Time Value of Shipment When Transportation Modes Are Imperfect Substitutes*

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Abstract

This paper finds four facts on air and ocean shipping that suggest an imperfect substitution ween two transport modes, which challenges our understanding of transportation in international trade. The imperfect substitution further allows within-product between-transportation differentiation. We first use a simple model with the elasticity of substitution across products equal to the one between transportation to show why it needs imperfect substitution assumption to explain the facts. Then we relax that assumption by adopting a nested CES preference to get a more general model. Based on the general model, we develop a tractable framework to estimate the tariff-equivalent of the time delay and find it relatively smaller than the ones obtained by Hummels and Schaur (2013). We also estimate the elasticities of substitution across and within product and find them quite close to each other, which implies a highly imperfect substitution between the two transport modes in trade. We further find higher time sensitivity for processing trade than ordinary trade.

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1 Introduction

Ocean and air shipping are the two dominant transport modes in international trade. Compared to ocean shipping, air shipping is higher in unit cost while faster in delivery. Understanding the roles of these two transport modes will help us better understand the time cost or value, which amounts through the global value chain. This paper seeks to answer what different transport modes mean to consumers and firms in international trade and how much consumers value the time of delivery.

Although a large fraction of trade value is shipped by vessels, air shipping has grown rapidly and taken up an increasing proportion of trade, which has been documented by Hummels (2007). This pattern is also observed in China's export sector. While seaborne trade took up 60-70% of China's export volume during 2000 and 2006, value share of airborne trade doubled from around 8% in 2000 to 16% in 2006.

Using China Custom Data and Chinese Manufacturing Firms Data, this paper finds four interesting facts. First, there are a number of observations that firms ship the same product to the same destination via both modes within a year, which govern over a third of export value. Moreover, in such mixed-mode export, neither modes take a trivial share. Second, the variation in shipping mode choices is largely explained by firms rather than products or destinations. Third, firms with higher productivity are more likely to export by air. Fourth, the revenues from airborne trade are lower than those from seaborne trade, ceteris paribus. And the shipment of a product via air has higher unit value than that of the same product via sea does.

These facts are puzzling and challenging our understandings of transportation in trade. First, the fact that both modes are adopted by firms to ship the same products to the same destination within one year implies imperfect substitution between two modes of transportation. If different modes are regarded as perfect substitutes for one another, a firm will choose only (or dominantly) one mode that is expected to bring it the largest profits. That means a firm will only choose either air or ocean mode to ship a product to a destination within a year, in which it is usually assumed that consumer preferences and other conditions do not change. In fact, when it comes to month level, the mixed-mode shipping still takes up to 20% of export. Second, under the assumption of perfect substitutable transportation in the existing literature, the fact that air shipping requires higher productivity while generating lower revenues seems to be in the contrary to what Melitz (2003) could predict.

The facts suggest an imperfect substitution between the two modes, which allow us to further differentiate a product into two "varieties" in different modes. This is also supported by the fact that the air shipment of a product has higher unit value than the ocean shipment of the same product does. This differentiation lays possible foundations of explaining the patterns of firms' exporting behavior in two modes.

We first use a simple model to explain the facts we find based on the assumption of imperfect substitution between two transport modes. The simple model uses a CES utility function and equalizes the elasticity of substitution across firms (products) and the one within a product, which makes a product in two transport modes become two monopolistic varieties to consumers. Although we do not seek to explain the underlying reasons for this imperfect substitution, we could rationalize it through demand and supply sides' stories. On the supply side, different transport freight rates induce different choices of quality production and pricing, which differentiate the very product into two different types. On the demand side, due to love for quality and different prices, the same product delivered via different modes could also mean differently to the consumer[1]. Thus, the firms could simultaneously choose two modes to ship the same product to the same destination as long as they bring positive profits. Since the costs of air shipping are higher, it requires higher firm's productivity to make an non-negative profit out of airborne goods. Therefore, more productive firms are more likely to ship goods via air. There are firms without enough productivity to "produce" air shipping goods and they will solely use ocean shipping. For firms that could bear air shipping, they will set a higher price for the airborne product due to higher freight rate and higher quality produced, which is also because of higher freight cost. The high price drives down the demand, further the revenues. Therefore, we could observe that although air shipping requires higher productivity, it bring fewer f.o.b. revenues. The model also predicts that the larger the gap between sea and air distances to the destination is, the more likely for the firms to choose air shipping.

We then relax the assumption of identical elasticities of substitution in the simple model by adopting a nested CES utility function. The elasticity of substitution across firms is now different (lower supposedly) from the one between different transport modes within a product. Therefore, the within-product Bertrand competition between different transport modes is introduced into firm's problem. Due to the complication of pricing and producing strategies in this framework, we mainly use this more general model to derive the equations for estimating the parameters of interest. The estimation results are suggesting a high level of "imperfectness" of substitution between ocean and air shipping goods. The substitutability between goods shipped via two transport modes is close to the one across different products. The imperfect substitution, according to our estimation results, is important and needs to be considered when modeling transportation in trade. We further see how time value varies across different regimes (ordinary and processing trade, recorded according to the Chinese Custom System). We find processing export goods bear higher time value than the ordinary trade goods.

This paper contributes to the literature in international trade studying transport modal choice by raising the idea of modeling imperfect substitution of transportation. Researchers tend to assume that different transport modes are perfectly substitutable in shipping goods (Coşar and Demir (2018), Ge et al. (2014), Hummels and Schaur (2013), etc)[2]. And the

[1] Admittedly, non-homogeneity of consumers is more likely to be the demand side story. But since we do not have detailed information on destination market buyers, we just use this differentiation to partially capture the consumer heterogeneity.

[2] Other methods of modeling transportation involve the idea of endogenous transport costs, such as Allen and

driven forces for choosing air shipping are therefore more about factors including time value (Hummels and Schaur (2013)), lover-for-fastness (Harrigan (2010)) and destination market characteristics (Ge et al. (2014)). This kind of approach falls short of explaining the facts observed in this paper, especially Fact 4.

One serious consequence of not modeling the imperfect substitution is that we might overestimate the value of time. According to the estimation results built on the perfect substitution in Hummels and Schaur (2013), the time value is relatively high with the largest being even equivalent to tariff of 2.1%. This is because when the goods are perfectly substitutable for each other in the two transport modes, the consumers should value the time in delivery more in order to make the demand of air shipping goods high enough, hence high revenues to overcome the high cost of transportation. But when thinking of the substitution as imperfect, a product gets to mean differently to consumers. And the power of consumers' love-for-variety will make time "less" important for them to be willing to pay. However, it does not mean the disutility of delivery is not important. Actually, they are aligning with each other to shape the international trade via different transportation modes.

This paper is also related to the literature decomposing the black box of trade cost. Different from endogenizing transport costs detailedly to study trade cost (Wong (2017) and Brancaccio, Kalouptsidi and Papageorgiou (2017)), this paper estimates one dimension of trade cost: time cost, which is important in the perspective of global value chain. We find high time sensitivity of processing activities, which shows the important role of time as a cost in the global value chain.

Finally, this paper is related to the literature on quality of goods. Hummels and Skiba (2004) find a positive relationship between exporter prices and shipping costs, which is an extended version of the Alchian-Allen hypothesis (Alchian and Allen (1964)). Our paper also confirms this phenomenon. We use the form of quality production in Feenstra and Romalis (2014), which could justify the quality-price relationship. Our estimation of the parameter that governs diminishing returns in the production of quality is close to theirs.

The rest of paper is structured as follows. Section 2 provides a description of data on trade and firms we use and the four facts discovered from the data. Section 3 proposes a model to explain the facts and then a more general theoretical framework. Section 4 discusses the estimation strategy of the parameters of interest and data. Section 5 shows the baseline results and the different time value between ordinary and processing trade. Section 6 concludes and looks forward to further research.

Arkolakis (2019), Brancaccio, Kalouptsidi and Papageorgiou (2017), Hummels, Lugovskyy and Skiba (2009) and Wong (2017). This paper does not seek to endogenize the transport freight rates to a comprehensive extent.

2 Data and facts

In this section, we will first briefly describe the data sources of trade and firms and the matching between them and then show the four facts we observe in the data. These facts suggest the imperfect substitution of different transport modes in the international trade.

2.1 Data on trade and firms

Two major datasets on trade and firms used in this paper are China's transaction-level custom data and Annual Survey of Manufacturing Firm Data between 2000 and 2006. The custom data provides detailed information including firm identifiers which could be used to match with manufacturing firm data, product codes (HS 8-digit codes), destination country, transport mode, transaction value and quantity.

Since the paper focuses only on air and ocean shipping, we leave out transactions in other modes, such as railway and bus. Besides, we keep the products and countries that have both air and ocean shipping records over these seven years so that two modes could potentially be comparable for these products and countries[3]. The comparable product-country pairs take up over 90% of total export value.

The firms in the custom data include intermediary firms who do not directly produce goods. These firms might not be well captured by the theories. Therefore, they will be dropped out in the analysis. And I screen these firms out by dropping the firms that do not appear in the manufacturing firm data. The matching between these two datasets by firm might not be comprehensive but we do our best by following the common approach (Yu (2015)).

2.2 Facts

Four stylized facts are present below. These facts imply imperfect substitution between air and ocean shipping modes for a product. They seem to be in the contrary to some Melitz-theory predictions, such as higher productivity firms should export larger quantities of goods than firms with lower productivity. These facts further inspire the theoretical model. We will first summarize the facts and then explain the underlying analysis.

2.2.1 Fact 1

Fact 1. *There are a number of observations that firms adopt both shipping modes to export the same product to the same destination within a year, which govern over a third of export value. Moreover, in mixed-mode export, neither modes take a trivial share.*

If different modes of transportation are regarded as perfect substitutes for one another, a firm will choose only one (or one dominantly) mode that is expected to bring it the largest

[3] Some products might not be able to shipped by air because they are not loadable on an airplane, such as natural gas and petroleum. And some countries might not open airlines for trade.

profits. That means a firm will only choose either air or ocean mode (dominantly) to ship a product to a destination within a year, in which it is usually assumed that consumer preferences and other conditions do not change.

This (dominantly) one-mode choice behavior has been used in papers discussing substitution of transport modes, as in Coşar and Demir (2018) and Hummels and Schaur (2013). Even if we allow some idiosyncratic shocks as in Allen and Arkolakis (2019), we should still expect to see that "traders are quite homogeneous so that the probability of taking any route that is not very close to optimal is exceedingly small."

However, in the data we found that two modes both appear in a firm-product-destination observations within a year. And in mixed-mode export, neither modes take a trivial share. We calculate the shares of mixed-mode export in total air and ocean export for manufacturing exporting firms in 2002, 2004 and 2006 and found them to be all as high as over 33% as is shown in Table 1. And for each of firm-product-destination observation with mixed modes, we calculate the average shares of airborne trade, which turn out to be around 20% and higher than the total air shipping share. That means the mix of transport modes is not by coincidence so that there might exist one mode, which we could imagine to be air shipping, that is trivial. When we look at the share of air shipping that takes place in the mixed-mode case, it approaches 50%. And the seaborne part of mixed-mode export takes up around 30% in total ocean export. This suggests that we could not well model the transportation modal choices without taking this mixed-mode shipping into account. Besides, idiosyncratic shock alone cannot be used to predict such patterns.

These patterns still hold when we separate the sample into different trade regimes: ordinary trade and processing trade[4]. We also look into a certain market: the U.S. All these statistics are significantly large in the export to the U.S.

Fact 1 implies that two modes might not be perfect substitutes in shipping goods. It is possible that a product shipped via air bears different demands from the same product shipped via sea in the same market. The other facts below will further support this possibility.

[4]China Custom Data has a code, shipment id, recording different regimes. The majority are these two regimes. The ordinary trade is recorded as 10 and processing trade is referring to 14 and 15.

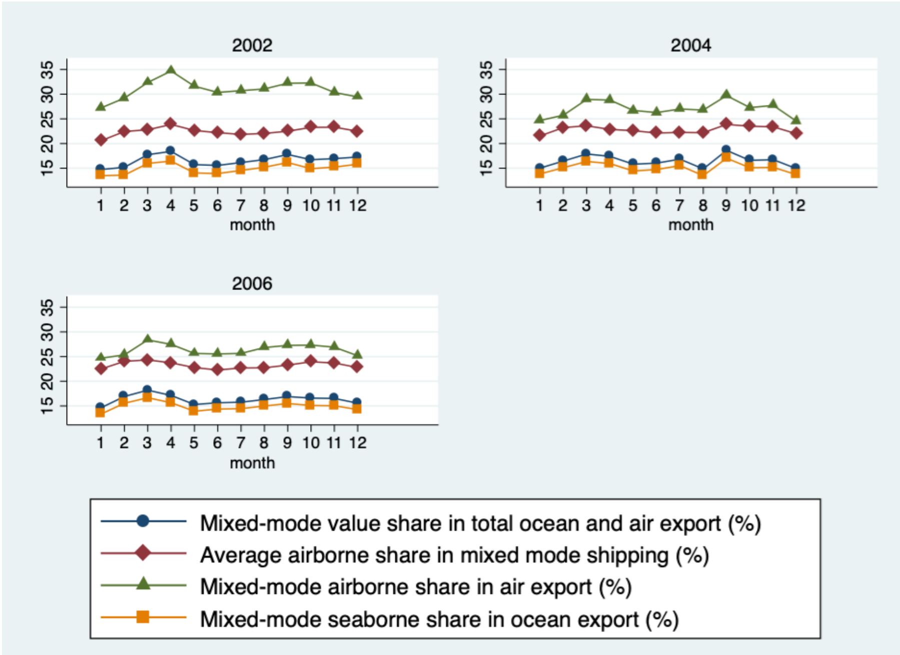
Table 1: Statistics for Fact 1

Statistics	Year	Sample			
		Total	Ordinary trade	Processing trade	To U.S.
Mixed-mode value share in total ocean and air export (%)	2002	36.87	30.12	34.98	45.77
	2004	36.81	32.68	33.9	47.06
	2006	37.17	33.17	33.73	48.32
Average airborne share in mixed mode shipping (%)	2002	19.2	19.74	21.92	17.72
	2004	19.82	19.75	23.55	17.81
	2006	20.36	20.14	24.4	18.92
Mixed-mode airborne share in air export (%)	2002	51.04	48.93	50.48	64.32
	2004	46.16	47.94	44.04	57.94
	2006	46.46	49.4	43.85	61.19
Mixed-mode seaborne share in ocean export (%)	2002	35.23	28.81	32.6	44.13
	2004	35.59	30.64	32	46.12
	2006	35.82	31.78	31.57	46.8

Note: The calculation is based on the data that only includes HS 8-country pairs with the record of both modes between 2000 and 2006. Only manufacturing firms that could match with Annual Survey of Manufacturing Firm Data in the Custom Data are included. "Mixed-mode" refers to the case when a firm adopts both air and ocean shipping to ship the same product (HS 8) to the same destination within one year. The ordinary trade is recorded as 10 in shipment ID variable in the Custom Data and processing trade is referring to 14 and 15.

People might criticize that there might still be some variation across a year so that firms will chooses mixed modes to handle some idiosyncratic shocks. But in fact, when we calculate these statistics at month level, the mixed mode phenomenon are still there as is shown in Figure 1. Mixed-mode value share, now being around 15-20%, is no longer that high but still not trivial.

Figure 1: Monthly statistics for Fact 1



Note: The calculation is based on China Custom Data in 2002, 2004 and 2006. The sample is restricted to manufacturing firms and product-country pairs with records of both shipping modes.

2.2.2 Fact 2

Fact 2. *The variation in shipping mode choices is largely explained by firms rather than products or destinations.*

In order to see what factors affect the transport mode decision making, I first take a look at how different components could explain the variation in modal choice. A priori, one may expect product characteristics to influence the choices. For instance, some fresh goods might expire if the delivery time is too long. Then firms might choose to export goods by air. Also, the characteristics of destination country could be taken into account for the distance from the origin country to the destination, infrastructure conditions and other country-level factors.

Following Coşar and Demir (2018), we run a series of fixed-effect regressions and use their fit to see the explanatory power of different components on the variation of modal choice. The direct effect is the adjusted $R^2$from regressing air shipping share on individual fixed effects. And we also look at the coefficient of partial determination isolating the unique contribution of each component. For example, run the regression $AirShr_{ipd} = \mu_i + \epsilon_{ipd}$ where $\mu_i$is the firm FE and $AirShr_{ipd}$ is the value share of the product (HS 8-digit) p product by firm i to destination country d via air. We use the adjusted R_i^2 from the regression as the direct effect. As for the coefficient of partial determination, we regress the air share on the firm fixed effect and product-country fixed effect, i.e., the regression $AirShr_{ipd} = \mu_i + \mu_{pd} + \epsilon_{ipd}$ to get $R^2_{i,pd}$ and on product-country fixed effect alone, i.e., $AirShr_{ipd} = \mu_{pd} + \epsilon_{ipd}$ to get R^2_{pd}. Then we calculate the coefficient of partial determination for firm by $(R^2_{i,pd} - R^2_{pd})/(1 - R^2_{pd})$, which accounts for the part of the unexplained variation captured when firm fixed effects are left out. This is to isolate the unique variation contribution of each component. Pairs of components are also considered in this analysis.

Both direct effect and partial determination shown in Table 2 indicate that the dominant component is firm and the destination country barely explains the variation. The product component only accounts for as half as the firm does. And when we analysis by pairs, we could see that the direct effect of firm and product combination is slightly larger than firm and country combination, which further suggests the importance of the firm's role. This pattern mostly holds for the partial determination. This result suggests that we should look for the underlying driven force of modal choice mainly at firm. Hummels and Schaur (2013) treat the firms within regions the same, which might not be well supported by this fact.

Now that we have observed those observations with both shipping modes to export the same product to the same destination, people might wonder which component explains the largest part of this kind of modal choice. Therefore, we conduct the similar analysis as above by replacing the left hand side of the air value share with the value share of exporting using both modes. Still, the firm component explains relatively more than other two components do, as is shown in the latter two columns of Table 2. We also divide the sample into two groups: one is the group of ordinary trade regime and the other processing trade. In Panel B and C, we find that the comparative patterns hold again. And we could observe that these components' explanatory contribution all increases. According to the results that product only explains quite a small part of variation, it is not the characteristics of products that could determine to the largest extend whether they could be simultaneously shipped via two transport modes. It also suggests that there would be bias without considering firm heterogeneity.

Table 2: Explaining the Variation

	Air shipping		Mixed-mode shipping	
Component	Direct effect	Partial determination	Direct effect	Partial determination
Panel A: all regimes				
Firm	0.425	0.275	0.138	0.094
Product	0.221	0.035	0.051	0.038
Country	0.02	0.019	0.042	0.055
Firm-Product	0.571	0.57	0.139	0.15
Firm-Country	0.545	0.436	0.139	0.128
Product-Country	0.292	0.108	0.091	0.044
Panel B: ordinary trade				
Firm	0.387	0.247	0.108	0.072
Product	0.197	0.033	0.042	0.033
Country	0.023	0.020	0.036	0.051
Firm-Product	0.544	0.542	0.087	0.102
Firm-Country	0.519	0.421	0.104	0.096
Product-Country	0.276	0.111	0.068	0.030
Panel C: processing trade				
Firm	0.606	0.413	0.238	0.163
Product	0.335	0.025	0.1	0.041
Country	0.02	0.012	0.063	0.054
Firm-Product	0.67	0.667	0.318	0.312
Firm-Country	0.682	0.534	0.213	0.161
Product-Country	0.371	0.063	0.11	0.022

Note: Firms in the sample for this analysis are all manufacturing firms. Panel A includes all types of export regime while Panel B and C focus on ordinary trade and processing trade respectively. The direct effect is the adjusted R^2 from regressing air usage on individual fixed effects. For example, run the regression $Air_{ipc} = \mu_i + \epsilon_{ipc}$ where μ_i is the firm FE and Air_{ipd} is the value share of the product (HS 8-digit) p produced by firm i to country c via air. We use adjusted R_i^2 from this regression as the direct effect. And for the coefficient of partial determination, we regress the air share on the firm fixed effect and product-country fixed effect, i.e., the regression $AirShr_{ipd} = \mu_i + \mu_{pd} + \epsilon_{ipd}$ to get $R^2_{i,pd}$ and on product-country fixed effect alone, i.e., $AirShr_{ipc} = \mu_{pd} + \epsilon_{ipd}$ to get R^2_{pd}. Then we calculate the coefficient of partial determination for firm by $(R^2_{i,pd} - R^2_{pd})/(1 - R^2_{pd})$.

There still remains a question, that is, whether air shipping is mainly used to satisfy some "emergent" demand. If that is the case, we are likely to observe that air shipping might be used more frequently in some months. However, monthly level trends of air shipment and value show no apparent sign of that as is shown in Appendix A.

2.2.3 Fact 3

Fact 3. *Firms with higher productivity are more likely to export by air.*

Given **Fact 2**, we further explore the role of productivity, which is one of the most important characteristics of a firm, in modal choice using 2004 custom and manufacturing firm data. The indicator of air shipping usage, Air_{ipdt}, for firm i shipping its product p to country d in month t is regressed on two different measures of firm i's productivity respectively. One is log of its sales per worker $\ln(sales/worker)_i$ and the other is its TFP_i[5].

Two kinds of productivity both show significantly positive correlation with the probability of air shipping after controlling the product-country-month fixed effect as are shown in column 1 and 2 in Table 3. The patterns still hold after further controlling firm and shipment types in column 3 and 4[6]. In order to see whether the positive correlations are linear, I divide each observations of both measures into four intervals respectively. Four intervals are for values within 0- 25 percentile, 25 to 50 percentile, 50 to 75 percentile and over 75 percentile of each measures. As an example, $TFP[\text{pct25}, \text{pct50}]_i$ equals to 1 if firm i's TFP falls in the interval between 25 and 50 percentile of all TFP observations and $\ln(s/w)[\text{pct25}, \text{pct50}]_i$ is the one for log of sales per worker. In column 5 and 6, there are no signs of non-linearity of these correlations.

[5] The TFP of firms is estimated using the method of Olley and Pakes (1996).

[6] Firm types are the registration types of firms, such as SOEs and private firms. Shipment types are referred to different categories of trade the shipments belong to, such as processing trade and ordinary trade.

Table 3: Firms' productivity and modal choices

VARIABLES	(1) Air_{ipdt}	(2) Air_{ipdt}	(3) Air_{ipdt}	(4) Air_{ipdt}
$\ln(unitvalue)_{ipdt}$	0.0632***	0.0634***	0.0633***	0.0634***
	(0.000791)	(0.000788)	(0.000779)	(0.000780)
$\ln(s/w)_{iy}^{[pct25,pct50]}$		-0.00232		
		(0.00173)		
$\ln(s/w)_{iy}^{[pct50,pct75]}$		0.00434**		
		(0.00185)		
$\ln(s/w)_{iy}^{[pct75,pct100]}$		0.0226***		
		(0.00227)		
$\ln(sales/worker)_{iy}$	0.0120***			
	(0.00119)			
TFP_{iy}			0.0101***	
			(0.00100)	
$TFP_{iy}^{[pct25,pct50]}$				0.00362**
				(0.00159)
$TFP_{iy}^{[pct50,pct75]}$				0.00872***
				(0.00173)
$TFP_{iy}^{[pct75,pct100]}$				0.0240***
				(0.00208)
Constant	0.0248***	0.0826***	0.0498***	0.0782***
	(0.00625)	(0.00169)	(0.00397)	(0.00170)
Observations	7,841,976	7,841,976	7,841,976	7,841,976
Adjusted R-squared	0.221	0.221	0.221	0.221
Industry FE	YES	YES	YES	YES
HS8-Country-Month FE	YES	YES	YES	YES
Unit Type	YES	YES	YES	YES
Shipment Type	YES	YES	YES	YES

Note: The dependent variable is the indicator of air shipping at the firm-product-country-month level. Each $\ln(sales/worker)$ and TFP are further divided into different intervals of percentiles. Robust standard errors clustered at the firm level in parentheses. Significance: * 10%, ** 5%, *** 1%.

An alternative check is carried out by replacing the dummy dependent variable with value share of air shipping at year level and also dropping out the log of transaction unit value since now it is no longer at transaction level. In Table 4, the results demonstrate the same pattern as above.

Table 4: Firms' productivity and modal shares

VARIABLES	(1) $AirShare_{ipdy}$	(2) $AirShare_{ipdy}$	(3) $AirShare_{ipdy}$	(4) $AirShare_{ipdy}$
$\ln(s/w)_{iy}^{[pct25,pct50]}$			-0.000838	
			(0.00184)	
$\ln(s/w)_{iy}^{[pct50,pct75]}$			0.00444**	
			(0.00191)	
$\ln(s/w)_{iy}^{[pct75,pct100]}$			0.0283***	
			(0.00236)	
$\ln(sales/worker)_{iy}$	0.0157***			
	(0.00114)			
TFP_{iy}		0.0137***		
		(0.00100)		
$TFP_{iy}^{[pct25,pct50]}$				0.00777***
				(0.00167)
$TFP_{iy}^{[pct50,pct75]}$				0.0132***
				(0.00187)
$TFP_{iy}^{[pct75,pct100]}$				0.0298***
				(0.00224)
Constant	0.0526***	0.0841***	0.129***	0.123***
	(0.00609)	(0.00381)	(0.00139)	(0.00138)
Observations	2,285,941	2,285,941	2,285,941	2,285,941
Adjusted R-squared	0.274	0.274	0.274	0.274
Industry FE	YES	YES	YES	YES
HS8-Country-Year FE	YES	YES	YES	YES

Note: The dependent variable is the value share of air shipping goods at the firm-product-country-year level. Each $\ln(sales/worker)$ and TFP are further divided into different intervals of percentiles. Robust standard errors clustered at the firm level in parentheses. Significance: * 10%, ** 5%, *** 1%.

2.2.4 Fact 4

Fact 4. *The revenues from airborne trade are lower than those from seaborne trade, ceteris paribus. And the shipment of a product via air has higher unit value than those of the same product via sea.*

Now that higher-productivity firms are more likely to export by air, it should be observed that air shipment generally has higher value than ocean shipment if we just think of two modes are perfect substitutes. To see whether this is the case, we regress log of shipment value $\ln r_{ipdt}$, quantity $\ln q_{ipdt}$ and unit value $\ln(unitvalue)_{ipdt}$ separately on air shipping indicator, controlling firms' productivity, types and shipment productivity and the product-country-month fixed effect. The sign of estimated coefficient for air shipping indicator is expected to be positive with the dependent variable $\ln r_{ipdt}$.

However, it is found that air shipment actually brings significantly smaller revenues to firms as is shown in column 1 in Table 5. Judging by the results in column 2 and 3, the main factor leading to lower value of air shipment is the much lower quantity of it than ocean shipment, especially when the unit value of air shipment is significantly higher than that of ocean shipment.

Since there are cases that two modes are both used in firm-product-destination observations, I further control the firm-product-country-month fixed effect to see the difference within such levels of observations in column 4-6. The coefficient of Air_{ipdt} in column 6 is significantly positive. That means for the same product produced by a firm and shipped to the same destination, it has higher unit value when it is shipped by air. It seems that the same product is different in two modes. In column 4 and 5, we see a significant higher export volume and lower revenues for ocean shipping within the same firm, product and destination.

Table 5: Shipping modes and shipment characteristics

VARIABLES	(1) $\ln r_{ipdt}$	(2) $\ln q_{ipdt}$	(3) $\ln(unitvalue)_{ipdt}$	(4) $\ln r_{ipdt}$	(5) $\ln q_{ipdt}$	(6) $\ln(unitvalue)_{ipdt}$
Air_{ipdt}	-1.687***	-2.253***	0.456***	-1.997***	-2.267***	0.122***
	(0.00961)	(0.0114)	(0.00601)	(0.0101)	(0.0112)	(0.00306)
TFP	0.0866***	0.00980	0.0868***			
	(0.00611)	(0.00769)	(0.00416)			
Constant	9.248***	8.126***	1.072***	9.993***	8.432***	1.611***
	(0.0228)	(0.0290)	(0.0163)	(0.00297)	(0.00330)	(0.000898)
Observations	7,754,586	7,811,655	7,841,976	2,521,915	2,575,686	2,623,674
Adjusted R-squared	0.301	0.486	0.709	0.436	0.605	0.899
Industry FE	YES	YES	YES	YES	YES	YES
HS8-Country-Month FE	YES	YES	YES	YES	YES	YES
Shipment Type	YES	YES	YES	YES	YES	YES
Firm-HS8-Country-Month				YES	YES	YES
Unit Type			YES	YES	YES	YES

Note: The dependent variables are the log of shipment value $\ln r_{ipdt}$, quantity $\ln q_{ipdt}$ and unit value $\ln(unitvalue)_{ipdt}$ for firm i's product p exported to destination d in month t. Robust standard errors clustered at the firm level in parentheses. Significance: * 10%, ** 5%, *** 1%.

2.3 Discussion on these facts

Based on these facts, we know that it is misleading to ask whether airborne shipping is more advanced shipping technology than sea shipment. According to Melitz-Helpman-Yeaple type explanation, a more advanced technology should have lower variable cost but higher fixed cost. It has been well documented that the air freight rate is higher than the ocean one, indicating that it is a less advanced shipping technology according to the Melitz-Helpman-Yeaple wisdom. We cannot assert that the air shipment is less advanced either, because it is found that firms with higher productivity are more likely to export goods by air, which is a sign of more advanced technology by Melitz-Helpman-Yeaple criteria.

Theoretically speaking, firms will end up using mostly the optimal mode if there is one and if different transport modes are perfectly substitutable. However, this is not supported by

Fact 1.

Fact 3 and **Fact 4** are in the contrary to Melitz-theory predictions, i.e. higher productivity firms should export larger quantities of goods than firms with lower productivity[7].

If two modes are perfect substitutes for each other, a firm would only choose one way to ship a product to a destination given that its productivity and demands are usually assumed to stay unchanged within a year. It further implies that the mode chosen by the firms with higher productivity must bring more revenues. Therefore, with these facts, we might be able to solve the puzzles by differentiating a product into two "varieties" due to the imperfect substitution between two transport modes. This seemingly bold hypothesis will guide the following theoretical model.

3 Theory

We will first use a simple model to explain the facts we find based on the assumption of imperfect substitution between two transport modes. The simple model uses a CES utility function and equalizes the elasticity of substitution across firms (products) and the one within a product, which makes a product in two transport modes two monopolistic varieties to consumers. By using the addictive form of transport costs and endogenous quality choice as in Feenstra and Romalis (2014), the model allows firms with higher productivity to be more likely to "produce" the air shipping goods while making smaller revenues out of them, mainly due to the higher prices of them. Besides, the products that are shipped via a more costly way have a higher level of original quality, which resonates with the Alchian-Allen hypothesis. In addition, the delivery time (measured as the number of days) comes into a multiplier that discounts the original quality to delivered quality as in Hummels and Schaur (2013). The model also predicts that the larger the gap between sea and air distances to the destination is, the more likely for the firms to choose air shipping.

We then relax the assumption of identical elasticities of substitution in the simple model and adopt a nested CES utility function. The elasticity of substitution across firms is now different from the one between different transport modes within a product. Therefore, the within-product Bertrand competition between different transport modes is introduced into firm's problem. Due to the complication of pricing and producing strategies under this framework, we mainly use this more general model to derive the equations for estimating the parameters of interest.

3.1 A simple model to explain the facts

Given the one exporting country, the importing countries are indexed by d whose representative consumer's utility function is a CES combination of quality-augmented quantities of

[7]See Appendix B that follows partially the set-up of the simple model in section 3.1 for an illustration

different varieties as:

$$U_d = (\int_{\Omega_d} (z_\omega q_\omega)^{\frac{\eta-1}{\eta}} d\omega)^{\frac{\eta}{\eta-1}},$$

where z_ω is the delivered quality and ω is the index of varieties. Since we simply assume that the elasticity of substitution between different transport modes of a product, η, is the same as the one across the products, the variety is actually a interaction between the product and its shipping mode. In other words, consumers now are treating a product shipped by different transport modes just in the way they treat other different products. This set-up is an "extreme" case where the substitution within a product is as "imperfect" as the one across products. Although we have argued there exists an imperfect substitution between different transport modes for a product, one might expect the elasticity of this substitution to be quite large, or at least larger than the one among other products[8]. However, as we will show below, these two kinds of elasticities are relatively close to each other. Here we just adopt this strong assumption for the simplicity of illustration. In the following section, we will relax this assumption.

This kind of differentiation allows for each variety to participate in a monopolistic competition. And the consumer's demand is

$$q_\omega = (U_d P_d^\eta) p_\omega^{-\eta} z_\omega^{\eta-1},$$

where the destination country price index is

$$P_d = (\int_{\Omega_d} p_\omega^{1-\eta} d\omega)^{\frac{1}{1-\eta}}.$$

Now we set up more detailed terms, starting with the delivered quality of goods. We denote a set of potential transport modes $M = \{A, S\}$, where A represents air shipping and S ocean shipping[9]. This set is actually endogenous since some transport modes might not be adopted by firms due to negative profits. For the product i shipped via transport mode m to the destination country d, it has an original quality z^o_{mid}. Long journey of delivery discounts this original quality in the way of not only depreciation but also consumer's disutility of slow delivery. We denote the discounting multiplier as t_{md} for the transport mode m to country d. Then the delivered quality of goods is

$$z_{mid} = t_{md} z^o_{mid},$$

where

$$t_{md} = e^{-\gamma d_{md}},$$

[8] The perfect substitution between two goods could be considered as the case when the elasticity approaches infinity.

[9] Here we just consider those two dominant transport modes in the world. But including other modes is also valuable in other contexts and the model allows for that.

in which γ ($\gamma \geq 0$) is the parameter of the delivery time (measured as the number of days) d_{md} in terms of disutility. It is easy to see that $t_{md} \leq 1$. The longer the delivery days are, the lower the multiplier is, thus, lower delivered quality. This form of disutility is the same as the one in Hummels and Schaur (2013).

Next we specify the supply side. We assume each firm produces a unique product, hence potentially two varieties under the two transport modes. The labor is assumed to be inelastically supplied to firms. The firm i is exogenously endowed with the productivity φ_i. We follow Feenstra and Romalis (2014) to assume that the firms combine labor with the productivity in the production of quality:

$$z^o_{mid} = (l_{mid}\varphi_i)^\theta,$$

where l_{mid} is the amount of labor the firm i uses to produce the product shipped via m to d. And $0 < \theta < 1$ reflects the diminishing returns to quality.

The marginal production cost is therefore assumed to be a function of the quality a firm choose to produce and its productivity as

$$C(z^o, \varphi) = \frac{(z^o)^{\frac{1}{\theta}} w}{\varphi},$$

where w is the wage. In our partial equilibrium, we could just normalize the wage to be one in the origin country.

In a world with Free-On-Board trade agreement, it is the buyer who pays the freight fees and tariffs, rather than the producer (exporter). Following the common set-up in the existing literature, we assume an addictive form of freight rate f_{md} for transport mode m to the destination d and an ad-valorem iceberg trade cost $\tau_d > 1$ that depends only on the destination[10]. Then we have the relation between the delivered price p_{mid} and the producer price p^o_{mid}, which is the f.o.b. price:

$$p_{mid} = \tau_d(p^o_{mid} + f_{md}). \tag{1}$$

For the product in each transport mode, the firm faces the following problem:

$$\max_{p^o, z^o} q_{mid}[p^o - C(z^o, \varphi_i)], \tag{2}$$

which gives a cost-minimizing original quality choice:

$$(z^o_{mid})^{\frac{1}{\theta}} = \frac{\theta}{1-\theta}\varphi_i f_{md}, \tag{3}$$

[10] Here we just assume that the freight rate is exogenous to the exporting firms and each firm faces the same variable transport cost for the same transportation to the same destination. Endogenous choices of freight rate is important and our model does allow for endogenous freight rates across products. But we do not seek to endogenizie the choice within a transport mode since it is not our focus.

and the corresponding optimal producer pricing strategy[11]:

$$p^o_{mid} = p^o_{md} = \frac{\eta\theta + 1 - \theta}{(\eta - 1)(1 - \theta)} f_{md} \equiv \kappa f_{md}. \tag{4}$$

Intuitively, the firms with higher productivity will be able to produce higher quality goods. And higher shipping cost accompanying higher quality of goods confirms the Alchian-Allen hypothesis. More importantly, these factors altogether allow for the products in the more costly way of shipping to have higher f.o.b. prices, which is recorded in Fact 4.

The consumption in the destination should be decided by the delivered quality and prices, which gives us the equilibrium quantity:

$$q_{mid} = (U_d P_d^\eta)(\frac{\theta}{1-\theta}\varphi_i)^{\theta(\eta-1)} \tau_d^{-\eta} (\kappa + 1)^{-\eta} e^{-\gamma(\eta-1)d_{md}} f_{md}^{\theta(\eta-1)-\eta}, \tag{5}$$

and the f.o.b. revenues:

$$r^o_{mid} = (U_d P_d^\eta)(\frac{\theta}{1-\theta}\varphi_i)^{\theta(\eta-1)} \tau_d^{-\eta} \kappa(\kappa + 1)^{-\eta} e^{-\gamma(\eta-1)d_{md}} f_{md}^{(\theta-1)(\eta-1)}. \tag{6}$$

It is easy to see that higher freight rates for air shipping will drive down the consumption of air shipping goods, further the revenues. The term of time value plays an effect of the opposite direction, though. Since the airborne consumption and revenues are systematically smaller than the ocean shipping as in Fact 4, we could expect the pro-effect of time value to be smaller than the freight rates' effect.

In order to understand the firms' modal choice, we calculate the producer's profits:

$$\pi_{mid} = \frac{r^o_{mid}}{\eta\theta + 1 - \theta} - F_{md}, \tag{7}$$

where we assume the fixed cost of exporting to country d via m is F_d. We could find a productivity cutoff $\bar{\varphi}_{md}$ for shipping via m to d by

$$\frac{r^o_{mid}(\bar{\varphi}_{md})}{\eta\theta + 1 - \theta} = F_{md}, \tag{8}$$

solving which gives us

$$\bar{\varphi}_{md} = f_{md}^{\frac{1-\theta}{\theta}} e^{\frac{\gamma}{\theta}d_{md}} \frac{1-\theta}{\theta} \kappa^{\frac{1}{\theta(1-\eta)}} (\kappa+1)^{\frac{\eta}{\theta(\eta-1)}} \tau_d^{\frac{\eta}{\theta(\eta-1)}} (U_d P_d^\eta)^{\frac{1}{\theta(1-\eta)}} F_{md}^{\frac{1}{\theta(1-\eta)}}. \tag{9}$$

Higher air freight rate pushes up the productivity cutoff for air shipping, allowing only firms with high enough productivity to ship goods via air. That describes the Fact 2.

Comparing these two cutoffs, we have

[11] The derivation of the optimal producer quality and price follows Feenstra and Romalis (2014). The optimal price is a markup timing the marginal cost: $p^0_{mid} = \frac{\eta}{\eta-1} C(z^0_{mid}, \varphi_i)$. Solving optimal quality requires to minimize the quality-average freight-rate-inclusive marginal cost: $\frac{C(z^o_{mid}, \varphi_i) + f_{md}}{z^o_{mid}}$, which gives $(z^o_{mid})^{\frac{1}{\theta}} = \frac{\theta}{1-\theta}\varphi_i f_{md}$. Substituting this into the optimal price will get the optimal price as a function of freight rates.

$$\frac{\bar{\varphi}_{Sd}}{\bar{\varphi}_{Ad}} = \left(\frac{F_{Sd}^{\frac{1}{1-\eta}} e^{\gamma d_{Sd}} f_{Sd}^{1-\theta}}{F_{Ad}^{\frac{1}{1-\eta}} e^{\gamma d_{Ad}} f_{Ad}^{1-\theta}}\right)^{\frac{1}{\theta}}. \tag{10}$$

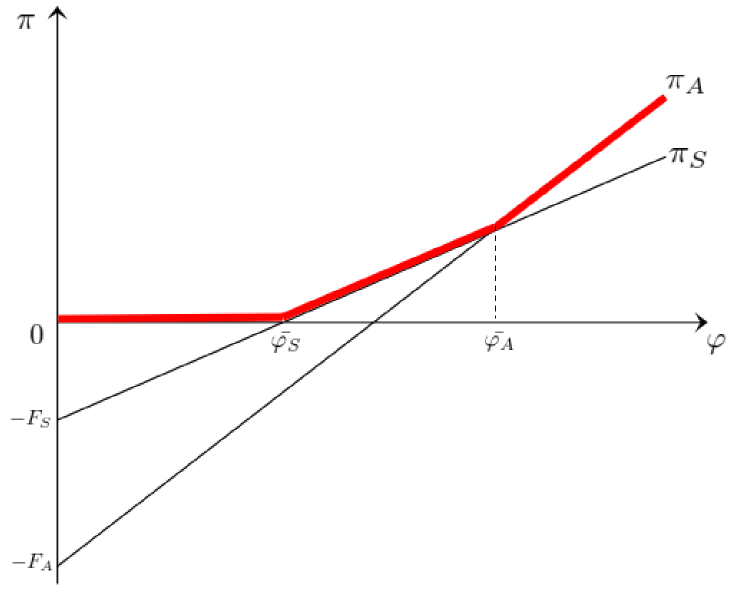
Considering that freight rates increase with traveling distance, we are able to predict that for the country d that has a larger gap between ocean and air distances, hence the larger this cutoff ratio. Then firms are relatively more likely to export via air.

To see this, we first look at the two distances. The great-circle straight-line distances are usually used as one part of trade costs. However, shipment does not often travel in that kind of ways, especially for the seaborne shipment. But we could take the great-circle distances as the ones airplanes travel between countries, hence bearing the airborne trade. On the other hand, the distances vessels travel are the ones seaborne trade are transported through. These two kinds of distances sometimes differ a lot from each other, such as the two between China and U.K. A vessel from Shanghai to London needs to take some detours due to the shape of continents, including crossing the Strait of Malacca and Suez Canal. This route will be much longer than the one airplane travels between two cities. While a vessel from Shanghai to Hokkaido might travel like a straight line as an airplane does. We could expect the difference between two distances in the former case to be larger than the latter. And we could expect the relative air freight rate over ocean one to be lower in the former. Relatively lower cost leads to firms being easier to export via air.

3.2 Perfect vs imperfect substitution

In this section we will show some differences between what is going on under two different assumption of transportation substitution. Figure 2 shows what the two profit lines look like and how the modal choice are made for different firms under perfect substitution. Of course now firms are abstracted by their productivity. In order to allow some firms to export via air when the air shipping cutoff is higher, the time value should be high enough to make the slope of π_A steeper than π_S, and larger fixed cost for air export. Given the fact that air freight rate is usually higher than ocean, ceteris paribus, we expect a very high time value parameter γ. Let us just suppose these conditions are satisfied. Then firms will compare two kinds of profits and choose air shipping not when it makes positive profits but when its profits exceed the ocean one. The red line represents the real profit line of firms based on their modal choices. Constant elasticity further implies higher revenues for air shipping when φ exceeds $\bar{\varphi}_A$, which is the productivity cutoff for air shipping. However, this is in contradictory to **Fact 4**. Variable markup or non-constant elasticity will not change this contradiction.

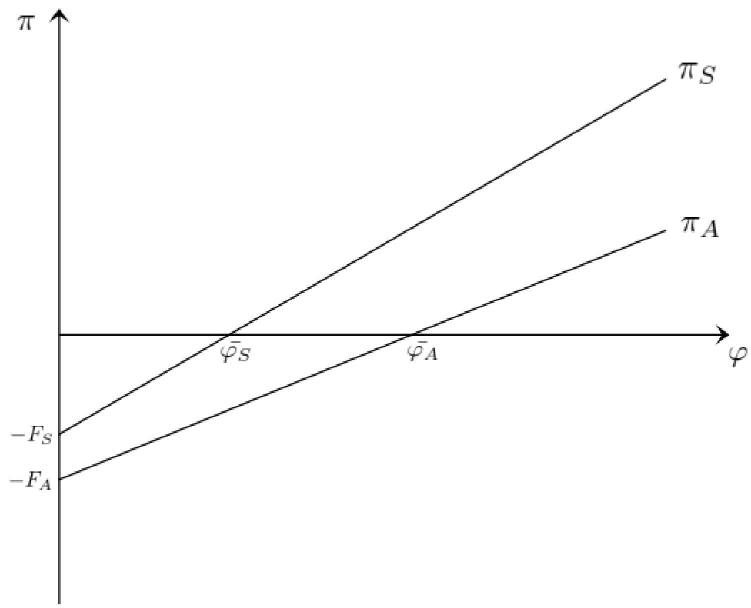
Figure 2: Profits and productivity under perfect substitution



Note: The mathematical ground for this figure is shown in Appendix B. φ is the firm productivity. F_S and F_A are fixed cost for ocean and air export. π represents the profits.

What happens when the substitution between transport modes are imperfect? In Figure 3, we could see that now firms make modal choice not based on the comparison between profitability of different ways of export. Thus, when the profits of air shipping turn positive, there will be air shipping. In addition, the profits of air shipping do not need to exceed the ocean to make it happen, which make it likely to fit the data patterns. And this further implies a lower time value.

Figure 3: Profits and productivity under imperfect substitution



Note: The mathematical ground for this figure is shown in section 3.3. φ is the firm productivity. F_S and F_A are fixed cost for ocean and air export. π represents the profits.

Now we summarize how this simple model could explain the facts we find. Under the imperfect substitution of transportation, a product could be further differentiated into different varieties in different transport modes. Although we do not seek to explain the underlying reasons for this imperfect substitution, we could rationalize it through demand and supply sides. On the supply side, different transport freight rates induce different choice of quality production and pricing, which differentiate the very product into two different types. On the demand side, due to love for quality and different prices, the same product delivered via different modes could also mean differently to the consumer. With such a differentiation, the firms could simultaneously choose two modes to ship the same product to the same destination, which explains the **Fact 1**. Since the costs of air shipping are higher, it requires higher productivity for firms to make an non-negative profit out of air shipping goods. Therefore, more productive firms are more likely to ship goods via air, which resembles the **Fact 2**. There are firms without enough productivity to "produce" air shipping goods and they will solely use ocean shipping. For firms that could bear air shipping, they will set a higher price for the product shipped via air due to higher freight rate cost and higher quality, which is also because of higher freight cost. The high price drives down the demand, further the revenues. Therefore, we could observe that although air shipping requires higher productivity, it bring fewer f.o.b. revenues. These explain the **Fact 4**.

3.3 A more general model

Now we relax the assumption that the elasticity across the products is equal to the one between transport modes within a product by using a nested CES preference[12]. This is essentially similar as Atkeson and Burstein (2008). The upper nest is given by

$$U_d = (\int_{I_d} Q_{id}^{\frac{\eta-1}{\eta}} di)^{\frac{\eta}{\eta-1}}, \tag{11}$$

where Q_{id} is a product-level aggregate that depends on the quality and the quantity of the varieties in different transport modes:

$$Q_{id} = [\sum_{m \in M_{id}} (z_{mid} q_{mid})^{\frac{\rho-1}{\rho}}]^{\frac{\rho}{\rho-1}}. \tag{12}$$

Here M_{id} is the set of transportation firm i would use to ship its product to d, which is an endogenous choice set. Intuitively, we expect the varieties are more substitutable within products than across products, and both are greater than 1: $\rho > \eta > 1$. Given (11) and (12), we have the country price index as

$$P_d = (\int_{I_d} P_{id}^{1-\eta} di)^{\frac{1}{1-\eta}}, \tag{13}$$

where P_{id} is a product-level quality-adjusted price index:

$$P_{id} = [\sum_{m \in M_{id}} (\frac{p_{mid}}{z_{mid}})^{1-\rho}]^{\frac{1}{1-\rho}}. \tag{14}$$

Furthermore, the demand for each transport mode of a firm is:

$$q_{mid} = (U_d P_d^{\eta}) P_{id}^{\rho-\eta} p_{mid}^{-\rho} z_{mid}^{\rho-1} \tag{15}$$

Next we could calculate the market share of the product i shipped via m to d in the total sales of firm i in d as

$$S_{mid} \equiv \frac{p_{mid} q_{mid}}{\sum_{m'} p_{m'id} q_{m'id}} = (\frac{p_{mid}/z_{mid}}{P_{id}})^{1-\rho}, \tag{16}$$

which further allows us to get the price elasticity of demand as a function of the market share:

$$\sigma_{mid} \equiv -\frac{d \ln q_{mid}}{d \ln p_{mid}} = \rho(1 - S_{mid}) + \eta S_{mid} = (\eta - \rho) S_{mid} + \rho. \tag{17}$$

since $d \ln P_{id} / d \ln p_{mid} = S_{mid}$. Here when η is very close to ρ, the elasticity of demand will just be more constant and close to ρ, which approaches the simple model discussed above.

When it comes to the firms' problem, the optimal original quality choice is still given by

[12] The variable notations that also appear above have the exactly same meanings here.

(3) while the optimal producer price becomes

$$p_{mid}^o = \frac{\sigma_{mid}}{\sigma_{mid}-1}C(z_{mid}^o, \varphi_i)$$
$$= \frac{\sigma_{mid}\theta + 1 - \theta}{(\sigma_{mid}-1)(1-\theta)} f_{md} \equiv \kappa_{mid} f_{md} \tag{18}$$

It is more close to the real world that κ_{mid} now changes with firms, transportation and destination instead of depending solely on the transportation and destination. Feenstra and Romalis (2014) do not need to care much about the razor-edge type of price because they rely on industry rather than firm-level prices. But in this paper, **Fact 2** implies that we could not neglect the variation at firm level. This more general form also enables us to better estimate the parameters by using the information at firm level, which is what Hummels and Schaur (2013) cannot do.

The profit-maximizing demand and the revenues are now more complicated as

$$q_{mid} = (U_d P_d^{\eta}) P_{id}^{\rho-\eta} (\frac{\theta}{1-\theta}\varphi_i)^{\theta(\rho-1)} \tau_d^{-\rho} (\kappa_{mid}+1)^{-\rho} e^{-\gamma(\rho-1)d_{md}} f_{md}^{\theta(\rho-1)-\rho}, \tag{19}$$

and

$$r_{mid}^o = (U_d P_d^{\eta}) P_{id}^{\rho-\eta} (\frac{\theta}{1-\theta}\varphi_i)^{\theta(\rho-1)} \tau_d^{-\rho} \kappa_{mid} (\kappa_{mid}+1)^{-\rho} e^{-\gamma(\rho-1)d_{md}} f_{md}^{(\theta-1)(\rho-1)}. \tag{20}$$

And we rewrite the market share using the optimal prices and quality as

$$S_{mid} = \frac{[(\kappa_{mid}+1) f_{md}^{1-\theta} e^{\gamma d_{md}} (\frac{\theta}{1-\theta}\varphi_i)^{-\theta}]^{1-\rho}}{P_{id}^{1-\rho}}. \tag{21}$$

Similar as the simple model above, the firms will choose the shipping mode if it brings the positive profits:

$$\pi_{mid} = \frac{\kappa_{mid}+1}{\kappa_{mid}\sigma_{mid}} r_{mid}^o - F_{md} > 0.$$

Again as in the simple model, it requires higher productivity to make revenues high enough to make a positive profit. When the productivity is not high enough to make $\pi_{Ad}(\varphi) > 0$, firms will only choose ocean shipping and $\sigma_{Sid} = \eta$, $\kappa_{Sid} = \frac{\eta\theta+1-\theta}{(\eta-1)(1-\theta)}$. As the productivity increases and exceeds the cutoff point such that share of air shipping becomes positive, the share of air shipping will increase, driving down the ocean shipping share. As a matter of fact, (21) will render several fixed point solutions for the share. This model is not able to demonstrate the relationship between the share and the productivity, therefore, we do not know what drives to the case when the firm will only choose air shipping, which only takes a small percentage of the total export. But it does allow share equals to 0 or 1 as solutions.

As is shown above, it is hard to get some analytical terms under a nested CES set-up. Therefore, we rely on this set-up for derivation of equations that could be used to estimate the time valuation parameter and elasticities of substitution. Unlike Hummels and Schaur (2013), our model could not back out a constant term that represents the price or tariff-equivalent of the time delay. But the range of it could be obtained. And we have a proposition for it:

Proposition 1. *The range of the price or tariff-equivalent of the time delay is* $[\gamma(1-\frac{1}{\eta}), \gamma(1-\frac{1}{\rho})]$.

Proof. See Appendix C. □

According to this proposition, as the substitutability goes down, i.e., ρ decreasing to η, the upper bound of time value decreases. It show that the goods substitutability and time value are two substitutable factors that drive the air shipping choice. Intuitively, if the goods are themself not that substitutable, then it does not need that much love for time to make the faster delivery happen. We need to estimate γ, η, ρ in order to know this range. The next section is to derive the equations that could be used for estimation.

4 Estimation strategy and data

This section mainly uses the equations derived above to estimate the parameters we are interested in, including valuation of time γ, the elasticity of substitution within product ρ, and the elasticity of substitution across firms η. Applying the theoretical structures to the real world could comes across complicated issues, including the measurement error problems. We adopt the exogenous sea and air distances as IVs to tackle the issues.

4.1 Estimation regression equations

One advantage of our estimation framework is that it could be carried out by simply reduced form regressions and the endogeneity issues are not serious or easy to deal with. By (19) and (21), we have:

$$\begin{aligned}
\frac{q_{Sid}}{q_{Aid}} &= \frac{(\kappa_{Sid}+1)^{-\rho} e^{-\gamma(\rho-1)d_{Sd}} f_{Sd}^{\theta(\rho-1)-\rho}}{(\kappa_{Aid}+1)^{-\rho} e^{-\gamma(\rho-1)d_{Sd}} f_{Ad}^{\theta(\rho-1)-\rho}} \\
&= \frac{[(\kappa_{Sid}+1) f_{Sd}^{1-\theta} e^{\gamma d_{Sd}}]^{-\rho} e^{\gamma d_{Sd}} f_{Sd}^{-\theta}}{[(\kappa_{Aid}+1) f_{Ad}^{1-\theta} e^{\gamma d_{Ad}}]^{-\rho} e^{\gamma d_{Ad}} f_{Ad}^{-\theta}} \\
&= (\frac{S_{Sid}}{S_{Aid}})^{\frac{\rho}{\rho-1}} e^{\gamma(d_{Sd}-d_{Ad})} (\frac{f_{Sd}}{f_{Ad}})^{-\theta},
\end{aligned}$$

the log form of which is:

$$\ln \frac{q_{Sid}}{q_{Aid}} = \frac{\rho}{\rho-1} \ln \frac{S_{Sid}}{S_{Aid}} + \gamma(d_{Sd}-d_{Ad}) - \theta \ln \frac{f_{Sd}}{f_{Ad}}. \tag{22}$$

Writing S_{mid} as $(p_{mid}+f_{md})q_{mid}$ in (22) and arranging $\frac{q_{Sid}}{q_{Aid}}$ to the left hand side allows us to have

$$\frac{q_{Sid}}{q_{Aid}} = (\frac{p_{Aid} + f_{Ad}}{p_{Sid} + f_{Sd}})^{\rho} e^{-\gamma(\rho-1)(d_{Sd}-d_{Ad})} (\frac{f_{Sd}}{f_{Ad}})^{\theta(\rho-1)},$$

the log form of which is:

$$\ln\frac{q_{Sid}}{q_{Aid}} = \rho\ln(\frac{p_{Aid} + f_{Ad}}{p_{Sid} + f_{Sd}}) + (\rho-1)[\theta\ln\frac{f_{Sd}}{f_{Ad}} - \gamma(d_{Sd} - d_{Ad})]. \tag{23}$$

The regression equation derived from (22) is:

$$\ln\frac{q_{Sipd}}{q_{Aipd}} = \beta_0 + \beta_1\ln\frac{S_{Sipd}}{S_{Aipd}} + \beta_2(d_{Sd} - d_{Ad}) + \beta_3\ln\frac{f_{Sd}}{f_{Ad}} + \epsilon_{ipd}, \tag{24}$$

where $\hat{\beta_2} = \gamma$ and $\hat{\beta_3} = -\theta$. These regressions are enough to estimate the time valuation parameter γ, along with the shape of quality production, θ. Here we use $\beta_0$to capture some constant shifters that might be missing in the model. After obtaining estimated γ and θ, we are able to construct a term that is needed to estimate ρ using a regression equation derived from (23):

$$\ln\frac{q_{Sipd}}{q_{Aipd}} = \alpha_0 + \alpha_1\ln(\frac{p_{Aipd} + f_{Ad}}{p_{Sipd} + f_{Sd}}) + \alpha_2[\hat{\theta}\ln\frac{f_{Sd}}{f_{Ad}} - \hat{\gamma}(d_{Sd} - d_{Ad})] + \epsilon_{ipd}. \tag{25}$$

where $\hat{\alpha_2} = (\rho - 1)$.

Rearranging (18) and using estimated θ, we are able to calculate the elasticity of demand by:

$$\sigma_{mipd} = \frac{(1-\theta)p^o_{mipd}/f_{md} + 1 - \theta}{(1-\theta)p^o_{mipd}/f_{md} - \theta}. \tag{26}$$

Ideally we could estimate $\eta - \rho$ from regression of (17), where the left hand side is the elasticity of demand and right hand side is the share term. However, this form of regression will mainly suffer from the simultaneous equation bias. Therefore, we need further manipulation of equations and assumption. First, it is innocuous to assume that the unobserved idiosyncratic shocks to (17) have zero mean:

$$\sigma_{mipd} = (\eta - \rho)S_{mipd} + \rho + v_{mipd}, \tag{27}$$

where $E(v_{mipd}) = 0$. Adding air and ocean versions of (27) together renders:

$$\sigma_{Sipd} + \sigma_{Aipd} = \eta + \rho + v_{Sipd} + v_{Aipd}.$$

Taking the expected form and rearranging it will give us:

$$\eta = E(\sigma_{Sipd} + \sigma_{Aipd}) - \rho.$$

Therefore, we could get an unbiased estimate of η as:

$$\hat{\eta} = \frac{\sum_{i,p,d}(\sigma_{Sipd} + \sigma_{Aipd})}{N} - \hat{\rho}. \tag{28}$$

where N is the number of firm-product-country.

The framework we develop here could overcomes several problems in Hummels and Schaur (2013). First, according to the Alchian-Allen hypothesis, quality choices are potentially correlated with freight costs and many papers, including ours, have confirmed that, but their estimation models fail to capture the quality part. In our framework, the quality choice is captured by the parameter θ, hence solving this potential omitted variables issue. Second, their not considering the imperfect substitution between transport modes will lead to the endogeneity from wrong functional form, and they also use some approximation that ignore the firm-level variation. Our estimation, on the other hand, could make use of the firm-level information and is based on an assumption of demand side that resembles the data patterns better. However, there is a shortcoming of this method: the sample could only contain the observations with both modes appearing in a firm-product-destination. There might be some product or destination countries not meeting this criteria, hence left out. In fact, for the single mode export, there will be no explicit way to estimate the parameters under imperfect substitution assumption.

4.2 Data in estimation

We describe the datasets and samples we use in this part of estimation. First, we need freight rates for the two transport modes. The trade data from COMTRADE that includes both exporter and importer reports for each flow of trade at HS 6-digit level. We use 2004 COMTRADE data because it is the latest one of what we have. Admittedly, it is not easy to back out some reasonable freight rates since the trade data itself has measurement error. The process of obtaining the two freight rates is show in Appendix D. Since the freight rates are estimated as functions of distances, it is not necessary to use some IVs to solve some endogeneity issues for them.

Then it comes to the shipping time data. Following Hummels and Schaur (2013), we set all numbers of air shipping days to one, which is a reasonable assumption as we could imagine. The ocean shipping days are calculated based on the vessels' traveling time we capture from Marinetime.com[13]. Since the earliest data are in 2017 and there was expected to be some transportation technology concerning traveling speed from 2004 to 2017, we have to admit that there are measurement error issues in the time difference variable as well.

We turn to IVs for solving measurement error issues. There are two variables that could be used as IVs for time difference ($d_{Sd} - d_{Ad}$). They are log forms of ocean distances and straight-line great circle distances. It is intuitive to think of them as IVs because traveling

[13]This website records the actual traveling information for almost all registered vessels in the world. We calculate vessel-number weighted shipping days to each destination country from China as the ocean shipping days.

time are undoubtedly correlated with traveling distances. We use the shortest maritime distance between countries from TRADHIST data provided by Fouquin, Hugot et al. (2016) and the great-circle distances between the most populated cities in two countries from CEPII. The former distances are actually counterfactual distances and are determined by natural geographic properties.

5 Results

5.1 Baseline results

The time valuation parameter and quality production function shape estimation, which uses (24), are shown in Table 6. In column (1) we estimate the regression without IVs and obtain the time value parameter γ as 0.00532 and θ as 0.411. After using IVs, γ is estimated to be 0.00856 while θ 0.585. These are all with the correct sign and θ the magnitude fitting the assumption, $0 < \theta < 1$.

Table 6: Estimating time valuation parameter

VARIABLES	(1) $\ln \frac{q_{Sipd}}{q_{Aipd}}$	(2) $\ln \frac{q_{Sipd}}{q_{Aipd}}$
$\ln \frac{S_{Sipd}}{S_{Aipd}}$	1.067***	1.068***
	(0.00139)	(0.00240)
$(d_{Sd} - d_{Ad})$	0.00532***	0.00856***
	(0.000279)	(0.00259)
$\ln \frac{f_{Sd}}{f_{Ad}}$	-0.411***	-0.585***
	(0.0367)	(0.166)
Constant	0.187*	-0.384
	(0.108)	(0.511)
Observations	42,789	42,789
R-squared	0.940	0.939
1st-stage F-stat		27.18

Note: The firms that appear in the data for this estimation are all manufacturing firms. The estimated coefficient of $(d_{Sd} - d_{Ad})$ is γ and that of $\ln \frac{S_{Sipd}}{S_{Aipd}}$ is $-\theta$. Robust standard errors clustered at the country level in parentheses for the model in column (2). The IVs are the log forms of ocean and air distances. Significance: * 10%, ** 5%, *** 1%.

We mark the IV-estimated parameters with a superscript "IV" and construct the RHS of interest in (25) using different estimated parameters. And we conduct the regression of (25) to estimate $\rho - 1$. The results are shown in Table 7. The estimated $(\rho - 1)$ are 1.589 and 1.051 from different pairs of γ and θ, both being statistically significant. The reason why we do not use the coefficient of $\ln(\frac{p_{Aipd}+f_{Ad}}{p_{Sipd}+f_{Sd}})$ is that this is a variable suffering serious endogenous problems as we could imagine. We denote $\hat{\rho} = 2.589$ and $\hat{\rho}^{IV} = 2.051$. The subscript "IV" refers to using γ and θ estimated with IV method.

Table 7: Estimating elasticity of substitution between transport modes

VARIABLES	(1) $\ln\frac{q_{Sipd}}{q_{Aipd}}$	(2) $\ln\frac{q_{Sipd}}{q_{Aipd}}$
$\ln(\frac{p_{Aipd}+f_{Ad}}{p_{Sipd}+f_{Sd}})$	1.762***	1.763***
	(0.0186)	(0.0186)
$\hat{\theta}\ln\frac{f_{Sd}}{f_{Ad}} - \hat{\gamma}(d_{Sd}-d_{Ad})$	1.589***	
	(0.177)	
$\hat{\theta}^{IV}\ln\frac{f_{Sd}}{f_{Ad}} - \hat{\gamma}^{IV}(d_{Sd}-d_{Ad})$		1.051***
		(0.112)
Constant	2.444***	2.344***
	(0.229)	(0.208)
Observations	42,789	42,789
R-squared	0.200	0.201

Note: The firms that appear in the data for this estimation are all manufacturing firms. The term, $\hat{\theta}^{IV}\ln\frac{f_{Sd}}{f_{Ad}} - \hat{\gamma}^{IV}(d_{Sd}-d_{Ad})$, is constructed using $\hat{\theta}^{IV}$ and $\hat{\gamma}^{IV}$. The coefficient of it is $\rho-1$. Significance: * 10%, ** 5%, *** 1%.

Merely estimating ρ to be a small value is not meaningful without comparing to the elasticity of substitution across firms (products), η. We need to estimate η to see how different they are. When estimating η using (28), the two elasticities of demand in this equation are constructed based on (26) and might not return reasonable magnitudes as a result of model's abstraction from the real world. Therefore, we need to screen the sample according to our theoretical assumptions. Firstly, we trim the constructed σ_{Sipd} and σ_{Aipd} at top and bottom 2.5%. Secondly, we drop out the sample with $\sigma_{Sipd}+\sigma_{Aipd}$ larger than $[2\hat{\rho}+2*\sigma(\hat{\rho})]$ or smaller than $[1+\hat{\rho}-\sigma(\hat{\rho})]$, where $\sigma(\hat{\rho})$ is the standard error of estimated $\rho-1$. This is to approximate the assumptions of $\rho>\eta>1$. Based on the parameters estimated using non-IV method, we have $\hat{\eta}=1.705$. The estimated $\hat{\eta}^{IV}$ is 1.508 when the parameters are obtained from IV method. The gap between $\hat{\rho}$ and $\hat{\eta}$ and the one between $\hat{\rho}^{IV}$ and $\hat{\eta}^{IV}$ are both very small. And we can calculate the intervals of tariff-equivalent of one day in transit as: [0.22%, 0.33%] from non-IV method and [0.29%, 0.44%]. We prefer the result from IV method as estimated γ is quite different from the one in non-IV method, which suggesting there exists measurement errors in $d_{Sd}-d_{Ad}$ term. In our baseline estimation, one day in transit equals to 0.29% to 0.44% of ad-valorem tariff.

The estimation results are suggesting a high level of "imperfectness" of substitution between ocean and air shipping goods. The substitutability between goods shipped via two transport modes is close to the one across different products. The imperfect substitution, according to our estimation results, is important and needs to be considered when modeling transportation in trade. One consequence of not modeling the imperfect substitution is that we might overestimate the value of time. According to the estimation results built on the perfect substitution in Hummels and Schaur (2013), the time value is relatively high with the lowest being equivalent to tariff of 0.6% and the highest even 2.1%. This is because the goods are perfectly substitutable for each other in the two transport modes. Then the consumers should value the time in delivery more in order to make the demand of air shipping goods high enough, hence high revenues to overcome the high cost of transportation. But when thinking of the substitution as imperfect, a product gets to mean differently to consumers. And the power of consumers' love-for-variety comes into effect when they are now different varieties: it will make time "less" important for them to be willing to pay. But it does not mean the disutility of delivery is not important. Actually, they are aligning with each other to shape the international trade via different transportation modes.

5.2 Ordinary and processing trade

Timeliness of production implies a process of accumulation of time cost. With our method of tariff-equivalent of one day in transit, we are able to decompose the time value for delivering goods in different parts of production. The Custom Data has a variable "shipment ID" recording different regimes of trade. We care about how different does the delivery time mean to two regimes: ordinary and processing trade. The definition of these regimes should be distinguished from the way intermediate goods and consumption goods are defined. The definition of processing trade is that "business activities in which the operating enterprise imports all or part of the raw or ancillary materials, spare parts, components, and packaging materials, and re-exports finished products after processing or assembling these materials/parts.". Therefore, processing trade could be considered as outsourcing activities while ordinary trade is usually exporting goods made from local materials and inputs (Manova and Yu (2016)). As we mentioned before, the ordinary trade is recorded as 10 while the processing trade includes assembly processing 14 and input processing 15.

We separate the data into two groups of regimes and estimate those parameters for these two regimes following the procedure above. Table 8 and 9 report the estimation results of γ, $-\theta$, and $\rho-1$ for ordinary and processing trade respectively. Looking at the IV method results, γ for ordinary trade is 0.0065 much smaller than 0.0119 for processing trade. The elasticity of substitution between transportation is 1.942 for ordinary trade lower than 2.315 of processing trade. The elasticity of substitution across firms is 1.482 for ordinary trade still lower than that for processing trade.

We just focus on the preferred IV method results and the time value interval for the ordinary trade is [0.2%, 0.29%] while processing trade [0.46%, 0.68%]. The difference is mainly driven by time sensitivity parameter γ rather than the elasticity. Time value is significantly higher for processing trade than ordinary trade. To rationalize this, we can think about how the roles of goods in ordinary are different from those in processing trade. The goods of processing trade could be thought as something needed in one stage of the production or sales for foreign firms. To domestic producers, they are involved in a externally determined plan of production or sales. Any cost included in the products of processing trade will be passed on and accumulated to the final demanders. Then it will be more time-sensitive. This comparative statistic demonstrates the important role of time as a cost in the context of global value chain.

Table 8: Estimation: ordinary trade

VARIABLES	(1) $\ln \frac{q_{Sipd}}{q_{Aipd}}$	(2) $\ln \frac{q_{Sipd}}{q_{Aipd}}$	(3) $\ln \frac{q_{Sipd}}{q_{Aipd}}$	(4) $\ln \frac{q_{Sipd}}{q_{Aipd}}$
$\ln \frac{S_{Sipd}}{S_{Aipd}}$	1.061***	1.061***		
	(0.00154)	(0.00242)		
$(d_{Sd} - d_{Ad})$	0.00310***	0.00605**		
	(0.000312)	(0.00242)		
$\ln \frac{f_{Sd}}{f_{Ad}}$	-0.511***	-0.671***		
	(0.0423)	(0.161)		
$\ln(\frac{p_{Aipd}+f_{Ad}}{p_{Sipd}+f_{Sd}})$			1.664***	1.665***
			(0.0205)	(0.0205)
$\hat{\theta} \ln \frac{f_{Sd}}{f_{Ad}} - \hat{\gamma}(d_{Sd} - d_{Ad})$			1.208***	
			(0.242)	
$\hat{\theta}^{IV} \ln \frac{f_{Sd}}{f_{Ad}} - \hat{\gamma}^{IV}(d_{Sd} - d_{Ad})$				0.942***
				(0.156)
Constant	0.0183	-0.508	2.232***	2.316***
	(0.125)	(0.495)	(0.372)	(0.321)
Observations	34,435	34,435	34,435	34,435
R-squared	0.938	0.938	0.181	0.182
1st-stage F-stat		27		

Note: The firms that appear in the data for this estimation are all manufacturing firms. The sample is also restricted to ordinary trade by keeping shipment ID equaling to 10. The estimated coefficient of $(d_{Sd} - d_{Ad})$ is γ and that of $\ln \frac{S_{Sipd}}{S_{Aipd}}$ is $-\theta$. Robust standard errors clustered at the country level in parentheses for the model in column (2). The IVs are the log forms of ocean and air distances. The term, $\hat{\theta}^{IV} \ln \frac{f_{Sd}}{f_{Ad}} - \hat{\gamma}^{IV}(d_{Sd} - d_{Ad})$, is constructed using $\hat{\theta}^{IV}$ and $\hat{\gamma}^{IV}$. The coefficient of it is $\rho - 1$. Significance: * 10%, ** 5%, *** 1%.

Table 9: Estimation: processing trade

VARIABLES	(1) $\ln \frac{q_{Sipd}}{q_{Aipd}}$	(2) $\ln \frac{q_{Sipd}}{q_{Aipd}}$	(3) $\ln \frac{q_{Sipd}}{q_{Aipd}}$	(4) $\ln \frac{q_{Sipd}}{q_{Aipd}}$
$\ln \frac{s_{Sipd}}{s_{Aipd}}$	1.073***	1.073***		
	(0.00318)	(0.00644)		
$(d_{Sd} - d_{Ad})$	0.00854***	0.0119***		
	(0.000591)	(0.00295)		
$\ln \frac{f_{Sd}}{f_{Ad}}$	-0.355***	-0.526***		
	(0.0671)	(0.158)		
$\ln(\frac{p_{Aipd}+f_{Ad}}{p_{Sipd}+f_{Sd}})$			1.806***	1.805***
			(0.0383)	(0.0383)
$\hat{\theta} \ln \frac{f_{Sd}}{f_{Ad}} - \hat{\gamma}(d_{Sd} - d_{Ad})$			1.862***	
			(0.239)	
$\hat{\theta}^{IV} \ln \frac{f_{Sd}}{f_{Ad}} - \hat{\gamma}^{IV}(d_{Sd} - d_{Ad})$				1.315***
				(0.172)
Constant	0.0301	-0.524	2.434***	2.515***
	(0.199)	(0.493)	(0.282)	(0.297)
Observations	9,141	9,141	9,141	9,141
R-squared	0.937	0.936	0.222	0.222
1st-stage F-stat		28		

Note: The firms that appear in the data for this estimation are all manufacturing firms. The sample is also restricted to ordinary trade by keeping shipment ID equaling to 14 and 15. The estimated coefficient of $(d_{Sd} - d_{Ad})$ is γ and that of $\ln \frac{s_{Sipd}}{s_{Aipd}}$ is $-\theta$. Robust standard errors clustered at the country level in parentheses for the model in column (2). The IVs are the log forms of ocean and air distances. The term, $\hat{\theta}^{IV} \ln \frac{f_{Sd}}{f_{Ad}} - \hat{\gamma}^{IV}(d_{Sd} - d_{Ad})$, is constructed using $\hat{\theta}^{IV}$ and $\hat{\gamma}^{IV}$. The coefficient of it is $\rho - 1$. Significance: * 10%, ** 5%, *** 1%.

6 Conclusion

This paper seeks to answer what different transport modes mean to consumers and firms in trade and how much consumers value the time of delivery.

Using China Custom Data and Chinese Manufacturing Firms Data, this paper finds four facts that had not been documented before. First, there are a number of observations that firms adopt both shipping modes to export the same product to the same destination within a year, which govern over a third of export value. Moreover, in mixed-mode export, neither modes take a trivial share. Second, the variation in shipping mode choices is largely explained by firms rather than products or destinations. Third, firms with higher productivity are more likely to export by air. Fourth, the revenues from airborne trade are lower than those from seaborne trade, ceteris paribus. And the shipment of a product via air has higher unit value than that of the same product via sea does. The facts suggest the imperfect substitution between the two modes, which makes it possible to further differentiate a product into two "varieties" in different modes. This is also supported by the fact that the air shipment of a product has higher unit value than the ocean shipment of the same product does. This differentiation lays possible foundations of explaining the patterns of firms exporting behavior in two modes.

We will first use a simple model to explain the facts we find based on the assumption of imperfect substitution between two transport modes. The simple model uses a CES utility function and equalizes the elasticity of substitution across firms (products) and the one within a product, which makes a product in two transport modes two monopolistic varieties to consumers. By using the addictive form of transport costs and endogenous quality choice as in Feenstra and Romalis (2014), the model allows firms with higher productivity to be more likely to "produce" the air shipping goods while making smaller revenues out of them, mainly due to the higher prices of them. Besides, the products that are shipped via a more costly way have a higher level of original quality, which resonates with the Alchian-Allen hypothesis. In addition, the delivery time (measured as the number of days) comes into a multiplier that discounts the original quality to delivered quality as in Hummels and Schaur (2013). The model also predicts that the larger the gap between sea and air distances to the destination is, the more likely for the firms to choose air shipping. This prediction will guide us later in the estimation to tackle the endogeneity issue.

We then relax the assumption of identical elasticities of substitution in the simple model and adopt a nested CES utility function. The elasticity of substitution across firms is now different from the one between different transport modes within a product. Therefore, the within-product Bertrand competition between different transport modes is introduced into firm's problem. Due to the complication of pricing and producing strategies under this framework, we mainly use this more general model to derive the equations for estimating the parameters of interest. The estimation results are suggesting a high level of "imperfectness" of substitution between ocean and air shipping goods. The substitutability between goods shipped via two transport modes is close to the one across different products. The imperfect substitution, according to our estimation results, is important and needs to be considered when modeling transportation in trade.

We further see how time value varies between different regimes (ordinary and processing trade) We find processing export goods bear higher time value than the ordinary trade goods. It shows the important role of time as a cost in the context of global value chain.

Further research will also focus on more disaggregated estimation of time value and using the model to see the economic impact of some counterfactual transportation technology improvement. Last but not least, we long for more precise data on transport freight rates for our analysis.

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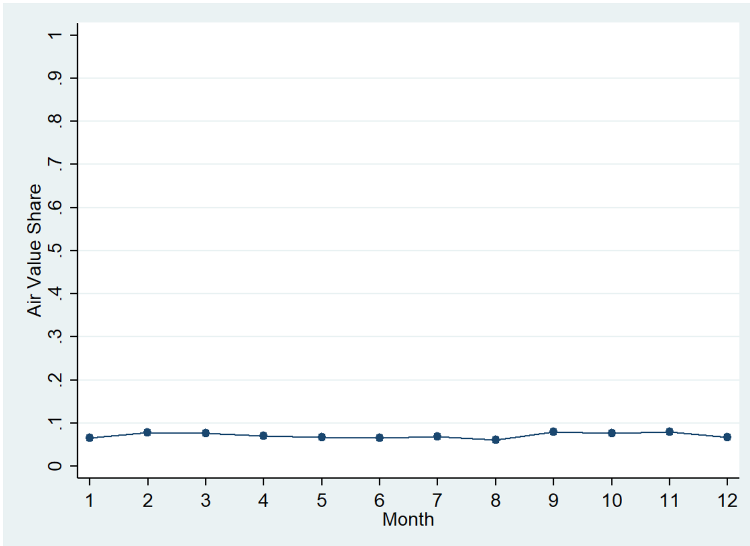
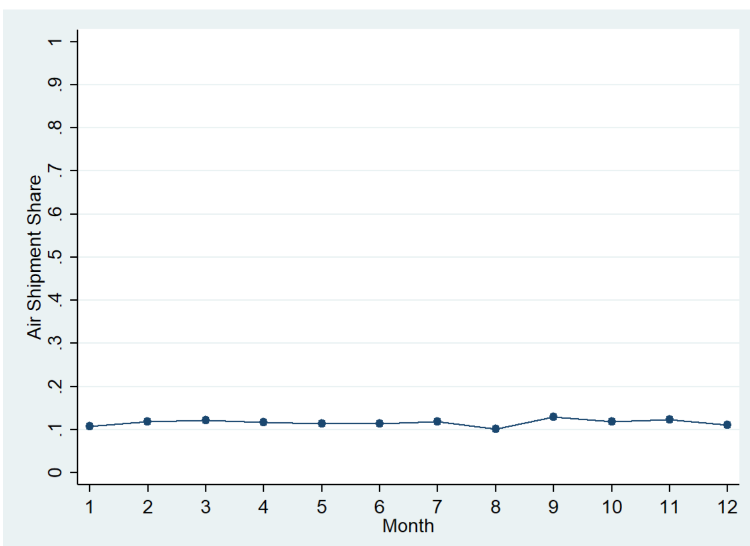
A Monthly trends of air shipping

Figure 4: Monthly trend of air shipping value share



Note: The calculation is based on China Custom Data in 2004.

Figure 5: Monthly trend of air shipment share



Note: The calculation is based on China Custom Data in 2004.

B Perfect substitution case

This section derives the model under the assumption of perfect substitution between modes and shows why it could predict results in contrary to the data. Following most set-up of the simple model in section 3.1 except for the different substitution, we first need to define ω to be just the index of firm (product) rather than shipping mode-firm (product) pair index. Thus,

$$U_d = (\int_{I_d} (z_i q_i)^{\frac{\eta-1}{\eta}} di)^{\frac{\eta}{\eta-1}}.$$

The other terms that contain ω change accordingly.

Different pricing and producing strategies under different modes are still the same. However, the firms now will decide on whether to ship via certain mode by comparing the profits from these two modes rather simply see if they make positive profits. That is, the firm will choose mode m_1 over m_2 if $\pi_{m_1 id} > \pi_{m_2 id}$. By **Fact 3** we know that the productivity cutoff of air shipping is supposed to be higher than the one of ocean shipping in this model. The productivity cutoff of ocean shipping is:

$$\bar{\varphi}_{Sd} = f_{Sd}^{\frac{1-\theta}{\theta}} e^{\frac{\gamma}{\theta} d_{Sd}} \frac{1-\theta}{\theta} \kappa^{\frac{1}{\theta(1-\eta)}} (\kappa+1)^{\frac{\eta}{\theta(\eta-1)}} \tau_d^{\frac{\eta}{\theta(\eta-1)}} (U_d P_d^{\eta})^{\frac{1}{\theta(1-\eta)}} F_{Sd}^{\frac{1}{\theta(1-\eta)}}.$$

Nevertheless, the productivity cutoff of air shipping is no longer the one in section 3.1 because now the air shipping profits need to surpass the ocean shipping so as to make it happen. That is,

$$\pi_{Ad}(\bar{\varphi}_{Ad}) = \pi_{Sd}(\bar{\varphi}_{Ad}).$$

After doing the math as in Coşar and Demir (2018), we can write firm revenues as follows:

$$r_d(\varphi) = r_{Sd}(\bar{\varphi}_{Sd})(\frac{\varphi}{\bar{\varphi}_{Sd}})^{\theta(\eta-1)},\ if\ \varphi < \bar{\varphi}_{Ad},$$

and

$$r_d(\varphi) = r_{Sd}(\bar{\varphi}_{Sd})(\frac{\varphi}{\bar{\varphi}_{Sd}})^{\theta(\eta-1)}(\frac{f_{Ad}}{f_{Sd}})^{(\theta-1)(\eta-1)},\ if\ \varphi \geq \bar{\varphi}_{Ad}.$$

Since $f_{Ad} > f_{Sd}$ all the time, the revenues from air shipping should be higher than the ones from ocean shipping, ceteris paribus. This is the opposite of what we have observed in the data.

C Proof of Proposition 1

First we rewrite the demand as:

$$q_{mid} = (U_d P_d^{\eta})[\sum_{m \in M_{id}} (\frac{p_{mid}}{z_{mid}})^{1-\rho}]^{\frac{\rho-\eta}{1-\rho}} p_{mid}^{-\rho} (e^{-\gamma d_{md}} z_{mid}^{o})^{\rho-1},$$

the log form of which is:

$$\ln q_{mid} = \ln(U_d P_d^{\eta}) + \frac{\rho-\eta}{1-\rho} \ln[\sum_{m \in M_{id}} (\frac{p_{mid}}{z_{mid}})^{1-\rho}] - \rho \ln p_{mid} - \gamma(\rho-1) d_{md} + (\rho-1) \ln z_{mid}^{o}.$$

Then we could obtain two derivatives:

$$\frac{\partial \ln q_{mid}}{\partial \ln p_{mid}} = \Upsilon_{mid} - \rho,$$

and

$$\frac{\partial \ln q_{mid}}{\partial d_{md}} = \Upsilon_{mid}\gamma - \gamma(\rho-1),$$

where

$$\Upsilon_{mid} \equiv (\rho-\eta) \frac{(\frac{p_{mid}}{z_{mid}})^{1-\rho}}{\sum_{m \in M_{id}} (\frac{p_{mid}}{z_{mid}})^{1-\rho}} = (\rho-\eta) S_{mid}.$$

Since one transportation might not be used, S_{mid} could range from 0 to 1. Therefore, $\Upsilon_{mid} \in [0, (\rho-\eta)]$.

Let

$$F_{mid} = \frac{\partial \ln q_{mid}}{\partial d_{md}} / (\frac{\partial \ln q_{mid}}{\partial \ln p_{mid}}) = \frac{\Upsilon_{mid}\gamma - \gamma(\rho-1)}{\Upsilon_{mid} - \rho}.$$

This is the price or tariff-equivalent of time delay. To understand this, we first need to see that $-\frac{\partial \ln q_{mid}}{\partial \ln p_{mid}}$ measures the percent of demand raised by a 1 percent price reduction, and $-\frac{\partial \ln q_{mid}}{\partial d_{md}}$ is the one raised by a one day reduction in delivery time. That means F translates days of delay into a price (or tariff) equivalent form, and $-\frac{\partial \ln q_{mid}}{\partial \ln p_{mid}}$ translates this into the quantity of lost sales.

We could easily see that

$$\frac{\partial F}{\partial \Upsilon_{mid}} = \frac{\gamma - 1}{(\Upsilon_{mid} - \rho)^2} < 0,$$

because γ is usually smaller than 1. That is, $F$is monotonically decreasing in Υ_{mid}.

Therefore,

$$F \geq \frac{(\rho-\eta)\gamma - \gamma(\rho-1)}{\rho-\eta-\rho} = \gamma(1 - \frac{1}{\eta}),$$

and

$$F \leq \frac{-\gamma(\rho-1)}{-\rho} = \gamma(1 - \frac{1}{\rho}).$$

D Obtaining freight rates

Many papers have found misreport in c.i.f. and f.o.b. data in COMTRADE. For example, c.i.f. unit value could be even smaller than f.o.b. one. In order to back out some reasonable freight rates from the gap between c.i.f. and f,o.b. value, we need to first trim the data. Firstly, we collapse China's Custom Data in 2004 to HS-6 digit-Country level with ocean and air export value and quantity. And we keep those without exporting in other transport modes.

Then we merge the part from Custom Data with COMTRADE data by each HS-6 digit and destination country. Since we have the total f.o.b. value and quantity calculated based on Custom Data for each HS-6 digit- country pair, which is more authentic than COMTRADE, we keep those pairs with difference from Custom Data not exceeding 5%. Besides, we drop those pairs with c.i.f. unit value being over ten times of f.o.b. unit value or being smaller than f.o.b. unit value. This step is to minimize the measurement error.

Accounting of freight rates goes as:

$$r_{pd}^{cif} - r_{pd}^{fob} = f_{Sd} \cdot q_{Spd} + f_{Ad} \cdot q_{Apd},$$

where p represents HS-6 level product.

In the reality there are certainly some variations across firms and products in freight rates to the same destination. In order to obtain the country-specific freight rates, we assume the freight rates as functions of log form of distances: $f_{md} = f_m(\ln dist_{md})$. More specifically, we assume them to be:

$$f_{md} = a_m + b_m \ln dist_{md},$$

or

$$f_{md} = a_m + b_m \ln dist_{md} + c_m (\ln dist_{md})^2.$$

We then use the sample with ocean shipping only to estimate the function form of ocean freight rate and the sample with air shipping only to estimate the one of air freight rate. It is because that we want to reduce the measurement errors of the left hand side freight rates. When the shipping method is simply one, it is easier for the custom to verify the data given one transport mode, thus, less chance of recording wrong number.

Now we need to back out the revealed freight costs for each HS-6 product to each destination by each transport mode, F_{mpd}. It is calculated by:

$$F_{mpd} = \left(\frac{r_{mpd}^{cif}}{q_{mpd}^{cif}} - \frac{r_{mpd}^{fob}}{q_{mpd}^{fob}}\right) / q_{mpd}^{fob},$$

which could be realized when the mode is only one. The regression result is in Table 10. We only adopt the forms with all parameters significantly estimated. The freight rate functions are:

$$f_{Sd} = 0.04 \times \ln dist_{Sd} + 1.267,$$

and

$$f_{Ad} = -97.567 \times \ln dist_{Ad} + 5.765 \times (\ln dist_{Ad})^2 + 438.68.$$

Table 10: Estimating freight rate function

VARIABLES	(1) F_{Spd}	(2) F_{Spd}	(3) F_{Apd}	(4) F_{Apd}
$\ln dist_{Sd}$	0.0398*	0.124		
	(0.0232)	(0.434)		
$(\ln dist_{Sd})^2$		-0.00478		
		(0.0246)		
$\ln dist_{Ad}$			1.359	-97.57*
			(2.997)	(54.51)
$(\ln dist_{Ad})^2$				5.765*
				(3.172)
Constant	1.267***	0.899	16.04	438.7*
	(0.220)	(1.903)	(26.70)	(234.1)
Observations	22,825	22,825	1,252	1,252
R-squared	0.000	0.000	0.000	0.003

Note: Significance: * 10%, ** 5%, *** 1%.