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HOW FAR GOODS TRAVEL:
GLOBAL TRANSPORT AND SUPPLY CHAINS FROM 1965-2020

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ABSTRACT

This paper considers the evolution of global transportation usage over the past half century and its implications for supply chains. Transportation usage per unit of real output has more than doubled as costs decreased by a third. Participation of emerging economies in world trade and longer-distance trade between countries contribute to this usage increase, thereby encouraging longer supply chains. We discuss technological advances over this period, and their interactions with endogenous responses from transportation costs and supply chain linkages. Supply chains involving more countries and longer distances are reflective of reliable and efficient transportation, but are also more exposed to disruptions, highlighting the importance of considering the interconnectedness of transportation and supply chains in policymaking and future work.

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The integration of countries and industries into global supply chains depends on cheap and efficient transport. We show the evolution of transport use and costs over the last 55 years, and establish their implications for international trade and global supply chains. To set the stage, consider a concrete example: the change in the manufacture of telephones from a century ago to the present day.

Built in 1905, the Western Electric Hawthorne Works factory in the Chicago suburb of Cicero, Illinois, manufactured 43,000 varieties of telephone apparatus for the parent Bell telephone monopoly (Weber 2002; Lantz 2014). It employed 40,000 people who worked in over 100 buildings. Even with a transcontinental railroad system, transport costs were substantial and excessive back-and-forth transport links were not common. As such, while this factory did source a few raw materials like Bakelite, rubber, and metal from remote locations, it manufactured many intermediate components internally— such as vacuum tubes in the early days and transistors later—before distributing finished telephone equipment across the country. This manufacturing complex effectively made handsets in a single location for the entire United States.

The factory operated until 1986, and large portions of the grounds were dynamited in 1994 to build a suburban shopping complex (Pelton 1994). In the age of globalization and low transport costs, a vertically integrated factory in a high-cost location no longer made financial sense.

The supply chain for the modern smartphone is quite different. The research and design activities for Apple's iPhone take place in the United States, with further engineering in the United States and Taiwan (including within its largest partner, Foxconn). Production directly involves 43 countries in six continents in addition to any further upstream manufacturers; key components are manufactured in Japan, Korea, Taiwan, and China, with final assembly in China and India (Dedrick and Kraemer 2017, Petrova 2018). Apple's direct subcontractors do not manufacture many of the components used and only assemble the final product before shipment around the world. With the exact mix depending on the model, components such as memory, microprocessors, optics, batteries, and screens are manufactured in both nearby Asian countries like South Korea, Taiwan, Japan, Malaysia, Vietnam, or even in the United States, Mexico, or European Union.

The supply chain for Apple's iPhone is not unusual. In Samsung's smartphone production process, design takes place in South Korea, manufacture of key components takes place in South Korea, Japan, and the United States, while the final assembly takes place in Korea, Vietnam, China, India, Brazil, and Indonesia (Dedrick and Kraemer 2017). These locations are connected by frequent and reliable shipping networks. The expansive use of global networks by companies like Apple and Samsung is a function of declining transportation costs (Hummels 2007). In 1890 it cost nearly $200 per ton (in 2020 dollars) to ship goods from California to Europe. A century later, the cost would be less than $2 per ton using a standard bulk ship (Harley 1988).

In this essay, we first set the stage with some facts and patterns. We document the dramatic rise in global transport use from 1965 to 2020, as measured either by weight in ton-kilometers traveled as is standard in the transportation literature, or by value in dollar-kilometers as is standard in the trade literature. After accounting for economic growth, real transport use per unit of final consumption has more than doubled over this period, increasing by 100% and 160% by weight and value respectively. We also document that while real transport use by weight continued increasing after the 2007 Great Recession, real transport use by value has substantially declined. Second, we establish trends on global transport costs and show that they have declined over the last half century by 33-39 percent and 48-62 percent, by weight and value respectively. Third, we consider the factors that contributed to the transport use increase, especially the participation of emerging economies; in particular, since 1990, China accounted for the entirety of the relative global transport use increase by weight. More generally, trade over longer distances, more than 5,000 km, accounts for most of the transport use increase, compared to shorter distance trade. Transport use increases by weight are also driven by natural resources and raw materials, while downstream manufactured goods drive the increase by value. Fourth, we consider some key technology and infrastructure changes which contributed to these changes, including container and jet airplane technology, economies of scale in shipping, and innovations in logistics management like "just-in-time" deliveries.

2 Transport Use Over Time

World trade has exploded since the end of World War II, accounting for an increasing share of production and consumption. The World Trade Organization reports that 2021 world trade is 43 times larger in volume in 2021 than in 1950 (World Trade Organization 2023).

We examine this increase in global trade and its link to increases in the use of global transport services—to not only ship more goods, but to ship them further as well. Specifically, we can think of the use of transportation services as primarily consisting of two components: the amount of goods that are transported, and how far these goods are transported (see Equation (1) in the Appendix A for details).

The first component, international trade flows, is captured using conventional trade statistics. The second component is important to incorporate as goods that are shipped further require more transportation services. This transport use measure captures what is often missing in traditional trade measures—the role of distance. If trade increases, but only between nearby countries, then the transportation use increase will be mostly driven by the first component—trade flows. But if trade between distant locations increases, then both components contributing to transportation needs will increase. Including distance directly captures transport use.

We measure transportation usage in two ways. The first method uses the *weight* of transported goods, multiplied by the distance travelled. Most transportation costs are primarily priced in either weight or volume (Hummels and Skiba 2004; Irarrazabal, Moxnes, and Opromolla 2015; Wong 2022). Bulk cargo transport costs are typically measured in tons, while containers are priced by volume as measured in "twenty-foot equivalent" units or TEUs. This weight-based measure is more reflective of goods with lower value-per-weight ratios, such as grain, coal, ore, or petroleum products. The second method uses the *value* of goods multiplied by the distance travelled. This value measure places emphasis on the transport of goods with higher value-per-weight, like machinery, automobiles, and electronics. In both measures, multiplying by distance gives a better sense of transportation use, which is often missing in traditional trade measures that sum exports and imports.

In Figure 1, the top two panels demonstrate that international transportation usage has increased from 1965 to 2020. We use all trade between origin and destination for 200 countries, measured in tons and in dollars (converted to 2000 US dollars), based on the NBER-UN Comtrade and CEPII BACI databases (Feenstra et al. 2005; Gaulier and Zignago 2010, Conte et al. 2021). For distance between countries, we use the population-weighted as-the-crow-flies distance as an approximation since we do not observe the specific route or transportation of goods.[1]

Insert Figure 1

Figure 1a shows that transport usage by weight increased more than ten-fold, from about 7.1 trillion ton-kilometers in 1965 to about 78 trillion ton-kilometers in 2020. Figure 1b shows a 14-fold increase when measuring transport use in value terms. From 4,000 trillion dollar-kilometers in 1965 to 67,000 trillion dollar-km in 2011, and a modest decline to 57,000 trillion dollar-km in 2020.

The two trends mirror each other from 1965 to the Great Recession. After 2008, the weight measure of transport usage (in ton-kilometers) continues its rapid growth, but trade use as measured in dollar-kilometers declines. Potential explanations include less trade of higher value-to-weight goods, and shorter transport distances of these goods. We will revisit the diverging trends in transport usage by weight and value later.

We could employ more direct measures of transportation use, but such measures are often only available for subsets of countries, for shorter time periods, and for specific modes of transportation. As an example, available Census Bureau trade data that breaks down non-NAFTA US imports and exports by air, ocean, and containers only starts in 1992. Similarly detailed data is not available for most other countries. Our approach allows us to measure

[1] As-the-crow-files distance is also known as the "great circle" or haversine distance. Some caveats are worth noting. While data on the value of trade is available over our entire sample period, weight data is only widely available after 2000. We impute the weight from prices using WIOD price index data and BACI price/weight data from 1995-2000. For natural resources from 1970-1985, data from the US Energy Information Administration (EIA) and the Organization of the Petroleum Exporting Countries (OPEC) are used to impute weights from prices. Full data details are in the appendix.

transportation use for more broadly—for 200 countries—and over a much longer period—55 years.

Since the world economy is growing rapidly during this time, we next account for this growth by normalizing total transportation usage by real global GDP (see Equation (2) in Appendix A). By normalizing relative to final output (as measured in GDP), this real transport use also captures the cumulative distance traveled by intermediate inputs in production, in addition to the distance traveled by the final good to its ultimate destination for consumption.

Returning to the telephone handset example, when calculating its real transport use in 1965, we simply include the distance travelled for raw materials from Asia, South and Central America to the US for use in intermediate input production at the Western Electric Factory. Subsequent final assembly all happens at the same location and adds no further distance in terms of international trade (Western Electric, 1938).

Today, with smartphones such as Apple's iPhone, raw materials from Brazil and Africa get shipped to Vietnam and the European Union to be made into plastic and silicon, which are then sent to Taiwan and South Korea to be manufactured into memory modules. These modules, along with a variety of other components, such as microprocessors and LCD screens, are then combined in India and China for products that are shipped globally for final consumption. Everything is shipped around the world, both low weight-to-value raw materials and high weight-to-value final assemblies (Dedrick and Kraemer 2017). Real transport use for smartphones is much higher compared to the telephone handset due to its production process taking place in many more countries, and both the raw materials and final assemblies being transported much further distances. By normalizing transport use relative to real global GDP, we can show the transport use changes after accounting for the growing world economy over this period.

As shown in Figure 1c, our measure of real transport use in weight has more than doubled over the past 50 years, from 0.67 ton-kilometer per dollar of real GDP in 1965 to 1.35 ton-kilometer per dollar of real GDP in 2020. As previously mentioned, the weight-based measure of trade is more reflective of the transport of raw materials. When using value measures in Figure 1d, this increase in normalized transport use is even larger than the weight measure—tripling from 1965 to 2007, before declining nearly 20 percent from the peak. As mentioned previously, this value measure is a closer approximation for the transport of final goods. More telephones are traded globally today than yesterday. In both bottom panels, transport use is increasing above and beyond the growth in the world economy.

We now compare our measures of transportation usage to conventional trade statistics. In Figure 2, we plot our two normalized transportation usage measures in weight-distance and value-distance from the bottom panels of Figure 1 against the growth of more conventional trade measures, trade values and trade weights as a share of global output.[2] The more conventional trade measures do not account for distance, and so this comparison allows us to highlight the role of distance over this period—are more goods being shipped to countries that are further apart?

Insert Figure 2

We emphasize three themes that emerge. First, when trade is measured by value, the growth of normalized transport usage in dollar-distance (gray dashed line) echoes the growth of trade value as share of global output (orange triangles)—more than tripling by 2007 relative to 1965, before decreasing after the Great Recession (Eaton et al. 2016). From 1965 to 2020, trade has increased by 2.5 times. In value, goods are being shipped more to both nearby and distant locations.

Second, when trade is measured by weight, the growth of normalized transport usage in weight-distance (black solid line) is quite different from with the growth of trade weight as a share of global output (green squares). These two series diverge early in our sample period. As mentioned before, transport usage in weight-distance steadily increases at a slower rate and more than doubles by 2020 (compared to the dollar-distance measure). However, as a share of the global economy, the aggregate amount of tonnage shipped has stayed relatively constant from 1965 to 2020 at around 0.24 to 0.26 shipped tons per $1,000 of real world GDP. Relative to the global economy, nations are not trading significantly more goods by weight. However, when nations do trade these goods, they are transported over increasingly further distances.

Third, the growth in our normalized trade statistics using ton-kilometer and dollar-kilometer parallel each other until 1990. After 1990, the growth in the normalized value measure accelerates through 2007 and then subsequently collapses. Meanwhile, growth in the normalized weight measure of trade continues to rise steadily throughout this period, largely unaffected by the 2008 recession.

In the last decade or so, nations have cut back purchasing higher value-to-weight goods like electronics – including devices such as Apple iPhones - relative to overall consumption, but trade in lower value-to-weight goods, which are more reflective of raw materials like coal or oil, continue to grow.

These points highlight a central tension at the intersection of the two fields of transportation and international trade. With some important exceptions, transport costs are typically treated as exogenous in the trade literature—approximated by distance empirically and by the "iceberg" functional form, where the value of shipped goods decreases ("melts") with distance. Trade also typically focuses on the value of trade flows, not on weight. However, while the collapse of the conventional measure of trade by value

[2] We can follow Johnson and Noguera (2012) to re-frame the value portion as value added. This dampens growth by 10-25 percent but does not alter the qualitative features of the comparison.

following the Great Recession is clearly visible in Figure 2, the measure of transportation usage by weight and distance barely changes. Even the costs of shipping actual icebergs are not well approximated by the "iceberg" functional form (Bosker and Buringh 2020). In contrast, in transportation economics the pricing structure is often at the per-unit level—for example, cost per ton or per container of goods. These transport prices/costs are equilibrium outcomes, jointly determined with trade and transport use. Both the assumptions of exogeneity and iceberg functional form, while providing tractability in most trade models, have nontrivial trade and welfare implications. We see bridging both literatures as a fruitful area for research.

3 Transport Costs Over Time

How have the costs of global trade evolved? Data limitations make this question tricky to answer. While aggregate data on transportation expenditures is widely available, such data is rarely differentiated by whether the expenditures are for domestic or international trade. Additionally, while data on the value of internal trade flows are available for a subset of countries, data on distances covered internally are hard to come by—especially over our extended period.[3]

We describe a method of using total expenditures in the transportation sector—based on national accounting and aggregate industry data—to recover an upper and a lower bound for a price to ship either a ton or real dollar of goods for one kilometer. Our approach begins with the sum of all global transportation costs for a given year, divided by one of our measures of trade use for that year— either tons of trade or value of trade, multiplied by distance (see Equation (3) in Appendix A).

We first construct a cost estimate where all aggregate transportation spending was on international trade. Because we are dividing total transportation spending by international transport use, this approach effectively calculates an upper bound on the time trend of international trade costs.

For our lower-bound estimate, we include both international and domestic transport. We approximate domestic transport by assuming that the internal distance transported is unchanged over time. We consider this a lower bound for international trade costs, based on the assumption that while internal trade distances may have increased, these distances may increase at a slower rate than international trade distances. For this assumption, our sample is restricted to 24 countries with complete data over our time period from the

[3] While domestic transport and distribution costs are not our focus here, they can be nontrivial. Anderson and Van Wincoop (2004) estimates that domestic distribution cost can be 55 percent of producer prices, more than twice the international transport costs (Echoed in India by Van Leemput (2021)). Atkin and Donaldson (2015) show that intranational trade costs can be especially high in developing countries: 4 times larger in Nigeria than in the United States.

World Input-Output Database (WIOD) database (Timmer et al 2015, see appendix for details and caveats). For our measure of the distance of internal domestic trade, we use the population-weighed as-the-crow-flies internal distance between jurisdictions (like US states), from the CEPII gravity database, multiplied by the gross value of internal trade.

Our estimates, illustrated by Figure 3, show that show that global transport costs have substantially decreased from 1965 to 2014, reflecting large productivity increases and technological advances. The aggregate weight-based measure of transportation costs from 1970 to 2014 has fallen by 33-39 percent. Value based measures have fallen by 48-62 percent.

Insert Figure 3

Although measures of transport costs of goods by value and weight both show a downward trend, they provide different perspectives. The cost to transport one ton of goods for one kilometer decreased by about 35 percent over this period (gray dotted lines, Figure 3). This trend exhibits significant volatility from 1975-1985, reflecting in large part increases in the price of oil due to OPEC supply restrictions. Additionally, the cost of transporting a dollar's worth of goods for one kilometer has decreased by over 50 percent (red solid lines, Figure 3). This declining trend for a dollar of good means that this cost decline does not just apply to bulky goods, but also all transported goods. In short, the transport cost trends with trade use measured in dollars decrease faster than when trade is measured by weights.

This finding is generally consistent with Hummels (2007) in this journal, who documents a dramatic decline in transportation costs from 1950 to 2007 using direct data on prices paid for a consistent set of transportation modes, and highlights difference in quality and the endogenous selection of different modes of transport. It also lines up with Harrigan (2010) which finds that cheaper airfreight and containerization allows for the shipment of higher value goods, while ocean bulk freight rates show less price movement.

Given that transport costs have fallen but the global economy is using more transport services, one natural question to ask is whether aggregate spending on transport services risen or fallen. We calculate global transport spending as a share of total gross output using the WIOD databases. The expenditure share on transport for these countries have mostly stayed constant: started around 4 percent in 1965 and increased to more than 4.7 percent by 1995, before declining back to 3.8 percent in 2015 (Appendix Figure A1).[4]

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[4] Using theory-based measures of aggregate trade costs that include all frictions to trade (as opposed to our accounting-based measure), Novy (2013) finds that US trade costs declined by about 40 percent between 1970 and 2000 while Jacks, Meissner, and Novy (2011) find a decrease of 16 percent from 1950-2000. In value-added terms, Redding and Turner (2015) show that US domestic transportation fell since 1965 from 4 percent to 3 percent of GDP: however, due to the nature of global shipping, this may be mis-attributed. The US economy may have simply outsourced some of its transportation costs.

The utilization of transport services is an equilibrium response to the cost of transport. One likely outcome is that these decreases in transport costs will alter the terms of the classic proximity-concentration trade-off: firms can either choose to expand production horizontally across borders to maximize proximity to foreign customers, or instead they can concentrate their production in one location in order to benefit from scale economies and instead export to these foreign destinations. There is little evidence that firms have sought the former—to maximize proximity to foreign users.

Echoing our introductory case study, telephone manufacturers are no longer located close to their customers, firms have expanded and even fragmented their production supply chains, altering the geographic location of economic activity (Antràs and Chor 2022; Redding 2022). Others have relied on lower transportation costs to expand exports: for example, using data on US multinational corporations, Brainard (1997) finds that as transport costs decrease multinationals exports outstrips overseas production. Helpman, Melitz, and Yeaple (2004) finds the same empirical pattern in a less developed countries.[5]

Finally, it is worth noting that transportation costs are not the only costs involved in trade. Indeed, direct transportation costs are a limited portion of overall distribution costs (Anderson and Van Wincoop 2004; Burstein, Neves, and Rebelo 2003), with wholesaling (Ganapati 2018; Chatterjee 2019) and retailing margins up to 50 percent. There are also costs of holding inventories, and costs of time spent in the transportation process. When Head and Mayer (2013) attempt to line up trade costs with transportation and freight costs with the costs implied in standard trade models, they find that 50-90 percent of trade costs are generally unobserved. We will return to some of these issues later in discussions of the air and container freight, along trade facilitation and inventory-holding behavior.

4 What Main Factors Have Contributed to Rising Transport Use?

What has contributed to the dramatic increases in transportation usage since 1965 as costs fell? We focus on three factors: (1) increasing participation of emerging economies in global trade, in particular China, (2) increasing trade between countries that are further apart, and (3) shifts in the composition of traded goods—natural resources, which are more upstream in supply chains, versus manufactured goods, which are more downstream.

4.1 Rise of Emerging Economies and China

Developing countries have increasing their participation in world trade, accounting for about 40 percent of world exports in 2020 (UNCTAD 2022), but as one might expect, China is one of the driving force behind this change.

We recomputed our earlier measures of transportation use by weight and distance, and by value and distance. For purposes of a rough comparison, we simply exclude both incoming

[5] Bernard et al. (2020) find firms offshore only low quality products, products with lower price-to-weight ratios (and echoed in Lashkaripour (2020)).

and outgoing trade with China in the numerator, as well as excluding Chinese GDP from world GDP in the denominator (see notes in Figure 4 for details). This metric is akin to considering world trade without China, and not trying to model the many other consequences to international trade that would surely occur. We just assume that trade with China vanishes, along with Chinese GDP vanishing.[6]

We first consider the role of China in real transportation usage considering the ton-kilometers of goods (Figure 4a). Between 1965 and the 1990s, transport usage with and without China is relatively similar. In 1965, $1 of real output represents 0.67 ton-kilometers of transportation usage and 0.68 ton-kilometers without China. By 1990, both the global average and the average without China, rose to 1.06 and 1.10 ton-km respectively for $1 of output. At this point the two trends diverge. By 2020, the global average with China had increased by 28 percent since 1990, but the average excluding China had instead fallen by 9 percent. By the weight of goods, the growth of post-1990 transportation usage largely reflects the growth of China—to the near exclusion of many other trends.

Insert Figure 4

Considering the value-based measure of trade, the dollar-distance trends with and without China mostly increase in tandem (Figure 4b), although we do see a divergence starting in 1990 that is much smaller and slower than the weight-distance trend. By 2007, the distance traveled for $1 of final good consumption was 1165 dollar-km, while the number without China was 976 dollar-km. Following the great recession, both numbers, with and without China faced a similar decline to 1049 dollar-km and 853 dollar-km respectively.

China's growth trajectory offers one reason for these differential trends. In 1990, China was importing and exporting raw materials and other similar low-value, high-weight products. These trends continued through the Great Recession, especially to and from China. However, China also started exported and importing high-value, low-weight goods, including large volumes of electronic components and smartphones. Trade in these goods, in China as in the rest of the world, leveled off following 2007. The collapse in value-based measures of trade after 2007 is not a China-specific trend (Baldwin and Evenett 2009; Eaton et al. 2016). However, these high-value, low-weight goods may face changes in the proximity-concentration trade-off. As it becomes cheaper for those raw materials to be imported, production locations for these products may be more reflective of where final demand is located.[7]

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[6] A fuller experiment would be to embed China in a model that simultaneously computes both trade flows, as well as transportation usages, as in Ganapati, Wong, and Ziv (2021).

[7] Antràs et al (2012) finds that emerging economies play different roles in global supply chains. Bangladesh is one of the most downstream countries in terms of manufacturing since it exports apparel which are sold directly to end consumers while Tajikistan is one of the most upstream countries since it exports processed alumina.

4.2 Longer-Distance Trade

Most of the growth in real transport usage in terms of weight is due to a rise in longer-distance trade between countries that are further apart. Figure 5 breaks down our two metrics for real transportation usage from Figure 1c and 1d into three sub-components: shorter distance trade under 5,000 kilometers, medium distance trade from 5,000 to 10,000 kilometers, and long distance trade over 10,000 kilometers. The short distance bin, within 5,000km, typically includes country pairs that are in the same region (for example, countries within the East Asia region, the European Union, or North America). The medium distance bin (5,000-10,000km) typically includes Asian-European countries while the long distance bin includes Asia-North America countries. The transport use of all three distance bins adds up to the aggregate transport use measure previously presented in Figure 1.

Insert Figure 5

In 1965, all three distance bins account for rough similar amounts of transport usage by weight (Figure 5a). But since the mid-1980s, the transport use by countries that are further apart increases by much more than the short-distance countries. Overall, short-distance countries increase their transport use in weight by 45 percent from 1965 to 2020, while longer-distance countries more than doubled their transport use—medium-distance countries increased by 114 percent and long-distance countries by 129 percent. Digging into the underlying data, much of the increase stems from raw material shipments, often originating from OPEC countries, Australia, and Brazil. These raw materials are often bound for processing and usage in distant locations, especially China.

When considering the transportation usage in value, Figure 5b highlights a different story. There are large increases across all three distances. Shipments for short-distances increased by 211 percent, medium-distances by 134 percent, and long-distances by 170 percent. The rough similarity of these trends highlights the near identical growth paths of trade value and transport use by value in Figure 2 over our period.

Overall, while heavier and lower value goods are being traded between countries that are further apart, lighter and higher value goods are being traded between locations that are both nearby and far apart. While the raw materials to make phone components are travelling even farther than before, so are the final smartphones themselves.

4.3 Composition of Trade

What types of goods have contributed most to the rise of transportation usage over the past 50 years—and where are these goods on the value chain? We study the how the composition of trade has contributed to transport use over this period by highlighting the role of raw materials—that is, agricultural and natural resource products—relative to manufactured goods in Figure 6.

Insert Figure 6

Figure 6a shows that while raw materials make up a higher share of aggregate transport use by weight throughout this period (accounting for 66 percent of the weight-distance measure in 2020), both raw materials and manufactured goods equally contributed to the growth from 1965 to the early 2000s. Since 2000, however, manufactured goods no longer contribute to the growth in ton-kilometers. Instead, all growth is due to raw materials.

Revisiting our phone example, raw materials have been essential since the early days of telephone manufacturing. Even though all US telephones were essentially manufactured in a single Western Electric factory, the manufacturing process still required 34 different raw materials including metal ores, rubber, mica, silk, and cotton from countries including India, Indonesia, Brazil, Madagascar, Japan, and China (Western Electric, 1938). These raw materials play a central role in manufacturing and have relatively high weight-to-value ratios values—contributing more to weight-based measures of transport use.

Considering value-distance of shipped goods in Figure 6b, we find very different results: the increase in transport use by value over this period are entirely driven by manufactured goods. While manufactured goods transport use grew 135 percent, raw materials grew by just 6 percent. Even though raw materials are a required input in much of economic production, as reflected by their dominance of transportation usage in ton-kilometers, they constitute a smaller and smaller share of total trade values. An assembled smartphone, even including packaging, may be under 250 grams taking up less than a liter of volume and has high value-to-weight ratio. The raw materials that are used in smartphone manufacturing, even though crucial, make up a small share of its final value.

Our finding that raw materials dominate the transport use growth by weight post-2000 (and in levels), but not value is consistent with Fally and Sayre (2018). While primary commodities—intensive in natural resources—only account for a modest 16 percent of world trade by value, these commodities are used as inputs into all production processes, are difficult to find substitutes for, and can be supplied by only a few countries. As the world economy grows, these raw materials are shipped farther distances (echoed in Berthelon and Freund (2008)). As trade costs fall, Antràs and De Gortari (2020) show that locating downstream production close to consumers is less important than for upstream production.

In Appendix A we replicate this analysis with final and intermediate goods and find qualitatively similar results (Appendix Figure A3).

5 Innovations and Implications for Supply Chains

We have established two main results so far. First, transport use has increased while transport costs have decreased over the past 50 years. Second, this increased demand for transportation is driven by emerging economies—especially China—participating in world trade, longer-distance trade between countries that are further apart, and differences at where products lie along the value chains. In this section, we consider the main drivers of changes in these international transport costs over the last five decades and their implications up and down supply chains.

We first highlight innovations in transport technology and infrastructure, especially in container and air shipping. We then outline developments in trade networks, trade facilitation, and investments in infrastructure. For an overview of the extensive literature that indirectly looks at the impacts of transport costs, we recommend Redding and Turner (2015).

5.1 Transport Technology Innovations: Container and Air Freight Shipping

Global trade is conducted using land, sea, and air. Transport costs have fallen across all three modes in the last 50 years (Ardelean et al. 2022). Two technologies have exhibited extraordinary cost decreases: containerized and air freight. Hummels (2007) documents that the cost of air transport fell more than 10 times between 1955-2004, and the container price index declined rapidly between 1985-2004. We focus on these innovations here.

Containerization refers to the standardization of a 40-foot-long reusable steel box that can be loaded onto purpose-built trains, trucks, and ships; easily transferring between various modes from origin to destination. After its introduction in 1956, almost 90 percent of countries had container-handling infrastructure by 1983 (Rua 2014), making the globalization of production possible (UNCTAD 2022).

Container ships offer a useful example of natural scale economies. The size of containerships has increased significantly over the years (Cullinane and Khanna 2000). Early container ships in the 1960s were modified bulk vessels, with capacities of 500 TEUs. By the start of the 1970s, the first ships dedicated to transporting containers were introduced with 2-4 times the capacities of their predecessors (Rodrigue 2020). By the end of our sample period in 2015, the largest containership built that year (the *MSC Oscar*) had a capacity 24 times the size of the first containerships—19,000 TEUs and nearly as long as four football fields laid end-to-end. To put the capacity of this ship in perspective, it can carry 39,000 cars, 117 million pairs of sneakers, or more than 900 million cans of dog food (Stromberg 2015).

While the total capacity of the containerized fleet capacity increased eight times from 1996-2021, the number of containerships only increased by three-fold (Ardelean et al. 2022). As crew size and fuel costs do not increase proportionally with ship sizes, larger ships take advantage of the cost savings from larger capacities. In 2013, the CEO of shipping firm Maersk explained that their decision to build larger ships was due to saving $300 to $400 per container for a round trip between Asia and Europe—that is, a savings of $5-$7 million per trip (Milne 2013).[8]

Time can also be a highly valued characteristic of trade (Hummels and Schaur 2013), and reliable and frequent air transport networks have made it much easier to coordinate the production of sensitive products across global transport chains. Increased air connectivity

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[8] Of course, the extent to which scale economies are passed along to buyers will be affected by the extent of completion. In transportation, Hummels, Lugovskyy, and Skiba (2009) and Asturias (2020) show large effects of market entry on reducing prices in international shipping. Ignatenko (2021) and Ardelean and Lugovskyy (2020) considers the effects of competition on the extent of price discrimination.

has positive impacts on local economic activity including population and income (Blonigen and Cristea 2015), industrial activity (Redding, Sturm, and Wolf 2011), as well as business links (Campante and Yanagizawa-Drott 2018). Additionally, it can have indirect positive effects on trade (Cristea 2011; Poole 2016; Yilmazkuday and Yilmazkuday 2017). For an useful overview of the development of air freight, see Proctor, Machat, and Kodera (2010).

What kinds of goods are more likely to be transported by containers and air, and can we characterize where are they on the supply chain? The use of containerization by land- and sea-based transportation accounts for many of the differences in trends between weight-based and distance-based measures. Moreover, the nature of containerization implies high fixed costs and minimal marginal costs as highlighted by Coşar and Demir (2018). Because container cost is typically per-unit, Hummels and Skiba (2004) shows per-unit transactions cost lowers the relative price of, and raises the relative demand for, high-quality goods with higher unit values.

A general pattern arises. Between air, containers, and bulk shipments, goods that travel by air have the highest value-to-weight ratio, followed by containers, and then bulk shipments.[9] In the global shipping fleet, for example, ships that only carry bulk goods, including agriculture, natural resources, and refined petroleum products, account for over 75 percent of the global shipping fleet by tonnage. Container ships—the ships that carry significant amount of consumer goods—only account for 13 percent. In terms of tons loaded, containers account for less than 2 million tons laded—out of more than 10 million tons (UNCTAD 2021).

As goods move down the supply chain, their value-to-weight ratio rapidly changes. In our example, a smartphone such as an Apple iPhone may require tons of coal and oil to generate electricity, bauxite to create aluminum enclosures, lithium ore for batteries, and sand to make silicon. These raw materials have very low value-to-weight ratios and are transported via bulk shipping. As mentioned previously, an assembled smartphone however, has a much higher value-to-weight ratio, and is often transported via air.

As such, the technological improvements from containerization and air transport have revolutionized the shipment of high-value final goods and downstream manufactured products but have minimal impact on the trade of raw materials and upstream manufactured products which rely heavily on bulk transport. Recalling our earlier discussion (in Figure 3) that trade costs using dollars have fallen between 48-62 percent over the relevant time period, while trade costs using physical weight has only fallen 33-39 percent. Thus, trade costs have fallen more for higher value goods far down the value chain, and not as much for goods further upstream. Correspondingly, transport use from downstream manufactured goods (compared to raw materials) contributed disproportionally to transport use growth by value (Figure 6b).

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[9] We omit discussion of pipelines versus tankers. Pipelines offer cheaper shipping but are only built in response to high expected usage.

For raw materials and bulk shipments, the corresponding change is not a greater quantity shipped, but a greater distance shipped. Figure 6a further reinforces this point by showing that raw materials make up a higher aggregate share of transport use by weight over the past 50 years, and contribute to all of the increase in transport use by weight in the last two decades.

5.2 Endogenous Transport Costs

Transport costs are equilibrium outcomes jointly determined with trade and transport. Interdependencies in transportation technologies create networks and feedback loops which can magnify the cost-reducing of the underlying technological improvements to transportation. Improving access within trade networks, like the 2016 Panama Canal expansion, can generate multiplicative trade returns (Heiland et al. 2019). We highlight two examples of how transport costs can be endogenous and their implications for international trade: (1) country linkages within round-trip routes, and (2) hub-and-spoke network effects and scale economies.

Modern container technology was introduced in 1956, triggering complementary technological and logistical innovations that have revolutionized the transport industry and international trade (Bernhofen, El-Sahli, and Kneller 2016; Levinson 2016). Examples of complementary innovations include shipping capacity increases through larger ships, automated port infrastructure and delivery time reductions through unified logistic communication systems. Containerization also facilitated multimodal transportation—it's much easier to have a crane move a container from ship to rail or truck at ports (Fuchs and Wong 2022).

These innovations result in linkages between countries from round-tripping—container ships, trucks, and air transport have fixed schedules, like buses, going back and forth between large trading partners in a round trip. If trade of goods is flowing mostly in one direction, the "backhaul problem" arises of how to make use of transportation capacity for its return journal (Jonkeren et al. 2011; Tanaka and Tsubota 2016; Friedt and Wilson 2018) and can shape the location of economic activity in the presence of agglomeration (Behrens and Picard 2011). These back-and-forth dynamics can also create backfiring effects from protectionist policies when limits on trade in one direction lead to less capacity for trade flowing in the other direction (Hayakawa, Ishikawa, and Tarui 2020; Wong 2022).

Second, the trade network of container (and air) shipping is a hub and spoke system where majority of trade is shipped indirectly—the median shipment to the United States stops at two additional countries before its destination (Ganapati, Wong, and Ziv 2021). The majority of these additional countries are hubs, or entrepôts, that play important roles in consolidating goods from nearby countries into larger ships, taking advantage of scale economies, and also connecting countries to each other globally by allowing countries to ship indirectly via the network. Similar phenomena occur elsewhere. Bulk shippers transport goods directly, but often have to search for loading opportunities after delivering their cargo, generating network effects between neighboring countries (Brancaccio, Kalouptsidi, and Papageorgiou 2020).

Emerging economies like China and longer-distance trade have driven the increase in transport use in recent decades (Figures 4 and 5). Indirect trade via trade networks facilitates this increase—while larger developed or emerging countries can utilize larger ships due to their size, smaller countries that are more remote are also able to take advantage of the same scale economies from larger ships when their goods are routed through entrepôts (Ganapati, Wong, and Ziv 2021). The country-level connections within a round-trip further contributes to these linkages.

5.3 Trade Facilitation and Infrastructure Improvements

"Trade facilitation" refers to policies that lower administrative barriers to trade by streamlining administrative processes, like filing of shipment documents at border crossings, which in turn decreases the management cost of supply chains (see Carballo, Schaur, and Martincus 2018 for an overview).

Various estimates suggest that at least half of trade costs are not observed in the aggregate national statistics of transportation spending (Head and Mayer 2013; Feyrer 2021; Allen 2014). However, the logistics and transportation industry have no trouble naming costs that economists label as "missing". We highlight two: logistic management technology and the services of freight forwarders.

Better computing technology and efficiency in logistics allows companies to coordinate large volumes of shipments to different locations, port authorities to manage these shipments through their ports, or shipping carriers keep better track of containers on their ships. One prominent example is the introduction of the cargo booking documents systems called INTTRA in the early 2000s. It allows non-vessel owning carriers and freight forwarders (discussed in a moment) to book cargo and access voyage schedules. Another example is the introduction of the Society for Worldwide Interbank Financial Telecommunication (SWIFT) messaging system in the 1970s which allows for efficient and secure transfer of funds by banks between importers, exporters, and transportation intermediaries, lowering their financial transaction costs. For an overview of the logistics of international trade, see Talley and Riggs (2018) or Hesse and Rodrigue (2004).

Transportation intermediaries like freight forwarders are responsible for cargo pickup, documentation, transport, and delivery from the beginning to the end of the value chain (for an overview see Blum, Claro, and Horstmann 2018). Without these middlemen, a trader would have to coordinate multiple separate steps: transport from factory to port, ship to a destination port, clearing customs, and then transport from port to the final destination. With a freight forwarder, the exporter only has to interface with one company. Container technology has contributed to the growth of freight forwarders and large-scale services were offered starting in the early 1970s (UNCTAD 2021). By 2018, major container shipping lines who only provide port-to-port service have largely disappeared from the market. Such middlemen roles are not new, and in other settings they are instrumental in facilitating trade (See Ganapati 2018 and Grant and Startz 2022).

Improved tools for logistics, transportation intermediaries, and national policies to facilitate border crossings all work together to reduce the broader transportation costs experienced in international trade. As transport use continues to rise and trade between countries that are further apart continues to grow, investments in transportation infrastructure play an increasingly important role; indeed, the quality of transport infrastructure has been shown to be directly proportional to transport costs (Limao and Venables 2001). Port efficiency can play a major role in facilitating trade flows (for an overview, see Blonigen and Wilson 2018). Other infrastructure investments, including railroad networks, pipelines, and high-capacity expressways, can have large benefits and result in direct decreases on transport costs (Coșar and Demir 2016; Donaldson 2018; Fan, Lu, and Luo 2019). In the case of emerging economies, infrastructure improvements could have even larger welfare impacts (Asturias, García-Santana, and Ramos 2019; Bonadio 2021; Carballo et al. 2021).

5.4 Just-In-Time Production

The less expensive and more reliable international transportation linkages have helped to spawn greater use of just-in-time deliveries, also called "lean manufacturing," in which inputs are received from suppliers only as needed for the production process. The benefits claimed for just-in-time include smaller inventories, less waste, and continual two-way feedback between suppliers and buyers. Toyota offers most famous and well documented case, which significantly reduced warehouse and inventory costs (Moore 2010). This broader shift in business practice is also visible in US Census Bureau and Bureau of Economic of Analysis data. For example, in US manufacturing, the inventory-to-sales ratio was around 1.7 before 1990. Since then, there has been steady decrease in the amount of inventory that businesses hold—the average ratio is about 1.3 between 2000-2019. See Appendix Figure A4 and A5 for details.

6 Going Forward: Resiliency and Vulnerabilities

In the aftermath of the supply disruptions during the COVID-19 pandemic, a key question is whether the patterns and changes we have described in this paper made modern supply chains and networks more resilient or more vulnerable to shocks. This is a growing area of research. Such shocks may be related to trade policy, like Brexit or the 2022 trade sanctions on Russia, or may relate to events that directly affect production and transportation, whether from pandemic or other natural disasters. For examples, Boehm, Flaaen, and Pandalai-Nayar (2019) consider how shocks from earthquakes propagate into upstream production; Feyrer (2021) looks at the closure of the Suez canal on aggregate trade flows; Khanna, Morales, and Pandalai-Nayar (2022) look at manufacturers during COVID-lockdowns and highlights the role of multiple sourcing; and Besedeš and Murshid (2019) study the impact of the eruption of an Icelandic volcano that closed European air space. This is a nascent literature, and here are some themes and connections we would emphasize as this research develops.

First, goods in the world economy are being transported over increasingly longer distances, by more diverse sets of countries, and often travelling indirectly to their destination, which further lengthens their trips. Longer shipment distances are mechanically more vulnerable to transportation disruptions because potential shocks can affect more locations. Similarly, longer-distance trade may have to cross many more choke points, like the Suez and Panama Canals, and the Straits of Malacca and Hormuz. The obstruction of the Suez Canal for six days in March 2021, and its subsequent supply chain disruptions, serves as an illustrative example of how longer-distance trade can be more subjected these potential disruptions. Trade may be less resilient to shocks because of the increasing importance of such chokepoints, but little research has touched on long run trends here and little is known concretely.

Second, transportation networks are not only longer today, but they also feature round-trip and hub-and-spoke networks that operate on fixed routes. With fixed schedules routes, a disruption to one leg of a trip not only affects goods on that leg, but can cascade throughout the network (Swanson, 2021). Additionally, larger and larger ships—both container ships and bulk freight—are built to take advantage of the per unit cost savings. These large ships concentrate the hub and spoke system further, and utilize the multimodal transport network more, resulting in further international links between countries which spill over into domestic intranational links between cities or regions as well. Changes to relationships between countries, like the recent disturbing turn to protectionism in parts of the world, have much more widespread spillover impacts due to transport networks and supply chains, and deserves further research.

Third, the vulnerabilities to trade may not be readily apparent. For example, when production of final goods happens closer to home, it may appear less risky due to less exposure to trade. However, this local production still requires upstream inputs in their production, and their ultimate reliance on trade and transport requires analysis of the entire value chain and alternatives. For example, while air transport may be considered to have a lower risk in terms of time delays compared to ocean shipping through the Suez Canal, air goods are produced using goods that are shipped by ocean—and thus may be exposed to the ocean disruption as well.

Fourth, the "bullwhip" effect refers to a situation where small perturbations upstream in a production chain are amplified downstream and become major issues (Fransoo and Wouters 2000; Lee, Padmanabhan, and Whang 1997;). Upstream production may use input products with a limited set of globally dispersed substitutes, while downstream may face many different alternatives that are more geographically concentrated. Several issues already mentioned, including longer distances, networks, choke points, congestion, and scale economies can be combined to create a bullwhip effect.[10]

With these issues in mind, we highlight two additional areas for fruitful research. First we consider the nexus between the environmental impacts of transportation and supply

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[10] Some papers have considered the endogenous responses of transportation costs to shocks (Fajgelbaum and Schaal 2020; Allen and Arkolakis 2022; Ganapati, Wong, and Ziv 2021; Brancaccio, Kalouptsidi, and Papageorgiou 2020). However, these studies are limited to looking at just fragments of both the transportation network and the value chain; none of these papers can integrate the upstream and downstream effects across modes of transport.

chains. Second, we highlight the interaction between market power and long run trends in transportation networks.

While transportation only accounts for 15% of greenhouse gas emissions, it also enables the shifting of pollution in other sectors across space, especially in agriculture and industry (Shapiro 2016). While a small literature considers how environmental policy can have adverse unintended effects on overall pollution within transportation (see Cristea et al (2013), Mundaca et al (2021), and Lugoskyy, Skiba, and Terner (2022)), few studies consider the role of transportation costs on both the distribution of pollution as well as on the aggregate levels though its interaction with other sectors.

Second, larger markets induce entry, driving down markups and prices, even if costs are constant. As absolute demand for transportation services increases, entry can further amplify the affect at entrants helping to discipline costs. In transportation, Hummels, Lugovskyy, and Skiba (2009) show large effects of market entry on reducing prices in international shipping. However a second countervailing trend exists, that of scale economies, as ships get bigger and airline shipping networks get denser, a smaller and smaller set of firms may dominate an industry and potentially extract large profits – muting the gains from trade.

Although the vulnerability of global supply chains is at the forefront of many minds (including our own!) in the aftermath of the post-pandemic congestion and disruptions, the long-term trends in this paper suggest a more nuanced approach to these issues. If one compares trade between, say, the United States or the European Union and a wide range of destinations around the world, for most of those destinations trade is considerably more resilient and less vulnerable than several decades ago—and those gains to resiliency are in fact apparent in the greater use of trade over longer distances, the expanded trade networks, better payment systems, better trade facilitation, and so on. Countries, and cities within countries, are more cohesively and reliably interconnected than in earlier decades because of the interaction between efficient transport and supply chains.

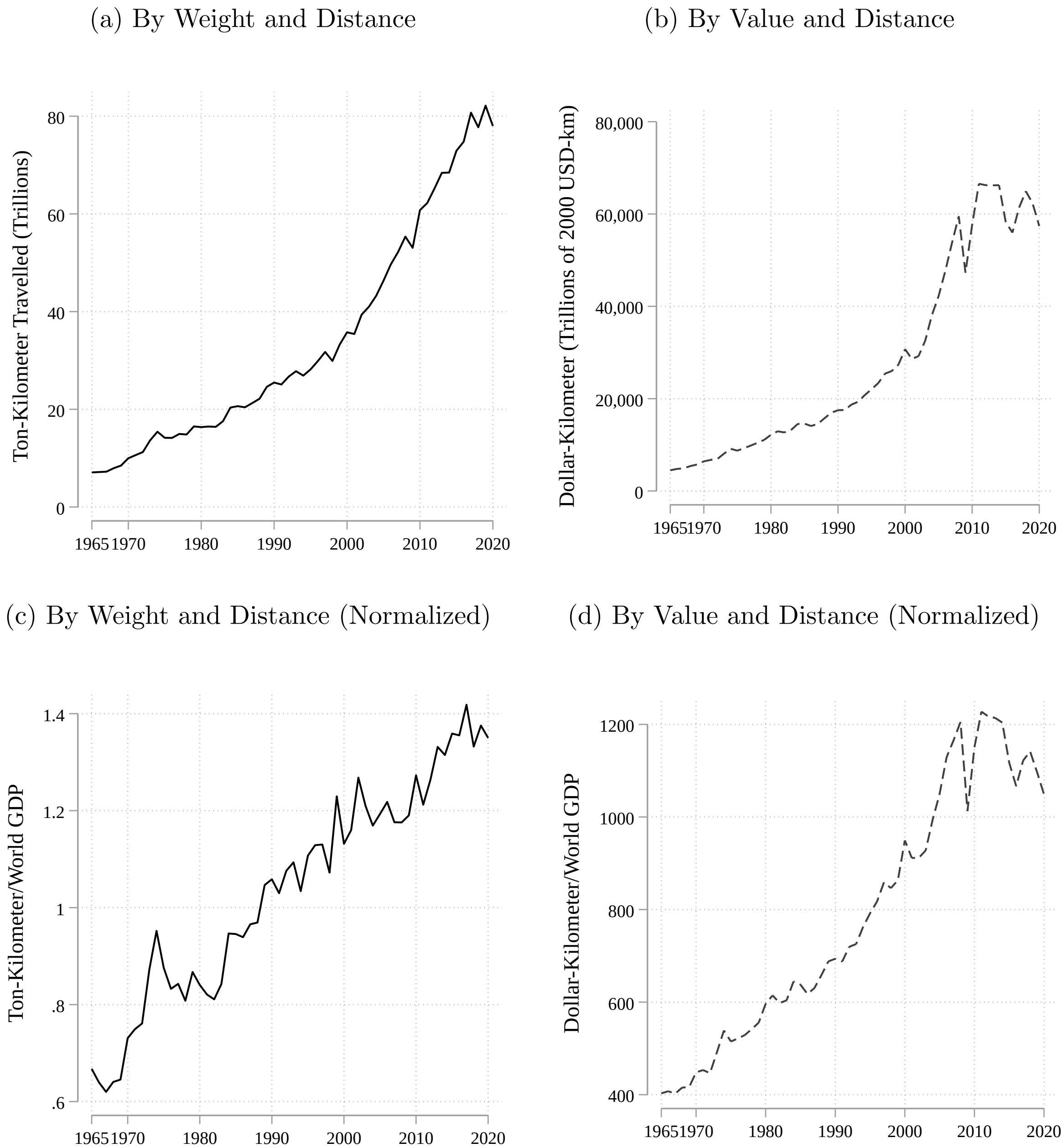
After Toyota's just-in-time production system showed vulnerability in 1997,[11] Toyota and other firms interviewed by Nishiguchi and Beaudet (1998) did not consider abandoning just-in-time, but instead focused on developing flexibility within their firm to better respond to future issues like this. Similarly, when faced with the recent supply disruptions and congestion of the pandemic, firms and countries should not start looking inwards in terms of production processes and decrease their transport use. Instead, unexpected events always teach us lessons about unforeseen risks: for example, it is not only important for a firm to have multiple suppliers, but also to know that those suppliers can use multiple trade routes. Consolidating the entire supply chain at home is both costly and as risky as a single sourced foreign location. Researchers should be able to study both sides of the coin: on one side, the gains to the world economy from increased transport reliability and use of

[11] In February 1997, a fire occurred at a Toyota parts supplier, which was the sole supplier of a crucial part all Toyota vehicles. The just-in-time system meant that the resulting ripple effect shut down all Toyota production for two weeks (Nishiguchi and Beaudet 1998).

trade, and on the other side, how local disruptions to production can have far and wide-reaching consequences through the interactions of trading networks.

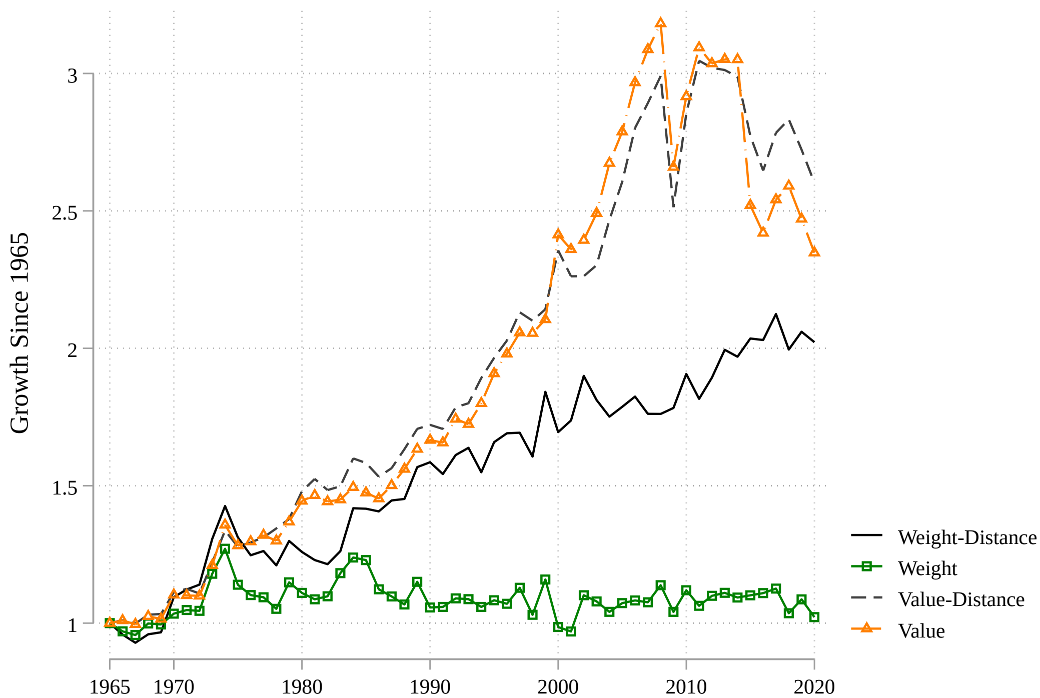
Figures and References for
How Far Goods Travel:
Global Transport and Supply Chains from 1965-2020
Sharat Ganapati and Woan Foong Wong

Figure 1: Transport Use, 1965-2020



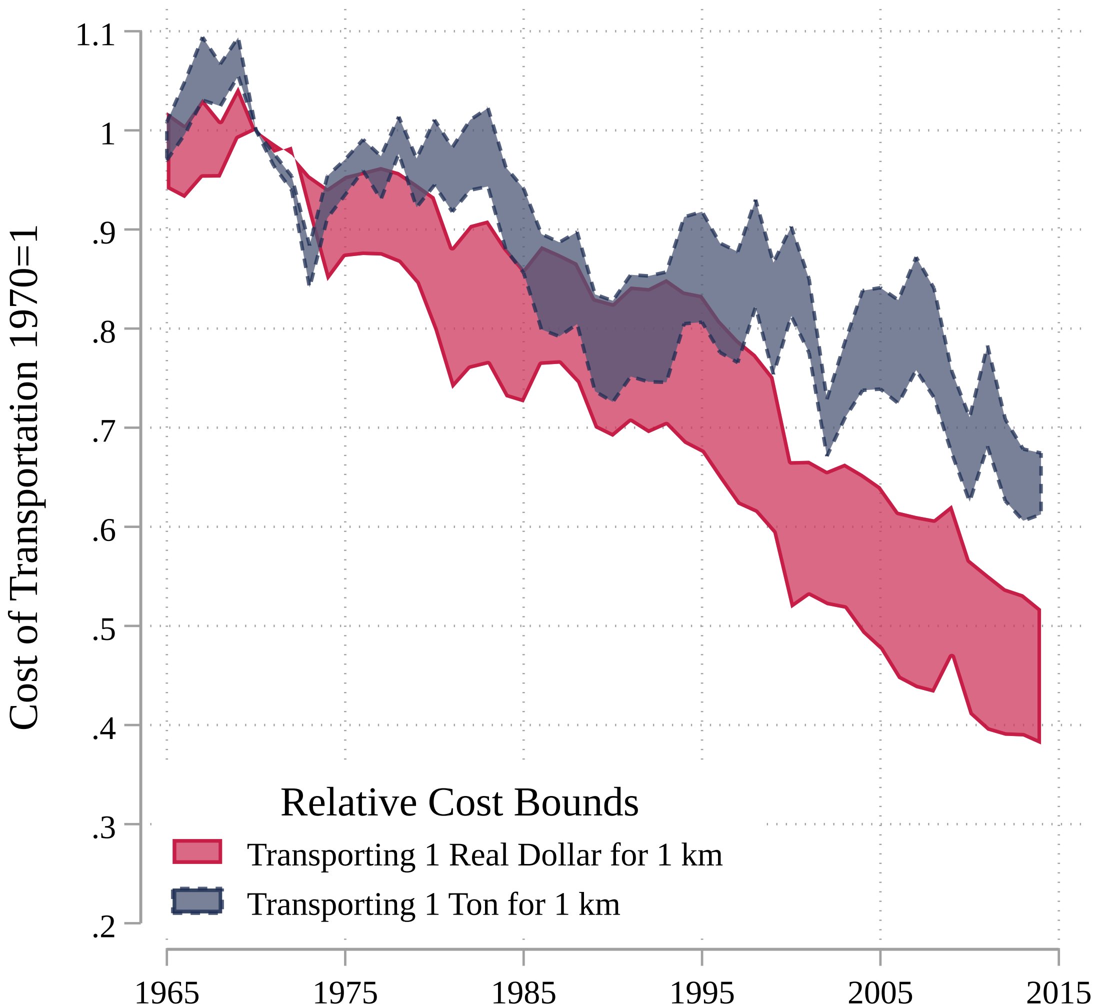
Notes: Figures 1a and 1b measure the distance shipped of goods, weighted by metric tons and real year 2000 US Dollars respectively (for further details see Equation (1) in Appendix A). While data on the value of trade is available over our entire sample period, weight data is only widely available after 2000. We impute weight data from prices using a variety of data sources. See Appendix B for full details. Figures 1c and 1d normalize the top two figures relative to the sum of the gross domestic product of all countries to calculate real transport use (for further details see Equation (2) in Appendix A). All monetary values are converted to year 2000 USD. Source: BACI, WIOD, UN-NBER-Comtrade, PWT, and associated output deflators.

Figure 2: Transport Use, 1965-2020



Notes: All series are normalized with respect to its 1965 value and can be read as growth since 1965. The black line is the real or normalized transportation use measured in ton-kms from Figure 1c. The dashed gray line is the real or normalized transportation use measured in dollar-kms from Figure 1d. The green squares are the total weight shipped relative to World GDP. The orange triangles are the value shipped relative to World GDP. All monetary values are converted to year 2000 USD. In addition to the data from the aggregate measures of trade and transportation from Figure 1, WIOD data is used for country-level GDP from 1965-2014, and the Penn World Table for 2015-2019 (Feenstra, Inklaar and Timmer, 2015), and UN statistics Division (2022a) for GDP data from 2015-2020. See the appendix for full details. Source: BACI, WIOD, UN-NBER-Comtrade, PWT, and associated output deflators.

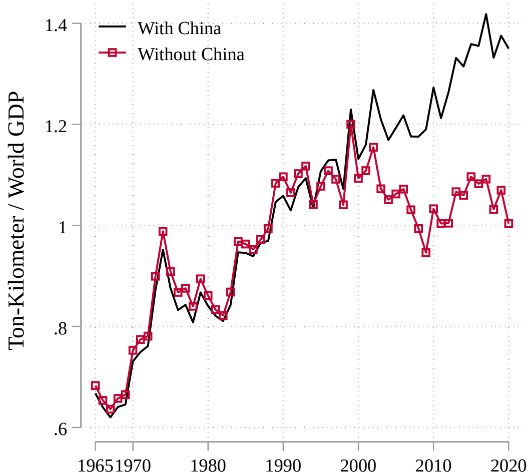
Figure 3: Transport Costs, 1965-2014



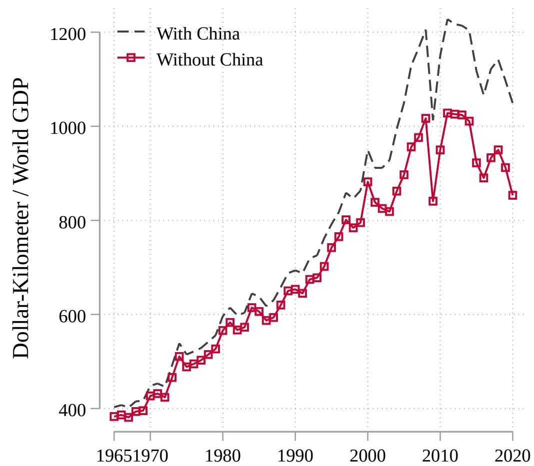
Notes: Figure 3 is calculated using the sum of all global transportation costs for a given year, divided by trade use for that year—either tons of trade or value of trade, multiplied by distance (see Equation (3) in Appendix A for more details). For transportation costs, we use data on transportation and storage expenditures from the WIOD database (ISIC codes I60-I63 (rev 3) and H49-H52 (rev 4)). The upper bound estimate is based on the scenario where all aggregate transportation spending was on international trade while the lower bound estimate reflects spending on both international and domestic trade. Values are normalized to 1 in 1970. Consistent sample of 24 countries representing 90% of world GDP. The time period for the World Input-Output Database (WIOD) ends at 2014 which restricts our sample (Timmer et al 2015).

Figure 4: The Role of Emerging Economies, Focusing on China, 1965-2020

(a) Transport Use by Weight and Distance



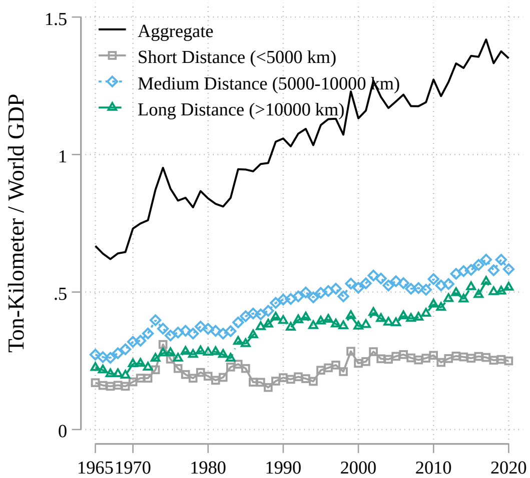
(b) Transport Use by Value and Distance



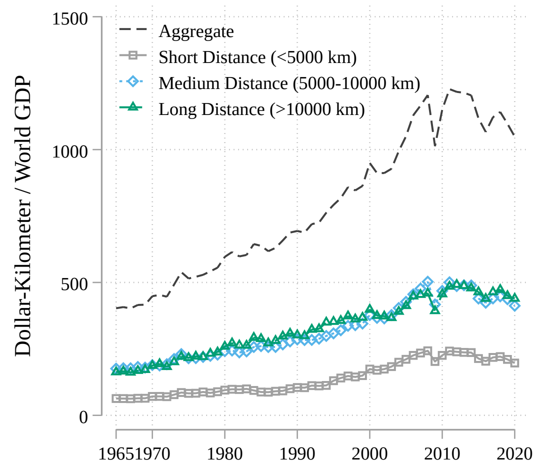
Notes: The real transport use measured in ton-distance, indicated by the black line in Figure 4a, is reproduced from Figure 1c for comparison. The real transport use measured in ton-distance *excluding China*, indicated by the red line with squares in Figure 4a, is calculated by recomputing Equation (2) in Appendix A to exclude both incoming and outgoing trade in weight with China in the numerator, as well as excluding Chinese GDP from world GDP in the denominator. The real transport use measured in dollar-distance, indicated by the black line in Figure 4b, is reproduced from Figure 1d for comparison. The real transport use measured in dollar-distance *excluding China*, indicated by the red line with squares in Figure 4a is calculated by recomputing Equation (2) in Appendix A to exclude both incoming and outgoing trade in value with China in the numerator, as well as excluding Chinese GDP from world GDP in the denominator. See Figure 1 notes and the Data Appendix for further details.

Figure 5: The Role of Longer Distance Trade, 1965-2020

(a) Transport Use by Weight and Distance



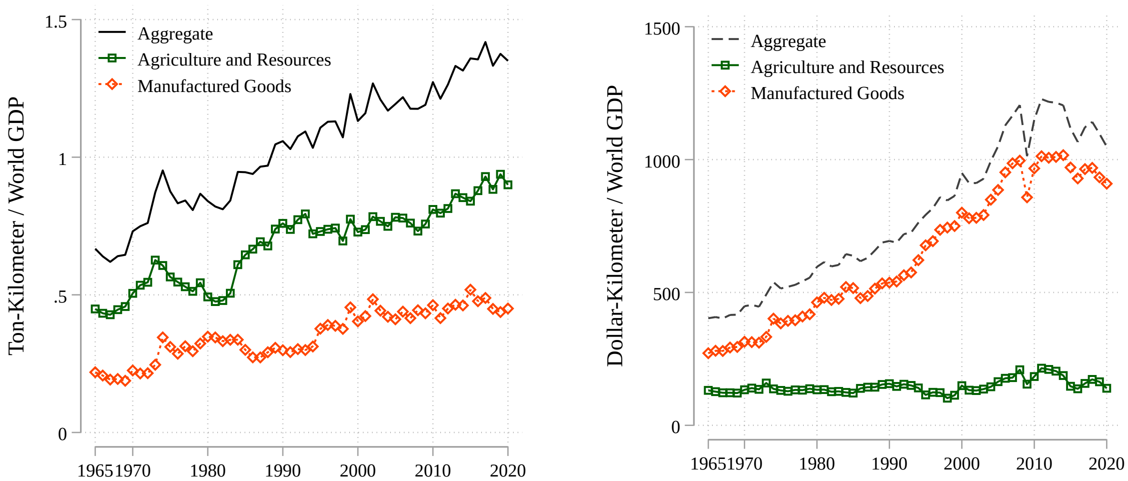
(b) Transport Use by Value and Distance



Notes: The real transport use measured in ton-distance, indicated by the black line in Figure 5a, is reproduced from Figure 1c for comparison. The remaining 3 lines in Figure 5a are calculated by breaking down the real transport use measure in weight into three sub-components that total the aggregate figures: transportation usage of shorter distance trade under 5,000 kilometers (gray line with squares), medium distance trade from 5,000 to 10,000 kilometers (blue line with diamonds), and very long distance trade over 10,000 kilometers (green line with triangles). The real transport use measured in dollar-distance, indicated by the black line in Figure 5b, is reproduced from Figure 1d for comparison. The remaining 3 lines in Figure 5b are calculated by breaking down the real transport use measure in value into three sub-components that total the aggregate figures: transportation usage of shorter distance trade under 5,000 kilometers (gray line with squares), medium distance trade from 5,000 to 10,000 kilometers (blue line with diamonds), and very long distance trade over 10,000 kilometers (green line with triangles). See Figure 1 notes and the Data Appendix for further details.

Figure 6: The Role of Natural Resources vs Manufactured Goods, 1965-2020

(a) Transport Use by Weight and Distance (b) Transport Use by Value and Distance



Notes: The real transport use measured in ton-distance, indicated by the solid black line in Figure 6a, is reproduced from Figure 1c for comparison. The remaining two lines in Figure 6a are calculated by breaking down the real transport use measure in weight into two sub-components that total the aggregate figure: agricultural and natural resource products (ISIC categories A and B, green line with squares), and manufactured products (orange line with diamonds). The real transport use measured in dollar-distance, indicated by the dashed black line in Figure 6b, is reproduced from Figure 1d for comparison. The remaining two lines in Figure 6b are calculated by breaking down the real transport use measure in value into two sub-components that total the aggregate figure: agricultural and natural resource products (ISIC categories A and B, green line with squares), and manufactured products (orange line with diamonds). See Figure 1 notes and the Data Appendix for further details.

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Online Appendix

How Far Goods Travel: Global Transport and Supply Chains from 1965-2020

Sharat Ganapati and Woan Foong Wong

A. Additional Background on Key Variables

A.1 Transport Use and Normalized (Real) Transport Use

We examine the usage of transportation services as primarily consisting of two components: (1) the amount of goods that are transported, and (2) how far these goods are transported. The first component can be reasonably approximated by international trade flows. The second measure is important to incorporate as goods that are shipped further require more transportation. This transport use measure captures what is often missing in traditional trade measures---the role of distance. If trade increases, but only between nearby countries and between locations that are far apart, then the global need for transportation may only marginally increase. But if trade between distant locations increases, then transportation needs will dramatically increase. Including distance directly captures transport use.

Specifically, we measure transport use, in either ton weight or dollar values for Figures 1a and 1b respectively, as follows:

$$\begin{aligned} Transport\ Use_t &= Total\ Trade\ Transported\ (tons\ or\ \$) \times Distance\ Transported\ (km) \\ &= \sum_o \sum_d X_{odt} \times D_{od} \quad where\ o, d \in N \end{aligned} \tag{1}$$

where X_{odt} is the total amount of trade between origin country o and destination country d in year t measured in tons or dollars, and D_{od} is the population-weighted great circle (as-the-crow-flies) distance between these countries measured in kilometers. Conventional trade statistics generally focus on the trade value between origin and destination countries (X_{odt}), which is included in our measure of transport use in addition to the distance between these countries. The underlying databases convert currencies into current US Dollars. All values are converted into year 2000 US Dollars using price index data from the World Input-Output Database (WIOD) database (Timmer et al 2015), Penn-World Tables, and BEA US GDP deflators.

While data on the value of trade is available over our entire sample period, weight data is only widely available after 2000. We impute weight data from prices using a variety of data sources. See Appendix B for full details.

Next, we account for the rapid growth in the world economy and normalize total transportation usage by real global consumption, in ton weight and dollar values for Figures 1(c) and 1(d) respectively. This *real or normalized transport use measure*, detailed below, captures the cumulative distance traveled by intermediate inputs in production, in addition to the distance traveled by the final good to its ultimate destination for consumption:

$$Real\ Transport\ Use_t = \frac{Total\ Trade\ Transported\ (tons\ or\ \$) \times Distance\ Transported\ (km)}{Total\ Gross\ Domestic\ Product} = \frac{\sum_o \sum_d X_{odt} \times D_{od}}{\sum_o GDP_{ot}}\ where\ o, d \in N \quad (2)$$

where all elements in the numerator replicate Equation (1) between origin country *o* and destination country *d* in year *t*, normalized by the GDP of country *o*.

A.2 Transport Cost

Next, we show how we approximate aggregate global transport costs. Instead of focusing on a subset of transport costs, which often do not include costs at the origin or destination, we use both our aggregate measure of transportation usage from the previous section, as well as the total expenditures in the transportation sector to recover the price to ship either a ton or real dollar of goods for one kilometer. We then return to the share accounted for by transportation in the overall economy—a function of both usage and the price for transportation services.

In order to compare the cost of transport over this long period, we calculate the cost to transport one ton or one real dollar of goods for one kilometer in each year *t* for Figure 3(a) as:

$$Transport\ Cost_t = \frac{Spending\ on\ Transport\ (\$)}{Total\ Trade\ Transported\ (tons\ or\ \$) \times Distance\ Transported\ (km)} = \sum_o \sum_d \frac{T_{odt}}{X_{odt} \times D_{od}} \quad where\ o, d \in N \quad (3)$$

where T_{odt} is the amount of spending on transport between an origin country *o* and destination country *d* in year *t* measured in real dollars, X_{odt} is the total amount of trade value between these countries measured in either tons or dollars, and D_{od} is the distance between these countries measured in kilometers.

For the numerator in Equation (3), we use data on transportation and storage expenditures from the WIOD database (ISIC codes I60-I63 (rev 3) and H49-H52 (rev 4)). While we consider storage and warehousing as an important part of transportation costs, the data has the undesirable feature of including passenger transportation as a component.[1]

A.3 Transportation Share of Global Economy

Given that transport costs have fallen but the global economy is using more transport services, has aggregate spending on transport services risen or fallen? We calculate global transport spending as a share of total gross output using the WIOD databases. As seen in Figure A1, the expenditure share on transport for these countries have mostly stayed constant: started around 4 percent in 1965 and increased to more than 4.7 percent by 1995, before declining back to 3.8 percent in 2015.

Insert Figure A1

Gross output measures capture the flows of goods every time these goods cross a border. These measures include the cost of inputs as well as the value added to the product by each country, leading to double counting (Johnson and Noguera 2012). An alternative measure of transport spending considers the value added of goods from 1965-2015. The value-added expenditure share for transport is slightly lower than the gross share, but mirrors the gross output trend throughout the entire time period.

We further use all countries in the United National GDP by Sector data base, as opposed to those with consistent time series in the WIOD database to create Figure A2.

Insert Figure A2

Figure A2 chart breaks down global GDP into components, transportation (including storage and communication), natural resources (agriculture, forestry, and mining), manufacturing, retail/wholesale distribution, and all other services. While the value added from manufacturing and resources is falling, the value added from transportation continues to stay constant. However, unlike the WIOD data used in the main text, this time series mixes communications and other transportation services.

A.4 Composition of Trade: Intermediate and Final Goods

As a robustness check, we examine the role of final and intermediate good consumption as defined by the WIOD global input-output database (Figure A*3*).

Insert Figure A3

When transportation usage is measured by weight-by-distance, intermediate goods use accounts for the majority of transport use, accounting for 85-90 percent of transport use over the whole time period (Figure A3a). We also find that the increase in transport use in ton-kilometers over this period primarily reflects growth in intermediate good consumption, which increased by 83 percent over this time span. Final good consumption

[1] A richer analysis would decouple passenger and freight transportation; however detailed US BEA value added data imply that passenger transportation expenditures follow a similar trend to freight transportation and accounts for less than 20% of the sector.

transportation usage, starting at much lower levels, increased dramatically by 246 percent over this same period. This effect of this increase on overall transportation use is limited, as final goods today only account for 17 percent of transportation usage, and whose share has held steady since the early 2000s and fallen since 2010.

However, when transportation usage is measured by value-by-distance, as in Figure A3b, the transport use of intermediate goods account less—roughly 60 percent of aggregate transport use throughout this period. This pattern is consistent with Johnson and Noguera (2012) finding that intermediate goods account for two-thirds of 2004 global trade in value. The transport use trends are initially in parallel for both intermediate and final goods. But since 2008, all the growth in transportation usage as measured by value has been in intermediate good usage. This finding, that intermediate goods consumption has contributed to the large increase in transport use by value, is consistent with Hummels, Ishii, and Yi (2001) who finds a 30 percent increase between 1970-1990 in the value of imported inputs used in producing exported goods for 10 OECD and four emerging market countries (which account for three-fifths of world trade).[2] As final goods typically have higher value-added and the transport usage for final goods have increased by much more than intermediates up until 2008, our results are also broadly consistent with the negative correlation between distance and bilateral ratio of value added to gross exports in Johnson and Noguera (2017) from 1970-2009.

A.5 Just-in-time production and inventory system

We now highlight the mechanism of one of the examples above–Just-in-time deliveries (JIT) (also called lean manufacturing). The JIT system is a strategy that aligns input orders from suppliers directly with production schedules, so that the inputs are received only as needed for the production process. The JIT system has resulted in smaller, more frequent shipments to reduce warehousing costs at the receivers' end. This, in turn, has increased demands on shipment costs and reliability to ensure the uninterrupted implementation of planned production processes. At the same time, JIT has led to a changing relationship between transport and warehousing costs. As this system is adopted by more and more businesses, the need to hold inventory on-site decreases. We start by establishing this trend for the US.

Figure A4 reports the inventory to sales ratio trends from the Census Bureau.[3] This ratio measures the amount of inventory that businesses hold relative to their sales. A higher

[2] See Hillberry and Hummels (2008) for analysis considering only domestic US trade and intermediate goods.

[3] The Census Bureau reports this data based on three surveys: the Manufacturers' Shipments, Inventories, and Orders Survey, the Monthly Wholesale Trade Survey, and the Monthly Retail Trade Survey. More recent data, from 1992 onward, is based on the North American Industry Classification System (NAICS) while historic data was based on the Standard Industrial Classification (SIC) codes. The SIC was phased out in 1997 by US statistical agencies. See (Fort

ratio indicates that businesses hold more merchandise relative to their sales in a period. Figure A4a reports this ratio for the manufacturing sector, which is the longest publicly available time series from January 1958 onwards.

Insert Figure A4

The average manufacturing inventory to sales ratio was around 1.7 before 1990. Since then, there has been steady decrease in the amount of inventory that businesses hold—the average ratio is about 1.3 between 2000-2019. This is an average decrease of about 24 percent. We do note that the manufacturing industry is shrinking as a share of GDP over this period—its value added share of GDP was 25% in 1960 (BEA (1947-1997)) and by 2019 it was about 11% (BEA (1998-2021)).

Figure A4b reports this ratio for the retail industry, where there is more muted but similar downward trend. The average was around 1.7 before 1990 and it decreased to about 1.5 between 2000-2019. An 11 percent decrease. The value added of the retail industry accounted for 6.8% of GDP in 1981 (BEA (1947-1997)). There are similar declines using the total series reported by the Census (Figure A4c).

As an alternative measure, we use more comprehensive BEA times series data. Figure A5 uses BEA data series on total private inventories (as opposed to the US Census series collected at the sectoral level). We present three versions. The black line delineates average annual inventories over U.S. gross domestic output. The second line only includes goods consumed or used for investment as the denominator. The third line subtracts exports and adds imports to the denominator. All show a substantial decline in private inventories at the national level. All series echo each other and demonstrate a significant decrease in inventories as a function of both the total economy's size, as well as the size of the economy that deals with physical goods.

While we are focused on these inventory patterns over a long period of time, there has been studies on how inventory holdings respond during periods of bad shocks. Focusing on 2008-2010 at the height of the trade collapse, Alessandria, Kaboski, and Midrigan (2011) shows that firm inventory holdings are much higher in response to persistent negative shocks. For developing countries, the cost of trade is much larger and inventory can serve as a buffer for these costs (Alessandria, Kaboski, and Midrigan 2010). Carreras-Valle (2021) studies the recent reversal of the declining trend in the manufacturing industry since 2005 and how much of it can be attributed to the longer delivery times and delays from sourcing foreign inputs that are further away.

Insert Figure A5

As a final measure, we investigate estimates of logistics expenditures broken into inventory or warehouse spending, and transport spending from the Council of Supply Chain

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and Klimek 2018) for a discussion on the how the classification change impacted the measurement of US economic activity.

Management Professionals (CSCMP).[4] In Figure A6, the inventory or warehouse spending estimates, as a percent of GDP, are similar in magnitude to transport in 1980 (around 7.6% and 7.4% respectively). While both the Census and CSCMP inventory decreases have decreased, the decrease in CSCMP inventory costs is much sharper at 67%.[5]

Insert Figure A6

B. Data Appendix

Our dataset of transportation usage and trade costs extends from 1965 to 2020 and requires the use of multiple sources. Data from the end of World War II to 1965 is not included due to the rapid pace of decolonization from European powers during that period. We start with two major sources of trade statistics.

BACI Database

For 1995-2020, we use the BACI database from Centre d'Etudes Prospectives et d'Informations Internationales (CEPII). This database reports values on quantities (in weight) and value for all bilateral trading relationships in the underlying UN Comtrade database. The researchers at CEPII correct underlying data to a consistent classification nomenclature, imputing data when necessary. We use the 2022 release of this data in 1992 Harmonized System nomenclature.

NBER-UN Comtrade Data

For complete trade data in value from 1965-2000, we use the NBER-UN Comtrade database compiled by Feenstra et al. (2005).

For the overlap period from 1995-2000, we take the BACI values as given and line up the UN Comtrade data adjusting by the average difference in the datasets between 1995 and 2000. We perform similar procedures wherever there is an overlap, taking the newer data levels as correct and adjusting up and downward by the period of overlap.[6]

For various denominators and supply-chain statistics, we turn to alternative sources of data.

World Input–Output Database (WIOD)

We use the combined Long-Run and updated World Input–Output Database (WIOD) to cover valued added and gross output statistics from 1965-2014. While the datasets only

[4] See Federal Highway Administration (2005) for discussion on the estimates.

[5] Domestic transport spending also decreased but by a smaller rate 32%.

[6] Please see the Stata subroutine 'splice' in our replication package.

contain detailed statistics for 24 and 43 countries, that cover over 90 percent of would output, with the remainder of countries consolidated in a "Rest of World" Aggregates.[7]

We additionally use the WIOD to provide sectoral level price deflators from 1965-2014.

Penn World Tables and UN National Accounts Databases

For aggregate GDP and global price deflators, we use data from the Penn World Tables Version 11 (PWT) from 2014-2019 at the aggregate level, and from the United Nations Statistics Division (UNSD) National Accounts Main Aggregates database for aggregates and sectoral level data not covered by the PWT. Due to differences in measurement of sectoral output between the UNSD and the WIOD, we refrain from extending our time-series on transportation costs and value added beyond 2014.[8] Just for 2019 and 2020, we additionally use the US Bureau of Economic Analysis GDP price indices assessed through the FRED database.

Value to Weight Conversions prior to 1995

After 1995, we directly use weight data from the BACI database. Prior to 1995, we backwards impute weights using BACI data and aggregate price series from the WIOD database. To do so, we use price index data from the WIOD.

This works well, except for natural resource and oil shipments from 1973-1985. We directly use oil price and oil import data from 1973-1985 to adjust quantity data over that time period for those exports and imports. We use oil price and shipment data from OPEC, as well as import statistics from the US Energy Information Administration and the price of domestic crude oil (West Texas Intermediary) to recover real shipment weights.

We concord all data to ISIC Rev. 3 (Prior to 2000) and ISIC Rev. 4 (After 2000) codes at the level of aggregation in the WIOD Database (2-digit sectoral aggregates). We use concordances from the UN Trade Statistics Division, OECD and the World Bank.

Gravity Data

For all countries we use population-weighted distance data from the CEPII Gravity Database (the 2022 revision).

Inventory to Sales Ratio

The Census Bureau reports this data based on three surveys: the Manufacturers' Shipments, Inventories, and Orders Survey, the Monthly Wholesale Trade Survey, and the Monthly Retail Trade Survey. More recent data, from 1992 onward, is based on the North American Industry Classification System (NAICS) while historic data was based on the

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[7] As an alternative, for data from 1995-2021, we also can use the OECD Input-Output Database. Due to differences in dataset design and industrial codes, we refrain from merging the two.

[8] Appendix Figure A.2 shows how UN Data conflates communication services with transportation, making it difficult to continue the time series.

Standard Industrial Classification (SIC) codes. The historic SIC data for Manufacturing is from the Census Manufacturing Branch under the Historical Time Series *(https://www.census.gov/manufacturing/m3/historical_data/index.html)* section. The historic SIC data for Retail is from the Census Retail Indicator Branch under the Historical Data (https://www.census.gov/retail/mrts/mrtshist.html) section. Historic SIC data for Wholesale is from the Wholesale Indicator Branch under the Time Series Data (Prior to NAICS) (https://www.census.gov/wholesale/www/historic_releases/monthly_historic_releases.html) section. The SIC was phased out in 1997 by US statistical agencies and is normalized relative to the recent NAICS data. NAICS data is from the Manufacturing & Trade Inventories and Sales *(https://www.census.gov/mtis/index.html)* data page. The shorter time period in retail and total series is due to lack of digitized data on the Census Bureau website.

BEA Private Inventory and US GDP Data

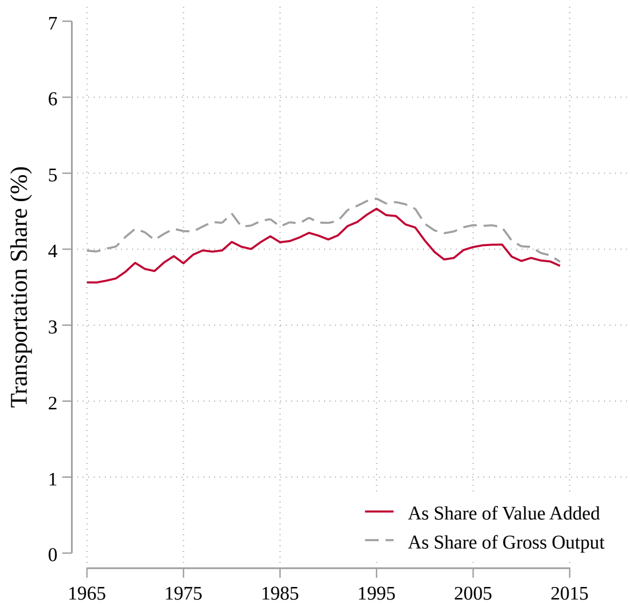
We use BEA private inventory data for Figure A5. We use the following time series from the FRED database: GDPDEF, A371RC1Q027SBEA, A809RX1Q020SBEA , GDPA, DGDSRC1A027NBEA GPDIA, A255RC1A027NBEA, A253RC1A027NBEA

Annual State of Logistics Report Datapoints

We digitize tables from historic Council of Supply Chain Management Professionals (CSCMP) "Annual State of Logistics Reports" to create figure A6. The Council of Supply Chain Management Professionals produces annual estimates of logistics expenditure for the United States. Logistics expenditure are broken down into inventory/warehousing, transport, and administrative. Administrative spending make up a very small portion of GDP and are omitted here.

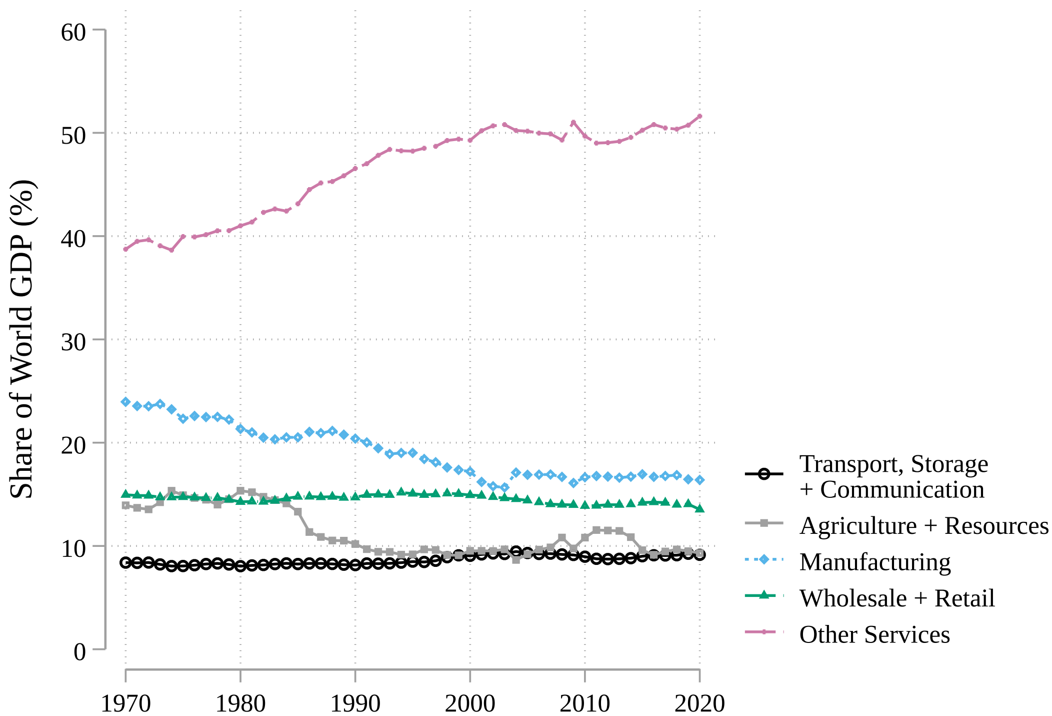
A Appendix

Figure A1: Aggregate Spending on Transport, 1965-2014



Notes: Consistent sample of 24 countries representing 90% of world GDP. For an alternative measure of Figure A1, see Appendix Figure A2 for UN data until 2020. Source: WIOD (Timmer et al 2015).

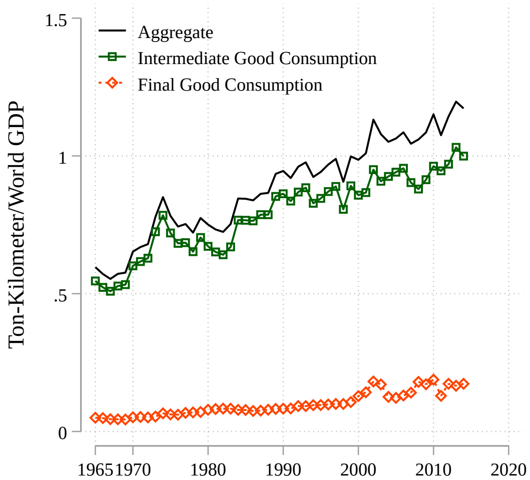
Figure A2: Global Sectoral Value Added, 1970-2020



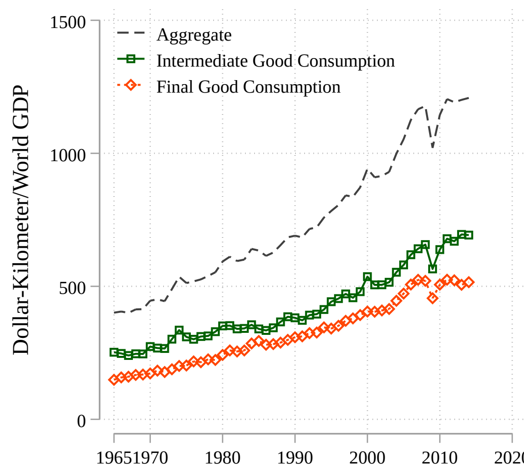
Notes: This chart breaks down global GDP into components, transportation (including storage and communication), natural resources (agriculture, forestry, and mining), manufacturing, retail/wholesale distribution, and all other services. While the value added from manufacturing and resources is falling, the value added from transportation continues to stay constant. However, unlike the WIOD data used in the main text, this time series mixes communications and other transportation services. Source: UN Statistics Division (2022a).

Figure A3: The Role of Final vs Intermediate Goods, 1965-2014

(a) Transport Use by Weight and Distance

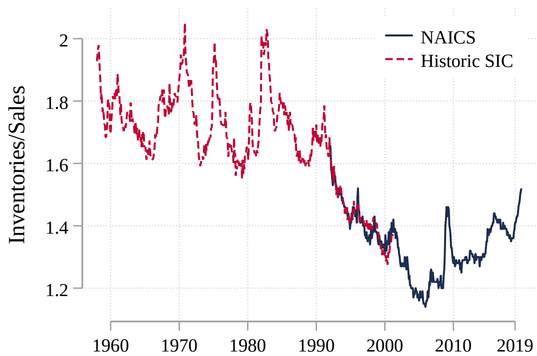


(b) Transport Use by Value and Distance

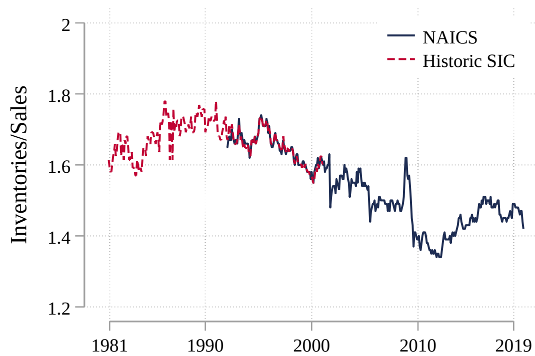


Notes: We end in 2014 due to data availability. The WIOD global input-output database ends in 2014 and we require I-O tables to separate final goods from intermediate good consumption. The real transport use measured in ton-distance, indicated by the solid black line in Figure A3a, is reproduced from Figure 1c for comparison. The remaining two lines in Figure A3a are calculated by breaking down the real transport use measure in weight into two sub-components that total the aggregate figure: final and intermediate good consumption (green line with squares and orange line with diamonds respectively). The real transport use measured in dollar-distance, indicated by the dashed black line in Figure A3b, is reproduced from Figure 1d for comparison. The remaining two lines in Figure A3b are calculated by breaking down the real transport use measure in value into two sub-components that total the aggregate figure: final and intermediate good consumption (green line with squares and orange line with diamonds respectively). See Figure 1 notes and the Data Appendix for further details.

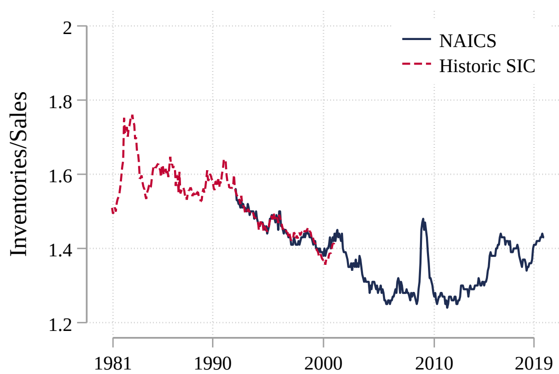
Figure A4: Inventory to Sales Ratio



(a) Manufacturing, 1958-2019



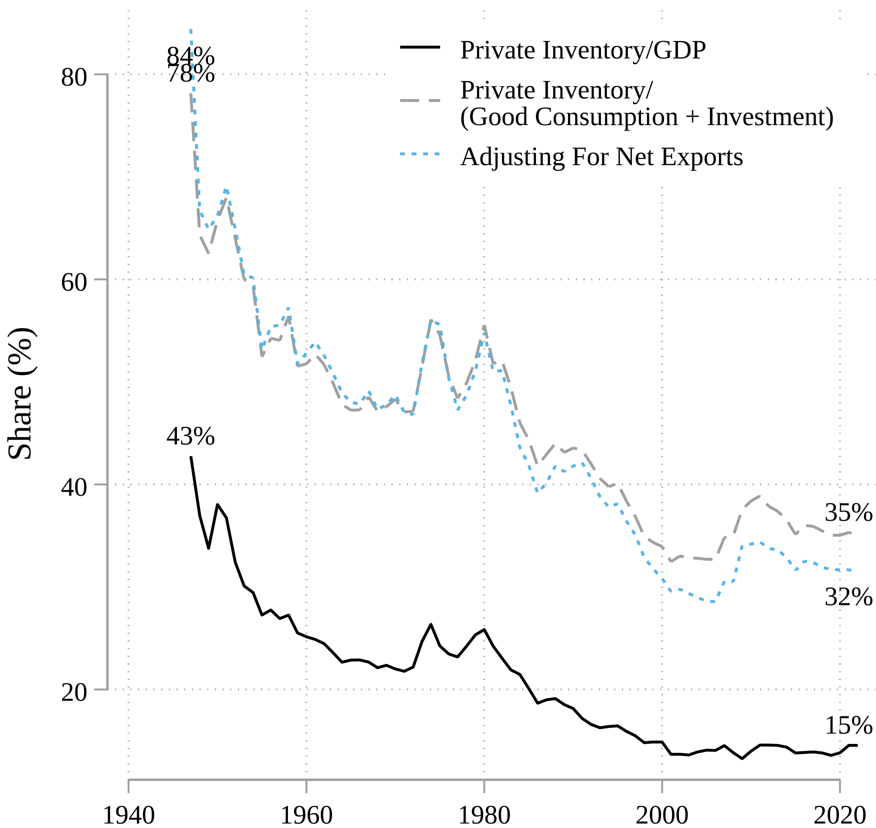
(b) Retail, 1981-2019



(c) Total, 1981-2019

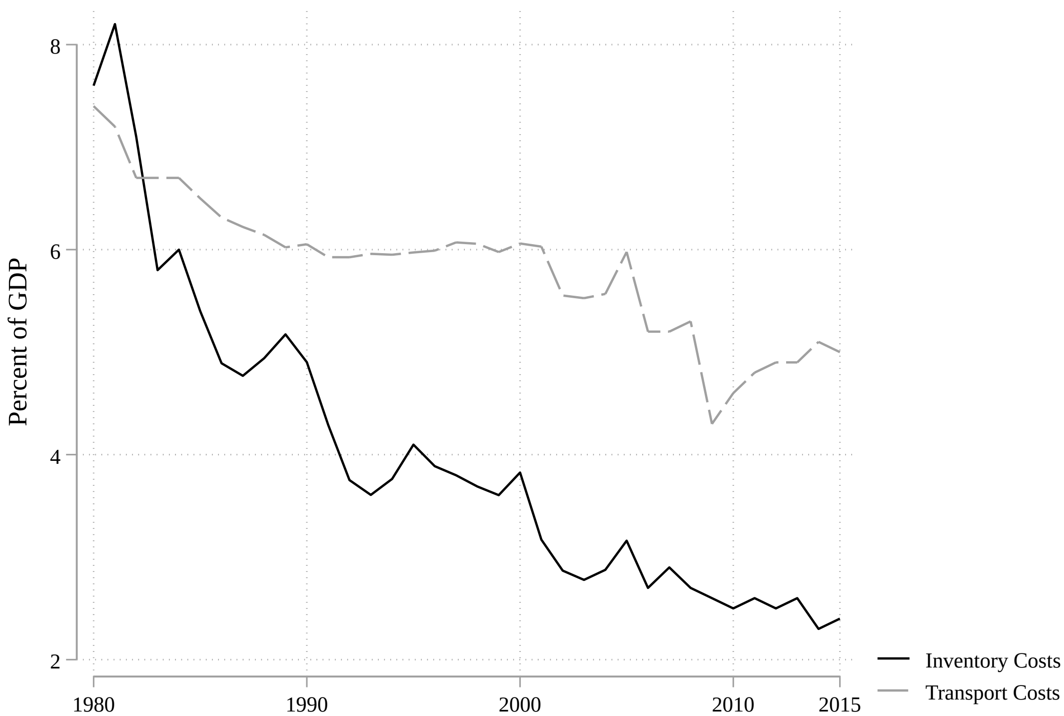
Note: The historic SIC data is normalized relative to the recent NAICS data. NAICS data for all three panels is from the Manufacturing & Trade Inventories and Sales data page. In Figure A4a, historic SIC data for Manufacturing is from the Census Manufacturing Branch under the Historical Time Series. In Figure A4b, historic SIC data for Retail is from the Census Retail Indicator Branch under the Historical Data section. In Figure A4c, the historic SIC series is constructed using the historic manufacturing, retail, and wholesale data. Historic SIC data for Wholesale is from the Wholesale Indicator Branch under the Time Series Data (Prior to NAICS) section. The shorter time period in retail and total series is due to lack of digitized data on the Census Bureau website. See Data Appendix for further details. Source: US Census Bureau

Figure A5: Inventory to Sales Ratio - National



Note: This chart uses BEA data series on total private inventories (as opposed to the US Census series. There are three series. The black line delineates average annual inventories over U.S. gross domestic output. The second line only includes goods consumed or used for investment as the denominator. The third line subtracts exports and adds imports to the denominator. All show a substantial decline in private inventories at the national level. Sourced from US BEA data and accessed through the FRED database.

Figure A6: Inventory and Transport Costs, 1980-2015



Notes: Digitized series of the annual *State of Logistics Report* of the Council of Supply Chain Management Professionals. The Council of Supply Chain Management Professionals produces annual estimates of logistics expenditure for the United States. See Federal Highway Administration (2005) for discussion on the estimates. Logistics expenditure are broken down into inventory/warehousing, transport, and administrative. Administrative spending make up a very small portion of GDP and are omitted here.

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