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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 truckingmarkets, 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 maybe 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 overtime, 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 ajob, 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 amodel 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 aska 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.

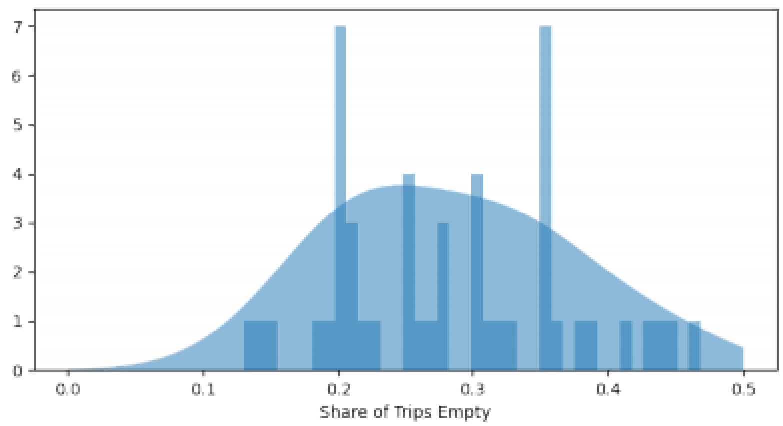
I decompose the estimates into those of High Income countries and those from other countries in Figure 2. High Income countries have lower rates of empty mileage, with median 20 percent empty trips compared to 30 percent empty trips for other countries. Under the Noortman and van Es (1978) model, this 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.

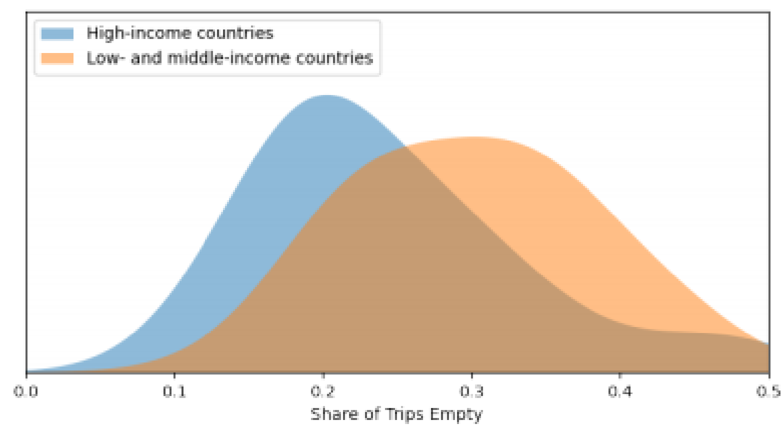
[5] For studies that did not report a confidence interval, I assume the data was sampled from a Bernoulli distribution and used the implied estimate of the confidence interval. For studies that did not report observation counts, I imputed sample sizes based on study type and region.



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

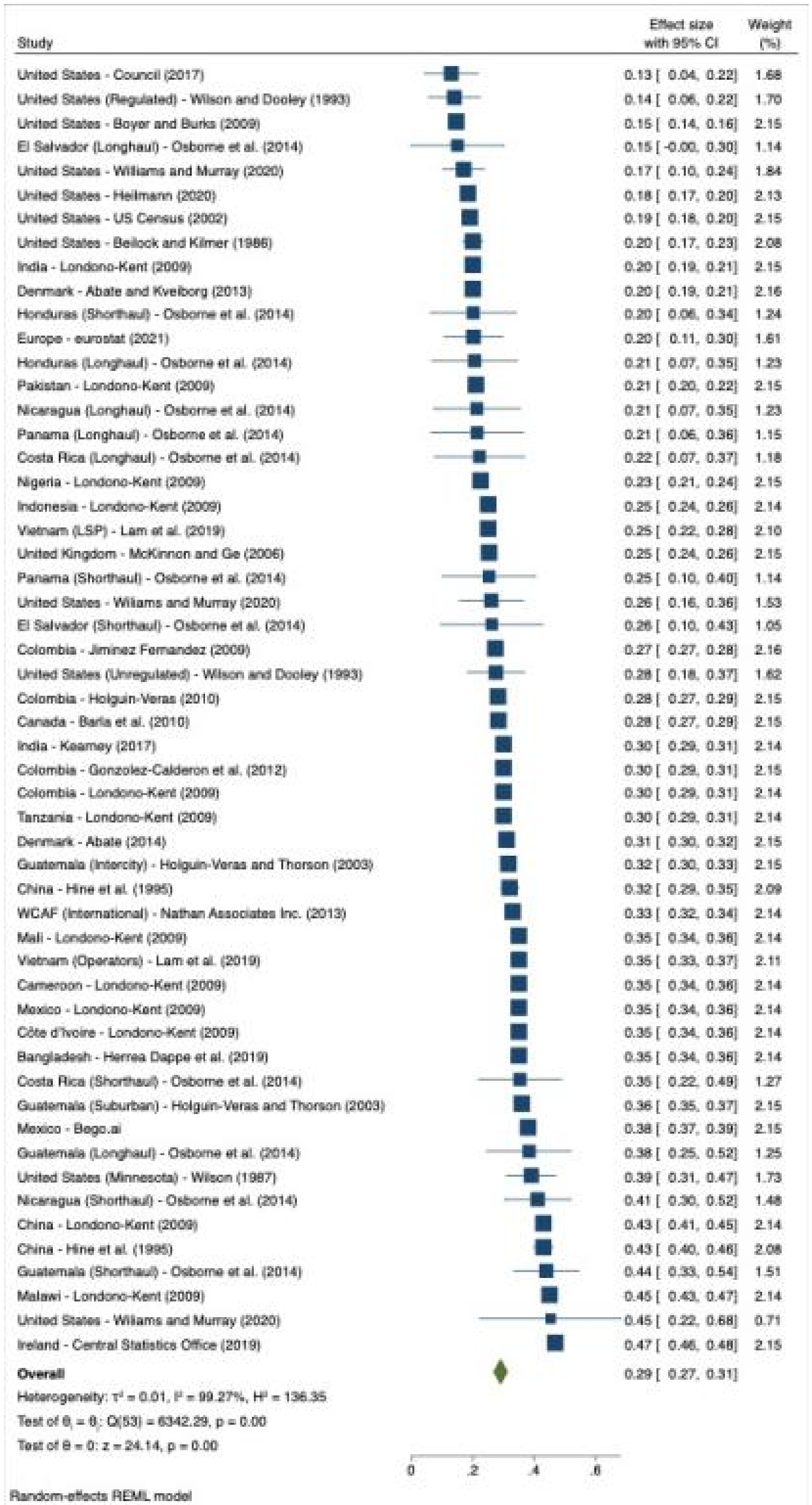
interval of 27 percent to 31 percent empty miles. Figure 3 presents the individual study estimates, their weights, and the mean estimate in a forest plot. The I^2 index is 99.27 percent, suggesting a very high degree of true heterogeneity across the studies.

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 anon-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.

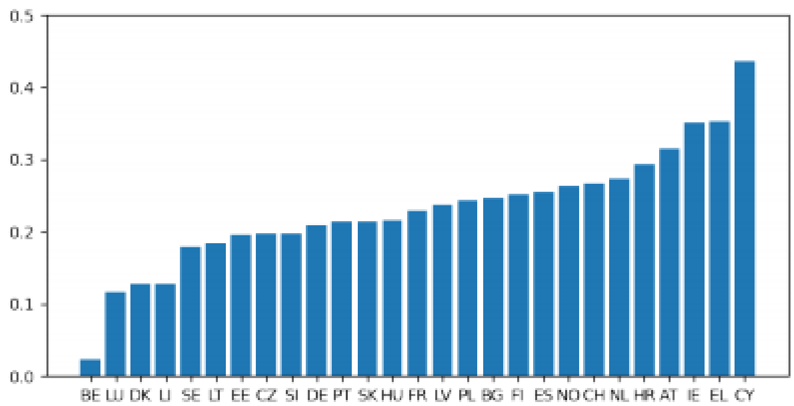
Figure 3: Univariate Meta Analysis

	(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

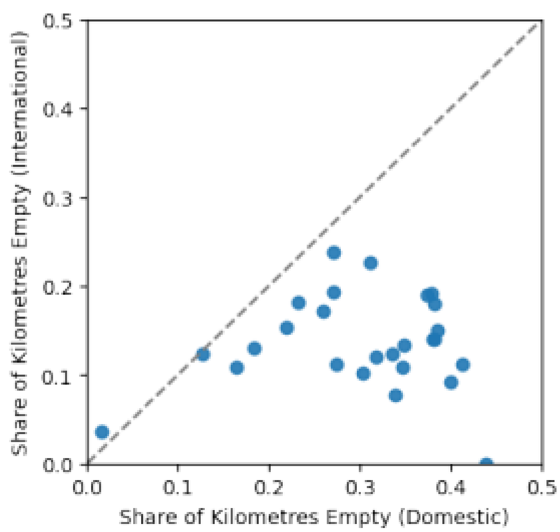
Note: Table 1 presents the results from random effects meta regressions of empty mileson study characteristics. Column 1 presents a regression without country moderators, while Column 2 presents a regression which adds column moderators. The base level for the categorical variables is a study of empty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

Table 1: Meta Regression Results

Panel A



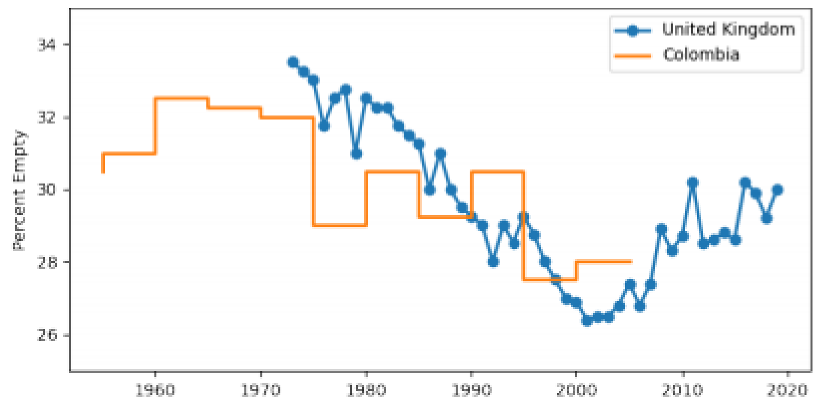
Panel B



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



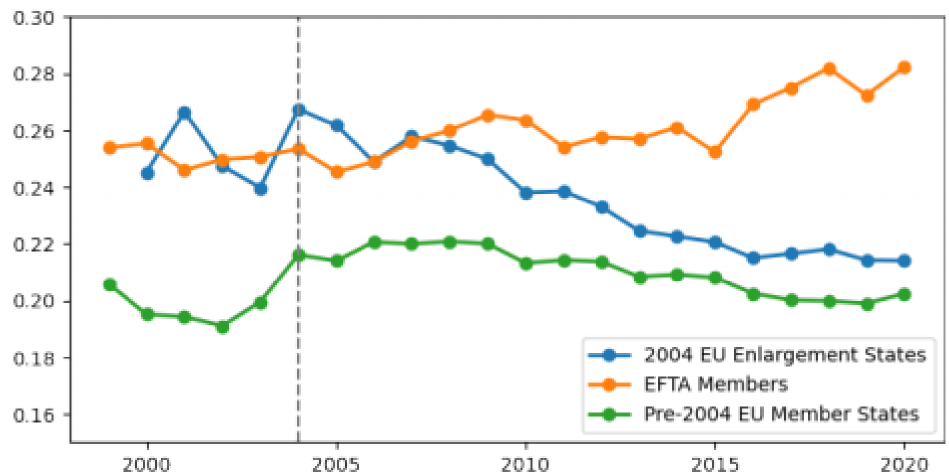
Source: Gonzalez-Calderon et al. (2012b) for Colombia,McKinnon and Ge (2006) for United Kingdom before 2000, UK Transport for United Kingdom after 2000.

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 overall 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.

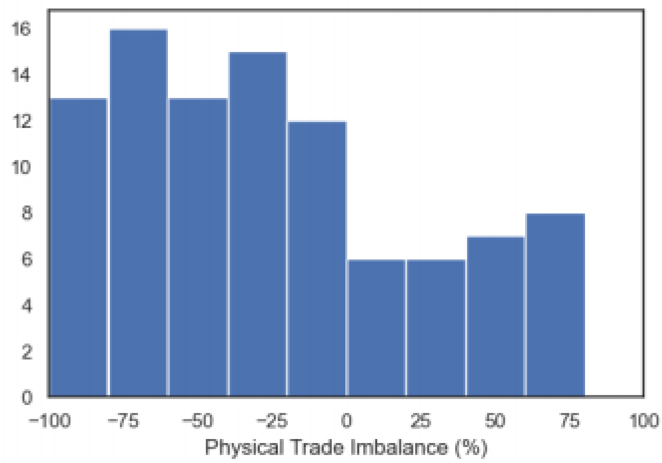
There are several caveats with a straightforward interpretation of these imbalances. First, export and import partners are not symmetric. A country might import from one country and export to another country, yielding many empty trips, but aggregating over trade partners obscures these bilateral imbalances. 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.

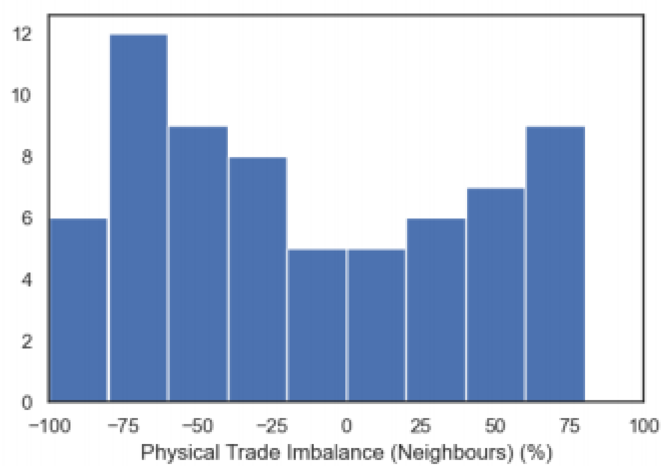
(in kilograms per dollar) as average exports or imports from that country. Alternatively, I could assume that missing weight values have the same value density as average trade in that commodity class.

[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.

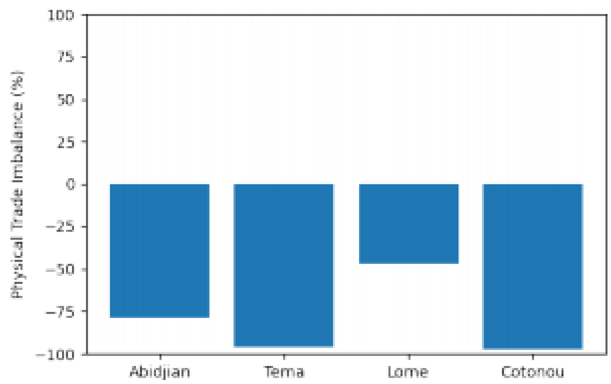
A literature studies the backhaul effect in the context of international oceanic freight. Intuitively, carriers foresee that they will have to make an empty return trip when they enter a net importing region. They therefore pass the costs of the empty backhaul trip to fronthaul prices. This causes freight 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 spillover 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, roundtrips 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

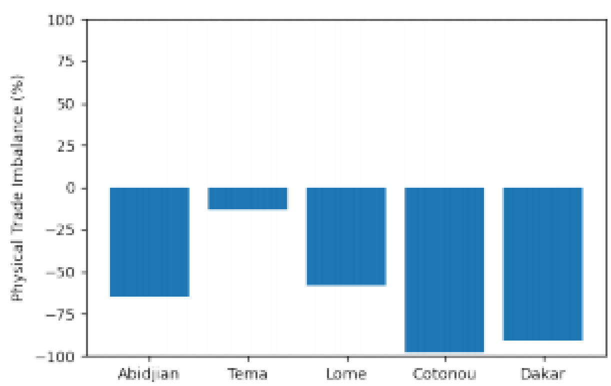
Search and matching frictions are present when there are both carriers and shippers willing to trade, but they are unable to transact immediately. Carriers may either wait and search for a job, or they may travel empty to another market with a higher chance of finding a job.

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).

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Backhaul	27.5%	63.75%	8.75%
Cabotage	82.5%	17.5%	0%
Transit	22.5%	71.25%	6.25%
	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

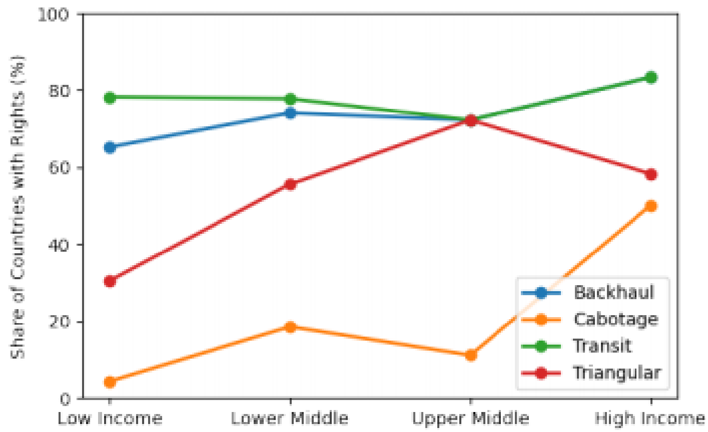
foreign carriers cannot complete domestic jobs, and set minimums on the share of international jobs performed by truckers from each country (Teravaninthorn and Raballand (2009)). Similarly, in Central America and Belize, prevailing regulation prohibits cabotage, despite trucking being a major mode of 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