Impacts of COVID-19 on the Global Supply Chain: A Case Study from the U.S. Less-than-Truckload Motor Carrier Industry

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Abstract

This paper examines, with quarterly firm-level data 2015Q1 to 2020Q4, the Covid-19 pandemic effects on shipping demand in the US less-than-truckload (LTL) carrier industry. The econometric model shows total U.S. business activity, prices paid by shippers, and the Covid-19 pandemic outbreak has had statistically significant effects on LTL shipping demand. Business environment lifts shipping demand while shipper price reduces it. Covid-19 brought a short-run boost to demand while rendering it more sensitive to overall economic activity and shipping prices.

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1. Introduction

As a lifeblood of the U.S. economy, trucking delivers roughly three-quarters of U.S. domestic freight weight. Almost every good in the US is at least once on a truck before consumed. In 2018, 7.95 million persons were employed in trucking-related activities. In 2019, trucks moved 72.5 per cent (11.84 billion tons) of all freight transported in the U.S. and represented 80.3 per cent of the nation's freight bill. (American Trucking Association, 2020). The rising demand for ground transportation, influenced not only by GDP growth but the globalization of manufacturing and retail supply chains, has affected every sub-sector of the industry: truckload (TL, above-10,000-lb shipments), less-than truckload (LTL), and small packages (under 100 lbs). Prior to Covid-19 at least, "after nearly a decade of thin profit margins, the LTL sector [had] become highly prosperous, with booming e-commerce, shortened supply chains, and the smaller, lighter shipments accompanying them" (Du and Buccola, 2020).

1.1 LTL Business and Its Operations

Less-than-truckload (LTL) carriers provide transportation of palletized shipments weighing between 100 and 10,000 pounds. Compared to other segments of the trucking industry, LTL shipments involve more handling, initial pickup, inspection, sorting, and final delivery. Like airlines, LTL carriers operate on a "hub-and-spoke" network system, collecting freight from various locations and consolidating them into enclosed trailers for line haul to a hub terminal. After inspection on these inbound shipments, the freight will be loaded onto an outbound trailer for forwarding or additional line haul to delivering terminal.LTL shipping thus is more capital and labor intensive than truckload is. The main advantage of using an LTL carrier is that a shipment can be transported for only a fraction of the cost of hiring an entire truck and trailer, as an exclusive full-truckload shipment requires. Meanwhile a number of accessorial services, not typically offered by TL carriers, such as lift gate or residential services at pick-up or delivery, are available from LTL carriers.

1.2 LTL Market Structure

Trucking deregulation since 1980, especially the Motor Carrier Act of 1980 increased the number of trucking companies and intensified competition. Furthermore, as the global economy continues to integrate, import traffic becomes more essential to the U.S. supply chain distribution process. Once overseas shipments hit the coast, shippers demand the same promptness as domestic LTLs do. Traditional LTL carriers changed their structure and operating system to adapt to this demanding work environment. Gradually, many mid-sized trucking companies have become increasingly vulnerable to the competition from large national companies with strong financial backup, capable of providing high-quality and efficient service through their established network infrastructure. Meanwhile, they also face the price-cutting from small local operators.

Mid-sized carriers have had to merge in order to survive this challenge. The result is an industry structure consisting of a few large, full-service logistics companies and many small niche LTL providers. The aftermath of the resulting mergers and acquisitions is that, of the 60 leading name-brand North American LTL carriers in 1983, only seven carriers exist today. In 2020, the top ten LTL carriers (FedEx Freight, YRC Worldwide, UPS Freight, Old Dominion Freight Line, XPO Logistics, Estes Express Line, R+L Carrier, ABF Freight, Saia and Southeastern Freight Line) accounted for around 80% of market revenue.[1]

1.3 Determinants of LTL Freight Business

Many supply chain factors influence the LTL market. According to Du and Buccola (2020), demand for LTL shipping services is highly sensitive to the merchandising sector of the US economy. LTL trucking, in other words, is heavily dependent on the business cycle. When the economy enters a recession, business sales growth slows and firms respond by reducing production and inventories. As they do, says the Bullwhip Effect, business-to-business (B2B) shipments will contract more than business-to-consumer (B2C) shipments do.[2] Because LTL carriers are mainly B2B providers, the demand for freight transportation falls. When the economy begins to recover, B2B sales pick up and firms expand both to satisfy market demand and restock inventories. Consequently, the demand for freight transportation rises.

Another important factor in LTL shipping volume is of course the price charged per hundred weight, since both the industry demand curve and, in this monopolistically competitive sector the demand facing each firm, is negatively sloped. Other possible demand determinants of LTL freight demand include fuel surcharges, service quality and efficiency, demand seasonality, marketing programs, advertising, on-time delivery performance, mergers and acquisitions, delivery network infrastructure, and supply chain shocks like Covid-19.Transit time in particular, an important measure of service quality, plays an important role in determining LTL firm freight demand. Shippers prefer transportation services with the shortest transit time from initial pickup to delivery, other factors the same. Still other measures of service quality and thus demand may include quickness of problem response, damage rates, newer and larger fleet size, and driver quality.

2. Literature Review

Previous studies of the LTL industry have been focused on the cost or supply side, including but not limited to a firm's shipment base charges (Kay and Warsing, 2009, Smith *et al*, 2007 and Özkaya *et al*, 2010), a shipper's service preferences (Danielis et al 2005; Danielis and Marcucci 2007, Fries *et al*, 2010, and Mesa-Arango and Ukkusuri, 2014), pricing structure and fuel surcharges (Grant and Kent, 2006, Kent, Smith and Grant, 2008, Du and Buccola, 2020, Du and Lau, 2021) and fuel efficiency (Vernon and Meier 2012, and Winebrake *et al* 2015a,b). Several other researchers have addressed cost saving by way of load planning (Katayama and Yurimoto, 2016), choices between the TL and LTL mode (Chu, 2005), weight discount practices (Carter *et al*., 1995), and fleet size optimization (Carbajal *et al*, 2012).

Supply shocks due to the Covid-19 outbreak in China in February 2020, and demand shocks followed by the subsequent global economy lockdown have brought uncertainties in production strategies and supply chains. Many analysts expect the global supply network to look significantly different after Covid-19 has passed (Shih, 2020). The present is effort to examine how Covid-19has affected the U.S. LTL carrier industry on especially the demand side of the supply chain, one providing forecasts all along that chain as well.

I use the most recent quarterly data from several major U.S. LTL motor carriers, 2015 Q1 to 2020 Q4. They are F edEx Freight (FXF) [(including FXF Priority (FXFP) and FXF Economy (FXFE)], XPO Logistics, Yellow Roadway Corporation Worldwide (YRC Regional and National), Old Dominion Freight Line (ODFL), ABF Freight, Saia, and United Parcel Service Freight (UPSF). Similar to Du and Buccola (2020), I consider LTL pricing and shipping volume at the firm level, enabling a clearer picture of carrier technology than industry-level data would. In particular, by including such important LTL carriers as XPO Logistics, ABF Freight, Saia, and UPSF that Du and Buccola had excluded, I will examine approximately 70% of the U.S. LTL industry, 2015 to 2020, compared to the only 40%,as of 2017,in Du and Buccola. A larger, more recent sample provides a significant opportunity to study the Covid-19 impact on the LTL sector.

[1]Data are from *Transport Topics Top100For-Hire Private Carriers2020.*

[2] See Lee, Padmanabhan, and Whang (1997).

3. Model Specification, Variable Definitions, and Data Sources

To understandCovid-19's impacts on the supply chain, we postulate the following econometric model. LTL firms usually don't separately report such data as service quality, transit time, and on-time delivery performance in their financial records, so our regression model will include only those explanatory variables whose data are available. Please refer to Appendix Table 1 for data descriptive statistics.

Table 1. Variable Definitions and Descriptive Statistics

Variable	Description and Unit	Mean	Std	Max	Min
ADW_{it}	Firm *i*'s Average Daily Weight at time *t* (in lbs)	52161	19879	98853	21836
$PRICE_{it}$	Firm *i*'s Yield per Hundred Weight in 1982 Dollars at time *t*	8.818	2.292	14.207	4.692
$BUSINESS_t$	Total Business Activity in 1982 Dollars at time *t*	1087724	48330	1188329	987929
W_{dt}	Diesel Price per Gallon in 1982 Dollars	1.108	0.121	1.293	0.872
W_{lt}	Average Hourly Wage in 1982 Dollars	23.978	0.869	25.553	22.753
W_{kt}	Capital Price Index (chain-type, 2012=100)	108.011	2.899	112.039	104.425
Dummy Variables					
$FIRM_i$	Coded as 1 for Firm *i*; otherwise 0	0.114	0.318	1	0
$COMB_t$	Code as 1 if time period is in or after 2017Q1 for Saia; otherwise 0	0.071	0.258	1	0
$COVID_t$	Coded as 1 if time period is in 2020Q2 and Q3; otherwise 0	0.085	0.28	1	0
$WINTER_t$	Coded as 1 if time period is in Q1; otherwise 0	0.256	0.437	1	0
$SPRING_t$	Coded as 1 if time period is in Q2; otherwise 0	0.256	0.437	1	0
$SUMMER_t$	Coded as 1 if time period is in Q3; otherwise 0	0.256	0.437	1	0

$$\begin{aligned} \ln(ADW_{it}) = {} & \alpha + \beta_1 \ln(BUSINESS_t) + \beta_2 COVID_t * \ln(BUSINESS_t) \\ & + \beta_3 \ln(PRICE_{it}) + \beta_4 COVID_t * \ln(PRICE_{it}) \\ & + \beta_5 COVID_t + \beta_6 COMB_{it} + \sum_{i=1}^{8} \gamma_i FIRM_i + \sum_{i=1}^{7} \theta_i COVID_t * FIRM_i \\ & + \delta_1 WINTER_t + \delta_2 SPRING_t + \delta_3 SUMMER_t + \varepsilon_{it} \qquad (1) \end{aligned}$$

All data are non-seasonally adjusted quarterly observations from 2015 Q1 to 2020 Q4. Continuous variables are in natural logs.

Average daily weight $ADW_{i,t}$ is firm *i*'s shipped weight in quarter *t* in thousands of lbs, computed as total weight divided by number of operating days that quarter, available from the firms' 10-Q financial reports.

$PRICE_{i,t}$is firm *i*'s mean price in quarter *t*, measured as financial revenue per hundredweight in 1982 dollars, computed as total revenue divided by transported weight in lbs and available from firms' 10-Q financial reports.

$BUSINESS_t$, is total business activity at quarter *t*, measured as the sum of quarterly US manufacturing, wholesale, and retail business sales in 1982 dollars, drawn from the US Bureau of Census.

$COVID_t$is a dummy variable indicating the outbreak of Covid-19 pandemic in quarter *t*. If the time period is in 2020 Q2 and Q3, the variable is coded as 1; otherwise 0.

$COMB_i$is the dummy variable indicating that LTL carrier Saia combined its TL data statistics into its LTL business financial report after 2017 Q1. In or after 2017 Q1 at Saia, this variable is coded 1; otherwise 0.

$FIRM_i$is the vector of firm dummies.

WINTER, *SPRING*, and *SUMMER* is the vector of seasonal dummies.

We expect the coefficient of $PRICE_{it}$ to be negative because, according to the law of demand, higher prices should except for Giffen goods bring lower purchases. The coefficients of $BUSINESS_t$ should be positive because rising total economic activity should boost purchase demand and so shipping volume. Taking account of its interactions with the other terms, *COVID*'s net effect should be negative insofar as its short-run disruptions – in effect, disequilibrations – to the global supply chain. On the other hand COVID also significantly boosted final consumers' online shopping demands where, far downstream on the supply chain, more trucking is needed.

Strong home delivery demand thus passes its influence back to the middle or upper portions of the supply chain, lifting overall LTL demand, with an even larger magnitude due to the Bullwhip Effect. Therefore, the net effect of *COVID* on the LTL shipping demand is uncertain.

I include in equation (1) interactions of Covid-19 incidence with total U.S. business volume, shipping price, and firm and season effects in order to determine how the outbreak's influence differed in these dimensions. I expect the coefficient of $COVID_t$* *PRICE* to be negative because the economic downturn a pandemic induces should, in intensifying competition among the monopolistically competitive suppliers, intensify the substitution effects in their individual demand curves, making them more elastic (negatively responsive to price). The sign of the coefficient of $COVID_t*BUSINESS_t$, in (1) is ex-ante unclear because as discussed just above, COVID's effect on the distribution of LTL shipping demand across the entire supply chain is generally uncertain.

Most importantly, equation (1) is a demand function because it excludes LTL firm cost factors while including U.S. business volume, which is a demand factor only. Price however not only affects demand but is itself affected by cost (supply) factors, so we have a biased estimate of demand in equation (1) if we fail to control for these supply elements. Although the full-truckload industry is generally regarded in the literature as perfectly competitive, the LTL sector is arguably monopolistically competitive (Du and Buccola, 2020). In particular, differentiated service quality and network structures allow individual LTL carriers some market power over the prices of their shipping services. A firm's service prices in a monopolistically competitive market thus are endogenous rather than exogenous as the would be in perfect competition. The LTL industry thus belongs to the category in which we must control for supply factors when estimating demand.

When price is endogenous in this way – implicated in both supply and demand -- it is correlated with the error term. The resulting bias can be eliminated by incrementing price (IV estimation) by regressing it on all exogenous factors in the system (2SLS). The exogenous factors I use for this purpose are all those on the right side of (1) except price, plus any additional exogenous factors that would affect supply. The latter include any compensation the LTL firm pays for its labor, fuel expenses, depreciation and amortization, transportation facilities, and repair and maintenance. Higher input prices raise LTL firm operating cost, reducing the supplies it offers the market and so pushing its service prices upward.

I use, besides the exogenous variables in equation (1), the following firm supply factors as instrumental variables:
$W_{d,t}$, the non-seasonally-adjusted retail price, in dollars per gallon, of U.S. No 2 diesel. Quarterly observations are obtained from *Energy Information Institute*, U.S. Department of Energy, and deflated with the Consumer Price Index (CPI), all urban consumers, 1982-84=100. The deflator series is obtained from the Bureau of Economic Analysis (BEA) U.S. Department of Commerce (DOC).

$W_{l,t}$, the non-seasonally-adjusted U.S. Transportation and Warehousing industry-average hourly wage rate, in 1982 dollars per hour, available from *Employment, Hours, and Earnings from the Current Employment Statistics Survey (National)*, Bureau of Labor Statistics (BLS) U.S. Department of Labor (DOL).

$W_{k,t}$, annual observations of the non-seasonally-adjusted capital price index for private fixed investment in transportation equipment: trucks, buses, and truck trailers (chain-type price index, 2012=100), available from Economic Research Division, Federal Reserve Bank of St. Louis.

$YLD_{i,\,t-1}$, the lagged firm *i*'s yield at time *t-1*.

I include one-quarter-lagged prices to reflect the firm's fixities that delay demand responses. Finally, firm fixed effects account for inter-firm technological and route configuration differences, which in turn influence their responses to the Covid-19 outbreak. Seasonal dummies reflect largely demand-side variations such as in the holiday season. Regressions are in natural logs so that parameters are in percentage or elasticity terms. For example, β_1 is interpreted as the percent increase in the demand for shipped weight induced by a one-percent increase in total business activity, all other factors constant. My sample contains 211 quarterly observations, running from 2015Q1 to 2020Q4.

4. Empirical Results

As for equation (1), log differentiating *ADW* with respect to *BUSINESS* gives:

$$\frac{\partial \ln(ADW)}{\partial \ln(BUSINESS)} = \beta_1 + \beta_2 * COVID \qquad (2)$$

When *COVID*=1,

$$\frac{\partial \ln(ADW)}{\partial \ln(BUSINESS)} = \beta_1 + \beta_2 \quad (3)$$

And when *COVID*=0,

$$\frac{\partial \ln(ADW)}{\partial \ln(BUSINESS)} = \beta_1 \quad (4)$$

Log differentiating *ADW* with respect to *PRICE* gives:

$$\frac{\partial \ln(ADW)}{\partial \ln(PRICE)} = \beta_3 + \beta_4 * COVID \quad (5)$$

When *COVID*=1,

$$\frac{\partial \ln(ADW)}{\partial \ln(PRICE)} = \beta_3 + \beta_4 \quad (6)$$

And when *COVID*=0,

$$\frac{\partial \ln(ADW)}{\partial \ln(PRICE)} = \beta_3 \quad (7)$$

The resulting IV estimates indicate most explanatory variables in equation (1) are statistically significant with the expected signs (Appendix Table 2).

Table 2. Regression Results: 2SLS Parameter Estimates

Variables	**Parameter Estimate**	**Std. Err.**	**t-ratio**
CONSTANT	0.537	1.34	0.40
$BUSINESS_t$	0.672	0.232	2.90****
$COVID_t*BUSINESS_t$	0.606	0.364	1.67**
$PRICE_{it}$	-0.325	0.166	-1.96***
$COVID_t*PRICE_{it}$	-0.347	0.138	-2.51****
$COVID_t$	-3.45	2.262	-1.53
$COMB_{it}$	0.111	0.011	10.55****
ABF	0.040	0.048	0.82
FXF_PRIORITY	0.506	0.016	31.69****
FXF_ECONOMY	0.142	0.034	4.20****
YRC_REGIONAL	0.271	0.025	10.82****
YRC_NATIONAL	0.290	0.030	9.83****
XPO	0.443	0.017	26.69****
UPSF	0.215	0.030	7.14****
ODFL	0.399	0.017	23.61****
$COVID_t$*ABF	0.051	0.033	1.53
$COVID_t$*FXF_PRIORITY	-0.019	0.021	-0.89
$COVID_t$*FXF_ECONOMY	-0.002	0.028	-0.09
$COVID_t$*YRC_REGIONAL	-0.133	0.042	-3.12****
$COVID_t$*YRC_NATIONAL	-0.016	0.023	-0.72
$COVID_t$*XPO	-0.046	0.021	-2.14***
$COVID_t$*ODFL	0.026	0.021	1.24
$WINTER_t$	0.004	0.007	0.50
$SPRING_t$	0.018	0.005	3.63****
$SUMMER_t$	0.016	0.005	3.30****
Adjusted *R square* =0.983	F value =497.91 ****		

****P-value=0.01; ***P-value=0.05; **P-value=0.10

Specifically, all else constant, a 1.0 % increase in LTL firm prices has reduced shipping demand by only 0.33% ($\frac{\partial \ln ADW}{\partial \ln PRICE} = \beta_3 = -0.325$). LTL shipping demand, in other words, is generally rather inelastic, implying the economy's rather sharp dependence on this industry's services as a whole. On the other hand, a 1.0 % increase in total business activity, as measured by manufacturing, wholesale, and retail trade sales volume, lifts LTL shipping demand by 0.67% ($\frac{\partial \ln(ADW)}{\partial \ln(BUSINESS)} = \beta_1 = 0.672$), implying demand's rather important dependence on the overall U.S. business and merchandising climate.

Afterthe COVID-19 outbreak, a 1% increase in total business activity increases LTL shipping volume by 1.28% ($\frac{\partial \ln(ADW)}{\partial \ln(BUSINESS)} = \beta_1 + \beta_2 = 0.672 + 0.606 = 1.278$), holding all else constant. In other words, COVID-19 has made LTL shipping demandmore responsive to overall business conditions. A 1% increase in the firm's price reduces shipping volume by 0.67% ($\frac{\partial \ln(ADW)}{\partial \ln(PRICE)} = \beta_3 + \beta_4 = -0.325 - 0.347 = -0.672$), implying COVID tends to flatten the shipping demand curve on account of greater competition among the monopolistically suppliers.

To determine the demand change induced by COVID-19, we first set *COVID*=0, so equation (1) can be rewritten as:

$$\ln(ADW_{it}^0) = \alpha + \beta_1 \ln(BUSINESS_t) + \beta_3 \ln(PRICE_{it}) + \beta_6 COMB_{it} + \sum_{i=1}^{8} \gamma_i FIRM_i + \delta_1 WINTER_t + \delta_2 SPRING_t + \delta_3 SUMMER_t + \varepsilon_{it} \quad (8)$$

When *COVID*=1 it becomes:

$$\ln(ADW_{it}^1) = \alpha + \beta_1 \ln(BUSINESS_t) + \beta_2 * \ln(BUSINESS_t) + \beta_3 \ln(PRICE_{it}) + \beta_4 * \ln(PRICE_{it}) + \beta_5 + \beta_6 COMB_{it} + \sum_{i=1}^{8} \gamma_i FIRM_i + \sum_{i=1}^{7} \theta_i * FIRM_i + \delta_1 WINTER_t + \delta_2 SPRING_t + \delta_3 SUMMER_t + \varepsilon_{it} \quad (9)$$

Subtracting (8) from (9), we have:

$$\ln(ADW_{it}^1) - \ln(ADW_{it}^0) = \beta_2 * \ln(BUSINESS_t) + \beta_4 * \ln(PRICE_{it}) + \beta_5 + \sum_{i=1}^{7} \theta_i * FIRM_i \quad (10)$$

Coefficient estimates of most the interaction terms between COVID and the firm dummies are statistically insignificant, the exceptions being for YRC Regional and XPO Logistics, so that most of COVID's effects on shipped weight are via *BUSINESS* and *PRICE*. Substituting the mean values ofln (*BUSINESS)* and ln (*PRICE)* into (10) and ignoring the largely nonsignificant interaction terms gives, on average:

$$\begin{aligned} \ln(ADW_{it}^1) - \ln(ADW_{it}^0) &= \beta_2 * \ln(BUSINESS_t) + \beta_4 * \ln(PRICE_{it}) + \beta_5 \\ &= 0.61 * \overline{\ln(BUSINESS_t)} - 0.33 \overline{\ln(PRICE_{it})} - 3.45 \\ &= 0.61 * 6.22 - 0.33 * 0.93 - 3.45 \\ &= 3.79 - 0.31 - 3.45 \\ &= 0.23 > 0 \end{aligned} \quad (11)$$

so that

$$\ln(ADW_{it}^1) > \ln(ADW_{it}^0) \Rightarrow ADW_{it}^1 > ADW_{it}^0 \quad (12)$$

and

$$\ln(ADW_{it}^1) - \ln(ADW_{it}^0) = 0.23 \Rightarrow ADW_{it}^1 = 1.259 ADW_{it}^0 \quad (13)$$

implying COVID-19's net effect was to boost LTL shipping demand by a substantial25.9%.

We should keep in mind however what is happening here. Covid simultaneously (i) flattens (makes more elastic) the mean demand function, (ii) renders it more *positively* sensitive to business conditions, *and*

(iii) shifts it to the left and so *reduces* demand. Furthermore, it is this last elasticity that is by far the greater of the three. And yet at a *p*-value of 12%, its statistical significance is also the lowest of the three. If we are to drop it from our computations here, we have a demand increase 3.5 times greater than the 25.9% just reckoned. And this *p*-value is somewhat sensitive to small changes in equation specification. In short, the magnitude of Covid's mean net influence on demand that we have estimated here is difficult to pinpoint. All we can say is that it was quite substantial.

Besides Covid effects I find that, except for ABF Freight, all firm dummy variables are strongly statistically significant, implying a significant heterogeneity in the technologies, route structures, and service qualities of these companies, and offering further support to my observation that the LTL market is monopolistically competitive (See also Du and Buccola, 2020).

5. Conclusions

This paper examines how Covid-19 affected the demand for U.S. less-than-truckload carrier services, an important element of the global merchandise supply chain. I find, using firm-level data, that both shipping price and total economic activity are significant factors in LTL demand. Consistent that is with expectations, the LTL market appears to be monopolistically competitive, carrier services differing enough across firms that they can price somewhat independently.

When firm-level data are the concern, the demand for LTL services are quite inelastic, suggesting both that competition from non-LTL shipping services is rather weak and that individual LTL firms can successfully price somewhat independently from one another. But demand does depend rather strongly on business climate. Understandably then, it reacted very strongly to the Covide-19outbreak. In particular demand became more price elastic and more sensitive to overall business activity.

However, Covid also seems to have reduced effective demand rather sharply in itself, shifting it sharply to the left. Because the average family's cash position actually rose during the pandemic, this result is somewhat questionable, and may well reflect the highly disequilibrial condition of the economy during the pandemic, complicating the task of distinguishing demand from supply. This perhaps can be alleviated by formally introducing the supply as well as demand equation into the picture. One also can examine how Covid affected LTL firms' multi-part pricing structures, in which the pricing of base services is distinguished from fuel services.

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