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Geographic Imbalance, Search Frictions, and Regulation

Causes of Empty Miles in Freight Trucking

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Abstract

How prevalent are empty miles in freight trucking markets, and what are the economic frictions that contribute to empty miles? This study collected estimates of empty trips, empty miles, and backhaul probabilities from the economics and transportation literature, covering 40 years and 27 countries. A meta-analysis provides an average empty mile share of 29 percent, with significant variation across settings. High-income countries tend to have lower shares of empty miles than low- and middle-income countries. This study reviews empirical evidence behind three potential mechanisms behind empty trips, geographic imbalances in freight demand, search and matching frictions, and regulatory barriers, and develops a stylized model to capture these sources and evaluate potential policies.

This paper is a product of the Transport Global Practice. It is part of a larger effort by the World Bank to provide open access to its research and make a contribution to development policy discussions around the world. Policy Research Working Papers are also posted on the Web at http://www.worldbank.org/prwp. The author may be contacted at ron.yang@sauber.ubc.ca.

Geographic Imbalance, Search Frictions, and Regulation: Causes of Empty Miles in Freight Trucking*

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1 Introduction

Empty miles are a common feature in many global trucking markets, with ongoing policy interest in ways to decrease the amount of empty driving. Empty trucking miles directly generate unnecessary negative externalities such as pollution and congestion. Beyond these direct effects, empty trips may increase the cost of freight transportation, as future empty trips are internalized by trucking carriers when negotiating prices. Finally, empty trips may affect the returns to other infrastructure policies, such as cost-reducing road investment, and the effectiveness of other public policies. Understanding the mechanisms which generate empty trips is therefore important for informing policies to reduce trade costs and improve the performance of transportation systems.

This paper studies the incidence of empty miles in freight trucking and explores the economic frictions which can generate them. I begin by collecting studies of empty trucking in different contexts, and I synthesize this existing literature in a meta-analysis for a big-picture estimate of the prevalence of empty miles. After establishing the empirical level of empty trucking, I survey the empirical literature on three main mechanisms: geographic imbalances in demand, search and matching frictions, and regulatory barriers. Finally, I develop a single stylized model which captures these three potential sources of empty trips, and I use this model to evaluate potential policies and interpret historical case studies.

To document empirical patterns of empty shipping, I collect 54 estimates of empty trucking across the economics and transportation literatures spanning 40 years and 27 countries. These studies may be conducted at the trip, truck, or firm level, and differ in measuring empty trips, empty miles, or backhaul probabilities. Using a set of assumptions, I construct a common measure of empty miles and conduct a univariate meta-analysis. I find an average estimate of 29 percent empty miles, or a 42 percent backhaul probability, with a significant degree of variation across the study settings. In a meta-regression, I find that high-income countries have significantly lower empty trip rates compared to non-high-income countries. In a smaller sample of European countries, carriers are more likely to be empty when traveling domestically. In a sample where I observe multiple studies of empty mile rates over time, some countries have experience significant long-run decreases in the empty mileage share, on the order of 5 to 10 percentage points.

Having established the level of empty miles, I develop a conceptual framework to understand the potential mechanisms generating empty miles. I focus on three main mechanisms, and review the empirical evidence behind each mechanism. First, a geographic imbalance in demand for shipping can generate empty miles as carriers serving the route with more demand (fronthaul) cannot find return trips (backhaul)[2]. At the national level, the median country has a physical trade imbalance of about 50 percent, indicating that it exports twice as many kilograms of goods as it imports, or vice versa. The imbalance can grow larger when one focuses on only neighbor-level or lane-level trade. Second, search and matching frictions can generate empty miles as carriers are unable to find a job and would prefer to travel empty to another market in search of jobs. Empirical research points to cases where improved matching technology lowered empty trip shares by 4 to 5 percentage points, while also cautioning that the effect of matching on empty trips may not be monotonic. Third, regulatory or capital restrictions may create barriers that prevent certain carriers from serving particular products or lanes. In a World Bank survey, the majority of countries restrict foreign carriers from at least some types of jobs, with cabotage trips being the most commonly restricted. This translates into significant empty miles; in the European context, carriers from countries with cabotage rights have 20 percentage point lower rates of empty miles than carriers from countries without cabotage rights.

Diving deeper into the mechanisms, I build a simple model that captures the effect of the three causes on empty trips. Shippers search for carriers to carry fronthaul and backhaul jobs. Carriers search for a fronthaul job; if they find a job, they travel to the destination and search for a backhaul job. There are fewer backhaul shippers than fronthaul shippers, capturing the role of demand imbalance. Search frictions cause fewer shipper-carrier matches to be produced than the number of searching shippers and carriers. Some carriers are ineligible to search for or accept a backhaul job, reflecting the presence of regulatory barriers to cabotage. In equilibrium, all three forces contribute to depress backhaul probabilities and raise fronthaul prices. However, search frictions behave differently from demand imbalances and regulatory restrictions, as they also affect the number of fronthaul jobs. As a result, reducing search frictions, for example through better shipper-carrier matching platforms, may have ambiguous effects on the overall number of empty miles in the economy. I conclude by examining several cases, both hypothetical and historical, from the lens of the conceptual framework as an example of thinking about when each friction may be most important.

This paper contributes to our understanding of transportation economics by synthesizing the empirical evidence on empty trips and empty miles. Compared to the existing literature, which typically focuses on single-country or region-level studies, my meta-analysis provides estimates of the level and dispersion of empty miles across different settings. This paper

[2]In this paper, I will focus on empty trips and truck underutilization in the short-run, where I hold the geographic distribution of freight demand (i.e., the location of factories, households, natural resources, ports, etc.) and the population of trucking firms fixed. In the long run, firms may enter and exit or households may migrate, in ways that alleviate or exacerbate truck underutilization. I treat these as outside the scope of this paper.

also develops a model of trucking markets that includes all three forces, including regulatory barriers to cabotage. While the existing theoretical literature on search and matching in transportation markets, such as Demirel et al. (2010); Brancaccio et al. (2020a), has focused on the role of demand imbalances and search frictions, regulatory barriers are empirically relevant in the context of trucking markets.

2 Estimates of Empty Driving

In this section, I survey estimates of empty driving from industry reports, local and national governments, and academic studies. The settings span many countries and range from the late 1970's to the present day. In terms of coverage, the mix of studies significantly over-weights North America and the European Union and under-weights Europe & Central Asia and the Middle East & North Africa. On the time dimension, the median study was conducted in 2009, with an overall large span of 40 years between the earliest and latest studies. As a result, controlling for the role of time will be relevant. For more details on geographic and temporal coverage, see Appendix A.

These estimates span different sampling methodologies, measure different objects, and cover different segments of the trucking market. Empirical estimates of empty trips have been generated by a variety of data sources. The dominant source is survey data, such as Colombia's Ministry of Transportation Freight Origin-Destination Survey program as used in Gonzalez-Calderon et al. (2012a). Firm surveys begin with a census of firms in the sector, and ask a sample of firms what their overall fleet-level empty trip share is. Vehicle surveys instead use a sample of registered vehicles and ask the vehicle's operator how often that vehicle was empty. Finally, site surveys stop a random sample of trucks as they pass a fixed site (such as a rest stop or administrative checkpoint), and interview the drivers for their empty or loaded status. These variations may result in different weights or accuracy for different segments of the market. Trip audits or diaries, such as the National Survey of Transport of Goods by Road conducted in Ireland and studied in Council (2017), offer deeper information on truck driving patterns. A sample of trucks is tracked over the course of several days, and the loaded or empty status tracked over that period. Finally, digitization of the trucking economy has generated new datasets of mobile app transactions, as studied in Heilmann (2020). App data has had limited penetration into the economics and transportation literature, but holds potential for future work which takes advantage of detailed histories of trips. However, app data also depends on the market share of the particular application or marketplace, and may generalize poorly to the rest of the market.

Most surveys aggregate over all segments of the trucking freight market within a country, but there are exceptions. Studies may distinguish between short haul and long haul trips, as in Osborne et al. (2014). Beilock and Kilmer (1986) present figures for specific trailer types: refrigerated (reefer) and specialized trailers. Lam et al. (2019) separately measure shares of empty miles by firm organization, finding that logistics services providers have lower rates of empty trips than (owner) operators. Finally, a few studies explicitly cover international trips, including Nathan Associates Inc. (2013)'s study of corridors in West and

Central Africa. Insofar as international trips may face greater regulatory barriers or search frictions, domestic surveys may underestimate the overall rate.

Individual surveys may collect the share of trips which are empty, the share of miles traveled which are empty, or the probability of not finding a backhaul job. I discuss each type of measure below.

Empty Miles The most direct way to measure the amount of empty driving is in terms of vehicle-miles (vehicle-kilometers). This information may be recovered from firm surveys and records, either conducted by private industry associations as in Williams and Murray (2020) or by national governments as in Eurostat (2021). Site surveys can infer an estimate of empty vehicle-miles if they collect information about the distance of trips in addition to the loaded/empty status. Similarly, trip audits as used in McKinnon and Ge (2006) that collect distance information can provide empty mileage estimates. Detailed location data from apps may also allow researcher to reconstruct empty miles under some assumptions, as Heilmann (2020) does with Uber Freight data. I present studies of empty miles in Table 4.

Empty Trips The next measure of empty driving comes from studies that estimate the number of empty trips. These estimates are most often generated by site surveys, which randomly poll trucks passing through a site (often a checkpoint or a rest stop) and ask whether the truck is loaded or empty. Some trip audits, such as the Danish study used in Abate and Kveiborg (2013) and Abate (2014) or the Irish study used in Central Statistics Office (2019), also measure whether or not a trip was loaded, independent of the distance traveled. I present studies of empty trips in Table 5.

Backhaul Probability The third common measure of empty driving estimates the probability that a truck can find a load for a backhaul trip. Typically, these estimates are recovered by directly asking firms about how often they can find backhauls, as in Council (2017) or Osborne et al. (2014). In some cases, a study infers the backhaul direction of a trip based on knowledge of geographic imbalance, as in Wilson (1987). I present studies of backhaul probability in Table 6.

Aggregation Several assumptions are needed to convert the three study types into a common measure of empty miles. To convert backhaul estimates into empty miles estimates, I assume that all trips involve a fronthaul and backhaul leg, and the fronthaul is always loaded. Under this assumption, the share of empty trips is half the probability of not finding a backhaul job[3]. To convert empty trip estimates into empty miles estimates, I assume that, on average, loaded and empty trips are of equal length, so that estimates of the share of empty trips are comparable to the share of empty miles[4].

These assumptions are not innocuous. For example, suppose that shorter fronthaul trips are more likely to be associated with empty backhauls. Since longer trips have more miles, the share of empty miles will be lower than the share of empty trips. This implies that my assumptions will over-estimate the share of empty miles, based on studies which measure the share of empty trips. Similarly, if there are some empty fronthauls, then my assumptions will under-estimate the share of empty miles based on estimates of the backhaul probability. If trips have more complex shapes than a fronthaul and backhaul leg, the backhaul probability may either over- or under-estimate the overall level of empty miles.

Distribution of Estimates With those caveats, my assumptions allow me to aggregate the studies in Tables 4, 5, and 6, along with additional studies in Table 7, to gain an overall picture of the prevalence of empty trips. To synthesize, I plot a smoothed density plot of these estimates in Figure 1. 95 percent of estimates fall between 15 percent and 45 percent, and the median estimate is 28 percent. 45 percent should be interpreted as fairly high; in a simple two-location model, it would imply that carriers who finish a fronthaul job have only a 10 percent chance of finding a return job.

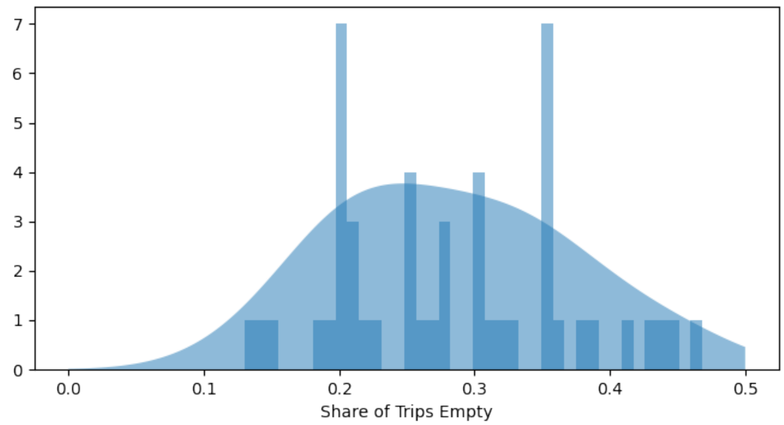
I decompose the estimates into those of High Income countries and those from other countries in Figure 2. High Income countries have lower rates of empty mileage, with median 20 percent empty trips compared to 30 percent empty trips for other countries. Under the Noortman and van Es (1978) model, this is roughly equivalent to a 20 percentage point difference in backhaul probability. As many of the High Income studies use U.S. data from the 1970s and 1980s, if I condition on more recent surveys, the gap between High Income and Non-High Income countries grows.

Meta-Analysis To formalize these comparisons, I conduct a meta-analysis of the 54 primary studies. I begin with a univariate random-effects analysis using a restricted maximum likelihood (REML) model, where the weights are estimated using the inverse-variance method[5]. I find a mean estimate of 29 percent empty miles, with a 95 percent confidence

[3]This may under-estimate the degree of empty trips if fronthauls are also sometimes empty (e.g., under search frictions), or if trips involve additional empty legs such as traveling from home to a trip origin

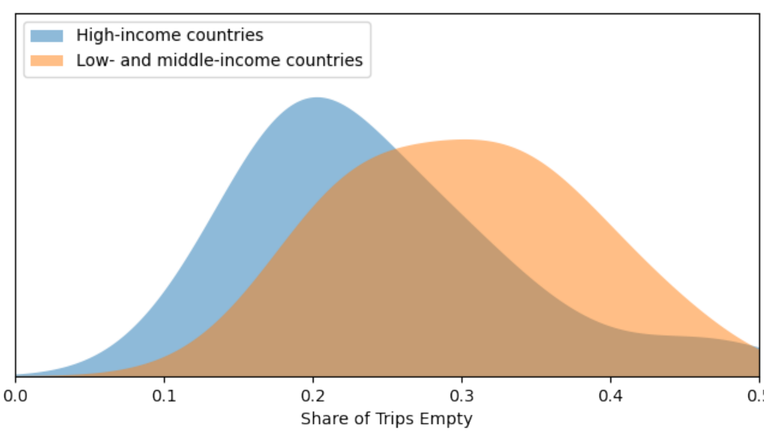
[4]This assumption would be violated if, for example, shorter empty trips are used to chain together longer loaded trips.

[5]For studies that did not report a confidence interval, I assume the data was sampled from a Bernoulli distribution and used the implied estimate of the confidence interval. For studies that did not report observation counts, I imputed sample sizes based on study type and region.



Source: Tables 4, 5, and 6
Note: Figure 1 plots a histogram of the distribution of estimates of empty mileage shares. When estimates are provided of backhaul probabilities, this figure assumes that all fronthaul trips are loaded. The figure also plots a kernel density estimate with bandwidth 0.05.

Figure 1: Distribution of Empty Mileage Estimates



Source: Table 7
Note: Figure 2 plots kernel density estimates of the distribution of estimates of empty mileage shares, broken up by High Income countries and non-High Income countries. When estimates are provided of backhaul probabilities, this figure assumes that all fronthaul trips are loaded. The kernel density estimates use a bandwidth of 0.05.

Figure 2: Distribution of Empty Mileage Estimates by WB Income Status

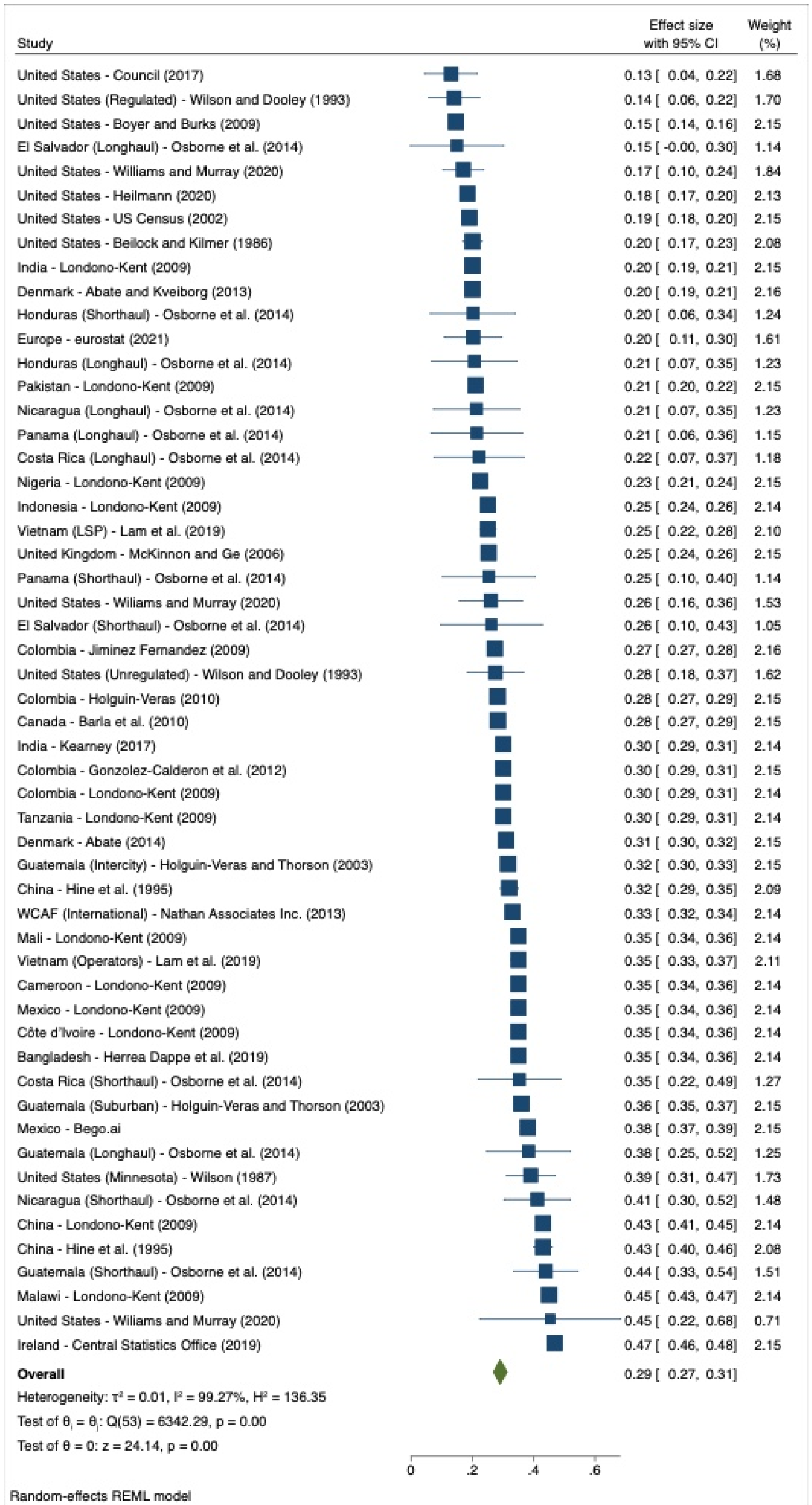
interval of 27 percent to 31 percent empty miles. Figure 3 presents the individual study estimates, their weights, and the mean estimate in a forest plot. The I^2 index is 99.27 percent, suggesting a very high degree of true heterogeneity across the studies.

Given the substantial heterogeneity across the studies, I conduct a meta regression of effect sizes on the statistic estimated, the data source, the year of the study, and an indicator for whether the country is High Income. I present the regression results in Column 1 of Table 1. Studies of High Income countries find significantly lower rates of empty miles compared to studies of Non-High Income countries. In addition, vehicle-level studies find lower levels of empty miles, suggesting that trip- or site-level studies may be more likely to sample empty trips relative to vehicle-level studies.

In Column 2, I extend the meta regression to include countries as moderators. Given the country moderators, High Income status has a stronger negative effect on empty trips. In addition, both site-based and vehicle-based studies find lower levels of empty miles than trip-based studies. Finally, backhaul studies tend to find lower levels of empty miles than empty-mile or empty-trip studies, which is consistent with a non-zero number of fronthauls biasing backhaul study estimates downward.

Regional Patterns Looking at the regional level, Eurostat has collected surveys of truck trips since 1999, for both European Union and European Free Trade Association members. In Figure 4, I report average empty trip shares for countries in the Eurostat dataset. In Panel A, which aggregates over all types of trips, there is significant variation in empty mile share within region, with island states such as Cyprus and Ireland having empty trip shares which are 15 to 20 percentage points higher than states like Belgium and Denmark. Panel B compares the empty share of domestic versus international trips for each country. The vast majority of countries have more empty trips when their truckers are traveling domestically compared to international trips.

Country-Specific Trends So far in this section, I have aggregated over many decades of studies. Over the past decades, different countries have experience divergent trends in the share of empty trips. While most studies are short-term and unable to capture time trends, Gonzalez-Calderon et al. (2012b) and McKinnon and Ge (2006) both cover several decades of consistent measurement by governmental agencies. I plot the time estimates in Figure 5. Up to 1975, both the United Kingdom and Colombia saw similar levels of empty miles between 30 and 35 percent. Both countries saw declines between 1975 and 2000, with Colombia seeing a rapid decline from 1975 to 1980 and a gradual decline afterwards, and the United Kingdom seeing consistent declines. After 2000, the United Kingdom saw a reversal



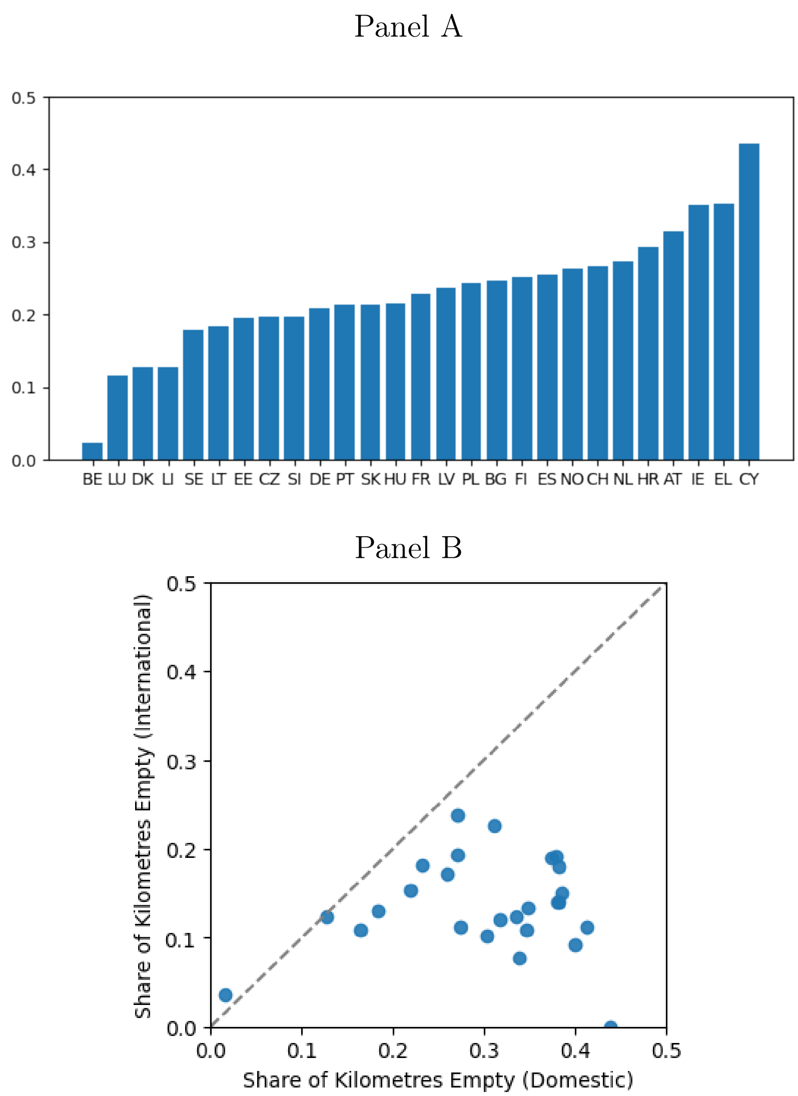
Note: Figure 3 plots a forest plot of a univariate, random effects meta analysis of the share of empty miles across the studies in Tables 4, 5, and 6.

Figure 3: Univariate Meta Analysis

	(1)	(2)
High Income	-0.127** (-0.215, -0.039)	-0.276** (-0.476, -0.077)
Year	-0.003 (-0.007, 0.001)	-0.005 (0.010, 0.001)
Study Type		
Site	-0.148 (-0.351, 0.0544)	-0.346* (-0.623, -0.069)
Trip	-0.019 (-0.150, 0.112)	-0.074 (-0.212, 0.063)
Vehicle	-0.193* (-0.383, -0.004)	-0.289* (-0.515, -0.062)
Statistic		
Empty Trips	0	0
Empty Miles	-0.061 (-0.156, 0.034)	-0.115 (-0.262, 0.030)
Backhaul	-0.146 (-0.326, 0.334)	-0.257* (-0.508, -0.007)
Constant	6.677 (-1.291, 14.644)	10.219 (-0.951, 21.389)
Country Moderators	No	Yes
τ^2	0.005	0.003
I^2	98.85	97.99
H^2	87.12	49.79
R^2	21.41	53.20

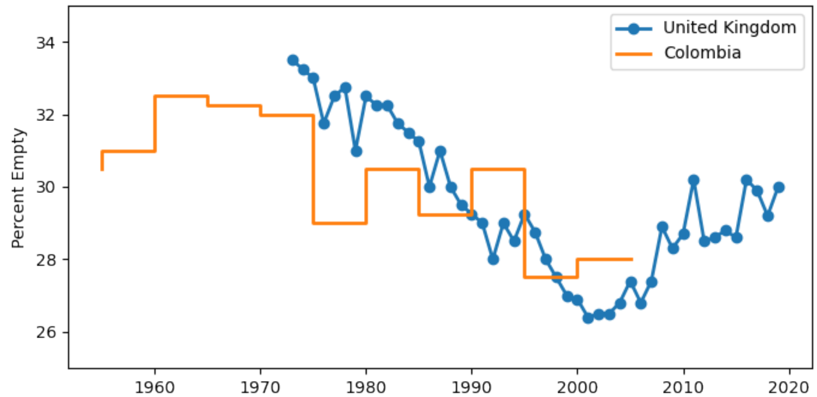
Note: Table 1 presents the results from random effects meta regressions of empty miles on study characteristics. Column 1 presents a regression without country moderators, while Column 2 presents a regression which adds column moderators. The base level for the categorical variables is a study of empty trips.

Table 1: Meta Regression Results



Source: Eurostat
Note: Panel A reports average empty vehicle-kilometer estimates by country, for the period 2006 to 2020. Estimates across years are weighted by the number of annual observations. Panel B is a scatter plot of the empty vehicle-kilometer share among international trips versus the empty vehicle-kilometer share among domestic trips. Each point is a country, averaged between 2006 and 2020.

Figure 4: Estimates of Empty Mileage for European Countries



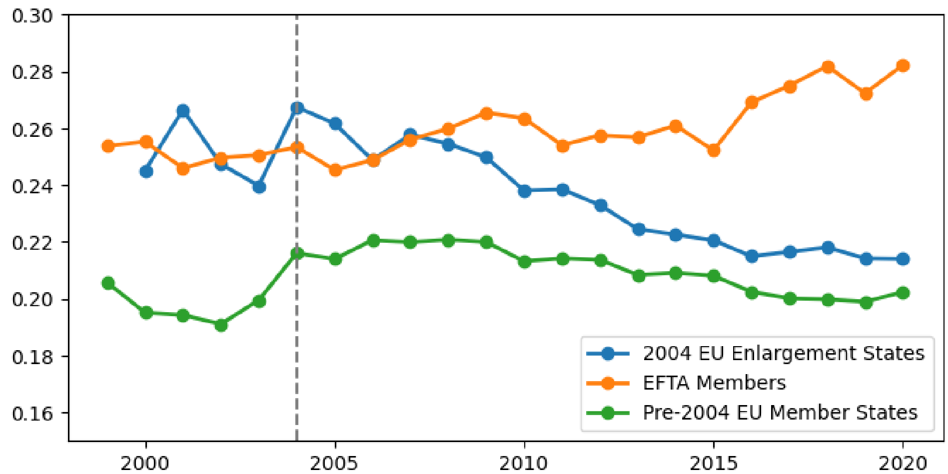
Source: Gonzalez-Calderon et al. (2012b) for Colombia, McKinnon and Ge (2006) for United Kingdom before 2000, UK Transport for United Kingdom after 2000.

Notes: Figure 5 presents historical trends in empty mileage shares in the United Kingdom and Colombia. Colombian estimates are five-year averages from the Colombian Ministerio de Transporte. United Kingdom estimates are one-year averages from the United Kingdom Department for Transport.

Figure 5: Trends in Empty Mileage Share in United Kingdom and Colombia

of previous gains, as empty shares increased to 30 percent.

In the European region, different sets of countries have experienced divergent trends. In Figure 6, I plot the average empty vehicle-kilometer shares for three broad categories of countries: Pre-2004 EU members, post-2004 EU members, and members of the European Free Trade Association (EFTA). In 2000, prior to the 2004 round of accession, the post-2004 states had similar levels of empty kilometers as the EFTA members, about 5 percentage points more than the pre-2004 states. After 2004, the post-2004 states rapidly converged to the empty kilometer level of the pre-2004 states, while empty kilometer shares among EFTA members have stayed constant or grown.



Source: Eurostat

Notes: Figure 6 presents historical trends in empty mileage shares for three categories of European States: Pre-2004 members, members which in 2004, and members of the European Free Trade Association. These shares average over all trips, domestic and international, and are weighted across countries by the number of observations. The grey dashed line indicates 2004, the year when the majority of post-2004 member states acceded to the European Union. Excluded countries include: United Kingdom (reported separately), Italy (does not separately report kilometers traveled on empty trips), Romania and Bulgaria (entered in 2007), and Malta (Exempt from reporting freight statistics).

Figure 6: Trends in Empty Mileage Share in Europe

3 Conceptual Framework

Having established the prevalence of empty trips across many settings, I develop a conceptual framework for understanding the causes and effects of underutilization. I begin by reviewing empirical evidence for three key frictions that generate empty trips: geographic imbalances in trade, search and matching frictions, and regulatory barriers. I integrate these three frictions into a stylized model of a trucking market with fronthaul and backhaul legs. This model offers suggestions for diagnosing the presence of each friction in a given market, as well as predictions for the effect of potential interventions. Finally, I use the model to interpret one hypothetical and three empirical case studies. This discussion focuses on the main causes of empty trips and is not exhaustive. In Appendix C, I discuss additional factors which affect empty trips and offer potential extensions of the stylized model.

3.1 Geographic Imbalances

Geographic areas vary in shippers' demand for importing and exporting. An imbalance arises when some regions are systematically net importers, so loaded carriers who arrive in those regions face a smaller supply of jobs out. The "backhaul" effect means that some of these carriers must travel empty. Symmetrically, if a region is a net exporter, then some carriers must arrive empty to fulfill all the loaded trips out. In some countries, this imbalance can be significant.

Physical trade imbalances may result from value-based trade imbalances, or from differences in the value-weight density of imported versus exported products. For example, according to Jonkeren et al. (2011), Rotterdam and Antwerp import bulk cargo to supply interior manufacturing firms which produce final goods. The greater value-density of these ports' export products generates an imbalance, as the weight and volume of manufactured exports is less than that of bulk imports. The relative mix of mining, agriculture, and manufacturing industries within a region therefore affects the region's geographic imbalances.

Measuring Physical Trade Imbalances At the highest level, geographic imbalances can occur at the national level. I use trade data from the United Nations Comtrade database to summarize the potential for geographic imbalances. In this context, the relevant measure of the magnitude of trade is physical units such as weight and volume, which correspond more closely to the number of trucks, ships, and other vehicles needed than trade in dollars. In particulary, I use Comtrade's estimates of weight (in kilograms) of imports and exports[6].

[6] For about 20 percent of total trade by value, I do not observe weight, but I do observed trade value in dollars. I assume that these missing country-commodity-directional observations have the same value density

Using these weight measures, I can compute net physical exports and exports (in kilograms) by country. To determine the potential for imbalances leading to empty trips, I define the physical trade imbalance as

$$\text{Physical Trade Imbalance (\%)} = 100 \times \frac{\text{Exports} - \text{Imports}}{\max(\text{Exports}, \text{Imports})}$$

This imbalance measure ranges from -100% to $+100\%$, where the magnitude captures the potential for empty trips and the sign indicates whether a country is a net physical exporter (positive) or a net physical importer (negative). I find that the median country has a net imbalance of -26.9 percent; that is, the median country is a net physical importer with exports weighing about one-quarter of imports[7]. I plot the distribution of physical trade imbalances across countries in Panel A of Figure 7.

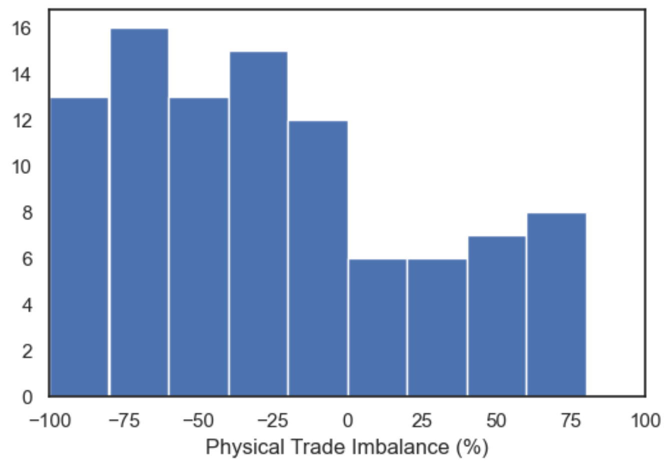
There are several caveats with a straightforward interpretation of these imbalances. First, export and import partners are not symmetric. A country might import from one country and export to another country, yielding many empty trips, but aggregating over trade partners obscures these bilateral imbalances. The aggregate physical trade imbalance is therefore a lower bound on the potential for empty trips. In addition, weight may not be the relevant metric of physical trade. If trucks face both weight and volume constraints, then whether weight translates one-for-one into truckloads depends on the average carrying capacity of the vehicle stock and the average density of trade commodities. I aggregate over many different commodities, which may require different types of capital to transport. For example, live animals are unlikely to be transported on the same trailer as natural gas. Finally, imports and exports may use different modes. If a country's main import origins are land neighbors, while its main export destinations are across the ocean, then we would expect to see empty trips along both land and oceanic modes.

Neighbor-Level Imbalance To explore the role of land neighbors, I extend my previous analysis by filtering for trade between countries and their land neighbors. In Panel B of Figure 7, I plot the resulting distribution of physical trade imbalances. The overall level of imbalance is similar, but countries are more likely to be net exporters to their neighbors. The median country has a net imbalance of -16.7 percent, or about 10 percentage points closer to balanced trade compared to when I aggregate over all trade partners.

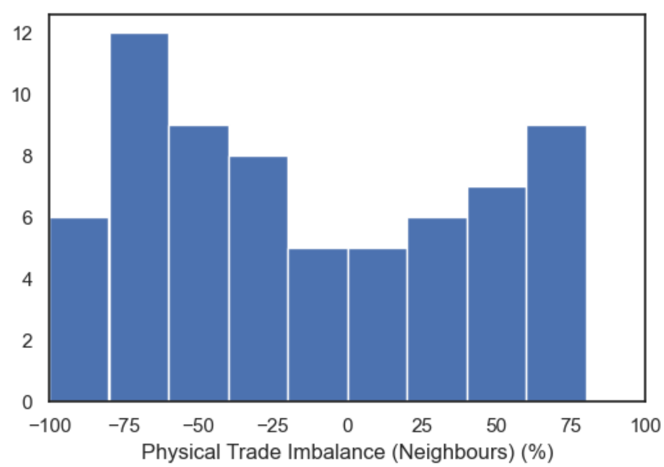
(in kilograms per dollar) as average exports or imports from that country. Alternatively, I could assume that missing weight values have the same value density as average trade in that commodity class.

[7]Since both net exporters and net importers have potential for empty trips, I can take the absolute value of the physical trade imbalance measure. The median country has an imbalance of 52.4 percent in absolute value, indicating either exports weighing one-half of imports, or imports weighing one-half of exports.

Panel A: Physical trade imbalance



Panel B: Physical trade imbalance (neighbors only)



Source: United Nations Comtrade

Notes: Panel A of Figure 7 presents the distribution of physical trade imbalances between each country and the world. The physical trade imbalance is defined as the difference between exports (kg) and imports (kg), divided by the maximum of exports and imports. Panel B presents the distribution of physical imbalances between each country and its land neighbors.

Figure 7: Physical Trade Imbalance by Country

Many countries which are net physical exporters in aggregate are net importers at the neighbor level; the correlation in net imbalance between the two measures is only 40 percent. At one end, Rwanda, Kenya, and Senegal are net importers from the world, but net exporters to their neighbors. On the other end, Brazil, Estonia, and Guyana are net exporters to the world, but net importers from their neighbors. In the case of landlocked countries such as Rwanda and Senegal, this discrepancy points toward international imports that must travel through neighboring countries. Since these flows also contribute to imbalances between landlocked countries and their neighbors, this suggests that analysis using country-country level remains inaccurate.

Corridor-Level Imbalance At an even finer level, I turn to evidence for geographic imbalances along specific routes or corridors, especially for landlocked countries. Using ports data, Teravaninthorn and Raballand (2009) find that Chad exports are only 30 percent of imports. In a frictionless world where all fronthaul trips are loaded, this suggests a lower bound of 35 percent of trips must be empty. In a more extreme example, Uganda has an imbalance of 10 percent, and the authors suggest this generalizes to other landlocked countries especially in the Sahel. Focusing on the corridor level, Annequin et al. (2010) find that exports from Burkina Faso to the port of Tema, Ghana, vary between 25 percent and 40 percent of imports. This imbalance is reflected in prices, where the average cost of shipping a 20' container from Tema to Ouagadougou was $4,800, over 2.5 times as expensive as the cost of shipping in the reverse direction.

Looking across multiple corridors into a single country, Nathan Associates Inc. (2013) also finds strong export-import imbalances for countries in West Africa. For example, landlocked Burkina Faso trades through four main foreign ports: Abidjian, Tema, Lomé, and Cotonou. In Panel A of Figure 8, I plot the physical trade imbalances by port for the top four ports used by Burkina Faso. Across all ports, overall exports fall significantly short of imports. In 2011, Burkina Faso exports through Abidjian and Lomé were a quarter of its imports, and the ratio for Cotonou and Tema were even more extreme. A back-of-the-envelope estimate would imply that, for example, trucks traveling between Burkina Faso and Abidjian must be empty at least 37.5 percent of the time. Panel B presents a similar picture for Mali and five main ports of Abidjian, Tema, Lomé, Cotonou, and Dakar. While trade along some ports, such as Tema, appears balanced, demand imbalances are strong along the routes to the other ports. This suggests that aggregating empty trips to the country level may miss the presence of demand imbalances along particular corridors. The same figure for Niger would be even more extreme: As 60 to 80 percent of Niger's exports by value is dense uranium, its export tonnage is less than 1 percent of its import tonnage to each of its main ports of Abidjian, Tema, Lomé, and Cotonou.

Imbalance along Other Modes Trade imbalance has been shown to be important for modes beyond trucking. Jonkeren et al. (2011) study geographic imbalance in the context of bulk shipping on the Rhine River. They document that the ratio of exports to imports of areas along the Rhine ranges from 0.656 in the Neckar area to 1.811 in Rotterdam. This trade imbalance for bulk shipping has implications for trade costs: Jonkeren et al. (2011) estimate that a one standard deviation increase in trade imbalance raises export prices by 7 percent.

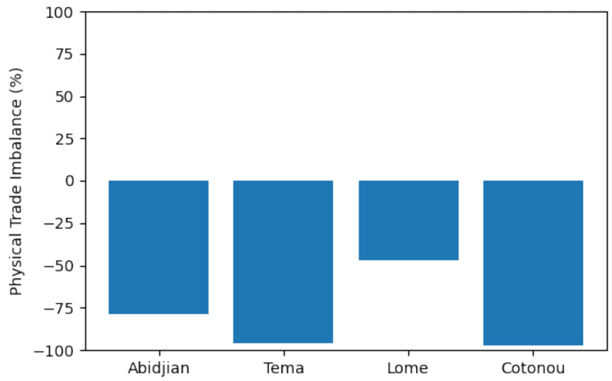
A literature studies the backhaul effect in the context of international oceanic freight. Intuitively, carriers foresee that they will have to make an empty return trip when they enter a net importing region. They therefore pass the costs of the empty backhaul trip to fronthaul prices. This causes freight costs along a lane to depend on the quantity of return shipping. Behrens and Picard (2011) find that, compared to a setting where carriers did not pass through backhaul costs, the backhaul effect increases trade costs for net exporting regions. In equilibrium, this effect disperses economic activity across the economy to minimize the amount of geographic imbalance. Ishikawa and Tarui (2018) study the interaction between backhaul effects and other trade costs in the context of a theoretical model. Because of the incentives of carriers, tariffs and other trade barriers spill over to other sectors, and may "backfire" by reducing domestic exports. Wong (2020) finds empirical evidence of this "round trip effect" and shows that, in the context of a trade and transportation model, round trips dampen the effect of shocks and causes tariffs to have opposite-direction spillovers. At the same time, the effect of geographic imbalances on prices can be muted. Teravaninthorn and Raballand (2009) observe that land-locked Uganda has 20 percent lower average transport prices than coastal Cameroon or land-locked Chad, despite having a much larger export/import imbalance than either country.

3.2 Search Frictions

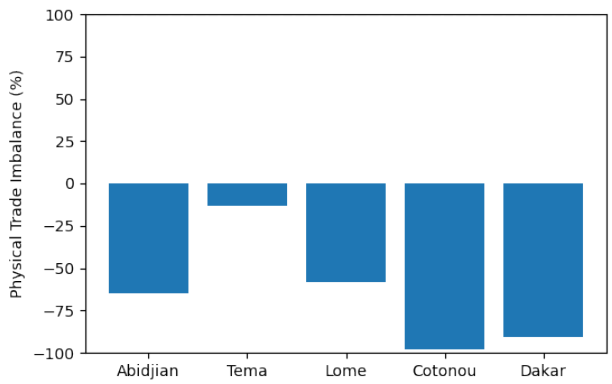
Search and matching frictions are present when there are both carriers and shippers willing to trade, but they are unable to transact immediately. Carriers may either wait and search for a job, or they may travel empty to another market with a higher chance of finding a job.

First studied in labour market contexts by Mortensen and Pissarides (1994), search and matching models were adapted to transportation by Lagos (2000, 2003) in the context of taxi cabs. More recently, Brancaccio et al. (2020a) adapted this technology to freight transportation, specifically the market for bulk shipping. Brancaccio et al. (2020a) document evidence for search frictions - ships often simultaneously enter and leave ports empty - and develop

Panel A: Burkina Faso



Panel B: Mali



Source: Nathan Associates Inc. (2013), Port Autonome d'Abidjian, Ghana Ports and Harbours Authority, Port of Lome

Notes: Panel A of Figure 8 presents historical trends in the physical trade imbalances between Burkina Faso and its four main ports. The physical trade imbalance is defined as the difference between exports (kg) and imports (kg), divided by the maximum of exports and imports. Panel B presents historical trends in export-import imbalances between Mali and its five main ports.

Figure 8: Demand Imbalances between Major West African Ports and Burkina Faso/Mali

a model which incorporates a realistic transportation sector into a broader trade model[8]. Using this model, they estimate the magnitude of search frictions. Demirel et al. (2010) develop a simple, two-location model to study the role of matching frictions for backhauls. In a frictionless market, when there are more carriers than shippers interested in a backhaul trip, the price of backhaul trips should fall to zero. Since these prices are empirically positive, Demirel et al. (2010) argue that matching frictions must be present, and calibrate a matching model with data from Rhine shipping.

The magnitude of search frictions depends on the effectiveness of matching platforms and information technology. A series of papers have focused on Electronic Vehicle Management Systems (EVMS) adoption in North America. Conceptually, EVMS reduces communications costs and therefore makes search and matching easier. Hubbard (2003) found that U.S. trucks with EVMS drove 12.7 percent more loaded miles. Looking at Canadian trucks, Barla et al. (2010) found that while EVMS reduced empty miles on backhaul segments, empty miles on fronthaul segments increased. They argue that falling search costs may induce more search, or encourage carriers to travel empty to more profitable markets. The relationship between search costs or information technology and empty trips may not be monotonic.

In an earlier setting, Mansell (2001) finds that freight exchanges reduced empty trips in the United Kingdom by 5 percentage points, from a baseline of 28 percent empty trips. Heilmann (2020) studies the effect of the Uber Freight platform on matching jobs and reducing empty trips. He finds that deadhead miles in the United States fall by 22.6 percent, or 4 percentage points, and that utilization increases from 81.6 percent to 85.8 percent. However, the effect of matching platforms may not be monotonic. Rosaia (2020) considers the effect of competing platforms within the NYC taxi market. He finds that competing platforms can exacerbate search frictions by creating two artificially thin markets. Similarly, Fréchette et al. (2019) find that when platforms have partial penetration, they can cause the market on and off the platform to become thinner. Ghili and Kumar (2020) find that small platforms concentrate around most dense areas of supply, which creates geographic inequalities.

3.3 Regulation

Regulations which restrict some carriers from taking jobs from available shippers are common, directly forcing some carriers to return empty. In an international context, cabotage restrictions protect domestic carriers by preventing foreign carriers from picking up within-country jobs after completing an international trip (Bove et al. (2018)). For example, 1999 agreements between Cameroon, Chad, and the Central African Republic established that

[8]For a broader survey of how to estimate matching functions, or equivalently, how to detect the presence of matching frictions, see Petrongolo and Pissarides (2001) and Brancaccio et al. (2020b).

	No Rights	Rights (License Required)	Rights (No License)
Backhaul	27.5%	63.75%	8.75%
Cabotage	82.5%	17.5%	0%
Transit	22.5%	71.25%	6.25%
Triangular	47.5%	47.5%	5%

Source: World Bank Survey
Notes: This table presents the percentage of countries which allow a type of travel (backhaul, cabotage, transit, or triangular), and the degree to which that travel requires prior licensing.

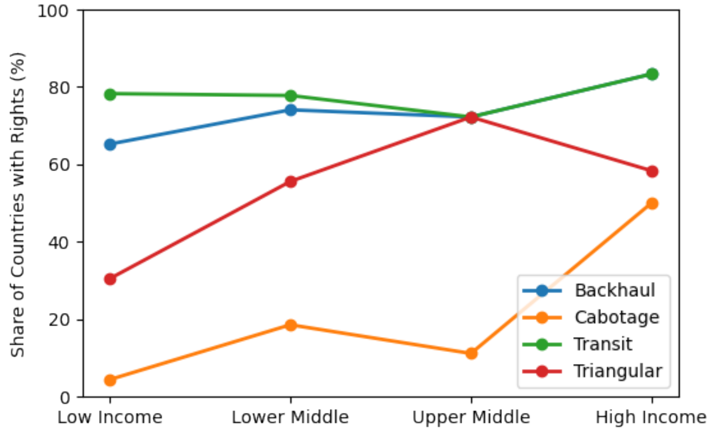
Table 2: Regulatory Practices

foreign carriers cannot complete domestic jobs, and set minimums on the share of international jobs performed by truckers from each country (Teravaninthorn and Raballand (2009)). Similarly, in Central America and Belize, prevailing regulation prohibits cabotage, despite trucking being a major mode of international trade (Guerrero and Abad (2013)). In contrast, the European Union features a more integrated regional trucking market where truckers are allowed to pick up as many as three cabotage loads after completing an international trip (Blancas and Briceno-Garmendia (2020)). Even in this more relaxed context, Commission (2014) reports that vehicles traveling outside their registration country were empty more than 45 percent of the time, while vehicles within their registration country were empty just over 25 percent of the time. This difference is present in both specialized and general freight markets, suggesting that cabotage restrictions, rather than search frictions, is the culprit.

Based on a 2018-2019 World Bank survey of regulatory practices, restrictions on cabotage are very common - over 80 percent of countries do not allow cabotage rights. Backhaul, transit, and triangular rights are more common, but in the vast majority of countries, they require particular licenses.

Across countries, higher income countries tend to have more permissive regulation. This is especially pronounced for cabotage restrictions, which is driven by permissive regulatory regimes in Europe.

Within markets, the right to transport regulated commodities may be restricted to a protected set of carriers, such as in the United States prior to the 1980 Motor Carrier Act. Wilson and Dooley (1993) find that, unsurprisingly, carriers with the legal ability to carry a wider variety of products have lower rates of empty trips. Beilock and Kilmer (1986) find that carriers with the regulatory authority to carry regulated goods are 23 percent more likely to be loaded. Similarly, under the Economic Community of West African States' IST Convention, bilateral treaties between states can define a list of "strategic" commodities which can only be hauled by trucks registered to the destination country (Zerelli and Cook (2010)). These lists can range from military supplies and food aid to fuel and building materials. As



Source: World Bank Survey
Notes: Figure presents the percentage of countries in each of four income categories which allow a type of travel, with or without a permit or license. On average, a higher share of higher income countries allow travel rights compared to middle and low income countries.

Figure 9: Prevalence of Rights Across Income Categories

a result, carriers from the destination country will have lower rates of empty trips, while other carriers will have elevated rates of empty trips. Even for the remaining non-strategic commodities, the IST allows for freight-sharing agreements that enforce a minimum share of international shipments be carried by carriers from the destination country.

Evidence from the taxicab market suggests that price regulations may also generate empty trips. Fréchette et al. (2019) consider the market for taxicabs in New York City, where prices are fixed by regulation. As a result, the market clears on the dimension of waiting time, rather than price. When demand is low, drivers spend large amounts of time searching for passengers rather than lowering their prices, and cabs are empty between 30 and 70 percent of the time. In addition, because taxi drivers drive in discrete shifts, they cannot adjust to low demand by stopping early, and continue to drive empty. These regulatory frictions can also amplify the effects of other frictions. Buchholz (2022) finds that, in the taxi cab context, price regulations exacerbate search and matching frictions by creating artificially thin markets. Relaxing pricing regulations can achieve a significant share of the welfare gains from eliminating all search frictions and optimally allocating drivers and passengers. On the other hand, regulations which limit the size of late fees may decrease the number of empty trips. OECD (2017) argues that strong pro-carrier regulations in Mexico, which limit the ability of shippers to punish carriers for delivering products late, causes carriers to spend more time searching for return loads. By making search time less costly, this decreases the share of empty backhauls.

3.4 Stylized Model

Given the evidence for these frictions, I present a model of trucking markets which organizes the main ideas in a simple setting. Using this framework, I walk through the intuition of how the three key frictions, geographic imbalances, search frictions, and regulatory barriers, generate empty trips. With this understanding, I discuss the implications for hypothetical as well as historical cases where empty trips are high.

This model is a simplification and extension of the models of Brancaccio et al. (2020a) and Demirel et al. (2010). Where those papers feature repeated decisions over time and multiple potential locations, I focus on a two-location, single-round-trip setting. This allows me to derive closed form comparative statics and highlight the intuition behind each friction. I also introduce the regulatory barriers, alongside the existing features of potential demand imbalances and search frictions in those paper, and show how the third force interacts with the others.

Model Setup Consider an economy with two locations, A and B, and two types of economic agents: shippers who demand shipping and carriers who provide shipping.

In each location $i \in \{A, B\}$, there is a population of D_i shippers, where $D_B < D_A$. The fronthaul (A) and backhaul (B) shippers search for carriers in their respective markets. If they find a match, they negotiate with the matched carrier over rates. On agreement, the shipper pays the rate and receives value v_i for the shipment. Otherwise, the shipper takes an outside option and does not ship.

There is a population of N_A carriers who reside in A,[9] whose decision process is described in Figure 10. They first search for a fronthaul job from A to B. If they find a job, they negotiate with the matched fronthaul shipper via Nash bargaining, where the shipper has bargaining γ. If they agree on a price, the carrier deliver the fronthaul shipment and travels to the destination at cost c_{AB}. Otherwise, the carrier takes an outside option with payoff 0. Given these outside options, the Nash bargain price p_A satisfies

$$(1-\gamma)(v_A - p_A) = \gamma(p_A - c_{AB} + V_A)$$

where V_A is the expected future profits of the carrier after they arrive in B.

[9] Another source of empty trips is if carriers do not live at the origin of fronthaul shipments. This is the source of empty trips considered in Allen et al. (2020), where home locations matter because carriers have to travel to the origin of shipments and back from the destinations.

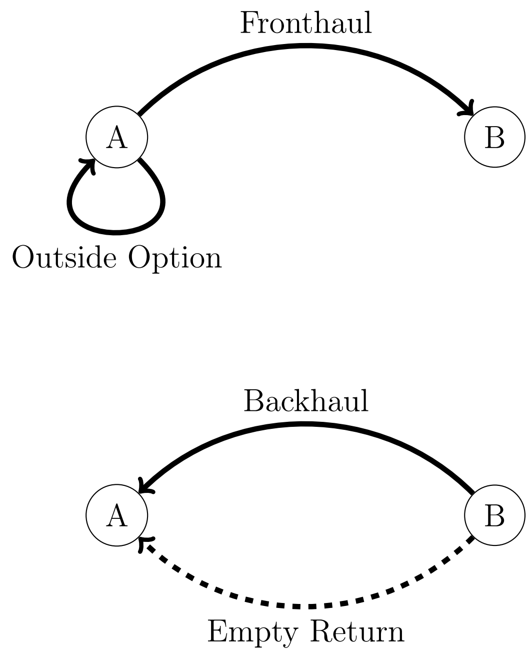


Figure 10: Model Geography

Notes: Figure 10 presents the two locations, A and B, and the two markets, the fronthaul and backhaul markets.

After arriving at B, due to regulation, the carrier is eligible to carry a backhaul with probability ϕ. If the carrier is eligible, they search for a backhaul job from B to A. If they find one, the carrier bargains over prices as in the fronthaul market, and delivers the backhaul shipment. If the carrier does not find a job, negotiations do not come to an agreement, or the carrier is ineligible to carry a backhaul, the carrier return empty. Either way, the carrier must pay cost c_{BA} to return to A. Given these outside options, the Nash bargain price p_B satisfies

$$(1-\gamma)(v_B - p_B) = \gamma((p_B - c_{BA}) - (-c_{BA}))$$

The number of matches produced in each location is a Cobb-Douglas function of the number of searching shippers, D_i, and the number of searching carriers, N_i. Specifically, the number of matches produced in B and A are, respectively,

$$M_B = \mu D_B^{\rho\alpha}(\phi N_B)^{\rho(1-\alpha)}$$
$$M_A = \mu D_A^{\rho\alpha} N_A^{\rho(1-\alpha)}$$

where $\mu \in [0,1]$ is the degree of search productivity, D_i is the number of searching shippers, and N_i is the number of searching carriers. ρ gives the degree of returns to scale. When

$\rho > 1$, then larger markets generate proportionally more matches than smaller markets. When $\rho = 1$, the search process is constant returns to scale, and when $\rho < 1$, the market experiences congestion. α is the elasticity of matches with respect to shippers, and $1 - \alpha$ is the elasticity of matches with respect to carriers.

The three frictions map onto three parameters in this model. First, $I = D_B/D_A$ is the relative size of the backhaul and fronthaul shipping demand, which captures the effect of fundamental trade imbalance. As I increases, demand becomes more balanced. Second, μ captures the level of overall matching efficiency. As μ increases, more matches are produced for a fixed number of searching shippers and carriers. Third, ϕ captures the strength of regulatory barriers on cabotage. As ϕ increases, a greater share of fronthaul carriers become eligible to take backhaul loads.

Outcomes of interest in this setting include the backhaul probability, the number of empty trips, total welfare, and the social return to changes in transport costs. Given this match production function, the probability of finding a backhaul (fronthaul) is $\theta_i = \frac{M_i}{N_i}$ where N_B, the number of searching carriers in B, is equal to M_A, the number of successful matches in the fronthaul direction. Empty trips, E, may be generated either by ineligible carriers or eligible carriers who fail to find return trips.

$$E = (1 - \theta_B)N_B$$

Total welfare is the sum of surplus from fronthaul shipments and backhaul shipments, less total transit costs.

$$\Pi = M_A v_A + M_B v_B - M_A(c_{AB} + c_{BA})$$

The social return to changes in total transport costs, $c = c_{AB} + c_{BA}$, is a function of the total number of trips,

$$\frac{d\Pi}{dc} = -M_A$$

Finally, I let $P = N_A/D_A$ be the relative size of the carrier population to the size of the fronthaul shipper population.

Proposition 1. Solution The equilibrium and key outcomes of this model are as follows:

$$
\begin{aligned}
p_B &= (1-\gamma)v_B \\
p_A &= (1-\gamma)v_A - \gamma(1-\gamma)[\phi^{\rho(1-\alpha)}\mu^{\rho(1-\alpha)}I^{\rho\alpha}P^{-\rho^2\alpha(1-\alpha)}N_A^{-\rho(1-\alpha)(1-\rho)}]v_B + \gamma(c_{AB}+c_{BA}) \\
\theta_B &= \phi^{\rho(1-\alpha)}\mu^{\rho(1-\alpha)}I^{\rho\alpha}P^{-\rho^2\alpha(1-\alpha)}N_A^{-\rho(1-\alpha)(1-\rho)} \\
\theta_A &= \mu P^{-\rho\alpha}N_A^{-(1-\rho)} \\
E &= \mu P^{-\rho\alpha}N_A^{\rho}(1-\theta_B) \\
\Pi &= \mu P^{-\rho\alpha}N_A^{\rho}[v_a - c_{AB} - c_{BA} + \theta_B v_B] \\
\frac{d\Pi}{dc} &= -\mu P^{-\rho\alpha}N_A^{\rho}
\end{aligned}
$$

Proof *See Appendix B.*

3.5 Effect of Frictions and Policy Responses

I use the model to study the effects of the three main frictions and possible policy responses. For each friction, I discuss the channels through which that friction affects the model's outcomes, and predict the effect of possible policies targeting that friction. For additional extensions and applications of the model, see Appendix C.

In this model, I have mapped the magnitude of each friction to a particular parameter: I for demand imbalance, μ for search frictions, and ϕ for regulatory barriers. In Proposition 2 below, I summarize the comparative static results of the model with respect to each of these friction parameters.

Proposition 2. Comparative Statics I summarize the key comparative statics in the following table.

Proof *See Appendix B.*

Trade Imbalance A trade imbalance manifests in this framework when $I < 1$, so demand in the fronthaul direction is greater than demand in the backhaul direction. As I falls, or demand becomes more imbalanced, mechanically more carriers must return empty. This lower backhaul probability affects prices through the bargaining channel: Carriers negotiating prices in the fronthaul market know that they risk not finding a backhaul job, so they therefore demand higher fronthaul prices. Overall, when demand is more imbalanced, total welfare falls because the number of empty trips increases relative to the number of profitable shipments.

Outcome	Demand Imbalance ($I \downarrow$)	Search Frictions ($\mu \downarrow$)	Regulatory Barriers ($\phi \downarrow$)
Prices (Backhaul)	0	0	0
Prices (Fronthaul)	+	+	+
Backhaul Prob.	-	-	-
Fronthaul Prob.	0	-	0
Empty Trips	+	?	+
Total Welfare	-	-	-
Transit Cost Effect	0	-	0

In this table, I present the direction of effect of an increase in demand imbalance (lower I), an increase in search frictions (lower μ), and an increase in regulatory barriers (lower ϕ) on the equilibrium outcomes.

Table 3: Comparative Statics

For a sense of the magnitude of this mechanism, we can use measures of physical trade imbalance: I corresponds to one minus the physical trade imbalance. Based on the evidence in Section 3.1, depending on the country and lane, I could range from 1 for a country with highly balanced trade to 0 for a country-lane with highly imbalanced trade such as the Burkina Faso to Tema lane, or the Mali to Cotonou lane.

Search Frictions Search frictions are stronger when μ falls below 1, which decreases the number of successful matches between carriers and shippers. This friction affects the market in two locations: the fronthaul market and the backhaul market. Note that the two are linked: the number of carriers looking for a backhaul job is equal to the number of carriers that successfully found a fronthaul job. In the backhaul market, a higher level of search frictions directly leads to fewer matches and a lower backhaul probability. However, there is also an indrect effect where higher search frictions lower the number of carriers searching for backhauls.

As a result, increasing search frictions may not always increase the number of empty trips. The intuition is as follows: When search frictions increase, fewer matches are made in both the fronthaul and backhaul markets. The overall number of trips falls, while the share of empty trips increases. Which effect dominates depends on the magnitude of other frictions (demand imbalances and regulatory barriers), the size of search frictions, and the degree of returns to scale in searching, ρ. For example, if it is easier to find a match in larger or thicker markets (i.e., search has increasing returns to scale), then increasing search frictions will decrease matches in the thinner backhaul market more than the thicker fronthaul market. This would imply a decrease in backhaul probability. Regardless of the returns to scale, larger search frictions decrease the probability that a carrier finds a match in the fronthaul market. This lowers the overall scale of the economy, reducing the number of profitable trips conducted and lowering total welfare. Finally, because they directly decrease the total number of trips taken, search frictions also reduce the gains to investing in cost-reducing infrastructure improvements.

Search frictions are more challenging to estimate than trade imbalances. Brancaccio et al. (2020b) identifies a common challenge is that data on one side of the market (e.g., the carriers) is much better than data on the other side of the market. As a result, without observing shippers who tried to search and failed to find a partner, distinguishing high search frictions from few searching shippers can be challenging. Demirel et al. (2010) calibrates μ at 0.80 for transport on the Rhine River.

Regulatory Restrictions Eligibility restrictions are tighter when ϕ is lower, which reduces the share of carriers in the backhaul market who are eligible to pick up a backhaul job. This has a direct effect on lowering the backhaul probability. Similar to the mechanism for trade imbalances, a lower backhaul probability is internalized by carriers in their fronthaul rate negotiations, so stricter restrictions are associated with higher fronthaul prices.

Regulatory barriers also have the potential to interact with geographic imbalances and search frictions. When some carriers are restricted, this effectively generates smaller markets, which can generate geographic imbalances that would not be present if all carriers were able to serve all jobs. In the presence of search frictions, barriers create artificially thin markets that yield fewer matches than a single united market.

Empirically, the magnitude of ϕ depends on a mix of regulatory policy and the distribution of carriers' homes. Suppose that the government in B does not allow any carriers based in A to accept the backhaul job, and all carriers available are either from A or B. The magnitude of ϕ would exactly equal the share of all carriers based in B. In a multi-country environment such as the Economic Community of West African States (ECOWAS) or the European Union, ϕ may be small. In such a context, the magnitude of ϕ could be estimated by comparing the empty trip shares of carriers from different countries.

3.6 Case Analysis

Next, I apply the framework to one hypothetical and three real-world cases.

Hypothetical Case In a hypothetical country, it was observed that the number of empty trips among trucks was high. A concerned policymaker is concerned about the role of search frictions, and develops a matching platform for trucking to help carriers and shippers search. The platform appears successful: utilization is high, and survey reports indicate that firms find it easier to find a counterparty. However, measured counts of empty trips as generated by surveys at highway sites report no change or even a slight increase in the total number of empty trips.

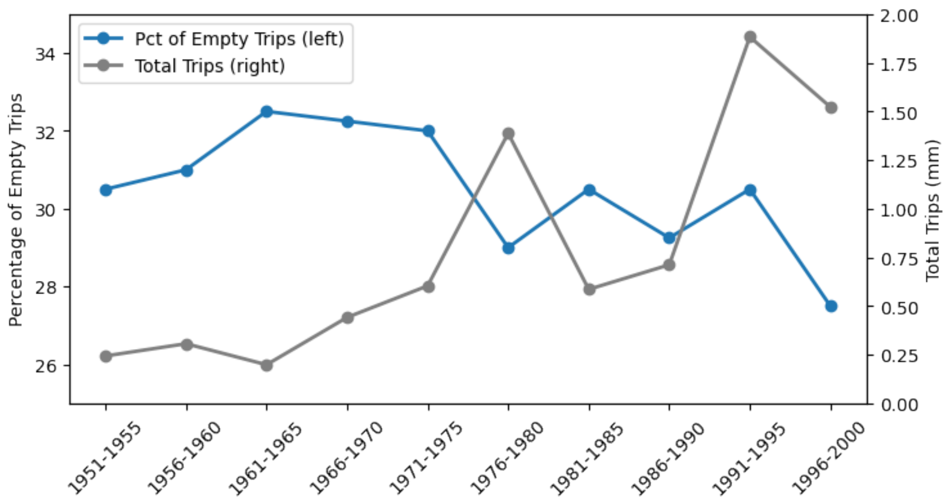
Under the conceptual framework, the data in the above hypothetical case is consistent with a setting where search frictions are important. After search frictions were alleviated in both the fronthaul and backhaul locations, more matches occurred as predicted. However, demand imbalances, regulatory barriers, or returns to scale in the matching technology meant that the proportional increase in matches was higher in the fronthaul market than in the backhaul market. As a result, even though each carrier is more likely to find a backhaul, the overall number of empty trips may remain constant or increase.

For confirmation, the conceptual framework suggests that measuring backhaul probabilities through surveys may show benefits from the platform even if counting empty trips does not. In addition, the number of idle carriers in the fronthaul location may have decreased, which provides another source of economic efficiency.

Case: United Kingdom McKinnon and Ge (2006) document that between 1973 and 2003, the share of empty trips fell by 7 percentage points, as can be seen in Figure 5. They attribute the trend to changes in the structure of shipping, improvements in load matching, and the growth in "reverse logistics" demand such as shipping demand for recycled products. Under the framework, these changes map to simultaneous decreases in search frictions and demand imbalances, which predicts a larger decrease in the share of empty trips than either change alone. To tease out which effect dominated, one could have measured the change over this period in idle vehicles as well as empty trips. If the change in idle vehicles was small, this suggests that reverse logistics may be more important, while if the change in idle vehicles was large, then the improvement in load matching may be more important.

Case: Colombia Between 1950 and 2005, Gonzalez-Calderon et al. (2012b) report that the percentage of empty trips in Colombia fell by about 0.66 percentage points every five years. The periods where this percentage fell the most, between 1976 and 1980 and between 1991 and 2005, were also periods where the total number of trips increased significantly.

Under the conceptual framework, the pattern in Colombia is consistent with a setting where search frictions exhibited returns to scale. When the market expanded in the late 1970s and the 1990s, the total number of carriers and shippers may have increased and thereby alleviated the existing search frictions. However, this is also consistent with a story where demand in the backhaul direction increased, alleviating the demand imbalance. Additional data on the direction of shipments, and the percentage of empty trips along different origin destination pairs, would clarify which effect dominated.



Source: Gonzalez-Calderon et al. (2012b), Ministry of Transportation of Colombia
Notes: Figure 11 presents historical trends in empty mileage shares and total trips in Colombia from 1951 to 2000. Estimates are five-year averages from the Colombian Ministerio de Transporte.

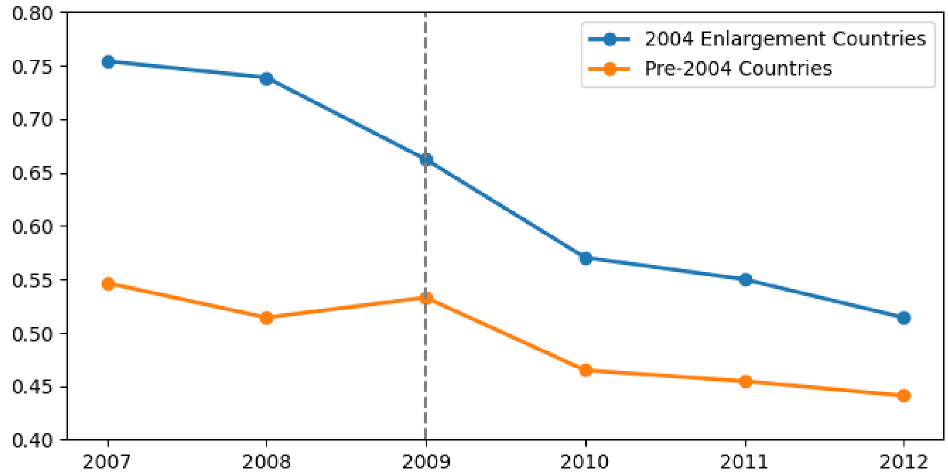
Figure 11: Trends in Total Trips and Empty Mileage Share in Colombia

Case: European Union In 2007, Eurostat reported that trucks registered in the nine states which joined the EU in 2004 spent over 75 percent of their kilometers empty, while trucks registered in eleven pre-2004 EU member states traveled only 55 percent of their kilometers empty (Commission (2014)). This indicated potential to close the gap by reducing cabotage restrictions. Between 2009 and 2012, member states agreed to relax restrictions on cabotage, and the share of empty kilometers for the post-2004 member states fell from 75 percent to 52 percent in 2012, as seen in Figure 12.

This case illustrates the importance of collecting data on the origin location of trucks when measure empty trips. In settings where regulatory barriers may be present, stark differences in empty shares across different types of trucks suggest the potential for relaxing regulatory barriers.

4 Conclusion

This paper has surveyed the empirical and theoretical literature on frictions that generate empty trips in trucking. The overall level of empty trips is high, and lower income countries experience more empty trips. This study has focused on several types of data, which are regularly collected based on the literature: counts of carriers, average fronthaul and backhaul prices, and increasingly survey- or census-based measures of the share of empty trips.



Source: Commission (2014), Eurostat, DG Move

Notes: Figure 12 presents historical trends in empty kilometers for vehicles in countries outside their registration country. The Pre-2004 countries indicate member states of the European Union prior to 2004, with the exception of Belgium, Italy, and the United Kingdom. The 2004 Enlargement countries indicate the states which joined the EU in 2004. The dashed line indicates 2009, when the cabotage restrictions were lifted on states which joined the EU in 2004 and 2007.

Figure 12: Cabotage Restrictions and Trends in Empty Kilometers in Europe

However, models, as shown by the conceptual framework, also suggests that the amount of time carriers and shippers spend idle or waiting is relevant, especially because in some settings, increases in search efficiency will not show up in measures of empty trips, and in other settings, waiting time is informative about the type of regulatory barriers.

Measuring idle or searching behavior is a potential opportunity to integrate additional data sources, such as GPS/cell phone data or weigh-in-motion studies. GPS or cell phone location data is generated by a variety of apps and reports the cell phone's location at regular or irregular intervals. Ping data can allow an analyst to reconstruct a sequence of trips - including time spent not moving. Weigh-in-motion data collects patterns of vehicles passing over a fixed piece of infrastructure, with the potential to measure the vehicle's height profile and infer whether it was loaded or empty. Both of these data sources have seen expanded implementation in recent years across a variety of countries. In other contexts, waiting time has been measured already, such as truck dwell times at ports, or waiting times at checkpoints and borders. Finally, questions about idle time, search time, and wait time could be added to existing surveys at the firm, vehicle, or site level.

Furthermore, collecting information about truck heterogeneity, such as the type of trailer, the national or regional origin, or the license status, is also useful for diagnosing the role of regulatory barriers. When looking at aggregate data alone, a demand imbalance and a cabotage restriction generate similar effects on prices and backhaul probabilities. This additional data helps tease the two frictions apart for the purpose of targeted policy. More broadly, this paper finds that some market-level characteristics, such as income, are predictive of the level of empty trips across different studies. Future work can extend this to other market characteristics.

Beyond the evidence reviewed in this paper, future work taking advantage of new datasets will provide clearer information about the markets and sub-markets that empty trips predominate in, how to diagnose the frictions generating them, and ultimately propose policy to reduce empty miles.

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Appendix A: Tables

Country	Submarket	% of Empty Miles	Source	Year	Type
United States	Non-Tanker	17%	Williams and Murray (2020)	2021	Firm Survey
United States		18.4%	Heilmann (2020)	2019	App Transactions
Europe		20.2%	eurostat (2021)	2020	Firm Survey
United Kingdom		25.25%	McKinnon and Ge (2006)	2002	Trip Audit
United States	Private	26%	Williams and Murray (2020)	2021	Firm Survey
China		32%	Hine et al. (1995)	1995	Site Survey
Mexico		38%	Bego.ai		
United States	Tankers	45.3%	Williams and Murray (2020)	2021	Firm Survey

Table 4: Estimates of Empty Vehicle Miles (Vehicle-KM)

Country	Submarket	% of Empty Trips	Source	Year	Type
United States		14.6%	Boyer and Burks (2009)	1997	Vehicle Survey
United States		19%	U.S. Census VIUS Survey	2002	Vehicle Survey
Denmark		20%	Abate and Kveiborg (2013)	2009	Trip Audit
United States (Florida)	Reefer	20%	Beilock and Kilmer (1986)	1982-1983	Site Survey
Colombia		27.31%	Jiminez Fernendez (2009)	2004	Site Survey
Colombia		28.2%	Holguín-Veras et al. (2010)	2000-2005	Site Survey
Canada		28.3%	Barla et al. (2010)	1999	Site Survey
Colombia		30%	Gonzalez-Calderon et al. (2012b)	1950-2005	Site Survey
Denmark		31%	Abate (2014)	2006-2007	Trip Audit
Guatemala	Intercity	31.59%	Holguín-Veras and Thorson (2003)		Site Survey
Bangladesh		35%	Herrera Dappe et al. (2019)		
Guatemala	Suburban	35.94%	Holguín-Veras and Thorson (2003)		Site Survey
China		43%	Hine et al. (1995)	1995	Site Survey
Ireland		46.8%	Central Statistics Office (2019)	2007	Trip Audit

Table 5: Estimates of Empty Trips

Country	Submarket	Empty Backhaul Probability	Source	Year	Type
United States	Private Fleet	26%	Council (2017)	2017	Firm Survey
United States (North Dakota)	Regulated	28%	Wilson and Dooley (1993)	1987-1988	Firm Survey
El Salvador	Long haul	30%	Osborne et al. (2014)	2011-2012	Firm Survey
Honduras	Short haul	40.3%	Osborne et al. (2014)	2011-2012	Firm Survey
Honduras	Long haul	41.2%	Osborne et al. (2014)	2011-2012	Firm Survey
Nicaragua	Long haul	42.6%	Osborne et al. (2014)	2011-2012	Firm Survey
Panama	Long haul	42.8%	Osborne et al. (2014)	2011-2012	Firm Survey
Costa Rica	Long haul	44.3%	Osborne et al. (2014)	2011-2012	Firm Survey
Viet Nam	LSP	50%	Lam et al. (2019)		Firm Survey
Panama	Short haul	50.6%	Osborne et al. (2014)	2011-2012	Firm Survey
El Salvador	Short haul	52.3%	Osborne et al. (2014)	2011-2012	Firm Survey
United States (North Dakota)	Non Regulated	55%	Wilson and Dooley (1993)	1987-1988	Firm Survey
Viet Nam	Operators	70%	Lam et al. (2019)		Firm Survey
Costa Rica	Short haul	70.6%	Osborne et al. (2014)	2011-2012	Firm Survey
Guatemala	Long haul	76.6%	Osborne et al. (2014)	2011-2012	Firm Survey
Nicaragua	Short haul	82.2%	Osborne et al. (2014)	2011-2012	Firm Survey
Guatemala	Short haul	87.8%	Osborne et al. (2014)	2011-2012	Firm Survey
United States (Minnesota)		78%	Wilson (1987)	1976-1979	Firm Survey

Table 6: Estimates of Backhaul Probabilities

Country	Submarket	% of Empty Miles	Source
India		20%	Londono-Kent (2009)
Pakistan		21%	Londono-Kent (2009)
Nigeria		22.5%	Londono-Kent (2009)
Indonesia		25%	Londono-Kent (2009)
Colombia		30%	Londono-Kent (2009)
India		30%	Kearney (2017)
Tanzania		30%	Londono-Kent (2009)
West and Central Africa	International	33%	Nathan Associates Inc. (2013)
Cameroon		35%	Londono-Kent (2009)
Côte d'Ivoire		35%	Londono-Kent (2009)
Mali		35%	Londono-Kent (2009)
Mexico		35%	Londono-Kent (2009)
China		43%	Londono-Kent (2009)
Malawi		45%	Londono-Kent (2009)

Table 7: Additional Estimates of Empty Miles

Table 7 collects additional estimates of the share of empty driving where the methodology was unclear, or it did not fit into measuring miles, trips, or backhaul probability.

Appendix B: Proofs

Proof of Proposition 1 Nash bargaining implies that the backhaul price is a function of the shipper bargaining power and the shipper's value of shipping,

$$p_B = (1-\gamma)v_B$$

Since the carrier in the backhaul market needs to return home whether or not they accept a job, the cost of the return trip does not affect prices. Given this expected backhaul price, the value of being in B is the expectation of being able to find a job, less the cost of returning home.

$$V_B = \theta_B(1-\gamma)v_B - c_{BA}$$

To find this, I solve for θ_B, noting that the number of carriers searching for return trips N_B is equal to the number of matches in the fronthaul market, M_A. As a result,

$$\theta_B = \frac{M_B}{M_A} = \frac{\mu\phi^{\rho(1-\alpha)}D_B^{\rho\alpha}M_A^{\rho(1-\alpha)}}{M_A} = \phi^{\rho(1-\alpha)}\mu^{\rho(1-\alpha)}D_B^{\rho\alpha}D_A^{\rho\alpha[\rho(1-\alpha)-1]}N_A^{\rho(1-\alpha)[\rho(1-\alpha)-1]}$$
$$= \phi^{\rho(1-\alpha)}\mu^{\rho(1-\alpha)}I^{\rho\alpha}P^{-\rho^2\alpha(1-\alpha)}N_A^{-\rho(1-\alpha)(1-\rho)}$$

When search is constant returns to scale ($\rho = 1$), the backhaul probability simplifies to a function of regulatory barriers, search frictions, trade imbalance, and the supply of carriers:

$$\theta_B^{CRS} = (\phi\mu)^{1-\alpha}I^{\alpha}P^{-\alpha(1-\alpha)}$$

As expected, the role of N_A, or scale, drops out. An increase in each of these terms raises the backhaul probability. The regulatory barriers, ϕ, and the search frictions, μ, enter symmetrically into the backhaul probability. The relative magnitude of trade imbalances, I, compared to the other two frictions depends on α, the elasticity of search with respect to shippers.

Next, I go to the fronthaul market. Given that I know the value of being in B, fronthaul prices are

$$p_A = (1-\gamma)v_A - \gamma(1-\gamma)\theta_{BH}v_B + \gamma(c_{AB} + c_{BA})$$

Fronthaul prices increase in the value of the fronthaul shipment and decrease in the value of backhaul shipment. The pass through of travel costs into fronthaul prices depends on the magnitude of On the fronthaul, the share of loaded trips is

$$\theta_A = \frac{M_A}{N_A} = \mu P^{-\rho\alpha}N_A^{-(1-\rho)}$$

These then imply the computed values for E, Π, and $\frac{d\Pi}{dc}$.

Proof of Proposition 2 The effect of an increase in I, a moderation of demand imbalance, is

$$\frac{dp_B}{dI} = 0$$
$$\frac{dp_A}{dI} = -(1-\gamma)\gamma\rho\alpha[\phi^{\rho(1-\alpha)}\mu^{\rho(1-\alpha)}I^{\rho\alpha-1}P^{-\rho^2\alpha(1-\alpha)}N_A^{-\rho(1-\alpha)(1-\rho)}]v_B < 0$$
$$\frac{d\theta_B}{dI} = \rho\alpha\phi^{\rho(1-\alpha)}\mu^{\rho(1-\alpha)}I^{\rho\alpha-1}P^{-\rho^2\alpha(1-\alpha)}N_A^{-\rho(1-\alpha)(1-\rho)} > 0$$
$$\frac{d\theta_A}{dI} = 0$$
$$\frac{dE}{dI} = -\mu P^{-\rho\alpha}N_A^{\rho}\frac{d\theta_B}{dI} < 0$$
$$\frac{d\Pi}{dI} = \mu P^{-\rho\alpha}N_A^{\rho}v_B\frac{d\theta_B}{dI} > 0$$
$$\frac{d^2\Pi}{dcdI} = 0$$

The effect of an increase in μ, a decrease in search frictions, is

$$\frac{dp_B}{d\mu} = 0$$
$$\frac{dp_A}{d\mu} = -(1-\gamma)\gamma\rho(1-\alpha)[\phi^{\rho(1-\alpha)}\mu^{\rho(1-\alpha)-1}I^{\rho\alpha}P^{-\rho^2\alpha(1-\alpha)}N_A^{-\rho(1-\alpha)(1-\rho)}]v_B < 0$$
$$\frac{d\theta_B}{d\mu} = \rho(1-\alpha)\phi^{\rho(1-\alpha)}\mu^{\rho(1-\alpha)-1}I^{\rho\alpha}P^{-\rho^2\alpha(1-\alpha)}N_A^{-\rho(1-\alpha)(1-\rho)} > 0$$
$$\frac{d\theta_A}{d\mu} = P^{-\rho\alpha}N_A^{-(1-\rho)} > 0$$
$$\frac{dE}{d\mu} = \underbrace{P^{-\rho\alpha}N_A^{\rho}(1-\theta_B)}_{>0}\underbrace{-\mu P^{-\rho\alpha}N_A^{\rho}\frac{d\theta_B}{d\mu}}_{<0}$$
$$\frac{d\Pi}{d\mu} = P^{-\rho\alpha}N_A^{\rho}[v_a - c_{AB} - c_{BA} + \theta_B v_B] + \mu P^{-\rho\alpha}N_A^{\rho}v_B\frac{d\theta_B}{d\mu} > 0$$
$$\frac{d^2\Pi}{dcd\mu} = -P^{-\rho\alpha}N_A^{\rho} < 0$$

The effect of an increase in ϕ, a reduction in cabotage or other regulatory barriers, is

$$
\begin{aligned}
\frac{dp_B}{d\phi} &= 0 \\
\frac{dp_A}{d\phi} &= -(1-\gamma)\gamma\rho(1-\alpha)[\phi^{\rho(1-\alpha)-1}\mu^{\rho(1-\alpha)}I^{\rho\alpha}P^{-\rho^2\alpha(1-\alpha)}N_A^{-\rho(1-\alpha)(1-\rho)}]v_B < 0 \\
\frac{d\theta_B}{d\phi} &= \rho(1-\alpha)\phi^{\rho(1-\alpha)-1}\mu^{\rho(1-\alpha)}I^{\rho\alpha}P^{-\rho^2\alpha(1-\alpha)}N_A^{-\rho(1-\alpha)(1-\rho)} > 0 \\
\frac{d\theta_A}{d\phi} &= 0 \\
\frac{dE}{d\phi} &= -\mu P^{-\rho\alpha}N_A^{\rho}\frac{d\theta_B}{d\phi} < 0 \\
\frac{d\Pi}{d\phi} &= \mu P^{-\rho\alpha}N_A^{\rho}v_B\frac{d\theta_B}{d\phi} > 0 \\
\frac{d^2\Pi}{dcdP} &= 0
\end{aligned}
$$

Appendix C: Additional Features and Extensions

The conceptual framework introduced in this paper can be extended in many different directions to capture additional features of a particular market. These features have the potential to amplify or dampen the effect of the three main frictions.

4.1 Additional Applications

Price Floors Another form of non-market intervention may be artificially high prices on backhaul trips, either implemented by government price floors or private collusion. In the context of the simple model, suppose that backhaul prices are set at $v_B > \bar{p} > (1-\gamma)v_B$. Since all shippers are homogeneous, the price floor does not change how many shippers enter and search. As a result, the backhaul probability is constant. This raises the expected value for a shipper of being in location B, which lowers fronthaul prices.

We can increase the realism of this extension by allowing shippers to respond to the price floor. Suppose that there is a distribution F of backhaul shippers with different entry costs. Each backhaul shipper chooses whether to enter and begin searching, given their expectations of the actual backhaul price. When the backhaul price is set at $\bar{p}$, then the mass of shippers that enter is $D_B(1 - F(\bar{p}))$. As the price floor increases, fewer shippers enter the market, lowering the price backhaul probability. When considering the effect on the fronthaul market, whether the positive effect of higher prices or the negative effect of lower backhaul probability dominates depends on the shape of the entry cost distribution, F.

Increased Scale If the matching function deviates from constant returns to scale, then growth in the size of the economy can affect matching outcomes. In the model, when I hold I, the demand imbalance, and P, the ratio of shippers to carriers, fixed, and increase N_A the number of fronthaul carriers, I effectively scale up the economy. The effect of an increase in

N_A, then is

$$\frac{dp_B}{dN_A} = 0$$
$$\frac{dp_A}{dN_A} = \gamma(1-\gamma)\rho(1-\alpha)(1-\rho)\phi^{\rho(1-\alpha)}\mu^{\rho(1-\alpha)}I^{\rho\alpha}P^{-\rho^2\alpha(1-\alpha)}\upsilon_B N_A^{-\rho(1-\alpha)(1-\rho)-1}$$
$$\frac{d\theta_B}{dN_A} = -\rho(1-\alpha)(1-\rho)\phi^{\rho(1-\alpha)}\mu^{\rho(1-\alpha)}I^{\rho\alpha}P^{-\rho^2\alpha(1-\alpha)}N_A^{-\rho(1-\alpha)(1-\rho)-1}$$
$$\frac{d\theta_A}{dN_A} = -(1-\rho)\mu P^{-\rho\alpha}N_A^{-(1-\rho)-1}$$
$$\frac{dE}{dN_A} = -\rho\mu P^{-\rho\alpha}N_A^{\rho-1}(1-\theta_B) + \mu P^{-\rho\alpha}N_A^{\rho}\frac{d\theta_B}{dN_A}$$

The sign of the comparative statics critically depend on whether $\rho > 1$, or there are increasing returns to scale, or if $\rho < 1$, and there are decreasing returns to scale. When $\rho > 1$, then scaling up the economy increases match efficiency. On the backhaul market, this raises the backhaul probability. In the fronthaul market, this also increases the share of fronthaul carriers who are able to find a match, and lowers fronthaul prices because carriers are more likely to find a backhaul.

4.2 Model Extensions

More Complex Geographies This framework focuses on a two-location setting where there is a clear fronthaul and backhaul market. At a high level, this captures inter-city and inter-regional transportation markets where, due to the location of agriculture, natural resources, manufacturing, or ports, a demand imbalance between two locations is most relevant. In other settings that feature more differentiated locations, or when considering transportation markets at smaller scales, the two-location model is less appropriate.

More Complex Routes This framework focuses on trip chains of zero-th order: carriers take one fronthaul and one backhaul job. In a richer model with more locations, carriers may also take trips of longer length. This may mitigate some of the effects documented above: even if a pair of cities suffers a demand imbalance, there may exist a path through a sequence of cities that has no such imbalance on net.

Entry and Exit of Truckers I have focused on a short-run model where demand for trucking is fixed, and the entry and exit of truckers is held constant. In the long run, shippers respond to changes in prices by reallocating their production, and truckers respond to prices by moving their home locations. These may lead to moderating effects over time, as shippers exit expensive fronthaul markets in favor of cheap backhaul markets.

4.3 Other Sources of Empty Trips

Contracting Frictions Pirrong (1993) studies bulk shipping and finds that spot markets are more common relative to long-term contracts when markets are thick. Hubbard (2001) studies trucking in the United States and similarly finds that contracting is more likely in thin markets. In particular, markets are defined by a combination of geography and trailer type. Hauling specialized trailers restricts the size and thickness of the potential backhaul market, and carriers respond by increasing their use of formal contracting. Hubbard (2001) also discusses connections between the contracts literature and truck transportation. When a carrier signs a formal contract, they are committing to a form of local investment by locating near the contracted origin location. This opens up the possibility that shippers could try to extract quasi-rents from carriers, which reduces the ex-ante returns to formal contracting. Finally, firms may vary in their ability to access long-term contracts. Lam et al. (2019) finds that smaller carriers have less ability to negotiate contracts with shippers, and therefore are forced to search more for backhaul loads.

Organizational Structure The form of business organization can affect the rate of empty trips through several, potentially counteracting, mechanisms. Broadly, trucking carriers can be organized as owner-operators, large for-hire carriers, or as private carriers. Owner-operators are small firms, often a single person who owns and operates a vehicle, and are typically the most informal segment of the market. Large for-hire carriers take in jobs and assign them to a fleet of drivers who drive either their own vehicles or vehicles owned by the carrier. Finally, private carriers primarily serve the shipping needs of a parent company, but may also have the legal ability to supplement with outside jobs.

A set of evidence suggests that private carriers are more likely to travel empty than small owner-operated for-hire carriers. Beilock and Kilmer (1986) document that private carriers in the United States are 12.6 percentage points less likely to be loaded, and Abate (2014) finds a similar pattern among Danish carriers. Abate (2014) suggests that private carriers often have follow-up commitments after completing a trip, limiting their ability to search for a backhaul load. Meanwhile, for-hire carriers have no future commitments, so they are better able to aggregate loads. Herrera Dappe et al. (2019) find that, in Bangladesh, private carriers dominate with a high incidence of empty trips. Since firms place a priority on high service levels, they prefer the control and flexibility of their internal fleet to the "for-reward" market, even if the high level of empty trips leads to higher costs.

In other settings, however, the opposite relationship may appear. In Viet Nam, Lam et al. (2019) find that truck operators have up to 70 percent empty backhaul rates while logistics services providers (large for-hire carriers) and private fleets have lower rates around 50 percent. They argue that this reflects the ability of LSPs and private fleets to sign long-term contracts compared to truck operators. The empirical relationship between firm organization and empty trips therefore depends on the relative magnitude of search frictions, contracting frictions, and shippers' patience.

Formality and sophistication also play a role in carriers' access to trips. Looking at surveys and public disclosures, Terrazas (2019) finds that large asset-based carriers in the United States achieve empty mile shares in the range of 9 percent to 17 percent. They contrast this with, in the same market, small independent carriers who may run over 30 percent of miles empty. This advantage for larger and more sophisticated firms may reflect their access to shippers and lower search costs. Wilson (1987) also finds that firms with longer histories or more experience also experience lower rates of empty trips.

Capital Specialization Carriers who haul specialized cargo, such as refrigerated trailers or hazardous materials, tend to experience more empty trips. Since specialized carriers cannot pick up general products, they face thinner markets which may have greater search frictions. In addition, specialized shipping markets may face more imbalanced demand, if raw materials or agricultural production is concentrated in specific regions. In a simulation based on data from the United Kingdom, McKinnon and Ge (2006) find that the need of products for specific temperature controls reduced the number of potential backhaul loads by 26 percent. In the United States, Terrazas (2019) found that trucks with the most general trailer types (van, reefer) drove about 34 percent of miles empty, while trucks with tank, flatbed, or other specialized trailers drove empty at higher rates of 38 percent, 44 percent, and 43 percent respectively.

Route Length Intuitively, the cost of an empty backhaul on a shorter route is lower than that for a longer route. Holding other frictions fixed, a carrier may spend less time searching for a return load if the cost of the empty trip is smaller. McKinnon and Ge (2006) find that shorter routes, which are less costly to travel empty, have larger rates of empty trips than longer routes. In a sample of Central American countries, Osborne et al. (2014) finds that trips greater than 150 kilometers are 8.4 percentage points more likely to find a backhaul compared to trips below 150 kilometers. Trip length also interacts with the probability of encountering regulatory restrictions across international borders. Londono-Kent (2009) reports that in Malawi, 15 to 20 percent of international trips are empty, while 30 to 60 percent of domestic trips are empty.

Market Power and Cartels Carriers with market power may be able to reduce the share of empty trips through several strategies. Hayakawa et al. (2020) present a model of monopolistic carriers who, when they face limited backhaul jobs, raise their fronthaul prices. This reduces fronthaul demand and increases the share of full trips, smoothing out imbalances. Farren et al. (2022) present a mechanism where carriers use waiting time to respond to uncertain backhauls. In their model, carriers provide enough capacity to maximize profits given expected demand, but they are unable to perfectly foresee future demand. When there are temporary mismatches between fronthaul and backhaul capacity, carriers with market power will prioritize finding backhauls at the cost of longer delays for shippers. Using data on truck shipments between Santiago and San Antonio in Chile, Farren et al. (2022) estimate that if carrier market power were eliminated, shippers would be 7 percent worse off, and a higher share of empty trips leading to higher prices would be a main mechanism.

On the other hand, collusion by carriers can increase the share of empty trips, either through mechanisms which selectively allocate freight or by setting a price floor in backhaul markets, as discussed in the West and Central African context in Bove et al. (2018). Cartels in other segments of the market, such as the broker or coxeur market, similarly misallocate freight jobs and lead to more empty trips.

Location of Drivers Allen et al. (2020) study trucking Colombia and the interaction of market power and firm heterogeneity. There are a limited set of truckers who vary in quality and where they live. In equilibrium, remote places are underserved because they are further from truckers, the truckers who are present extract larger markups, and they are served by lower quality truckers. Empty trips in this model arise because truckers travel empty from their homes to their origin and back from their destination.In a higher-frequency setting, Castillo et al. (2021) study the case of inefficient dynamic responses to demand shocks. When prices rise, drivers are allocated from too far away. Drivers therefore spend more time empty as they drive in.