Incomplete Contracts in Commodities Trade: Evidence from LNG

Swati Dhingra, Ningyuan Jia, Gianmarco Ottaviano, Thomas Sampson, and Catherine Thomas
LSE, Bocconi, CEP, and CEPR

PRELIMINARY. PLEASE DO NOT CITE.

September 18, 2023*

Abstract

Long-term contracts between buyers and sellers of commodities are common even in industries where goods are also traded on global spot markets. This paper investigates the relative efficiency of the long-term contracts in liquefied natural gas (LNG) that accounted for 75% of total industry volumes from 2009 to 2019. Shipment-level data are used to estimate a structural model of LNG supply and demand where sellers exert relationship-specific effort in relationships governed by incomplete contracts. The model is identified by exogenous demand shifts from weather shocks and variation in shipment delivery times. The results suggest sellers' efforts help ensure contract shipments fit buyers' desired quantities and timings better than their alternative spot market options. Local spot markets are thin due to their small size and supply-side frictions due to bulky vessels and the long distances between buyers and sellers. A counterfactual that supplies all shipments to spot markets, holding quantities and final destinations constant, shows that contracts increased the value of the global industry by over 50% over the period studied because the returns to seller effort within contractual relationships outweighed the negative spillovers on spot market size.

*We thank Enrico Cavallotti and Edoardo Tolva for excellent research assistance. We are very grateful to Kpler for providing the detailed industry data and thank Shell for enabling access to these data. Heski Bar-Isaac, Jordi Blanes, Bob Gibbons, and Davin Chor, as well as seminar participants at LSE, Lucca IMT, and ERWIT provided very helpful comments. All conclusions are our own.

1 Introduction

Long-term contracts are common in situations where buyers and sellers are locked into bilateral relationships having made transaction-specific durable investments (Klein, Crawford, and Alchian (1978), Williamson (1979), Masten and Crocker (1985)). This can be more efficient than arm's length transactions if contracts reduce costly future contention about how to divide the quasi-rents. However, ex ante investments with long time horizons require contractual arrangements that are flexible enough to adapt to unpredictable changes to supply and demand without being impractical to design and implement.

The paper examines the efficiency of long-term contracts in the global liquefied natural gas (LNG) industry that last up to twenty years. Natural gas provides around 23% of the world's energy and nearly 40% is supplied in its liquefied form (IEA, 2021), with around three quarters of these volumes being transacted within long-term bilateral contractual relationships. Our research question here is how well contracts achieve potential gains from trade by mitigating bargaining frictions while adapting to varying circumstances. We also estimate the distribution of the gains between buyers and sellers, within contracts and in local spot markets.

Sellers of LNG have made large capital investments in liquefaction plants, called trains, and marginal production costs are very low. As a result, plants tend to produce at close to capacity and total output is unresponsive to spot prices. LNG is then transported from sellers to buyers in large, specialized vessels that are often owned by either the seller or buyer. Buyers, who have also made large capacity investments in regasification terminals, and who typically operate with some excess capacity, are subject to demand shocks due to unexpected weather conditions. Contracts specify an annual quantity to be transacted between the buyer and seller at a price that is typically indexed to oil prices rather than to destination-specific LNG spot prices. Zahur (2020) analyzes the timing of contract signing relative to capital investments and documents that contracts duration can be as long as the typical productive life of the initial investments. This paper focuses on how contracts operate from week to week, as buyers and sellers bilaterally negotiate the arrival times of individual contracted shipments throughout the year.

Data on shipment times and weather conditions in the largest LNG destinations between 2009 and 2019 show that the quantity of contracted LNG arriving at a destination responds to local weather shocks. That is, in weeks when it is unexpectedly cold, buyers receive more LNG under contract. Sellers deliver LNG at times when it is particularly valuable to their contract partners: the buyers in contractual relationships are treated as "priority customers". It is notable that these times coincide with when the seller's outside option—selling on the spot market—is most valuable because spot prices are also positively correlated with weather shocks.

Our analysis shows buyers have a higher value for delivered contract shipments than for the shipments they purchase on local spot markets. Although LNG is itself a commodity, it is available on spot markets

only in discrete quantities that may not coincide with buyer demand at any point in time. We find that sellers exert relationship-specific effort within contractual relationships to deliver shipments at valuable times. We estimate sellers must extract around one half of the overall contract relationship value via the contract price in order for them to find it incentive compatible to exert costly effort and forgo their spot market outside options when they fulfil contract requests. We also find that contracts contribute to the total industry gains from trade. A counterfactual industry-level analysis finds that converts all contract shipments to spot is welfare-reducing.[1]

The shipment-level data used in this paper were made available to us by the company Kpler, a provider of data and analytic solutions for commodity markets. The data include information on the origin and destination of each LNG shipment, the volumes at origin and destination, the nature of the vessel, and the voyage duration. The data on LNG spot prices was downloaded from EIKON and destination-specific weather data came from the World Bank Climate Knowledge Portal.

The paper has three sets of empirical analysis. The first is a reduced-form investigation of variation in volumes at the route-week level. The quantities flowing to destinations are larger when it is unseasonably cold. We show that contract volumes respond to weather shocks. These findings are evidence that sellers try to send contract shipments to their relationship partners at times when buyers have the highest value for those shipments.[2]

The second analysis explores the hypothesis that buyers value contract shipments over spot shipments given observed spot prices and quantities. The logic underlying this hypothesis is that if it were not the case, there would be no contract relationship surplus that could be shared with the seller, and no economic rationale explaining why sellers are consistently willing to send contract shipments rather than sell on the spot market exactly when the spot prices are high. Using buyers' revealed preference for contract shipments at times of similar demand conditions but varying spot prices, we estimate a lower bound on the typical contract premium. Intuitively, this premium must be sufficient to compensate sellers for not deviating from the contract when spot prices are high and compensate buyers for not deviating from the contract when spot prices are low. The estimated mean of the relative value for the contract shipments studied is \$1.66 per mmbtu of LNG, which compares to a mean average spot price over the period of \$8.64.

This second analysis is limited in that it focuses only on contract shipments arriving at times when the

[1]Contractual relationships have proved to be very resilient during the energy crisis due to the war in Ukraine. Sellers continued to deliver contract shipments despite all-time high spot prices. Two notable exceptions were Eni and Gunvor in early 2022, who did not deliver anticipated contract shipments to Pakistan S&P (2022). While the total share of spot volumes had been increasing up to 2020, this trend has recently reversed, "LNG term contract volumes have leapt this year, as energy security becomes paramount worldwide" S&P (2023).

[2]Contract volumes are more responsive to weather shocks on routes where shipping is done by either seller (DES) or the buyer (FOB) than on routes where the shipper is a third party.

buyers also purchased at least one spot shipment. These are likely the times when willingness to pay for LNG was high. More importantly, it is a partial analysis in that it provides estimates of contract value holding fixed spot market equilibria prices. To ask the more fundamental question of how much value contracts create compared to the counterfactual of no contracts at all, and to investigate how that value is created and shared along the value chain, we turn to the third analysis in the paper, which constructs and estimates a structural model of the LNG industry.

In the model, we allow buyer value for LNG to be a function of local weather. For contract shipments, buyer value is also a function of the relationship-specific effort exerted by sellers to deliver the ideal quantities at the ideal times. The amount of effort the seller exerts depends on how much their effort contributes to buyer value, the costs of effort, and the share of contract surplus the seller extracts. In each period, buyers observe weather conditions and choose whether to request a contract shipment or to buy on the spot market. The spot value depends on an idiosyncratic shock drawn from a distribution with an expected value that is an increasing function of local spot market thickness in that period.[3] The model delivers a set of theoretical moments related to the probability a contract buyer calls in a contract shipment in a given week as a function of the weather and model parameters.

Because the model focuses on route-week-level buyer decisions, it abstracts from several key features of the industry. Critically, it does not take into account explicitly any capacity constraints for the seller or any trade-offs the seller has to make between demand from multiple contract partners. We do two things to accommodate the seller-level dependencies across contracts. First, we include a fixed cost of fulfilling contract shipments that is a function of the number of contract requests a seller fulfils in a week, relative to the typical number of contract shipments. Second, we estimate the model parameters on a subset of the data—route-weeks where the seller sells at least some positive quantities on the spot markets. These are quantities that sellers could have allocated to contract partners without being capacity constrained.

We estimate the model using maximum likelihood and parameter identification is made possible by independent variation in the relationships between contract timing and spot prices, holding weather constant, and between contract timing and weather shocks, holding spot prices constant. Using the model estimates to predict the untargeted moments of the elasticity of contract shipments with respect to weather shocks and spot prices gives values that are close to those in the data.

The results include distributions of estimates of the willingness to pay for the LNG in contract and spot shipments on each route-week in the sample. An mmbtu via a contract shipment is more than twice as valuable, on average, given the current size of the spot markets.[4] The lower bound on the share of contract

[3]Spot market thickness is measured as the relative size of the spot market in the region and how well distribution of vessel sizes in the spot market fits the distribution of local contract demand.

[4]We note that a part of this difference arises because buyers tends to request contract shipments during weeks when they experience positive demand shifts.

shipment surplus that sellers must extract via the contract price in order for contractual relationships to be incentive compatible is estimated to be 0.56.

Finally, the counterfactual analysis asks how much long-term contracts contribute to industry value compared to a world where no contracts exist. We are able to do this by holding fixed total global supply and sellers' allocations of shipments to destinations in each week. We convert all arriving contract shipments to spot and add them to the spot shipments already arriving at the destination in a given week, giving us a counterfactual spot market in each destination. Because we have estimated the relationship between local spot market thickness and expected spot value, we can simulate the values buyers would obtain in these enlarged spot markets.[5]

We find that the efficiency of the LNG industry would have been significantly reduced in the absence of contracts between 2009 and 2019. The gains from sellers' relationship-specific efforts in contracts outweighs the fixed and variable costs of maintaining the contracts as well as the externalities imposed on spot market thickness. We estimate that the gains from trade in the industry were 57% greater over this period than in the counterfactual scenario.

In all the analysis in this paper, we take the existing contract network as fixed and do not address why some routes have contracts and others do not. We have also not modeled transport costs explicitly.[6] One other important issue we have sidestepped in our analysis is the question of seller market power. In theory, it could be that sellers choose to fulfil contract shipment requests in order to withhold quantities from spot markets and gain from the resulting higher spot prices. We do not allow sellers' supply decisions to include these strategic considerations. The main reason for this choice is that the routes between sellers and buyers—where buyers are defined at the country level in our analysis—tend to either be contract or spot. That is, if a seller has a contract with a buyer, it is unlikely that they are also selling on the spot market at that destination, and vice versa.[7]

This paper relates to several literatures. Most prominently, Zahur (2020) has studied the LNG industry in depth and has focused on the long-term contracts that we investigate here. He shows that contracts allow greater capital investments at the cost of allocative efficiency. Our analysis is motivated by his observation that contracts are often signed around the time of the capital investments, which, due to the long life of capital, raises the issue we explore here of the efficiency implications of contract flexibility in

[5]We note that this approach allows us to sidestep the challenge of simulating counterfactual spot prices because we focus on the total surplus created by each shipment as a function of weather conditions, rather than how the (unobserved counterfactual) spot price divides this surplus.

[6]We note that the counterfactual estimation holds the distances traveled by each vessel fixed and, as such, transport costs play no role in the welfare calculations.

[7]While there are several large firms in this industry that have minority ownership stakes in multiple sellers, the majority ownership stake is often a state energy company with no cross-country links.

delivery timing.[8]

In our setting, unpredictable weather causes exogenous demand shocks that we exploit to identify how value chains respond. We establish that long-term contracts are sufficiently flexible to allow the supply side to adapt and add to overall industry value. This finding complements (Forbes and Lederman, 2009, 2010) studying vertical integration in the airline industry. They show that major airlines are more likely to own regional airline partners when adverse weather is more likely and where a route is more integrated into the major's network. Integrated routes also respond to weather shocks and perform better than non-integrated routes at the same airport on the same day. Costinot, Oldenski, and Rauch (2011) show that the boundaries of U.S. multinational firms reflect the extent to which sectors involve non-routine tasks. Vertical integration along the supply chain is more likely in sectors with high problem-solving intensity, consistent with ownership facilitating adaptation to changing circumstances. We find that long-term contracts enable adaptation in terms of delivery volumes and timing.[9]

A recent literature on relational contracts establishes how the prospect of future rents effectively deters short term opportunism in a range of empirical settings (Macchiavello (2022)). Macchiavello and Morjaria (2015) use the dynamic incentive compatibility constraints implied by repeated seller-buyer interactions to estimate lower bounds on the value of the relationship in the Kenyan flower industry, a setting of imperfect contract enforcement. We show that the future value of formal contracts in the LNG industry governs the short term actions of the sellers in the industry, enabling sufficient flexibility to allow buyers to compare contemporaneous costs and benefits in interpreting contracts as call options to request shipments at times when they are particularly valuable.

One recent industry-specific study that examines the externalities that contracts exert on spot markets is Harris and Nguyen (2022).[10] They estimate the incentives that govern both relationship formation and the actions of buyers and sellers in U.S. trucking. Relationships form between trading partners with a high match quality, but a large number of contract relationships leads to thin spot markets, increasing the search costs for trading partners. In their setting, too, eliminating contracts in favor of a centralized spot market reduces industry efficiency. This is because those formerly in contracts incur counterfactual search costs and lose the match specific gains from relationships. We don't account for any search costs in LNG spot markets but, instead, allow the expected value from any spot market shipment to reflect the

[8]Because our counterfactual does not vary each shipment's destination, we do not address allocative efficiency.

[9]In this paper, we take the set of contracted routes as given, reflecting their long time horizon, and examine how volumes respond to weather shocks. However, our analysis has implications for which routes are more or less likely to enter into a contract and, indeed, for whether the shipping activity is undertaken by a third party or is integrated into either the buyer or seller.

[10]Kranton (1996) sets out theoretically how externalities can be large enough or small enough to determine whether relationships are efficient.

share of spot shipments in the destination and the overlap of available spot vessel size with the size of vessels demanded via contract at that destination. We estimate the contract value production function that shows that costly relationship-specific seller effort increases buyer value and find that seller costs increase with the total number of contract shipment requests they fulfil. Even though these costs are saved in the counterfactual that eliminates contracts, the increased thickness of the spot market is insufficient to compensate for the lost returns of seller effort.

Our interpretation of the relatively low buyer values for spot market shipments is that frictions related to bulky shipping technology and the long distances between buyers and sellers mean buyers are often unable to purchase the quantities of LNG that they need at the ideal time on their local spot market, even in the counterfactual thicker spot markets. Brancaccio, Kalouptsidi, and Papageorgiou (2020) documents how frictions arise in global shipping when country-level trade imbalances in dry bulk commodities lead to shipping price differences across markets. We note that LNG vessels are specialized and there is almost no two-way trade. In addition, vessels are very large relative to total weekly demand, an indivisibility that amplifies the distance-related time lag between requesting and receiving a shipment. We infer that contracts remain efficient in this industry because the total market size remained too small, over the time period studied, for spot markets to overcome the frictions arising from technology and geography.

This paper proceeds as follows: Section 2 describes the industry and summarizes the data. Section 3 is the reduced-form analysis relating contract volumes to weather conditions. Section 4 estimates lower bounds on buyers' values for contract shipments given prevailing spot prices. Section 5 presents the structural model. Section 6 discusses estimation and Section 7 presents the results. Section 8 is the counterfactual analysis. Section 9 concludes.

2 Industry and Data

2.1 Industry overview

The global LNG industry allows the gas produced in dispersed, oil-rich, locations to be liquefied by cooling it to $-160°$ centigrade and transported via ships to locations with regasification capacity. The industry is characterised by large, long-lived, location-specific capital investments at both origins and destinations that are typically located far apart, and a costly shipping technology. Demand is concentrated in East Asian countries, although regas terminals continue to be built at ports worldwide.[11]

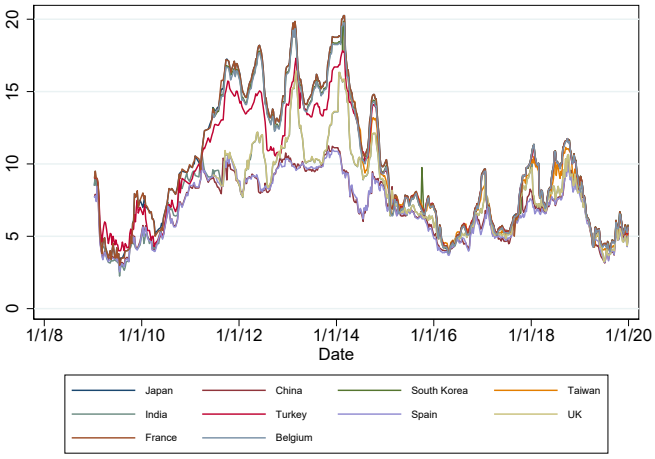
Long-term sales and purchase agreements (SPAs) are contracts between sellers and buyers that govern the bulk of delivered volumes and that are signed before or after capital investments are made (Zahur

[11] Recent disruptions to pipeline gas in the EU due to the Russia-Ukraine war have led to many new regasification investments. The import capacity in the EU and the UK is set to increase by one third by 2024, after expanding only modestly in the 10 years to 2022. https://www.eia.gov/todayinenergy/detail.php?id=54780.

(2020)). Contracts specify annual volumes and a pricing formula. Much of the detail in the contracts relates to their "take or pay" nature, a feature shared with pipeline gas contracts (Masten and Crocker (1985)). Prices are often indexed to local oil prices, which means that the seller bears risk related to the forgone opportunity of selling LNG at high spot prices when they occur. The buyer typically bears the quantity risk, in that there is an obligation to take the total quantity over the course of the year, whether they need it or not, or incur demurrage charges to compensate the seller. Contracts also contain various clauses related to unforeseen contingencies and the length of acceptable delivery windows. However, the exact timing of individual contract shipments during the year is not contracted. While parties typically operate under a three-month forward-looking schedule, shipments are governed by separate Confirmation Notices that specify timing, quantity, and other shipment-specific details. Confirmation Notices are agreed bilaterally prior to shipping.

Residual LNG volumes are traded on global spot markets. There is significant variation in the destination-specific local spot price over time, and also across countries at any one point in time (Zahur (2020)). Figure 1 shows the price data we use in this paper.

Figure 1: LNG spot prices by destination country over time, USD



Appendix A shows that the largest exporters in 2019, the last year of data used in this study, were Qatar, Australia, the USA, and Russia. Malaysia, Nigeria, and Indonesia, the three next largest suppliers, jointly supplied less than each of Qatar and Australia. Australia's destinations were concentrated in Japan and China, whereas Qatar's were more spread out. LNG is relatively inelastically supplied up to capacity at each liquefaction plant once capital investments have been made. However, every now and again there are planned or unplanned supply outages due to routine maintenance or unplanned events. There is much less global liquefaction capacity than global regasification capacity.

2.2 Data

We have shipment-level data on 52,151 shipments from January 2009 to December 2019 that were either contract or spot shipments. 15 countries imported more than 500 shipments in total over the 11 years in the data. Japan has been, by far, the largest importer historically, with over 1,250 shipments in each year. South Korea had the second highest number of shipments per year (364 to 634). China has steadily increased shipment imports, from around 100 in 2009 to 977 in 2019, and has been the largest importer in some recent years. For each shipment, our data contain distance traveled, time taken, vessel capacity and type, volume at origin and volume at destination, which permits a boil off calculation.[12]

We have 36 origins in the data that we currently use. Of these, 17 are countries where liquefaction is under control of one (often state-owned) company, and integrated oil companies often have minority stakes in these state-owned oil companies. The countries are: Algeria, Angola, Brunei, Cameroon, Egypt, Equatorial Guinea, Indonesia, Malaysia, Nigeria, Norway, Oman, Papua New Guinea, Peru, Qatar, Trinidad and Tobago, United Arab Emirates, and Yemen. The other 19 origins are separate liquefaction facilities in Australia (10), Russia (3), and the USA (6). We treat them separately because of geography: The Russian plant Sakhalin is in the far East, very near Japan, and Yamal and Vysotsk are in the West of Russia. The Australian plants are also located on different sides of the country, as well as being separate companies, albeit with some overlapping ownership.

We have 39 destinations, which are the regasification terminals aggregated to the country level. These are all the countries that received some positive quantities over the time period studied. The largest individual buyers are often state or city energy providers. For example, the largest single buyer in the data is the only South Korean buyer, KOGAS, a public natural gas company. The next largest is CPC Corporation, the sole LNG importer in Taiwan, which is a state-owned company. CNOOC is the largest importer in China, the state owned China National Offshore Oil Corporation. In Japan, the three largest importers are the Tokyo Electric Power Company (TEPCO), which is majority-owned by the government of Japan, and its joint venture JERA, as well as the Tokyo Gas Company.

We hence have 1,404 possible origin-destination pair routes in each of 11 years, but since some facilities came online during the sample, we have 8,570 route-years pairs where the plant and terminal are both active during the year. Of all feasible route-years, only 2,178 contain any positive flows, reflecting the relatively large size of each vessel and the supply capacity at each origin. In the empirical analysis, we restrict attention to the 13 destinations that have LNG spot markets, with available weekly spot price

[12]The volume arriving at the destination is always lower than the volume that left the origin. A note on conversion factors. To convert mmBtu into cubic metres of LNG: $1mmBtu = 0.048$ cubic metres of LNG. Equivalently, $1m^3 = 21.04mmBtu$. Source: http://www.lngplants.com/conversiontables.html

data. These are the destinations shown in Figure 1.[13]

The shipment-level data allow us to see the total volume at origin and at destination traded on a given route in a given week by summing up the shipment volumes. Because we can see whether any given shipment is contract or spot, we can also compute the total contract and spot volumes.

We complement these data with information from the Wood Mackenzie LNG platform, and from Shell, about ownership of origin installations. This allows us to divide total volumes by the way they are organized. We create indicator variables for whether the seller is integrated with the charterer, the charterer is integrated with the buyer, or whether all three are commonly owned, or there is no integration along the supply chain. Appendix B details how we construct these indicators. We distinguish between contracted volumes that are integrated (in some form) versus those that are not integrated in Section 3.

We use data from several other data sources. The location-specific LNG spot prices shown in Figure 1 are from EIKON. These are weekly data for 13 different spot markets. Country-specific temperatures are from the World Bank climate knowledge portal.[14] We select the mean monthly temperature in each country for each year.[15]

2.3 Descriptive statistics

Of all the possible origin-destination routes where both the plant and the terminal are operational in a given year, the 8,570 observations, we first look at the probability that the route-year is active, that is, it is one of the 2,183 route-years that has some positive flows.

Table 1 examines whether flows follow gravity. It contains three regressions of the indicator for a route-year being active on the log of the direct distance (in ′000km) between the origin and destination and variables relating to the total volume produced (received) by the origin (destination). Column 1 shows that an increase in route distance of 1,000 km lowers the probability of the route-year being active by 20% (the coefficient is 0.204). Column 2 includes the total volume of the origin and destination as controls, and column 3 includes origin and destination fixed effects. In this final column, an increase in distance of 1000 km reduces the probability of being active by 16%. In other words, distance matters in that having any

[13] Argentina, Belgium, Brazil, China, France, India, Japan, Mexico, South Korea, Spain, Taiwan, Turkey, and the United Kingdom all have spot prices (although the Mexico price is not included in the figure). We note that there is a spot price also in the US, but we have excluded the US as a destination as it is predominantly an exporter of LNG. Also note that we assume buyers in Taiwan can purchase on the China spot market due to its proximity. In future versions of the paper, we will do robustness tests including a larger set of destinations, relating shipments to the spot price in the nearest spot market.

[14] https://climateknowledgeportal.worldbank.org/download-data

[15] All the results are robust to using the minimum monthly temperature in each year to measure weather shocks. We also have distances between origins and destinations from the website https://www.distance.to/, but are not currently using these data.

positive flows follows gravity.

Table 1: Probability route active in a year.

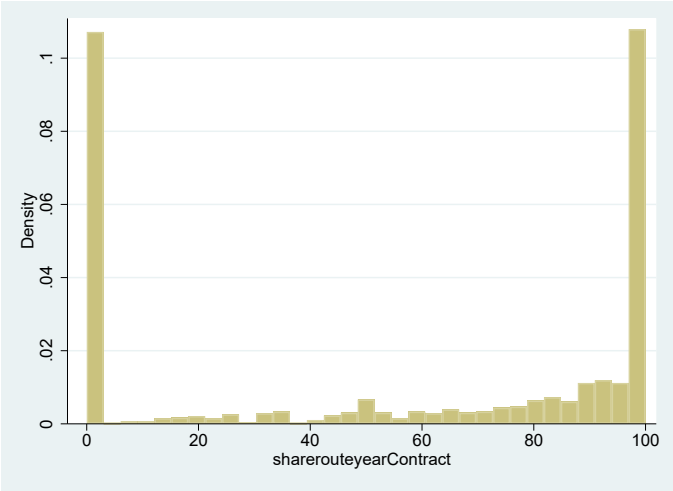
	(1)	(2)	(3)
lnairlinedistancekm	-0.204***	-0.187***	-0.164***
	(0.007)	(0.006)	(0.006)
totalvoloryear		0.003***	
		(0.000)	
totalvoldestyear		0.005***	
		(0.000)	
Observations	8,555	8,555	8,555
R^2	0.103	0.305	0.525

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Turning to the set of route-years that are active, the volumes traded on a given route in the year tend to be either contract or spot volumes. Figure 2 shows the bi-modal share of volumes on a route-year that is under contract. Based on this figure, we construct an indicator variable for whether an active route-year

Figure 2: Share of route-year volumes that is under contract

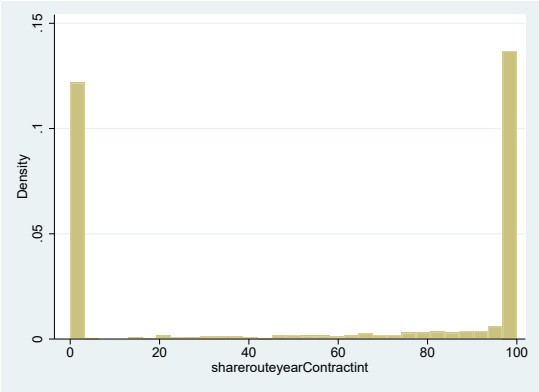


is mostly under contract, defined as having at least 50% of total flows in the year being contract flows. Regressing this indicator on the log of the distance variable and controls for origin and destination total year volumes shows that gravity variables don't help explain why certain routes have contracts.

Focusing on route-years where the majority of flows are via contract, we next look at the share of volumes that are integrated versus not integrated. Of all route-years that had at least some positive

contract volumes, we plot the share of those volumes where the charterer was integrated with either the seller or the buyer, or both.[16] Figure 3 shows that route-years' volumes tend to be either 100% integrated or 100% non-integrated.

Figure 3: Share of route-year contract volumes that is integrated



We study the volumes and number of shipments at the route level in a given week. In the 2,183 active route-years, there are 110,996 route-week observations. We can match a destination-level LNG spot price to 60,385 of these observations because they are in one of the 13 locations with an active spot market. Of these, only 18,439 route-weeks have positive volumes. That is, the route-weeks with zero shipments are important in the data.

Table 2 summarizes the data used in Section 3, the volumes of LNG at the route-week level between 2009 and 2019. The first row of column 2 shows that the mean volume per route-week is 74.7 thousand cubic meters. Conditional on there being some positive volumes, the mean volume is 240 thousand cubic meters, and the mean number of shipments on a route-week is 1.7. The mean vessel capacity in the shipment-level data is 130 thousand cubic meters.

3 Reduced form analysis

This section examines the relationships between volumes on a route-week for active routes and destination-specific temperatures. We also show how local LNG spot prices relate to temperatures. Active routes are defined as those where plants at both the origin and destination are operational and there is at least one shipment on that origin-destination route during the calendar year. The weather variable is the minimum temperature at the destination in a given month. We use various fixed effects to control for destination-month average weather, across all years in the data, so that the variation in the weather variable is the deviation from the expected minimum temperature at that time.

[16] For a very small number of observations, the seller, charterer, and buyer are all integrated, and for an even smaller number the seller and the buyer have common owners but the charterer is arms' length.

Table 2: Active route-weeks, 2009 to 2019

	Volumes, '000 cubic metres				
	Obs	Mean	Std.dev	Min	Max
All	60,385	74.7	144.7	0	1904.4
Contract	60,385	58.0	131.6	0	1758.8
Non-contract	60,385	11.2	43.9	0	702.7
Int. contract	60,385	51.6	124.9	0	1750.8
Non-int. contract	60,385	7.3	34.5	0	649.0
Local spot price, USD	60,385	8.66	3.95	2.12	20.25
Local mean temp, °C	60,385	13.92	9.28	-8.99	31.25

In the first set of specifications, we use indicator variables characterizing how a given route is organized. We regress total volumes (in '000 cubic meters) on mean monthly temperature as follows:

$$Q_{udt} = \alpha w_{dt} * O_{udy} + \Gamma_{dm} + \epsilon_{udt}, \tag{1}$$

where Q_{udt} is the volume on active route ud in week t, w_{dt} is the minimum temperature at d in week t, and Γ_{dm} are destination-month fixed effects. The variables O_{udy}, included in some of the specifications, are indicator variables for how the route is organized. The first indicates whether 50% or more of the volumes on the route in a calendar year are under contract. As seen in Figure 2, this route is bi-modal: routes tend to be contract routes or not. The second indicates whether 50% or more of contract volumes on a route in a calendar year are shipped via an integrated shipper, either the seller or buyer, and is defined only when the contract route indicator is equal to 1. Figure 3 shows that contract routes tend to be either integrated or not.

The results of estimating equation (1) are shown in Table 3. Column 1 shows that the total volume is lower by 2.637 thousand cubic meters when temperature is 1 degree higher. This corresponds to a 5% increase in total volume when temperature is 1 degree lower than is typical at a given destination-month. Column 2 shows that nearly two thirds of this reduction is within-route over time because it controls for route-year fixed effects. The remainder of the effect can be attributed to variation across routes when temperatures vary. Column 3 includes the interaction of temperature with the indicator for whether the route is a contract route. The negative significant coefficient on the interaction shows that the responsiveness to weather shocks is larger for routes where the majority of volumes are via contract. Column 4 looks only at contract routes and includes the interaction of temperature with the indicator for being an integrated contract route. The negative significant coefficient shows that it only integrated contract routes where volumes respond to weather shocks.

Table 3: Route-week responsiveness to local temperature.

	(1)	(2)	(3)	(4)
Temp.	-2.637***	-1.669***	-1.195*	-1.516
	(0.643)	(0.636)	(0.719)	(1.224)
Temp.*Org form			-1.124**	-1.595**
			(0.468)	(0.779)
Org form			78.915***	131.979***
			(6.172)	(10.109)
Observations	60,385	60,385	60,385	38,728
R^2	0.109	0.625	0.160	0.229
Fixed effects	dm	odm	dm	dm

The second set of reduced form specifications changes the dependent variable to be contract volumes on a route-week, spot volumes on a route-week, and then integrated contract volumes and non-integrated contract volumes. The estimated equation is:

$$Q_{udt} = \alpha w_{dt} * O_{udy} + \Gamma_{odm} + \epsilon_{udt}, \tag{2}$$

where Q_{udt} are volumes for each organizational form. In these specifications, Γ_{odm} are route-month fixed effects, and the coefficients can be interpreted as within-route volume variation over time as the temperature at the destination changes. The results are given in Table 4.

The route-month fixed effects in these specifications mean that the coefficients reflect variation in volumes on a given route in a month across years. In column 1, the dependent variable are the contracted volumes on a route-week. The negative significant coefficient of 1.533 tells us that volumes are around 3.5% lower when the temperature is one degree higher. Column 2 has a smaller coefficient, but the total spot volumes are also lower, and corresponds to flows that are 5.2% lower when the temperature is one degree higher. Columns 3 and 4 show that the responsiveness of contract volumes to temperature is only for volumes where the shipper is integrated with either the seller or the buyer.

As some additional evidence that weather shocks are indeed shocks to local demand at the destination, we show that spot prices vary with minimum monthly temperature. Table 5 shows that when the temperature is colder than expected in a given month, the spot price is significantly higher. Controlling for destination-year fixed effects, a cooler than average month by one degree leads to a spot price increase

Table 4: Route-week responsiveness to local temperature.

	(1) Con	(2) Spot	(3) Int.Con	(4) Non-Int.Con
Temp.	-1.533***	-0.458*	-1.514***	-0.001
	(0.564)	(0.275)	(0.537)	(0.197)
Observations	60,371	60,371	60,371	60,371
R^2	0.644	0.178	0.656	0.197
Fixed effects	odm	odm	odm	odm

of around 3 cents. The coefficient is slightly higher when destination oil prices are included as a control variable.

Table 5: Spot price responsiveness to temperature.

	(1) localspotprice	(2) localspotprice
localminmonthtemp	-0.027**	-0.030***
	(0.010)	(0.010)
localcontractoilprice		0.085
		(0.051)
Observations	2312	1999
R^2	0.972	0.975

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

4 Buyer values for contract shipments given prevailing spot prices

This second empirical analysis estimates lower bounds for the value of receiving LNG in a contract shipment rather than a spot shipment, given the thickness of the spot market and the status quo spot prices. Our approach builds on the intuition developed in Section 3 that the buyer requests contract shipments in periods when they have positive demand, which is also when spot prices tend to be high. We add to this the constraint that a contract relationship is also incentive compatible for the seller over the duration of a

contracting period, here assumed to be a calendar year.

We first introduce some notation, which will also be used in the model in Section 5. When there is a contract in place on a given seller-buyer route, the downstream buyer, d, has a value V_{udt} for one mmbtu's worth of LNG arriving from seller u in a contract shipment at time t.[17] The value d has for the same LNG quantity in a spot shipment in t is V^s_{dt}, which is not u-specific. The per mmbtu prices for LNG arriving via contract and spot are denoted p^c_{udt} and p^s_{dt}, respectively. A seller can deliver the shipments they have at time t to any of their contract partners or sell on any spot market (subject to transport costs), so the relevant spot price for the seller is the highest available spot price in t. We denote this p^s_{ut}. The object of interest in this section is $V^c_{udt} - V^s_{dt}$ and the challenge is that only p^s_{dt} and p^s_{ut} are observed in the data.

We start by considering the buyer's surplus from a contract shipment, $V^c_{udt} - p^c_{udt}$ and appeal to revealed preference: whenever the buyer receives a contract shipment, it must create more value for them than would a spot shipment at the local prevailing spot price. Our first assumption is that V^c_{udt} is the same across all time periods in which the buyer faces similar demand conditions, and so is V^s_{dt}. Turning to our main dataset of $44,879$ shipments between 2009 to 2019 for which we know the local spot price and weather shock at the destination for $32,212$, we regress the local minimum monthly temperature on destination-month fixed effects and save the regression residuals. This variable can be thought of as a measure of the extent of the local weather shock relative to destination-month norms. We take the negative of the residual so that a larger positive value means it was colder than expected. For each of the 13 destinations, we group together observations where the demand shock is "similar" by allocating each observation to one of 25 demand-shock bins.

We then narrow attention to the $21,311$ contract shipments received during months where d received at least one contract shipment and also purchased multiple spot shipments. For each of these months, we consider all the time periods within the same destination-specific demand bin and, if d had bought on the spot market at varying spot prices, we can define $\overline{S^s_{dt}} = V^s_{dt} - p^{min}_{dt}$ and $\underline{S^s_{dt}} = V^s_{dt} - p^{max}_{dt}$ as the maximum and minimum value that the buyer obtained from the spot market across under the relevant demand conditions.[18] We infer that $\overline{S^s_{dt}} \geq \underline{S^s_{dt}}$ and also that $\underline{S^s_{dt}} \geq 0$. Hence, $\overline{S^s_{dt}} - \underline{S^s_{dt}} \geq 0$.

Our second assumption is that given d received at least one contract shipment in all time periods when $\overline{S^s_{dt}}$ and $\underline{S^s_{dt}}$ are defined, such contract shipments were incentive compatible for the buyer:

$$(V^c_{udt} - p^c_{udt}) - (V^s_{dt} - p^s_{dt}) \geq 0,$$

and, specifically, that $V^c_{udt} - p^c_{udt} \geq \overline{S^s_{dt}}$. It must then also be the case that $V^c_{udt} - p^c_{udt} \geq \overline{S^s_{dt}} - \underline{S^s_{dt}}$. Therefore,

[17] Note that s is used to denote a spot shipment and not a seller.

[18] Note the fact that the buyer also bought on the spot market under similar demand conditions implies that buyer would have liked to get more shipments from their contract partners, but it was not made available to them.

a lower bound on the buyer surplus from the contract shipment is:

$$V^c_{udt} - p^c_{udt} \geq V^s_{dt} - p^{min}_{dt} - V^s_{dt} + p^{max}_{dt} = p^{max}_{dt} - p^{min}_{dt}. \tag{3}$$

Next, turning to the seller: we infer that fulfilling a contract shipment is incentive compatible for the seller, on average, over the year, $p^c_{udt} \geq p^s_{ut} (= max_d(p^s_{dt})$, where the max is defined over all the spot prices where the seller could deliver the shipment at time t). If, for now, we say sellers break even on average, so that buyers extract all the surplus from contracts, then we can set $p^c_{udt} = p^s_{ut}$.[19] This allows us to write equation (3) as:

$$V^c_{udt} - p^s_{ut} \geq p^{max}_{dt} - p^{min}_{dt}. \tag{4}$$

We then look at the buyer's surplus from a spot shipment, $V^s_{dt} - p^s_{dt}$. A third, conservative, assumption is that the highest observed spot price that d pays under similar demand conditions is an estimate of d's willingness to pay for all spot shipments in t. That is, $V^s_{dt} = p^{max}_{dt}$ for all spot shipments purchased in a destination-specific demand bin. In other words, the buyer broke even on the highest price spot transaction in the demand bin. Subtracting this willingness to pay for spot from each side of equation (4) gives us the relative value of a contract shipment as:

$$V^c_{udt} - V^s_{dt} \geq p^{max}_{dt} - p^{min}_{dt}. \tag{5}$$

While we have made some strong assumptions to derive these lower bounds on the value contract shipments create for buyers under prevailing spot prices, some intuition for the logic can be seen by noting that inequality (5) can be rewritten:

$$(V^c_{udt} - V^s_{dt}) \geq (p^c_{udt} - p^s_{dt}) + (p^s_{dt} - p^{min}_{dt}), \tag{6}$$

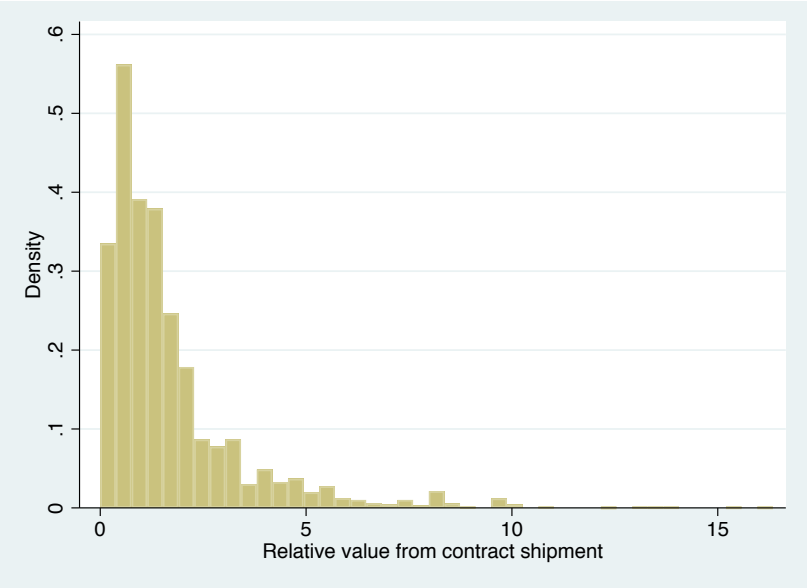
which shows that the relative value from a contract is sufficient to compensate the seller for not switching to the spot market when the spot price is high (first term on the right hand side) together with the amount required to compensate the buyer for not switching to the spot market when the price is low at times of similar demand (second term on the right hand side).[20]

Figure 6 is a histogram of the estimated lower bound of the relative value per mmbtu of LNG arriving at the destination in a contract shipment compared to an available spot shipment for the 21,311 contract shipments in this analysis. The mean value is \$1.66, the standard deviation \$1.71 and the median is \$1.15. Variation in relative contract value can be attributed to year fixed effects, with years with more volatile spot prices associated with higher values. A regression of contract value on 10 year fixed effects has an

[19] We are not taking future value into account, such as reputation value. Also missing are fines on both sides from breaching annual contracted quantity.

[20] For now, we abstract from transport costs. In later work, we will add transport costs here, according to which party is shipping and the travel time between u and d.

Figure 4: Relative value of contract shipments



adjusted R-squared of 0.15. Including only 18 country of origin fixed effects, or 12 destination country fixed effects, gives adjusted R-squareds of 0.04 and 0.12, respectively. A fully saturated regression with fixed effects for the interaction of 145 routes with the 10 year fixed effects gives an adjusted R-squared of 0.29.

The contract shipments in this data sample are potentially those that are most valuable to buyers, as they arrive in months when the buyer also purchases spot shipments. The estimated lower bounds should also be interpreted as the value of a contract shipment over a unilateral deviation to a spot shipment in the same week, conditional on the vector of global spot prices at that time. In order to evaluate the effects of more far-reaching counterfactuals where spot prices react to changes in the number of contract shipments, we need a structural model that delivers estimates of LNG demand and the relationship between spot market size and buyer spot value, as well as the nature of seller investments in contracts and the division of contract surplus. This is the purpose of the Section 5.

5 Model

5.1 Set up

We describe the industry as a three-stage value chain: liquefaction by a seller u (upstream); shipping by a charterer m (midstream); and regasification by a buyer d (downstream). The stages are indexed by $j \in u, m, d$. As long as both u and d have installed operational capacity, each ud pair is a potential route of fixed mileage. The purpose of the model is to relate contract value to how shipment timing varies with weather shocks.

The presence of a contract on route ud means the parties at both ends of the route have agreed to

transact an annual quantity Q_{ud}. The exact timing and quantity of any one delivery are non-contractible and are agreed bilaterally throughout any one year. The contract price is endogenous.[21] There is also an LNG spot market in each d. d can buy from the spot market at time t and u can sell in any global spot market at time t. Spot markets equilibrate at the spot price p^s_{dt} every period.

Every shipment on route ud, whether contract or spot, has an organizational form, O_{ud} indicating which stage(s) of the value chain, if any, are under common control, $O_{ud} \in (SCB, SC, CB, SB, none)$. SC implies DES, where u is responsible for stage m, and CB implies FOB, where d is responsible for stage m. For other organizational forms, DES or FOB varies. If neither u or d does the shipping, one or other of them must secure an independent shipper at a shipping price that is positively correlated with LNG spot prices. Note that if there is a contract on a route, v is fixed over the life of the contract.

The timing is as follows: In $t = 0$, u and d decide whether to contract. If they do, they also decide v_{ud}, Q_{ud}, and the contract price P_{udt}. Either before or after deciding about contracting, u and d make long-lived capital investments in total capacity. Zahur (2020) discusses the timing of contract signing and capacity investments. We take the contracting decisions as exogenous in this analysis. At the start of each period $t > 0$, d experiences a demand shock (e.g. weather) and all parties form expectations of the vector of spot prices p^s_{dt} based on global shocks across all d. u produces a given quantity, which is unrelated to destination demand shocks and prices, and has vessels available to it of a predetermined size distribution.

Then, d decides whether to request a contract shipment in t from each of its contract partners.[22] On receiving a set of requests from contract partners, each u chooses whether to fulfil each request, and, conditional on accepting a request, decides how much relationship-specific effort to exert to fit vessel capacity and arrival time to buyer needs. Shipments are dispatched and shipping costs are incurred by u, d, or m, depending on how the transaction is organized. Destination prices p^s_{dt} are realized across all spot markets, equilibrating the residual spot demand and supply in each location. Payments are made for contract and spot shipments and the outstanding remaining annual contracted quantities for each contract route are calculated.

5.2 How shipments are organized

5.2.1 Contract shipments

We allow buyer value from a contract shipment, V^c_{dt} to depend on the demand conditions related to weather shocks at the destination, w_{dt}, and on the amount of relationship-specific investment made by the seller, $h_{udt} \geq 0$. There is a constant marginal cost of effort the seller, c_u.There is also a fixed cost, F. We specify

[21] Each contract's price is indexed to the destination region's oil price, P^o_{dt}, but the exact indexing rule is unobserved.

[22] Note that this decision is made on the basis of expected spot prices, $E(p^s_{dt}) \forall d \in D$ and d-specific demand in t.

a functional form for V^c_{dt}:

$$V^c_{dt}(w_{dt}, h_{utc}) = v(w_{dt})(1 + h_{udt})^{\mu} \tag{7}$$

In this "contract value production function", μ is the intensity with which u's input is used. This parameter also captures any returns to scale in seller effort.

An endogenous fraction β of contract value goes to u and is built into the pre-agreed contract price.[23] Hence, the first order condition for u is:

$$\beta_u v(w_{dt})\mu(1 + h_{udt})^{\mu-1} = c_u \tag{8}$$

Rearranging equation (8) and simplyfing gives:

$$(1 + h_{udt})^* = \left(\frac{1}{v(w_{dt})}\right)^{\frac{1}{\mu-1}} \left(\frac{c_u}{\beta\mu}\right)^{\frac{1}{\mu-1}}. \tag{9}$$

Because the exponent term in equation (9) is negative, total effort is increasing in the intensity of investment, μ, and decreasing in marginal effort costs, c_u. A larger share of surplus going to the seller, β, also leads to higher levels of seller effort. Note that the production function implies potential complementarities between u's effort, the responsiveness of buyer value to the weather shock, and the share of surplus going to the seller.

From the assumption that marginal effort costs are linear, and, hence, we can rearrange the first-order condition in equation (8) to find c_u, then substitute into the expression for $c_u(1 + h_{udt})$ to obtain:

$$c_u(1 + h_{udt}) = (1 + h_{udt})\beta v(w_{dt})\mu(1 + h_{udt})^{\mu-1} = \beta v(w_{dt})\mu(1 + h_{udt})^{\mu}.$$

Hence, variable costs are:

$$c_u(1 + h_{udt}) = \beta\mu v(w_{dt}) \left(\frac{1}{v(w_{dt})}\right)^{\frac{1}{\mu-1}} \left(\frac{c_u}{\beta\mu}\right)^{\frac{1}{\mu-1}}. \tag{10}$$

The surplus value from the contract shipment, defined here as the value to the buyer less the fixed cost, F, in terms of the model parameters, the endogenous variable β, and the function $v(w_t)$, is:

$$S^c_{udt} = v(w_{dt}) \left(\frac{1}{v(w_{dt})}\right)^{\frac{\mu}{\mu-1}} \left(\frac{c_u}{\beta\mu}\right)^{\frac{1}{\mu-1}} - F = v(w_{dt})^{\frac{\mu}{1-\mu}} \left(\frac{\beta\mu}{c_u}\right)^{\frac{1}{1-\mu}} - F \tag{11}$$

Note that S^c_{udt} is deterministic, conditional on the weather shock and model parameters. It is increasing in the weather shock, in the intensity with which u effort contributes to value, and in the share of value going to the seller, and decreasing in the marginal cost of seller effort. The share of this surplus going to each party is determined by the parameter β.

[23] Actual contract prices P_{udt} are unobserved in our data.

5.2.2 Spot shipments

Buyer d's payoff from buying a spot shipment in their local market in t is $V^s_{dt} - p^s_{dt}$. We assume is no relationship-specific investment made by the seller for these shipments.

To reflect the nature of the differentiated shipments in the spot market, we assume there are shocks to the spot value in each market, ϕ^s_{dt}:

$$V^s_{dt} = \frac{v(w_{dt})}{\phi^s_{dt}}.$$

d observes its destination-time-specific ϕ^s_{dt} before making any decisions.[24] We let $\phi^s_{dt} \geq 1$ follow a Pareto distribution F_ϕ with pdf $f_\phi = \frac{\lambda}{\phi^{\lambda+1}}$, where λ parameter is a function of the size of the global spot market in t to capture the idea that d is likely to get a better fit for its demand needs when there are more spot shipments available.

Seller u's payoff from selling a given shipment in the spot market is highest spot price available at time t, $max_d(p^s_{dt})$.

5.3 Contracting partners' discrete choices

5.3.1 Buyer's incentive compatibility constraint

This subsection derives two threshold values of ϕ^s_{dt} that govern d's choices in period t. At the time of deciding whether to request a contract shipment, d has observed all shocks, but does not yet know the spot price. Decisions are, hence, made on the basis of expected spot prices.

First, d calls in a contract shipment in t iff $(1-\beta)S^c_{udt} \geq V^s_{dt} - E(p^s_{dt})$. From equation (11), the threshold shock to the spot value, ϕ^s_{dt}, above which it is incentive compatible for d to call in a contract shipment, ϕ^{s*}_{dt}, is:

$$\phi^{s*}_{dt} = \frac{v(w_{dt})}{(1-\beta)\left[v(w_{dt})^{\frac{\mu}{1-\mu}}\left(\frac{\beta\mu}{c_u}\right)^{\frac{1}{1-\mu}} - F\right] + E(p^s_{dt})}. \tag{12}$$

The intuition is that d calls in a contract shipment from contract partner u when the demand shock is sufficiently high that d's share of the contract surplus, given u's relationship-specific effort, is greater than the value of a spot shipment, given the fit of the spot shipment with the buyer's needs.

Second, d prefers a spot shipment over no shipment when $\frac{v(w_{dt})}{\phi^s_{dt}} - E(p^s_{dt})) \geq 0$. We define a second threshold shock to the spot value, $\bar{\phi}^s_{dt}$, above which the buyer prefers no shipment:

$$\bar{\phi}^s_{dt} = \frac{v(w_{dt})}{E(p^s_{dt})}. \tag{13}$$

Given the weather shock, w_{dt}, the surplus from a contract shipment, S^c_{udt}, and both thresholds ϕ^{s*}_{dt} and $\bar{\phi}^s_{dt}$ are determined. When $\phi^s_{dt} \geq \phi^{s*}_{dt}$, the contract shipment incentive compatibility constraint is satisfied,

[24] We have not allowed for uncertainty in contract shipment value, so, implicitly, $\phi^c_{dt} = 1$, reflecting the fact that the shipment characteristics are agreed bilaterally by d and u before shipment departure from u.

and contract shipments give d a higher expected payoff. Second, when $\phi^s_{dt} \geq \bar{\phi}^s_{dt}$, the d's expected payoff from the spot market is negative so no shipment is observed on the route ud at time t.

At times t when there is a positive weather shock (e.g. an unexpected cold spell) that is sufficiently large so that $S^c_{udt} \geq 0$ (which also implies $\phi^{s*}_{dt} > \bar{\phi}^s_{dt}$), the probability that d requests a contract shipment from u is the probability $\phi_{dt} \geq \phi^{s*}_{dt}$, which is:

$$\Pr(\phi^s_{dt} \geq \phi^{s*}_{dt}) = 1 - F_\phi(\phi^{s*}_{dt}) = (\phi^{s*}_{dt})^{-\lambda},$$

and the probability that d goes to the spot market is the probability of a spot market fit good enough that ϕ^s_{dt} is less than ϕ^{s*}_{dt} (so d prefers spot over contract). This probability is given by

$$\Pr(\phi^s_{dt} \leq \min\{\phi^{s*}_{dt}, \bar{\phi}^s_{dt}\}) = F_\phi(\min\{\phi^{s*}_{dt}, \bar{\phi}^s_{dt}\}) = 1 - (\phi^{s*}_{dt})^{-\lambda}$$

and given that $S^c_{udt} \geq 0$, the probability there are no shipments is zero.

At times t when there is a negative weather shock (e.g. an unexpected warm spell) that is sufficiently large so that $S^c_{udt} \leq 0$, d will not request a contract shipment. The probability d goes to the spot market is the probability ϕ^s_{dt} is low enough that the spot shipment creates positive value for d and is given by:

$$\Pr(\phi^s_{dt} \leq \bar{\phi}^s_{dt}) = F_\phi(\bar{\phi}^s_{dt}) = 1 - (\bar{\phi}^s_{dt})^{-\lambda}$$

The probability of having no shipment is hence:

$$\Pr(\phi^s_{dt} \geq \bar{\phi}^s_{dt}) = 1 - F_\phi(\bar{\phi}^s_{dt}) = (\bar{\phi}^s_{dt})^{-\lambda}$$

5.3.2 Seller's incentive compatibility constraint

We note that d is more likely to request a shipment when they receive a negative weather shock, which is exactly when u's outside option of selling on the spot market is likely to be high value. We assume that the seller finds the contract relationship incentive compatible if, over the course of all future periods ($t^* > t$), the share of contract surplus it receives, β, less the variable effort cost it incurs, outweighs the revenue it would earn from selling the same quantities in the spot market with the highest spot price in each period $t^* \geq t$.

Then, u's incentive compatibility constraint for the year can be written as follows:

$$\sum_{t^* \geq t} (\beta S^c_{udt^*} - c_u(1 + h_{udt^*})) \geq \sum_{t^* \geq t} E(max_n(p^s_{nt^*})), \tag{14}$$

where n indexes all destinations with spot markets. We note that in a non-random subset of time periods (good weather time periods), the contracted quantities on a route will be zero because d will not exercise its option to call in a contract shipment. The incentive compatibility constraint in inequality (14) places a lower bound on β.

6 Estimation

We estimate the model parameters that govern buyer and seller decisions to understand the trade offs between the relationship-specific effort within contracts and the goodness of fit distribution for spot market shipments. The parameters of interest are those that relate the weather to demand (in the function $v(w_{udt})$), the investment elasticity μ, the shape of the Pareto distribution of spot value shocks, λ, the marginal and fixed costs associated with contract shipments, c_u, and F, and the endogenous share of contract value going to u, β.

We specify the value function to be a power function, governed by two parameters, α and k, so $v(w_{udt}) = kw_{dt}^{\alpha}$. Because the relationship between spot market thickness and its value will be of key importance in the counterfactual analysis, we estimate λ flexibly to be $\lambda = \lambda_0(Th_{dt})^{\lambda_1}$, where Th_{dt} is the measure of spot market thickness, discussed below, and estimate λ_0 and λ_1. In order to allow the fixed costs of fulfilling a contract shipment to vary with how many contract requests a seller receives in each period, we specify $F = F_0(NC_{ut})^{F_1}$, where NC_{ut} is the deviation from the typical number of contract shipments a seller fulfils in each period.

Along with the seller effort intensity in creating contract shipment value, μ, and the variable cost of seller effort, c, as well as the share of contract surplus going to the seller, β, this gives us a total of nine parameters to estimate. These are: $(k, \alpha, \lambda_0, \lambda_1, \mu, c, F_0, F_1, \beta)$.

6.1 Theoretical moments

We first specify a simple functional form for how the baseline value of a shipment depends on destination-time-specific weather.

$$V_{dt}^{f} = \frac{kw_{dt}^{\alpha}}{\phi_{dt}^{f}}$$

for $f \in c, s$, and, implicitly, $\phi_{dt}^{c} = 1$. As mentioned above, $\phi_{dt}^{s} \sim F$ with pareto distribution pdf $f_{\phi} = \frac{\lambda}{\phi^{\lambda+1}}$.

This gives the surplus from a contract shipment, from equation (11), as:

$$S_{udt}^{c} = (kw_{dt}^{\alpha})^{\frac{\mu}{1-\mu}} \left(\frac{\beta\mu}{c_u}\right)^{\frac{1}{1-\mu}} - F.$$

The threshold value of the shock above which a contract shipment is preferred to a spot shipment, ϕ_{udt}^{s*}, from inequality (12) is:

$$\phi_{udt}^{s*} \equiv \frac{kw_{dt}^{\alpha}}{(1-\beta)S_{udt}^{c} + E(p_{dt}^{s})}$$

We can write theoretical moments giving the probability a contract shipment is observed in udt, conditional on $S_{udt}^{c} \geq 0$, as:

$$\Pr(\phi_{dt}^{s} \geq \phi_{dt}^{s*}) = \begin{cases} \left(\frac{kw_{dt}^{\alpha}}{\bar{S}_{udt} + E(p_{dt}^{s})}\right)^{-\lambda} & S_{udt}^{c} \geq 0 \\ 0 & S_{udt}^{c} < 0 \end{cases}$$

where $\tilde{S}_{udt} = (1-\beta)S^c_{udt}$ is a function of all model parameters other than λ.

Some intuition for parameter identification comes from observing that if w_{dt} is held constant, then the numerator and first term in the denominator of the theoretical moments are fixed, and variation in the probability of receiving a contract shipment is determined only by variation in expected spot prices, allowing us to identify λ. Similarly, given the functional form assumptions for V^f_{dt} and holding $E(p^s_{dt})$ fixed, variation in the probability of receiving a contract shipment comes only from variation in w_{dt}, allowing us to estimate k, α, μ and a term that is a function of both β and c_u. We will later use u's incentive compatibility constraint to put lower bounds on β and give an estimate of c_u.[25]

6.2 Data selection for model estimation

Because the model in Section 5 is at the route-week level, it abstracts away from several key aspects of the buyer and seller's problems. For the purposes of model parameter estimation, we select a subset of the available data to limit the impact of this simplification.

For the seller, the route-week model does not take into account the total supply constraint and the fact that the total quantity, and number of vessels, a seller can dispatch in any one week is more or less fixed. It also does not account for the fact that the seller may receive multiple requests for contract shipments in any one week and has a certain distribution of vessel capacities available. To ensure these seller constraints do not introduce biases into our estimation, we focus only on route-weeks where the seller sells positive quantities in at least one spot market, meaning they could have sold more via contract if they chose to do so.

We include only weeks where the buyer received contract shipments and/or spot shipments. This ensures that $S^c_{udt} \geq 0$ (which also implies $\phi^{s*}_{dt} > \bar{\phi}^s_{dt}$). Hence, the buyer's decision is only whether or not to request a contract shipment, conditional on having positive demand. In weeks where buyers receive both contract and spot shipments, our model implicitly suggests these are times when the buyer would have preferred to receive more contract shipments, but their additional requests were unfulfilled by the seller.

There are two further dt-specific variables that we use as model inputs to help us understand how sellers' fixed costs of contract shipments vary with the number of requests they receive, SC_{ut}, and the relationship between spot market thickness and spot shipment value, Th_{dt}.

We define SC_{ut} as the de-meaned share of contract shipment requests that the seller delivers in the month of week t. Scheduling vessel capacity and loading to fulfil contract requests is an ongoing seller-level

[25] We do not currently use the threshold shock value below which a spot shipment is preferred to no shipment, $\bar{\phi}^s_{udt}$, in our parameter estimation. However, given the baseline value functional form assumption, from inequality (13), this threshold is:

$$\bar{\phi}^s_{udt} \equiv \frac{k w^{\alpha}_{dt}}{E(p^s_{dt})}$$

management challenge and the more requests they receive in the weeks around the week in question, the more costly it could be to allocate resources to any one individual contract request. We use deviations from the typical share of contracts to allow for the possibility that sellers who routinely handle a large number of contract shipments have likely made fixed investments in this management, and vessel, capacity.

Our preferred measure of spot market thickness at a destination in each period, Th_{dt}, varies with two things. First is the relative size of the spot market in the region in that period compared to the destination's contract demand in that period. If buyers have total demand for a large number of shipments, and much of it is fulfilled via contract, then their spot market options are more limited. Second, using data on the distribution of vessel capacities, we adjust the relative size of the regional spot market by the extent of overlap between the vessel capacities requested by the buyer under contract and the vessel capacities available on the local spot market.[26]

6.3 Empirical moments and estimation

Taking all the route-week observations that satisfy the restrictions in subsection 6.2 gives us 23,426 observations where we observe positive volumes. We construct an indicator, C_{udt} equal to 1 if there is at least one contract shipment in udt. This indicator is equal to 0 if there are no contract shipments, which, given sample restriction, means d is buying spot shipments in t. The variable is undefined if d received no shipments in t.

Because u is defined at the country level, other than for Australia, Russia and the United States, and d is also at the country level, there are many udt observations where there is more than one contract shipment and/or d buys more than one spot shipment. In the estimation, we weight observations according to the sum of the number of spot shipments d buys in t and the number of contract shipments on udt.

Although local spot price variation is associated with weather shocks, there is sufficient independent variation in this empirical probability variable that both spot price and weather shocks are significantly correlated with the probability of receiving a contract shipment when both are included in a regression. We will use the coefficients in this regression as untargeted moments in our estimation as a robustness check for the parameter estimates. The weighted regression generating these two coefficients is:

$$C_{udt} = \alpha_1 w_{dt} + \alpha_2 p^s_{dt} + \gamma_{dm} + \varepsilon_{udt} \tag{15}$$

The estimated coefficients are $\hat{\alpha}_1 = 0.069$ and $\hat{\alpha}_2 = 0.074$, and both are significant.

We form the joint likelihood of weeks where contract shipments are observed by taking the product across all udt:

$$L = \sum_{udt} [C_{udt} log \Pr(\phi^s_{dt} \geq \phi^{s*}_{dt}) + (1 - C_{udt}) log(1 - \Pr(\phi^s_{dt} \geq \phi^{s*}_{dt}))] \tag{16}$$

[26] A detailed description of how Th_{dt} is constructed is available in Appendix C.

7 Results

7.1 Parameter estimates

Estimating the model by maximizing the log likelihood in equation (16) gives the following parameter estimates: All estimates are significantly different from zero. The positive value function parameters k

Parameter	Estimate	Confidence Interval
k	9.97	[9.88, 10.07]
α	0.25	[0.24, 0.27]
λ_0	0.36	[0.30, 0.43]
λ_1	0.27	[0.20, 0.35]
μ	0.63	[0.63, 0.64]
c_u	2.98	[2.96, 3.02]
F_0	1.13	[0.94, 1.33]
F_1	0.01	[0.00, 0.01]

and α show that the value d receives from a shipment is higher when there is a weather shock, that is, when it is unexpectedly cold. The positive estimates of λ_0 and λ_1 show that the value d receives from spot market shipments is positively associated with Th_{dt}, our measure of local spot market thickness at time t. The coefficient μ of 0.63 shows that relationship-specific seller effort contributes positively to contract shipment value. The positive coefficients F_0 and F_1 show that there are fixed costs associated with each contract shipment that are increasing in the deviation from the typical share of contract requests that a seller fulfills that month.

To find the remaining β estimate, we return to inequality (14):

$$\sum_{t^* \geq t} (\beta S^c_{udt^*} - c_u(1 + h_{udt^*})) \geq \sum_{t^* \geq t} E(max_n(p^s_{nt^*})),$$

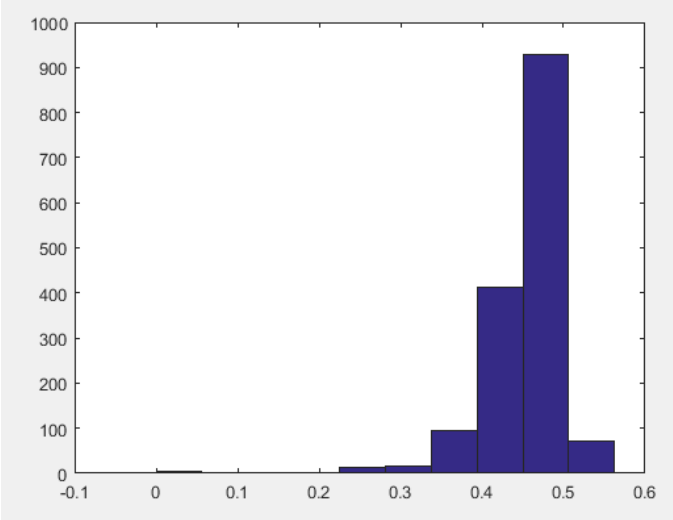
which delivers an estimate of β for each udt. The distribution of these estimates is given in . Since we need our estimate of β to satisfy all of these constraints, we take it as the maximum of the distribution in Figure 5, which is 0.56, with a confidence interval $[0.56, 0.57]$.

The parameter predictions allow us to predict the responsiveness of C_{udt}, whether or not a contract shipment is observed in a route-week, to observed variation in weather and spot prices using equation (15). These untargeted moments are close to the actual data, with the model predicting slightly more variation with weather shocks and spot prices.

7.2 Shipment value estimates

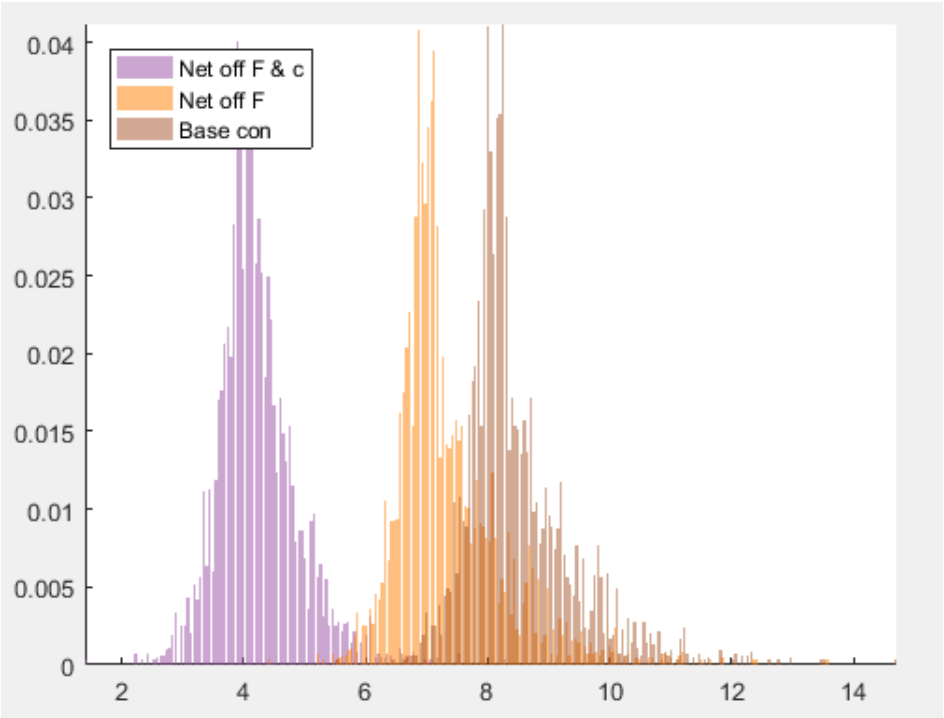
The estimated values of the observed contract shipments are shown in Figure 6. The brown histogram

Figure 5: Estimated lower bounds on β



Coefficient	Data	Model predictions
w_{dt}	0.069**	0.082***
	(0.028)	(0.001)
p^s_{dt}	0.074***	0.080***
	(0.011)	(0.001)

Figure 6: Estimate value of contract shipments



show calculated values of equation (7):

$$V^c_{dt}(w_{dt}, h_{utc}) = \alpha w^k_{dt}(1 + h_{udt})^\mu$$

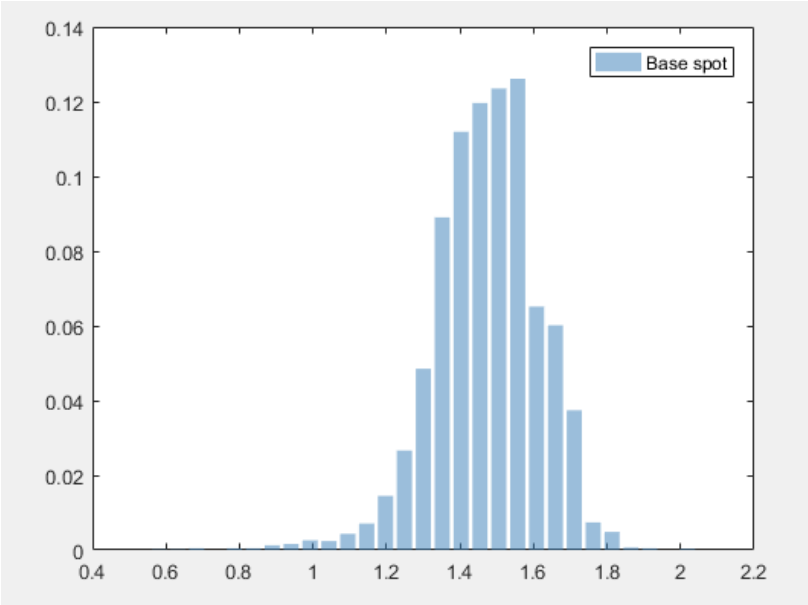
The orange histogram subtracts estimated fixed costs, F_{udt}, showing the distribution of S^c_{udt}. The purple histogram is the surplus of contract shipments net of estimated variable seller effort costs, $c(1 + h_{udt})$. The mean of the purple distribution is 4.24 and the median is 4.15. These values can be compared to the normalized distribution of the local spot price per mmbtu, the mean of which is 0.41. That is, we estimate that the mean value of a contract shipment is eight times higher than the mean spot price over the period studied.

The expected spot market shipment value can be calculated from local weather and the estimate of $\lambda = \lambda_0 Th^{\lambda_1}_{dt}$, where Th_{dt} is the observed thickness of the local spot market.[27] as:

$$E(V^s_{dt}) = E\left(\frac{kw^\alpha_{dt}}{\phi^s_{dt}}\right) = kw^\alpha_{dt}\frac{\lambda}{\lambda + 1} \tag{17}$$

Figure 7 shows the calculated expected spot values. In the figure, the blue histogram gives the expected

Figure 7: Expected value of spot shipments



values of spot shipments when at least one spot shipment is observed in udt, weighted by the actual number of spot shipments observed in the data. We note that there tended to be more spot shipments in udt when the average value was higher. The mean of the distribution is 1.50 and the median is also 1.51. That is, the estimated mean value of a spot shipment is more than three times as large as the normalized mean spot price. In other words, we find that just under one third of the gains from trade in the current spot

[27] The derivation is: $E(V^s_{dt}) = E\left(\frac{kw^\alpha_{dt}}{\phi^s_{dt}}\right) = kw^\alpha_{dt}\frac{\lambda}{\lambda+1} = kw^\alpha_{dt}E(\frac{1}{\phi^s_{dt}}) = kw^\alpha_{dt}\int \frac{1}{\phi^s_{dt}}\frac{\lambda}{(\phi^s_{dt})^{\lambda+1}}d\phi^s_{dt} = kw^\alpha_{dt}\lambda\int \frac{1}{(\phi^s_{dt})^{\lambda+2}}d\phi^s_{dt} = -kw^\alpha_{dt}\frac{\lambda}{\lambda+1}(\phi^s_{dt})^{-(\lambda+1)}|^\infty_1 = kw^\alpha_{dt}\frac{\lambda}{\lambda+1}$

market go to the seller and more than two thirds goes to buyers. Note that we estimate $\beta = 0.56$, which is the share of surplus going to sellers in the contract relationships, suggesting that the sellers extract a larger share of the larger gains from trade from contract shipments.

8 Counterfactual Analysis

We now ask how much long-term relationships contribute to industry value relative to a situation where the same vessels arrived in each destination in each period and were transacted via the spot market. That is, the counterfactual is larger spot markets in each udt where contract shipments are currently observed. The trade-off is that all shipments become "anonymous" arm's length transaction, and sellers exert no relationship-specific effort and incur zero contract fixed and variable costs.

We are able to estimate this counterfactual because the λ parameter estimates allow us to calculate the expected spot shipment value, as a function of the observed weather shock and the counterfactual spot market thickness, Th_{dt}, using equation (17). The measure of Th_{dt} typically becomes equal to 1 because the share of regional supply (demand) that is spot is now 100%. In addition, because the vessel sizes that were demanded under contract by each buyer are now a subset of the distribution of vessel sizes available via spot, the distributions of vessel sizes become equivalent (see Appendix C).

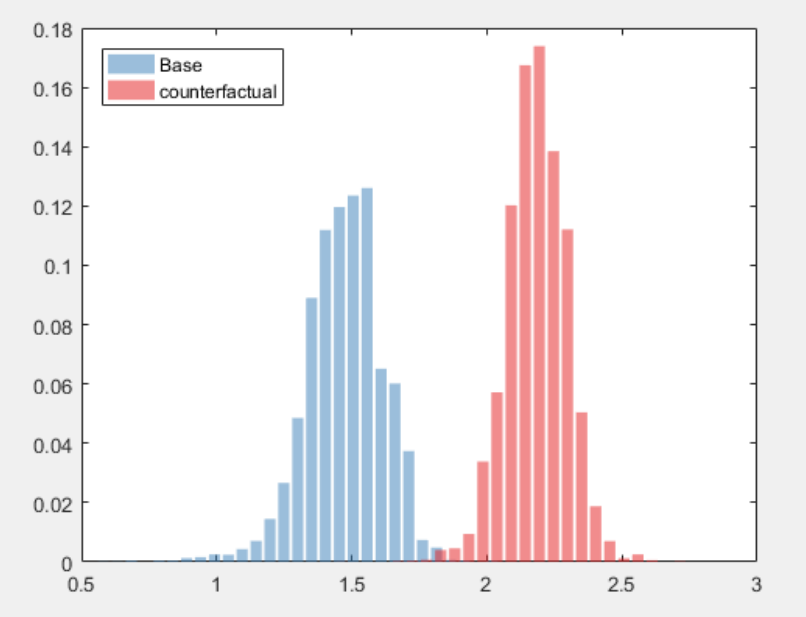
One major appeal of this approach is that we do not need to simulate counterfactual spot prices. We also don't need to address the seller's allocation problem, that is, where they would send vessels in the absence of contracts. A related benefit is that our counterfactual estimates are invariant to transport costs, which are currently excluded from the analysis, but which remain constant in the counterfactual.

In the sample of data used to estimate the model, we see $23,238$ contract shipments and $6,296$ spot shipments in total. For the counterfactual analysis, we estimate the values of all contract and spot shipments, including those that did not satisfy the estimation sample restriction in Subsection 6.2. If, instead, all of these contract shipment in this enlarged sample were sold on local spot markets, arriving at the same destinations at the same times as before, we can predict the distribution of expected spot shipment values in the market.

The predicted value of the entire spot market is given in the red histogram in Figure 8. For comparison, the blue histogram is the distribution of actual spot shipment values given the observed much smaller number of spot shipments, as shown in Figure 7. The red histogram reflects higher spot values as buyers receive a spot shipment that is a closer fit to their needs in the counterfactual larger spot market. This counterfactual distribution has a mean value of 2.21 and a much smaller variance than the observed distribution. This is because there is no variation in Th_{dt} in the counterfactual.

Because the counterfactual holds all transport costs fixed, and varies only the value created for buyers, it is possible to compare total welfare in the observed and counterfactual cases. Figure 9 shows the observed

Figure 8: Counterfactual spot shipment values



shipment surplus for contracts (purple) and the expected value of spot shipments (blue) in the data, as given in Figures 6 and 7, respectively. The counterfactual expected value of the spot market in the absence of all contracts, that is the expected industry value, is shown in red.

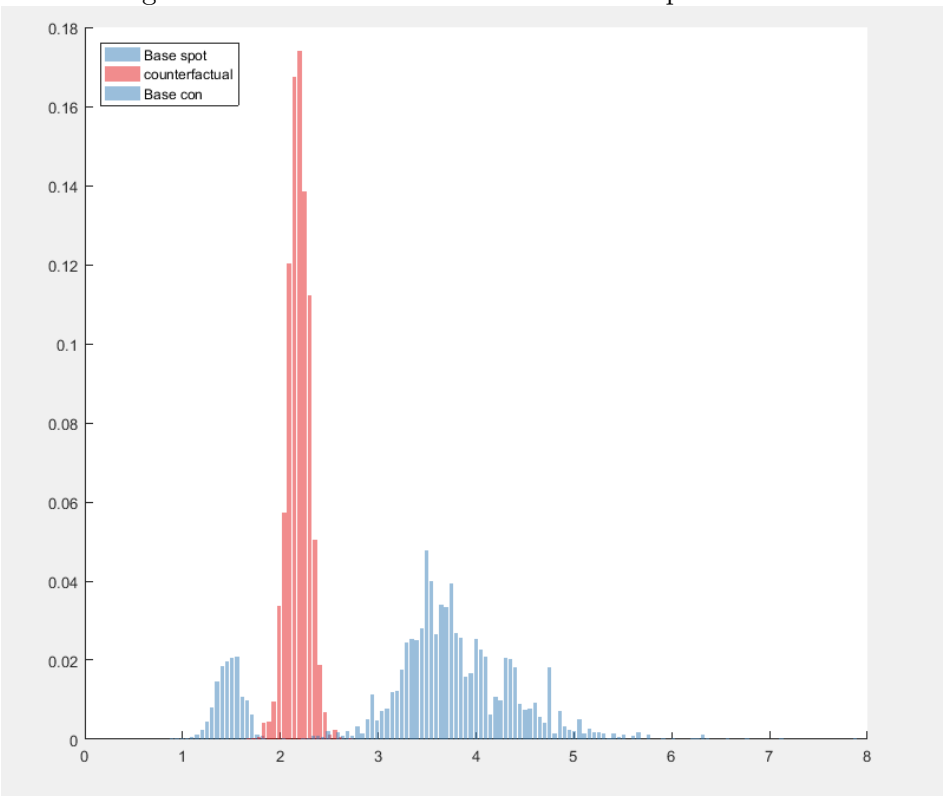
The total change in welfare can be decomposed into three parts:

$$\begin{aligned}\Delta W &= \Delta W_s + \Delta W_c \\ &= Q_s^* E(V_s^*) - (Q_s E(V_s) + Q_c(V(h) - F - ch)) \\ &= (Q_s + Q_c)E(V_s^*) - (Q_s E(V_s) + Q_c(V(h) - F - ch)) \\ &= Q_s(E(V_s^*) - E(V_s)) + Q_c(E(V_s^*) - V(h)) + Q_c(F + ch) \end{aligned} \tag{18}$$

The first term in equation (18) is the percentage increase in the value of the spot market in the counterfactual where it is much larger. This change is 5.04%. The second term is the percentage reduction in the value of the shipments that are currently transacted via contracts, and is estimated to be 181.48%. This loss can be attributed to the loss in shipment value from the fact that sellers exert no relationship-specific costly effort. The third term in equation (18) is the welfare gain coming from the savings in the seller's variable effort costs and fixed costs associated with contract shipments. This saving is equivalent to 119.08% of current industry value.

The net impact of the removal of contracts is a reduction in industry value that suggests the presence of these long-term contracts between buyers and sellers increased industry value by 57%. We infer that total industry size remains too small for spot markets to deliver shipments to buyers that fit their demand even if all industry supply were transacted on global spot markets rather than via contracts.

Figure 9: Observed and Counterfactual Shipment Values



9 Conclusion

Long-term contracts dominate the LNG industry and the nature of these relationships shapes LNG prices around the world. This paper brings insights from recent advances in the theory of incomplete contracts to bear on detailed transaction-level data. Our main contribution is in quantifying the role played by relationship-specific costs incurred by the seller in creating value for the buyer. Our model estimates show that contracts are a mechanism that allows sufficient incentives for efficient seller effort. The counterfactual analysis reveals that contracts increased the value of the global LNG industry by around 60% between 2009 and 2019.

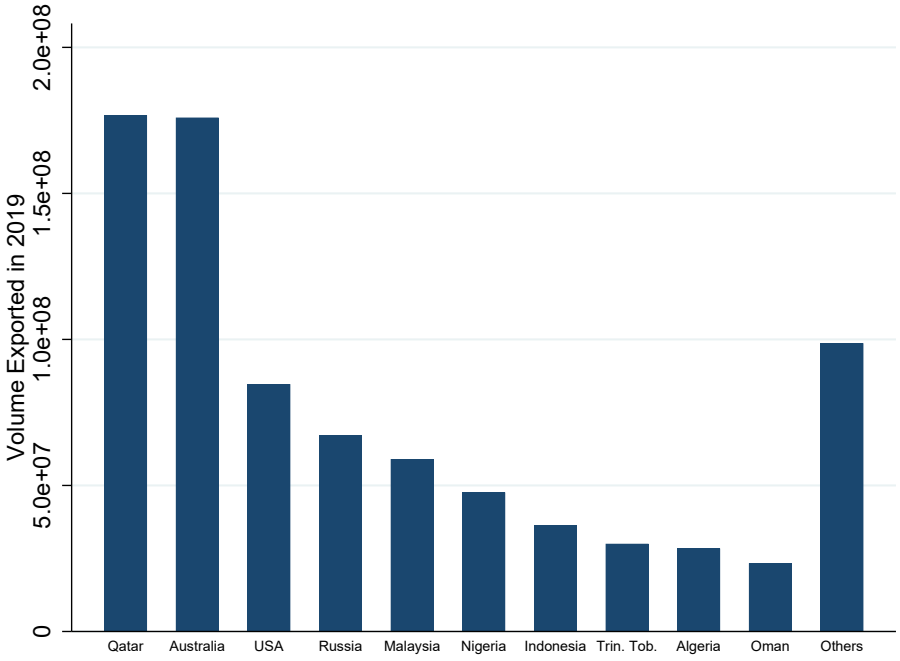
Appendix

A Global supply and demand in 2019

A.1 Supply

The shipment-level data we use, which runs from the start of 2009 to the end of 2019, contains shipments from 19 countries. Qatar has been the largest exporter historically, with over 500 shipments in each of the 11 years. Australia has increased exports over the time period, and exported more than 500 shipments in the last four years in the data. After Qatar and Australia, the largest exporter countries are Malaysia, Indonesia, Algeria, and Nigeria. Figure A.1 focuses on 2019, and shows total volumes exported by source country in cubic metres. The USA, Russia, and Trinidad and Tobago are more prominent in 2019 than in the period as a whole.

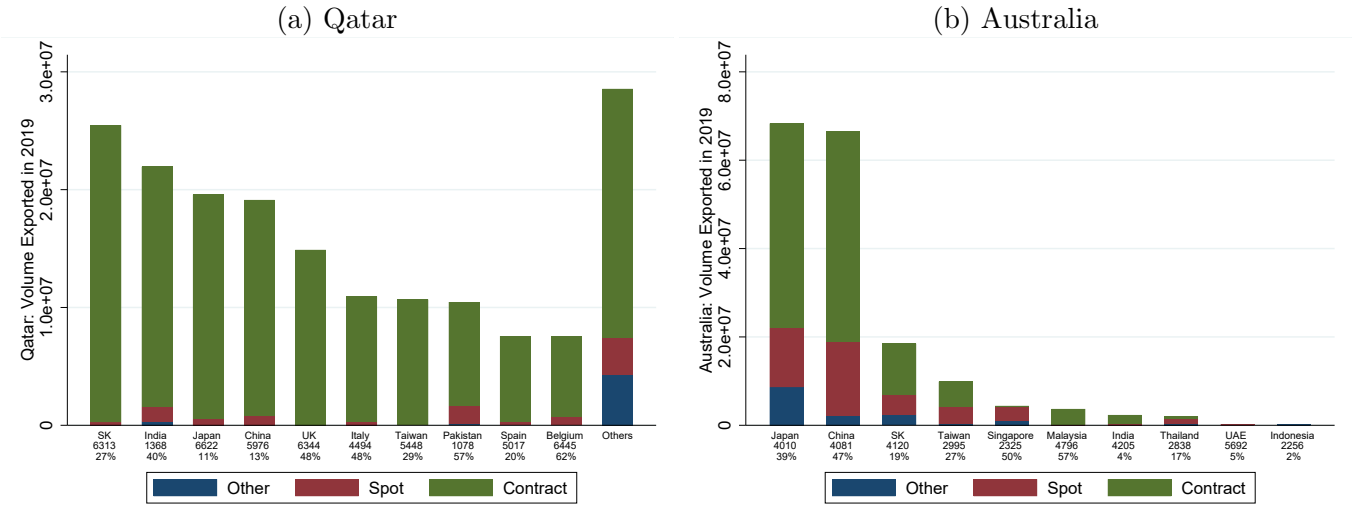
Figure A.1: Largest exporter countries in 2019



Because the LNG industry is a costly shipping technology for a commodity product, we might think that both sellers and buyers have incentives to minimize the distance travelled. The overall flows confirm this, in general. For example, Figure A.2 shows that the two largest destinations for Australia are the relatively close Japan and China, where Australia supplies 39% and 47% of these countries' LNG, respectively. Qatar supplies less of these countries' demand, at 11% and 13%. The figures below the country name show the average mileage travelled on routes between the source and destination countries. The LNG travelling to Japan and China from Australia travels much shorter distance than the LNG from Qatar.

However, there are exceptions. For example, Qatar supplies 27% of South Korea's LNG and 29% of

Figure A.2: Volume by Destination, 2019



Taiwan's despite LNG having to travel over 5,000 miles to get there. Australia is much closer to both destinations and supplies only 19% and 27%, respectively.[28] We suspect deviations from gravity relate to the staggered timing at which liquefaction and regasification capacity was installed in different countries and the agreed long term contracts between buyers and sellers.

Figure A.2 also offers some insight about how shipments are organized. The bulk of LNG exports from Qatar in 2019 were contracted quantities, meaning very little LNG from Qatar ended up in the spot market. For Australia, spot volumes were relatively more common. Figure A.3 turns to another source of variation that is of primary interest for us. It takes the volumes exported under contract from Qatar and Australia in 2019 and shows how much of it is delivered FOB and how much is DES. There is variation in the proportion arriving DES in each country from a given exporting country, and variation across exporting countries in the share sent via DES to a given destination.

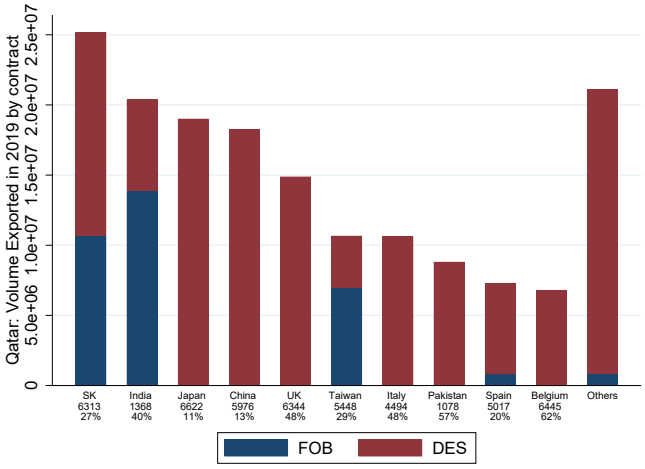
Figure A.4 focuses on 2019, and shows total volumes imported by destination country.

Table A.5 shows the volumes arriving in Japan in 2019 by source country. The figures below the country names are the average distance travelled and the share of that country's LNG exports arriving in Japan. There are some interesting comparisons. Australia sends Japan 39% of its output but is much further away than Malaysia, which sends a similar share of its total output to Japan. There is variation across source countries in the share of LNG arriving in Japan from integrated and non-integrated charterers. The majority of LNG from Australia arrives FOB, while almost all LNG from Qatar is DES.

[28] We have some data on production costs. Qatar has a much lower operating production cost than the installations in Australia (see supply functions in earlier update), so the delivered cost from Qatar may still be much lower than from Australia.

Figure A.3: Contracted volumes by Destination, 2019

(a) Qatar



(b) Australia

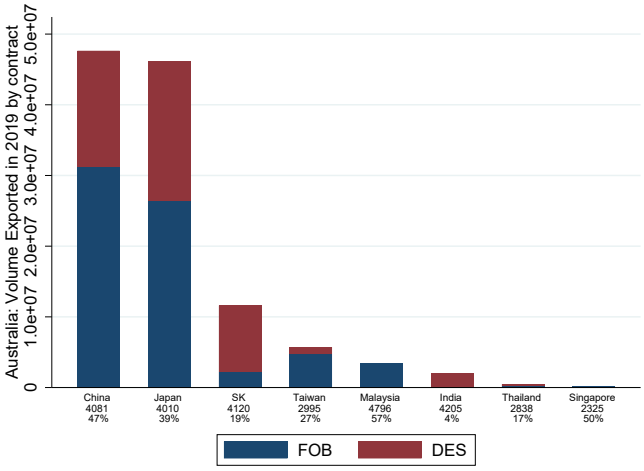


Figure A.4: Largest importer countries in 2019

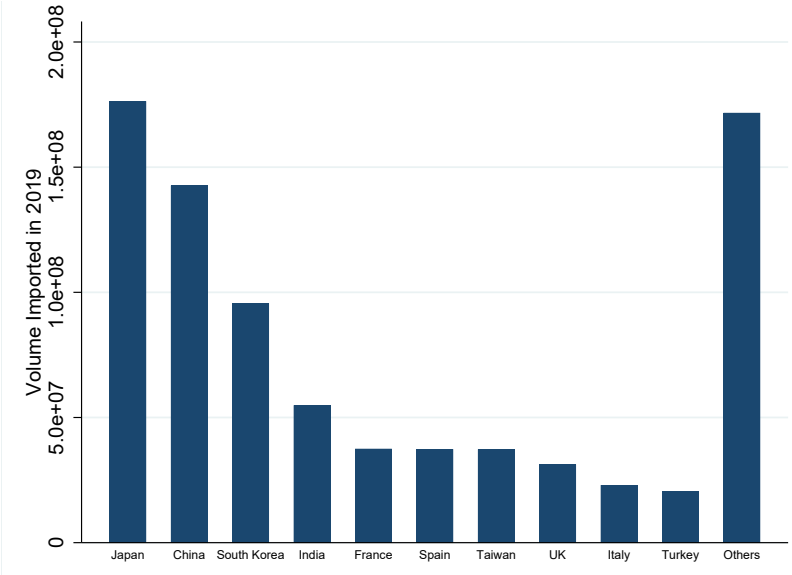


Figure A.5: Japan imported volumes by Origin, 2019

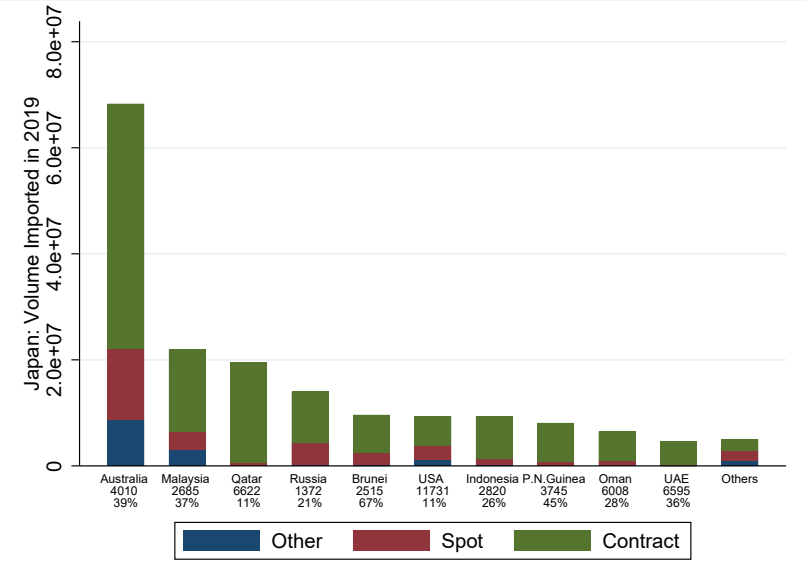
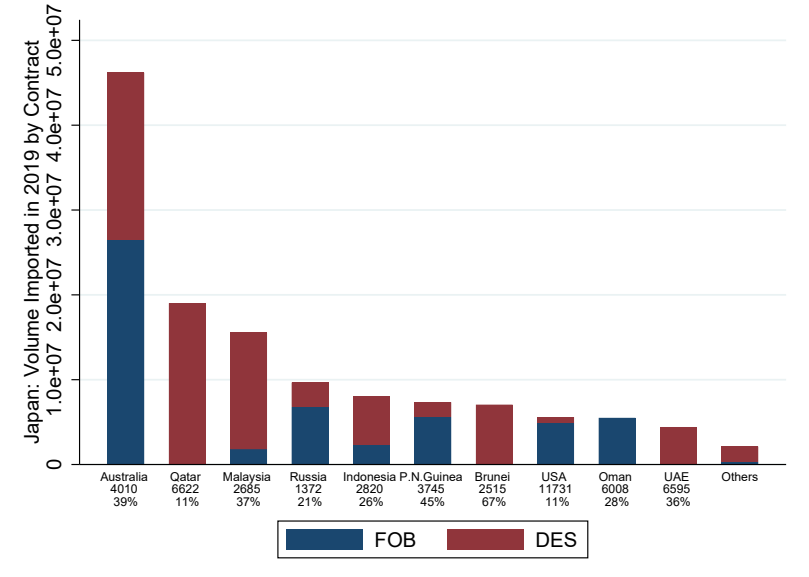


Figure A.6: Japan imported contracted volumes by Origin, 2019



B Constructing the organizational variables

Describing the nature of integration at the shipment level is an important part of this project. We start with the Kpler variables that include firm names.

- The **sellerorigin** variable contains company names. There are up to 11 firms per shipment, appearing in different orders, with $1,214$ unique combinations. We don't know the share of the cargo sold by each firm. We order the names alphabetically, remove gaps in each name, and construct unique combinations of sellers, independent of name order. The trades.do file contains some individual changes related to unusual cases, e.g. Qatargas. There are 144 unique seller firm combinations in this variable SellerOriginNew. Some of the combinations are almost overlapping, e.g. four common names and one different.

- The **buyerdestination** variable contains company names. Again, there are up to 11 firms per shipment, in different orders, and $1,805$ unique combinations. When firm names are ordered and gaps removed, we obtain 329 unique buyer firm combinations in this variable called BuyerDestNew.

- The **charterer** variable is almost always a single firm. We remove gaps and make some case by case adjustments. There are 139 unique charterers.

The seller firms are often owned by one or multiple parents. We have data from Wood Mackenzie on the owners of seller firms and also some origin installations. For each, we match the owning firms to each of the up to 11 names in the sellerorigin variable and the installationorigin variable. We do the same for the charterers. At the end of this, we have seller firms, the owners of seller firms, the owners of origin installations, the charterer firms and the owners of charterer firms, and the buyer firms.

To construct the variables of interest, we search through all the firm names at each stage for each shipment. Each shipment is classified into one of five organizational structures:

- The seller-charterer integration variable is an indicator of at least one common firm among the seller firms or owners of seller firms and the charterer firm or owners of the charterer firm. 52% of shipments.

- The charterer-buyer integration variable is an indicator of at least one common firm among the buyer firms and the charterer firm or an owner of the charterer firm. 21% of shipments.

- The seller-charterer-buyer variable indicates that there is at least one seller-charterer link and one charterer-buyer link. It does not need to be the same firm at each of the three stages. 4% of shipments.

- The seller-buyer variable indicates a common seller and buyer but no common seller and charterers or charterer and buyers. 1% of shipments.

- Finally, the no integration variable indicates that there is no common ownership of any of the four types. 22% of shipments.

C Measuring spot market thickness, Th_{dt}

. For each destination-week, the measure Th_{dt} is the product of two terms.

First, we find the share of spot shipments in the region (Europe or Asia) in that month, which is the total number of spot shipments delivered to all destinations in the region divided by the total number of spot and contract shipments delivered in the region. The higher is this share, the more likely any buyer in the region could purchase spot shipments at the time they demand it.

Second, we turn to the match of spot shipment capacities with those demanded via contracts. We find the distribution of spot vessel sizes that have been delivered in the region over the last three months. We then add to these shipments the contract shipments delivered to the destination that month to give the capacity distribution of typical region spot shipments together with the destination's contract capacity demand. We use the Kolmogorov-Smirnov statistic to tell us how similar these two distributions are. If they are very similar, we infer that the destination's demand contract capacities could be catered to by the region's spot market. The more similar the distributions the thicker the local spot market, in terms of shipment capacity availability.

For the counterfactual, by construction, both of these terms go to 1. Hence, the spot market in each destination-week achieves the maximum spot market thickness that is ever observed in the actual data. The buyer values for this enlarged spot market are still discounted due to the value of ϕ^s_{dt} in V^s_{dt} being determined by the estimated λ_0 and λ_1 parameters delivered in Section 7.

References

Brancaccio, Giulia, Myrto Kalouptsidi, and Theodore Papageorgiou. 2020. "Geography, transportation, and endogenous trade costs." *Econometrica* 88 (2):657–691.

Costinot, Arnaud, Lindsay Oldenski, and James Rauch. 2011. "Adaptation and the boundary of multinational firms." *The Review of Economics and Statistics* 93 (1):298–308.

Forbes, Silke J and Mara Lederman. 2010. "Does vertical integration affect firm performance? Evidence from the airline industry." *The RAND Journal of Economics* 41 (4):765–790.

Forbes, Silke Januszewski and Mara Lederman. 2009. "Adaptation and vertical integration in the airline industry." *American Economic Review* 99 (5):1831–1849.

Harris, Adam and Thi Mai Anh Nguyen. 2022. "Long-term Relationships and the Spot Market: Evidence from US Trucking." .

Klein, Benjamin, Robert G Crawford, and Armen A Alchian. 1978. "Vertical integration, appropriable rents, and the competitive contracting process." *The journal of Law and Economics* 21 (2):297–326.

Kranton, Rachel E. 1996. "Reciprocal exchange: a self-sustaining system." *The American Economic Review* :830–851.

Macchiavello, Rocco. 2022. "Relational contracts and development." *Annual Review of Economics* 14:337–362.

Macchiavello, Rocco and Ameet Morjaria. 2015. "The value of relationships: evidence from a supply shock to Kenyan rose exports." *American Economic Review* 105 (9):2911–2945.

Masten, Scott E and Keith J Crocker. 1985. "Efficient adaptation in long-term contracts: Take-or-pay provisions for natural gas." *The American Economic Review* 75 (5):1083–1093.

S&P. 2022. "Gunvor backs out of LNG deliveries to Pakistan for April-June deliveries." https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/lng/032822-gunvor-backs-out-of-lng-deliveries-to-pakistan-from-april-june-officials. Accessed: 2023-09-12.

———. 2023. "Demand for term LNG contracts firms amid supply security concerns." https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/lng/071223-demand-for-term-lng-contracts-firms-amid-supply-security-concerns. Accessed: 2023-09-12.

Williamson, Oliver E. 1979. "Transaction-cost economics: the governance of contractual relations." *The journal of Law and Economics* 22 (2):233–261.

Zahur, Nahim Bin. 2020. *Essays on International Energy and Transportation Markets*. Cornell University.