very far removed. But the lessons in construction, design, and port handling learned there were soon applied to chemical carriers, combination carriers, natural gas tankers, and, of course, dry bulk carriers. The use of our series on world mercantile gross tonnage will necessarily have to then come with the assumption that changes in aggregate tonnage are highly correlated with changes in the tonnage of dry bulk carriers.

Finally, we need to acknowledge the fact that our measure of the shipping fleet size perhaps does not capture equally important changes in shipping utilization. That is, a given stock of ships can be ran faster – but generally at a more than proportionate cost of fuel – and thereby increase the effective capacity of shipping in response to a positive shipping demand stock. Likewise, owners can voluntarily remove their ships from active service in response to a negative shipping demand shock, during which time their ships may be completely idled or sent for repairs and service. An example may be instructive in this last case. In the midst of the Great Depression, the British Chamber of Shipping estimated that "due to trade depression ... about 18,000,000 tons of vessels, or about 20 percent of world tonnage, were laid up at the end of 1931" (Sollohub 1932, p. 410). We can then compare this estimate of laid-up tonnage to the observed change in world mercantile gross tonnage as depicted in Figure 5: from 1930 to 1931, it actually increased by 0.75%; and from there, it only slowly declined by 7.5% into 1935 (after which it began to climb again). This matters in that the separate processes of laying-up and reactivating tonnage each come with their own fixed costs which likely lead to non-linearities in the effective supply of shipping services.

Our proposed means of dealing with these issues is as follows. To account for the slowly evolving changes in naval architecture and propulsion discussed above, we use the annual percentage change in world mercantile gross tonnage as our measure of shipping services in the structural VAR below. Thus, if we can assume these transitions are roughly linear over the long run (as Panel A of Figure 4 would indeed suggest), then changes in effective shipping services due to changes in technology will be roughly constant on a year-to-year basis and will effectively be differenced out. Likewise, to account for unobserved changes in effective shipping services due to time-varying utilization rates either from changes in the speed of shipping services or the process of laying up/recommissioning part of the fleet, we will interpret the residual term in the structural VAR below as primarily capturing utilization shocks among other orthogonal components.

3. Structural Vector Autoregression

We build on a structural vector auto-regressive model with sign restrictions to set-identify shocks in the dry bulk freight market. Faust (1998), Canova and De Nicolo (2002), and Uhlig (2005) pioneered this model which has become a standard of the applied macroeconomics literature. Kilian and Murphy (2012, 2014), in particular, apply this model to decompose changes in the real price of crude oil into components driven by different types of shocks. Kilian, Nomikos and Zhou (2020) showed how these tools may be used to analyze the market for oil tankers in the Arabian Gulf. The same methodology makes it possible to set-identify the various shocks that drive dry bulk freight rates at any one moment that might have an offsetting impact. This allows us to deal with two notable problems, namely unobserved structural shocks and reverse causality.

3.1 Identification

We set-identify four orthogonal shocks to real dry bulk freight rates. We interpret these as a fuel price shock, a shipping demand shock, a shipping supply shock, and a residual shock. We relate them to one another and real dry bulk freight rates via supply-and-demand analysis as summarized in Table 2. In what follows, we normalize all shocks to have a positive effect on the real freight rate index.

The first shock is intended to capture exogenous shifts in the demand curve for shipping which are associated with unanticipated changes in the global business cycle. To identify this shipping demand shock, we assume that a positive shock leads to higher global real GDP, global mercantile tonnage, real fuel prices, and real freight rates. The second shock corresponds to a shipping supply shock. We assume that an unexpected inward shift of the supply curve negatively affects global real GDP, global mercantile tonnage, and real fuel prices, but increases real freight rates. Likewise, we interpret the third shock as a fuel price shock. We assume that a positive fuel price shock negatively affects global real GDP and global mercantile tonnage while it positively affects real fuel prices and real freight rates.

Finally, we include a residual shock designed to capture idiosyncratic shocks not otherwise accounted for. This could relate to shifts in the demand for shipping due to forward-looking behavior or to other demand shocks specific to the market for shipping driven by changes in preferences, regulation, or technology. This type of shock may also capture exogenous shocks to capacity utilization in the global shipping fleet (see Kilian, Nomikos, and Zhou, 2020). Here, we assume that the residual shock negatively affects global real, positively affects global mercantile tonnage, and leads to higher real freight rates. However, we leave the effect of such a residual shock on real fuel prices unrestricted.

3.2 Econometric Model

We include K endogenous variables $y_t = (\Delta Y_t, \Delta Q_t, \log(F_t), \log(P_t))'$, namely the percentage change in global real GDP (ΔY_t), the percentage change in global mercantile tonnage (ΔQ_t), the log of the real fuel price index F, and the log of the real freight rate index P, on their own lags p and the lags of all other endogenous variables in our structural VAR model:

$$(2)\ \ B_0 y_t = B_1 y_{t-1} + \cdots + B_p y_{t-p} + \Pi^* D_t + B_0 \epsilon_t.$$

The matrix of deterministic terms (*D*) consists of a constant and a linear trend. These deterministic terms account for long-run trends in productivity growth in the shipping industry, the costs of energy and shipping production, trade costs, and other factors. We also add annual dummies for World War I and the three subsequent years after its conclusion (that is, from 1914 to 1921) as well as World War II and the three subsequent years after its conclusion (that is, from 1939 to 1948). These annual dummies control for the war-related market distortions introduced by government policy and restrictions to trade.

The matrix B_0 governs the instantaneous relationship among the endogenous variables. The inverse of this matrix B_0^{-1} is called the structural multiplier matrix which relates to the reduced form coefficients of the endogenous variables $A_i = B_0^{-1} B_i$ with the dimension of $B_i = 1, \ldots, p$ being $K \times K$. The structural form matrix for the deterministic terms is $\Pi^* = B_0^{-1}\Pi$. The $K \times T$ matrix ϵ is assumed to consist of serially and mutually uncorrelated structural innovations. It relates to the reduced form residuals u_t through the structural multiplier matrix B_0^{-1} namely $u_t = y_t - A_1 y_{t-1} - \ldots - A_p y_{t-p}$. These equations allow us to express the mutually correlated reduced-form innovations, u_t, as weighted averages of the mutually uncorrelated structural innovations, ϵ_t. The elements of the structural multiplier matrix B_0^{-1} are the weights.

3.3 Historical Decomposition

Based on the structural model, a historical decomposition allows us to decompose fluctuations in the real dry bulk index into the respective contributions of the accumulated effects of each structural shock and the deterministic terms. Basically, we compute what the counter-factual freight rate series would have looked like based on the emergence of only one type of shock, removing the effects of the other shocks.

We decompose the four endogenous variables according to:

$$(3)\ \widetilde{y_t} = \sum_{i=0}^{t-1} \Phi_i B_0^{-1} \epsilon_{t-1} + \sum_{i=0}^{t-1} \Phi_i \Pi_0^{-1} D_{t-1} + \Gamma_1^{(t)} y_0 + \ldots + \Gamma_p^{(t)} y_{-p+1},$$

where Φ_i are the estimated reduced form impulse responses which capture the responses of the endogenous variables to one-unit shocks i periods ago. They are computed from $\Phi_i = J\boldsymbol{A}^i J'$ and $\left[A_1^{(t)}, \ldots, A_p^{(t)}\right] = JA^t$, with $(K \times Kp)$ matrix $J = \left[I_K, 0_{(K \times K)}, \ldots, 0_{(K \times K)}\right]$. The companion matrix $\boldsymbol{A}$ is defined as a $(pK \times pK)$ matrix:

$$\boldsymbol{A} = \begin{bmatrix} A_1 & \cdots & A_{p-1} & A_p \\ I_K & & 0 & 0 \\ & \ddots & & \vdots \\ 0 & & I_K & 0 \end{bmatrix}$$

The matrix B_0^{-1} is the estimated structural multiplier matrix of the endogenous variables and Π_i^* is the structural form matrix for the deterministic terms. We denote variables that are derived from the historical decomposition by upper tildes. The first term on the right-hand side of equation (3) contains the sum of the cumulative contributions of the five structural shocks on each of the endogenous variables. The second term is the contributions of the deterministic terms to the endogenous variables. The last term on the right-hand side includes the cumulative effect of the initial states on the five endogenous variables which become negligible for stationary processes as $t \rightarrow \infty$.

3.4 Estimation and Inference

We estimate the sign-identified VAR model using the standard Bayesian approach based on Rubio-Ramirez, Waggoner and Zha (2010) and Arias, Rubio-Ramirez and Waggoner (2018). Sign-identified VAR models rely on inequality restrictions such that they do not generate unique point estimates of the impulse responses (like in VARs with short- or long-run restrictions) but a possibly large set of admissible models. Each of these admissible models is consistent with the data and satisfies the sign-restrictions. We construct the set of admissible models as discussed in Kilian and Lütkepohl (2017).

We assume a conventional diffuse Gaussian-inverse Wishart prior on the reduced-form parameters $A = [A_1, \ldots, A_p]$ and the residual variance-covariance matrix Σ_u. and a uniform prior for the orthogonal rotation matrix *Q*. Given the vector of reduced-form parameters and the lower triangular Cholesky decomposition of the residual variance-covariance matrix, $P = chol(\Sigma_u)$, with positive diagonal elements, we generate a large number of candidate solutions for the structural impact matrix B_0^{-1}. To do so, we draw 20,000 realizations of the rotation matrix *Q* such that *PQ* is a candidate solution for the structural impact matrix B_0^{-1}. This is based on a QR decomposition using the Householder transformation following Rubio-Ramirez, Waggoner, and Zha (2010). For each candidate solution of the structural impact matrix B_0^{-1}, we construct the structural model compute the set of implied structural impulse responses.

We repeat this procedure for each of the 5,000 draws from the posterior distribution of (A, Σ_u). We retain structural models with impulse response functions that satisfy all identifying sign restrictions and discard the others.

For Bayesian inference we evaluate the joint posterior density value of the set of admissible structural models under Dirac delta loss (Inoue and Kilian, 2013, 2019, 2020,2021). We compute the modal (that is, the most likely model) and the 68% joint credible sets of the admissible structural models.

4. Results

4.1 Impulse Response Functions

Figure 6 presents the credible set of impulse response functions for the four endogenous variables. The functions show how (from left to right) the percentage change in global economic activity, the percentage change in world mercantile gross tonnage, the log of the real fuel price index, and the log of the real dry bulk index react to a one-standard deviation change in (from top to bottom) the shipping demand shock, the shipping supply shock, the fuel price shock, and the residual shock through time. The mode and the joint credible sets of the admissible structural models are depicted in black and red, respectively.

In the main, the impulse response functions demonstrate that the reaction of real dry bulk freight rates to the different types of shocks are either in line with what one would reasonably expect or – in effect – indistinguishable from zero. A positive shipping demand shock and a positive fuel price shock both increase real dry bulk freight rates, but with the former leading to stronger and more long-lasting effects than the latter. Likewise, a negative shipping supply shock increases real dry bulk freight rates while a residual shock does not have a clear effect on freight rates. On average, shipping demand shocks are, by far, the most persistent with their effects lingering up to 10 to 15 years. This is followed by fuel price shocks and shipping supply shocks which are significantly less persistent with effects that only last for a few years. Finally, the effect of residual shocks is, for the most part, fairly minimal.

4.2 Historical Decompositions

Historical decompositions show the contribution of each shock in driving variation in the real dry bulk freight rate series. They quantify the independent contribution of the four shocks to deviations in real dry bulk freight rates from their base projection. Figure 7 allows us to visually discern the historical drivers of booms and busts in the dry bulk shipping industry. The vertical scales are identical across the four sub-panels so that the figures clearly illustrate the relative importance of a given shock. Another way of intuitively thinking about these historical decompositions is that each of the sub-panels represents a counterfactual simulation of what real dry bulk freights rates would have been if it had only been driven by this particular shock.

For instance, we can consider the case of shipping demand shocks by integrating the lessons of economic and financial history on variation in global output. The historical decomposition starts in 1880 when dry bulk freight rates were likely somewhat depressed due to the negative accumulated effects of shipping demand shocks during the Long Depression of the 1870s. Afterwards, the effects of shipping demand shocks are in line with our historical knowledge about the business cycles in major economies at the time. For example, the effects of the large negative shipping demand shock in the late 1900s can be associated with the Panic of 1907. Likewise, real dry bulk freight rates plummeted in the early 1930s as the Great Depression dramatically reduced global trade and the demand for shipping services.

After World War II, positive shipping demand shocks led to increases in real dry bulk freight rates in the wake of the immediate post-war efforts at re-industrialization and re-urbanization in much of Europe and Japan as well as the later economic transformation of the East Asian Tigers and Japan. From 1950 to 1980, this amounted to a nearly uninterrupted — but far from constant — string of positive shipping demand shocks. This long swing was reversed in the period from 1980 to 2000. However, from the early 2000s, a series of positive commodity demand shocks emerged which were clearly related to unexpectedly strong global growth driven by the industrialization and urbanization of China. Indeed, this period represents the most dramatic upswing in the cumulative effects of shipping demand shocks seen in these 140 years of global macroeconomic history. The lingering effects of the Global Financial Crisis are also clearly visible in the series for the accumulated effects of shipping demand shocks. Finally, the historical decomposition shows that shipping supply shocks, fuel price shocks, and residual shocks alike had much less of an important role in driving deviations in long-run real dry bulk freight rates from their underlying trend.

Table 3 more precisely quantifies these impressions by numerically summarizing the contribution of each shock by period. For the full period from 1880 to 2020, shipping demand shocks explain 49% of the variation in real dry bulk freight rates while shipping supply shocks explain 22%. These two types of fundamental shocks which are related to simple supply and demand conditions, thus, explain a significant majority (71%) of the medium- and long-run variation in real dry bulk freight rates. Fuel price shocks and residual shocks respectively explain 11% and 18% of the same.

It is also possible to replicate this decomposition for shorter spans of time by using the parameter estimates derived from the full sample in combination with the respective size of shocks for various sub-periods. In the lower half of Table 3, we consider the independent contribution of the four shocks in the pre-World War I era from 1880 to 1913, the interwar years from 1919 to 1939, and the post-World War II era from 1949 to 2020. In the pre-World War I era, we find a more balanced contribution across shipping demand shocks and shipping supply shocks with shares of 34% and 29%, respectively. We also find that the contribution of shipping demand shocks to variation in real dry bulk freight rates increased substantially to 56% in the interwar years while the contribution of shipping supply shocks decreased substantially to 17% in the same. What is more, the share of shipping demand shocks remains elevated at 50% and the share of shipping supply shocks remains suppressed at 20% in the post-World War II era. While there may be several potential explanations for this phenomenon (see below), we must leave their exploration for future research. In contrast, the contribution of both fuel price shocks and residual shocks remained roughly constant through the three sub-periods, not straying very far from the headline numbers of 8% and 19% reported above.

4.3 Sensitivity analysis

Our results are relatively robust to a number of different approaches to the data. First, we have previously noted that the use of real global GDP may not be ideal, given changes in the composition of GDP over time away from goods production and towards services. To this end, we substitute the series of real global GDP with the series of US industrial production depicted in Panel B of Figure 3. And while the pairwise correlation for changes in world real GDP and US industrial production is 0.95, we may also reasonably expect some changes in the values of parameter estimates from the structural VAR. Likewise, we also substitute the series of real global GDP with the proxy for world industrial production which covers the OECD plus Brazil, China, India, Indonesia, Russia, and South Africa and which is depicted in Panel C of Figure 3. Unfortunately, this times series only starts in 1958. Finally, we substitute the series of real fuel prices inclusive of sail tonnage with an index of real fuel prices which excludes sail tonnage and which is depicted in Panel C of Figure 4.

Rather than display and try to visually compare the associated impulse response functions and historical decompositions, we instead reproduce the decomposition exercise in Table 3 and numerically summarizing the contribution of each shock by period across the three alternate specifications. The first panel of Table 4 reports the shares for our benchmark specification. This is then followed by the shares from the specification using the index of US industrial production, the specification using the index of OECD +6 industrial production, and finally the specification using the real fuel price index which excludes sail tonnage.

There, we find that relative to the benchmark specification, the substitution of the index of US industrial production for real global GDP leads to an 18 percentage point reduction in the share of shipping demand shocks from 1880 to 2020. Most of this reduction is then evenly split in between increases in the share of shipping supply shocks and fuel price shocks. Shipping demand shocks retain pride of place only during the interwar period, while supply shocks become most important over the full sample and for the other two sub-periods. On balance, we are not too concerned about this result. It is an open question how much interpretative weight to place on these figures, given the geographic specificity of this proxy for global economic activity, the waning US share of world industrial production and the importance of agricultural goods in the early parts of the sample.

More reassuringly, the substitution of the index of OECD+6 industrial production for real global GDP delivers results which are numerically more consistent with those for the benchmark specification in the post-World War II period. Thus, the share of shipping demand shocks decreases by 9 percentage points while the share of shipping supply shocks remains roughly constant. However, the largest changes occur: (1) for fuel price shocks which are now reckoned to explain 25% of the variation in real dry bulk freight rates (a result which is perhaps not surprising given the size of these shocks in the past 60 years); and (2) for residual shocks which are now reckoned to explain a mere 13% of the same (a figure which also represents the lowest share of the residual across all specifications and sub-periods).

Finally, the substitution of the real fuel price index derived without sail tonnage for the real fuel price index derived with sail tonnage yet again sees shipping demand shocks prevail in the full sample and for two of the three sub-periods. In sum, these results suggest that while numerical values change across specifications, the relative ordering of the importance of these shocks remain relatively invariant: shipping demand shocks are with one exception the most important driver of booms/busts in the dry bulk shipping industry followed, in order, by shipping supply shocks, residual shocks, and fuel price shocks.

5. Conclusion

This paper is the first to provide evidence on the drivers of real maritime transport costs in the very long-run. To this end, we develop and analyze a new and large dataset on dry bulk freight rates for the period from 1850 to 2020, finding that, in real terms, these followed a downward, but undulating path with a cumulative decline of 79% between 1850 and 2020. We relate this secular decline to a historical literature which documents significant productivity growth as radical changes in goods handling and storage in ports, naval architecture, and propulsion took place (Harley, 1988; Mohammed and Williamson, 2004; Tenold, 2019).

Our next step came in understanding the drivers of booms and busts in the dry bulk shipping industry. Here, we speak to both a recent academic literature and a long-standing professional consensus which emphasize the role of shipping demand in governing cyclic patterns of investment and profitability in the dry bulk industry. Somewhat reassuringly, we find that shipping demand shocks do indeed strongly dominate all other shocks as a driver of real dry bulk freight rates over the long run. Furthermore, while shipping demand shocks have increased in importance over time, shipping supply shocks in particular have become less relevant.

What remains as tasks for the future comes in developing disaggregated measures of maritime transport costs across commodity classifications and destination/origin pairings. That is, it would be useful to have a characterization of the respective shares of shocks for particular commodity-destination-origin combinations which could then be matched with known features of commodity and industrial production and their geographical determinants. An additional way forward would also come in developing a much more refined measure of shipping supply, specifically as it relates to the dry bulk sector. Here, we have had to abstract away from the implications of increasing specialization by ship type, technological change in propulsion, and time-varying utilization rates which may vitally affect any measure of the effective – as opposed to the observed – supply of dry bulk shipping services. Thus, in any final reckoning of the respective role of fundamentals in the dry bulk shipping market, shipping supply may yet reemerge as a more dominant force if our current measure of mercantile gross tonnage diverges too far from actual conditions in the industry.

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Appendix A

This appendix details the sources of global economic activity, real fuel prices, real maritime freight rates, and world mercantile gross tonnage used throughout this paper.

Global economic activity

In the paper, we consider three measures of global economic activity depicted in Panels A through C of Figure 3. Our benchmark measure is world GDP derived from Maddison (2010) with updates from Stuermer (2018).

Our second measure is an index of US industrial production for the period from 1850 to 2020 formed by chaining Davis' (2004) annual USIP index, Miron and Romer's (1990) monthly USIP index, and the Federal Reserve Economic Data's (2020) non-seasonally adjusted monthly USIP index. The sources are as follows:

Davis, J.H. (2004), "An Annual Index of US Industrial Production, 1790-1915." *Quarterly Journal of Economics* 119(4), 1177-1215. https://doi.org/10.1162/0033553042476143.
Federal Reserve Economic Data (2020), IPB50001N, Industrial Production: Total Index, Not Seasonally Adjusted; https://fred.stlouisfed.org/series/IPB50001N
Miron, J.A. and C.D. Romer (1990), "A New Monthly Index of Industrial Production, 1884-1940." *Journal of Economic History* 50(2), 321-337. https://doi.org/10.1017/s0022050700036469.

Finally, for the period, from 1958 to 2020, we also consider an index of world industrial production which covers the OECD plus Brazil, China, India, Indonesia, Russia, and South Africa. This series was originally published by the OECD in its Main Economic Indicators database. However, the organization discontinued the series in 2011. Baumeister and Hamilton (2019) have extended and updated the OECD series based on the same methodology.

Real fuel prices

The share of world mercantile gross tonnage by fuel type from 1879 depicted in Panel A of Figure 4 were derived from the world fleet statistics website administered by the Lloyd's Register Foundation: https://hec.lrfoundation.org.uk/archive-library/world-fleet-statistics

The real fuel price indices depicted in Panels B and C of Figure 4 were then constructed off the shares above and the real price of petroleum taken from Jacks (2019) and of Welsh best steam coal taken from Wegerich (2016) with extensions from 1962 using the real price of coal taken from Jacks (2019).

Real maritime freight rates

Freight rates quoted in Great British pounds were converted into real 1990 GBP using the CPI deflator in O'Donoghue, Goulding, and Allen (2004) with updates from the Bank of England. Freight rates quoted in US dollars were converted into real 1990 USD using the CPI deflator in Officer and Williamson (2020) with updates from the Bureau of Labor Statistics.

O'Donoghue, J., L. Goulding, and G. Allen (2004), "Consumer Price Inflation since 1750." *Economic Trends* 604: 38-46.

Officer, L.H. and S.H. Williamson (2020), "The Annual Consumer Price Index for the United States, 1774-Present." http://www.measuringworth.com/uscpi/

The underlying sources for the nominal freight rate data are as follows:

Andrews, F. (1907), "Ocean Freight Rates and the Conditions Affecting Them." *USDA Bureau of Statistics Bulletin no. 67*. Washington: GPO.

Angier, E.A.V. (1920), *Fifty Years' Freights 1869-1919*. London: Fairplay.

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United Nations, *Review of Maritime Transport*, various issues.
Vierteljahreshefte zur Statistik, various issues.

World mercantile gross tonnage

The changes in world mercantile gross tonnage from 1880 depicted in Figure 5 were primarily derived from the world fleet statistics website administered by the Lloyd's Register Foundation: https://hec.lrfoundation.org.uk/archive-library/world-fleet-statistics

In particular, this series is based on figures for vessels of 100 gross tons and larger. Unfortunately, no equivalent figures for the period prior to 1879 are available (although Lloyd's does provide information on registered ships in the British Empire back to 1761 and fragmentary evidence on worldwide tonnage back to 1864).

There are also a few significant gaps in the numbers reported on the website related to the World Wars. In particular, the series is missing observations from 1917 to 1918 and from 1940 to 1946. For 1917 and 1918, changes in gross tonnage were taken from Table A2 of Klovland (2017). For 1940 to 1946, changes in gross tonnage were made proportionate to estimates of wartime construction of Liberty ships and destruction of worldwide tonnage reported on the world fleet statistics website.

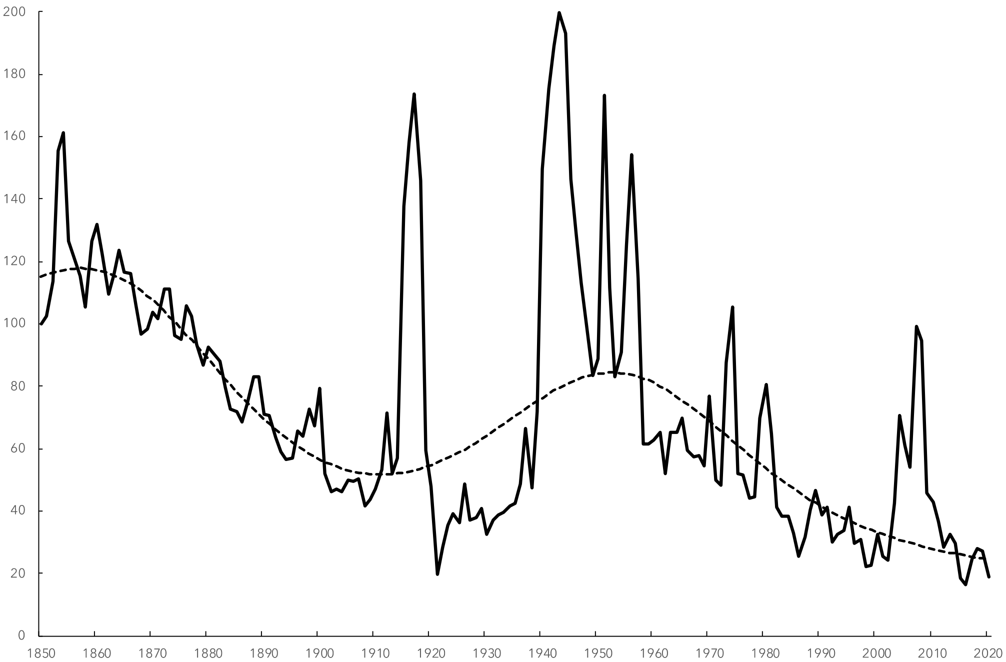
After 1999, the Lloyd's numbers are extended by using data reported by UNCTAD (2020): https://unctadstat.unctad.org/wds/TableViewer/tableView.aspx?ReportId=93

Table 1: Composition of dry bulk freight rate data

Currencies	British Pound	84.7%
	US Dollar	15.3%
Destinations (top 5 only)	United Kingdom	30.2%
	NW Europe	12.8%
	Egypt	6.3%
	Italy	5.2%
	Netherlands	4.4%
Goods (top 5 only)	Coal	41.6%
	Grains	40.1%
	Ore	9.3%
	Fertilizer	3.9%
	Seeds	3.1%
Origins (top 5 only)	United Kingdom	36.5%
	United States	18.1%
	Russia	4.2%
	Brazil	3.7%
	Australia	3.7%
Total observation count		10,448

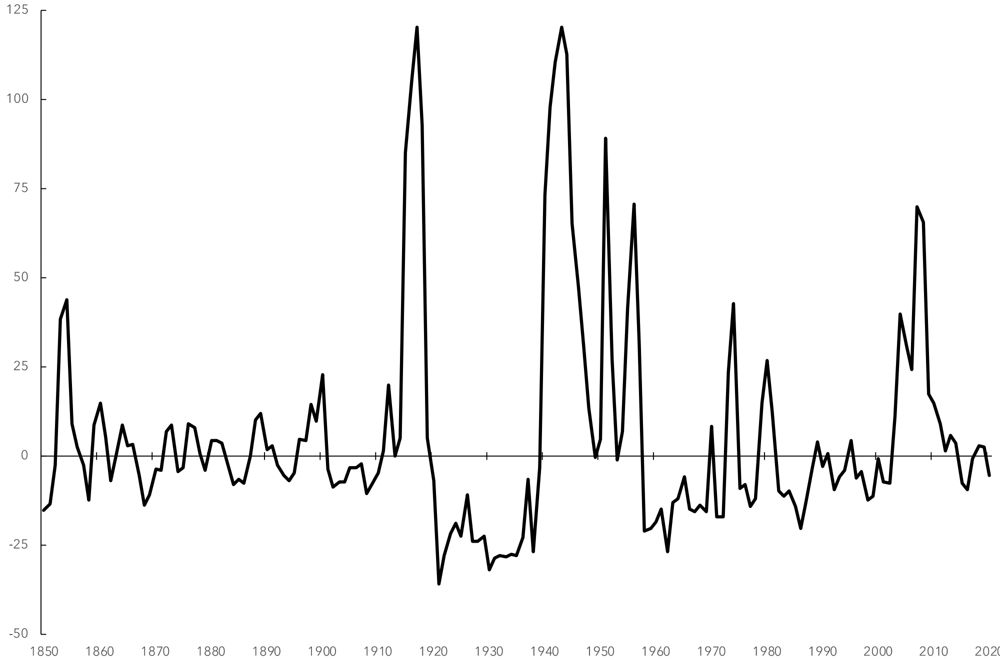
Notes: For presentation purposes only, individual observations have been aggregated up into destination/origin groups by country (e.g. London into UK) and into goods group by commodity (e.g. wheat into Grains).

Figure 1: Real Dry Bulk Index, 1850-2020 (1850=100)



Notes: The solid black line represents the real dry bulk freight rate index, constructed as described in the text. The dotted black line is an estimate of the long-run trend derived from the Christiano-Fitzgerald band pass filter which assumes a cyclical component of 70 years duration in the real dry bulk freight rate index.

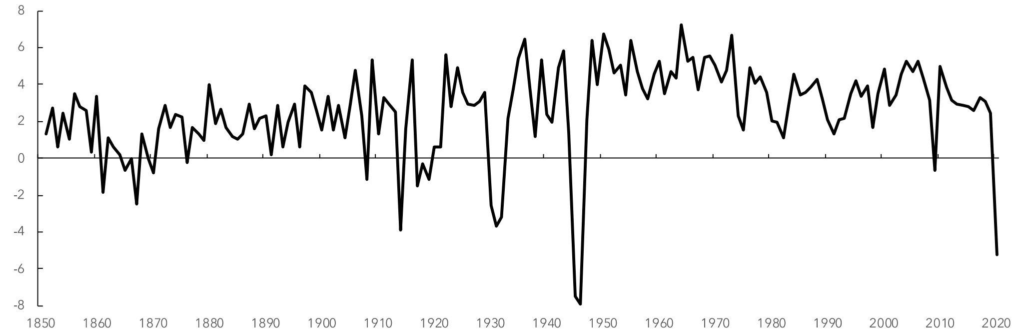
Figure 2: Real Dry Bulk Index, de-trended, 1850-2020



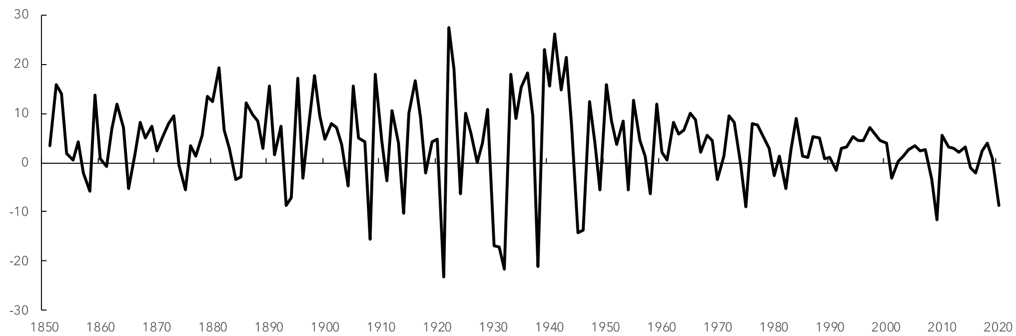
Notes: The solid black line represents the observed deviation of the real dry bulk freight rate index from the estimated long-run trend depicted in Figure 1.

Figure 3: Changes in Global Economic Activity (in percent)

Panel A: Real World GDP, 1850-2020



Panel B: US Industrial Production, 1850-2020



Panel C: OECD+6 Industrial Production, 1958-2020

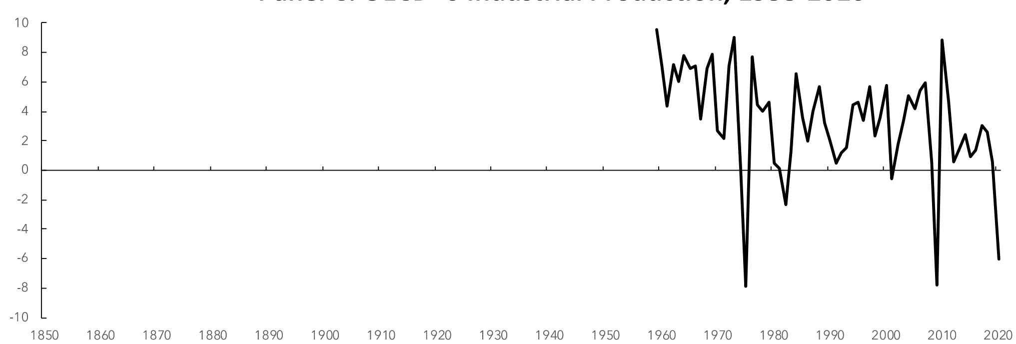
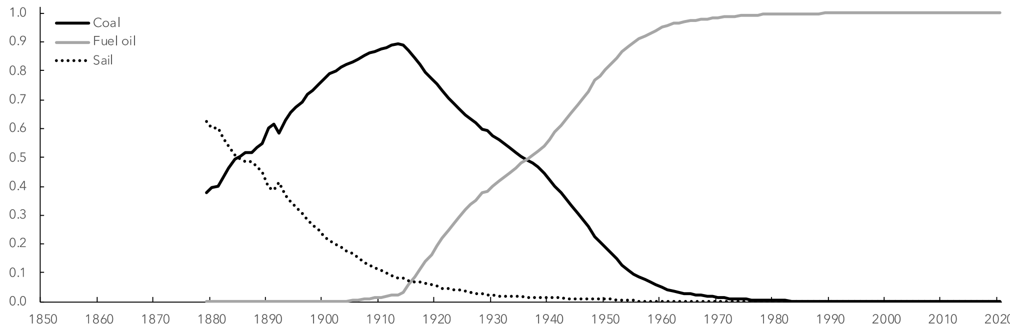


Figure 4: Real Fuel Prices for Shipping

Panel A: Share of World Mercantile Tonnage by Fuel Type, 1879-2020



Panel B: Real Fuel Price Index with sail (in logs), 1879-2020

Panel C: Real Fuel Price Index without sail (in logs), 1879-2020

Figure 5: Changes in World Mercantile Gross Tonnage (in percent), 1880-2020

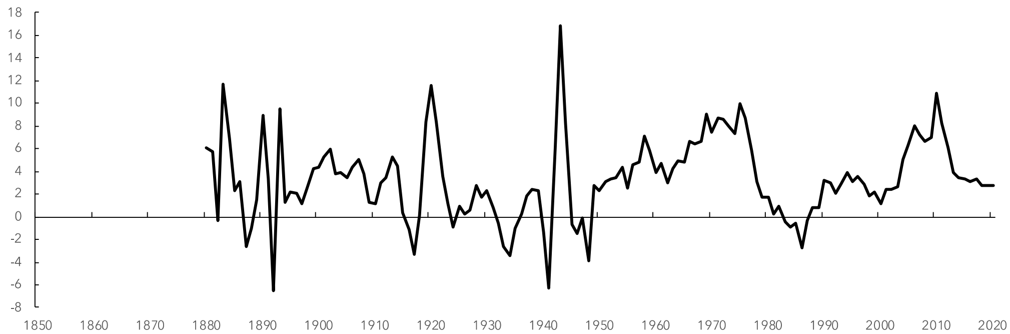
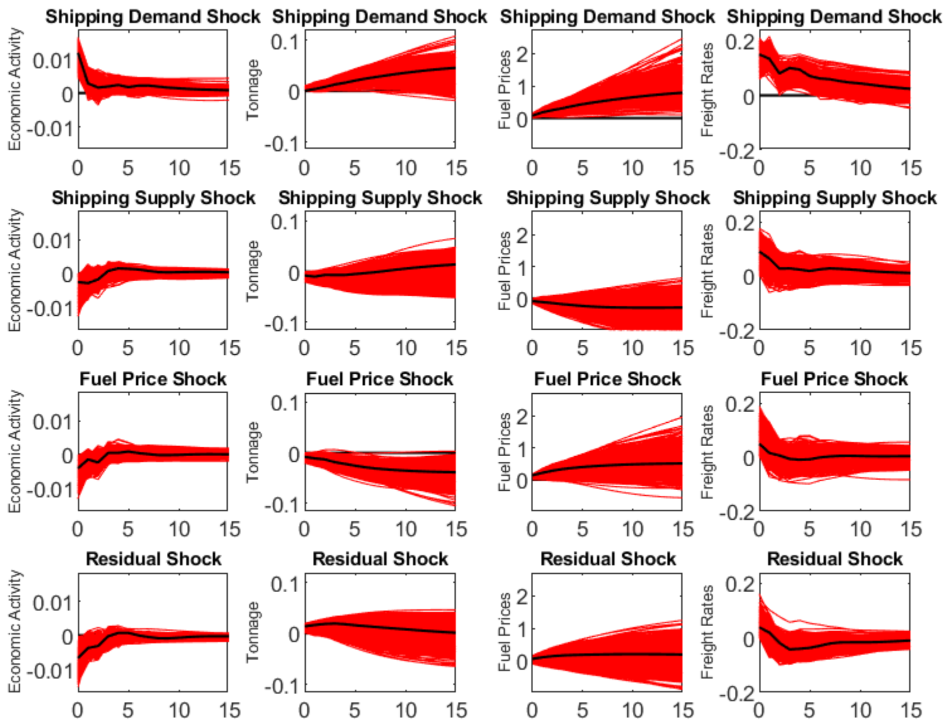


Table 2: Sign Restrictions in the Structural VAR Model

	Global Real GDP	Mercantile Tonnage	Real Fuel Price Index	Real Dry Bulk Index
Shipping demand shock	+	+	+	+
Shipping supply shock	–	–	–	+
Fuel price shock	–	–	+	+
Residual shock	–	+		+

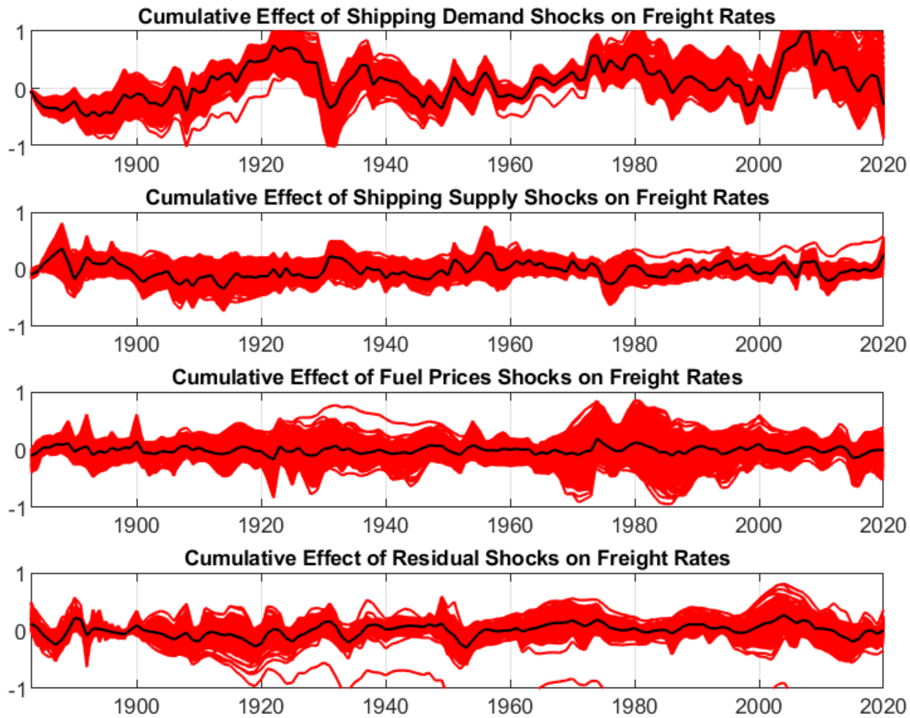
Notes: Table 2 summarizes the sign restrictions imposed on the responses of the endogenous variables to the four shocks in the structural VAR model. All structural shocks have been normalized to imply an increase in the real dry bulk index. A missing entry (as in the fourth row) means that no sign restriction is imposed.

Figure 6: Impulse Response Functions for Four Shocks on the Real Dry Bulk Index



Notes: The chart shows the impulse responses from the 68% joint highest posterior density sets obtained from the posterior distribution of the structural models. The impulse responses implied by the most likely structural model (modal model) are depicted in black. Impulse responses are normalized such that each shock has a positive effect on freight rates. Details of their construction can be found in Inoue and Kilian (2013, 2019). The results shown are based on 5,000 draws from the reduced-form posterior distribution with 20,000 draws of the rotation matrix each.

Figure 7: Historical Decompositions of Real Freight Rates



Notes: The chart shows the historical decompositions from the 68% joint highest posterior density sets obtained from the posterior distribution of the structural models as in Inoue and Kilian (2013, 2019). The cumulative effects implied by the most likely structural model (modal model) are depicted in black. The results shown are based on 5,000 draws from the reduced-form posterior distribution with 20,000 draws of the rotation matrix each.

Table 3: Shares of Shocks in Explaining Booms and Busts in Freight Rates by Period

	Shipping demand shock	Shipping supply shock	Fuel price shock	Residual shock
Full sample: 1880-2020	49%	22%	11%	18%
Pre-World War I: 1880-1913	44%	29%	11%	16%
Interwar: 1919-1939	56%	17%	8%	19%
Post-World War II: 1949-2020	50%	20%	11%	18%

Notes: Table 3 reports the share of variation in the real dry bulk index explained by the four structural shocks for the entire period from 1880 to 2020 and three sub-periods.

Table 4: Shares of Shocks by Period, Alternative Specifications

BENCHMARK	Shipping demand shock	Shipping supply shock	Fuel price shock	Residual shock
Full sample: 1880-2020	49%	22%	11%	18%
Pre-World War I: 1880-1913	44%	29%	11%	16%
Interwar: 1919-1939	56%	17%	8%	19%
Post-World War II: 1949-2020	50%	20%	11%	18%
With US IP	Shipping demand shock	Shipping supply shock	Fuel price shock	Residual shock
Full sample: 1880-2020	31%	35%	15%	20%
Pre-World War I: 1880-1913	28%	41%	12%	18%
Interwar: 1919-1939	43%	26%	12%	19%
Post-World War II: 1949-2020	28%	33%	17%	21%
With OECD+6 IP	Shipping demand shock	Shipping supply shock	Fuel price shock	Residual shock
Full sample: 1880-2020	-	-	-	-
Pre-World War I: 1880-1913	-	-	-	-
Interwar: 1919-1939	-	-	-	-
Post-World War II: 1958-2020	41%	21%	25%	13%
Without sail in fuel prices	Shipping demand shock	Shipping supply shock	Fuel price shock	Residual shock
Full sample: 1880-2020	43%	24%	12%	21%
Pre-World War I: 1880-1913	34%	31%	12%	23%
Interwar: 1919-1939	51%	20%	8%	20%
Post-World War II: 1949-2020	45%	22%	13%	20%

Notes: Table 4 reports the share of variation in the real dry bulk index explained by the four structural shocks for the entire period from 1880 to 2020 and three sub-periods across four potential specifications.