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Freight rates up and down the urban hierarchy

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Abstract

This paper investigates how freight rates paid by shippers are affected by the characteristics of urban areas of origin and destination. It is based on a commodity flow survey between 45 Japanese prefectures from 2000 to 2010. Through an analysis of freight rates, authors seek to identify the advantages and disadvantages faced by shippers depending on the spatial arrangement of their freight flows. The results show that shipping cargo from small to large urban areas is less costly than in the reverse direction, other things being equal. This difference may be due to the higher probability for truck companies to find back-haul cargo when the destination is a large urban area, usually involving a larger truck transport market. Another important finding of this study is that intra-urban freight rates are positively correlated with population size. The latter may result from higher levels of congestion, labour costs, weight and size restrictions on vehicles, as well as higher proportions of light goods such parcels and courier flows.

Keywords: Urban hierarchy; freight flows; freight rates; truck transport;
commodity flow survey; regression model; Japan

1. Introduction

This paper analyses freight between urban areas (UAs). It aims to take account of the UA in context as part of the region and also as the origin and destination point for freight movements. It analyses the spatial distribution of freight rates between UAs. It discusses whether the positions of UAs of origin and destination of flows are likely to affect freight rates¹. It considers evidence from a Commodity Flow Survey between Japanese prefectures and discusses the potential relationship between the population size of urban areas of origin and destination, the flow of freight flows and freight rates.

Freight volumes and rates are analysed between different levels of the urban hierarchy. The aim is to identify regularities in Japan, which can eventually be compared with other regions in the world where commodity flow surveys are available. By providing an insight into the spatial patterns of inter-urban freight, this paper also aims to support with empirical evidence how transport remains a critical and a scarce resource, whose proprieties greatly vary from one place to another (Hall et al, 2006)

The paper contributes to the extant literature in several ways. First, for the first time, it measures the relationship between freight rates and the position of origin and destination firms within the urban hierarchy. Former studies have analysed the geographical organisation of freight rates (Alexander et al., 1958; Sagers and Green, 1985) but without considering the relationships of urban areas within the urban hierarchy. Other works have analysed the geographical/hierarchical distribution of freight flows but without taking in account the relationships with freight rates (Guerrero and Proulhac, 2014; Ullman, 1957; Pred, 1964; Murayama; 2000). Hence, “freight rates

¹ Freight rates are the price of transport services provided by transport firms and paid by shippers.

are of greatest value in outlining regions and in affecting their organisation” (Alexander et al., 1958, p. 1). Second, while the existing works on the determinants of freight rates have indirectly tackled the interrelation with urban hierarchy through the population density of urban areas (Tanaka and Tsubota, 2017), the relative positions of origins and destination UAs within the urban hierarchy have not been considered. Here, we demonstrate that freight rates also depend on the trade patterns of shippers with regard to an urban hierarchy. Third, this paper contributes to the further understanding of freight advantages affect the ability of regions to position themselves more effectively in national space economies (Lim and Thill, 2008, Chisholm, 1985, 1992). By revealing the structure of freight rates between urban areas of different size, the paper also aims to contribute to existing research on urban freight. This is particularly relevant to studies aiming to simulate the generation of freight flows within urban areas but often neglecting the relationships with other urban areas (Gonzalez-Feliu et al., 2012; Lawson et al., 2012). Finally, the paper uses the case of Japan to contribute to existing theories related to urban hierarchy and freight transportation within transport geography more broadly (Nojiri and Ishikawa, 1994).

The paper is structured as follows:

The next section reviews the relevant contributions in the literature and the third section develops the theoretical framework. Section four presents data and geographical context, while section five presents the results of a regression analysis. The sixth section concludes by highlighting the main implications of this paper.

2. Related literature

The interrelationships between freight rates and the urban hierarchy have not

been studied as such in the literature, but they have rather been approached transversally. In this section, the related literature is reviewed in terms of how the urban hierarchy interrelates with freight flows, and how the flows affect freight rates.

2.1. Urban hierarchy and freight distribution

Zipf (1949) empirically analysed the concept of urban hierarchy and observed the distribution of urban areas followed a simple rule: the population size of the largest urban area is twice the size of the second largest one, thrice the third and so on. This regularity in the spatial arrangement of urban regions is considered to be the result of a tension between the advantages for geographic concentration of industry within a metropolitan area on one side, and diseconomies associated with large urban areas in the other (Henderson, 1974). Although the distribution of population between urban areas within a country is relatively simple and easy to predict, the factors that create it are complex (Krugman, 1996, Fujita and Mori, 1997) and beyond the scope of this paper.

What matters for our purpose is that large urban areas tend to be more attractive for firms than smaller ones, even if ‘population alone’ is not an accurate measure of their central importance (Ullman, 1941). The attractiveness of large urban areas is particularly strong for certain types of activities, either serving final or *nonfinal* consuming markets (Pred, 1964), such as wholesale trade, transportation, warehousing, and certain types of manufacturing activities related to the former. This attractiveness has been approached in the transportation literature through the prism of accessibility. Holguin-Veras et al (2005) showed that accessibility was an important decision criteria for most of the firms recently established in New Jersey. However these firms are not necessarily sensitive to the same scope of accessibility. While the firms selling goods

and services to distant areas place a premium on inter-urban accessibility, other services are more attached to local / intra-urban accessibility.

These differences have been empirically analysed through commodity flow surveys (for example, Ullman, 1957; Berry, 1966; Murayama, 2000). A recent study, based on the results of the French shippers' survey, studied these differences through the prism of the urban hierarchy (Guerrero and Proulhac, 2014). Manufacturing flows are not dominated by an upward (ex. from small urban area (UA) to a large ones) or downward pattern (ex. from large UA to small UA). These result from the fact that manufacturing activities are spread in urban areas of different size. On the other hand, wholesaling flows are strongly organised from Paris and large urban areas to smaller ones. Although most wholesalers are located in large urban areas, highly differentiated patterns are observed depending on the activity type: some are concentrated mainly in large urban areas, while others are ubiquitous. Medium-sized urban areas act as intermediate centres between large and small urban areas. Therefore, the wholesale trade organisation looks like a water stream falling step-by-step from the top to the bottom of the urban hierarchy. This hierarchical pattern is strongly suggestive of the concept of step migration used to explain movements of people from rural areas to small UAs, and then to large UAs (Ravenstein, 1885; Plane et al., 2005), although in the opposite direction.

Another significant characteristic of wholesale trade is that inbound flows tend to travel over longer distances than outbound ones (Guerrero and Proulhac, 2014; Hayashi and Hino, 1988). This is because wholesale trade activities tend to locate close to the markets (retailers and manufacturers), especially in large urban areas, to deliver manufactured goods produced everywhere, both within countries and abroad.

2.2 Freight rates and directionality

The hierarchical organisation of inter-urban freight flows reflected by rates, which vary not only depending on the distance and size of urban areas but also the direction of flows (Alexander et al., 1958). The impact of directionality on rates was investigated for different transport modes (i.e., Felton, 1981; Cariou and Wolff, 2006).

In the case of truck transport, when a truck firm is working from A to B, the transport costs of $A \rightarrow B$ cannot be separated from those of $B \rightarrow A$. This results, for example, by the need of bringing the driver and vehicle back to the origin. Economists refer to this as *joint costs*, being the result of producing two or more outputs in fixed proportions: “for each outbound truck movement, there is a corresponding inbound truck movement; the ratio is fixed and unchanging.” (Felton, 1981, p. 255). Despite some additional costs incurred on returning a vehicle loaded rather than empty, the total production cost (per mile) is lower when trucks are fully loaded in both directions.

For truck firms, the probability of finding backhaul cargo is usually higher while transporting between large urban areas than between smaller ones, as presented by Ferguson (1972) within the context of Australia. Freight rates are then estimated on different types of routes based on their backhaul potential.

Tanaka and Tsubota (2017) in Japan have recently confirmed the impact of the characteristics of urban areas of origin and destination on freight rates. Their work showed that freight rate imbalances basically resulted from differences in population density of the urban regions of origin and destination. Namely, the widest is the gap in population density between the origin and destination UAs, the highest the gap between front and backhaul rates. This paper aims to expand the former works on freight rates by considering the relative positions of urban areas within an urban hierarchy.

3. Theoretical framework

The following hypotheses are tested to analyse the hierarchical structure of freight flows and rates between urban areas:

3.1. Distance and inter-urban freight rates

Road transport cost consists of several components. Some of them vary with distance, for example, driver's salary, fuel, maintenance and use costs, or the tolls paid for using the motorways. Other components are distant-invariants such as loading and unloading operations, moving the truck from the parking to the pick-up point in shippers' establishment, complying with administrative formalities, and so on. Given the above, the following hypothesis is expected to hold:

- (1) *H1: The longer the distance of the freight movement, the lower is the inter-urban freight rates (by tonne-km).*

The relationship between distance and freight rates is already verified within other regional contexts. In France, using a survey with 53,000 truck movements, Jeger and Thomas (1999) confirmed that transport freight rates by tonne-km were lower for distant trips.

3.2. Population size of the urban area and intra-urban freight rates

A truck performing the collection and distribution of load units usually move in densely urbanised and/or industrialised zones. They may experience congestion and the consequent private delays, and may also impose delays on other vehicles whose costs are counted as an externality (Janic, 2007).

(2) *H2: The larger the UA, the higher the intra-urban freight rate.*

Several factors cause this situation. On the one hand, prices such as labour and land costs in large urban areas tend to be higher. Conversely, the average distance of trips is slightly shorter in large urban areas (Allen et al., 2012), which means that the share of fixed costs per t-km is generally higher. On the other hand, larger urban areas are more congested and transport is generally less efficient, with a higher proportion of empty running and lower lading factors (Allen et al., 2012) The former effects are somewhat limited due to more intense competition between truck companies in large urban areas.

3.3. City size (or urban hierarchy) and inter-urban freight rates

(3) *H3: Shipping downwards is more expensive than upwards.*

This situation results from the difficulty for truck companies to find backhaul cargo when going to less-populated areas with less local demand for truck transportation. The lower probability of finding a backhaul cargo locally, make truck firms to charge higher rates on fronthaul trips, as shown by Ferguson (1972). Conversely, opportunities for finding backhaul cargo when going to large urban areas are more because of higher local demand, which will contribute to lower the front haul freight rates.

3.4. City size, trade (or freight) flow, and inter-urban freight rates

(4) *H4: The larger is the total flow between an OD (Origin-Destination) pair, the lower are the freight rates.*

This is related to scale economies in truck transportation, namely the opportunities to optimise the capacity of trucks. Moreover, a larger market allows more room for competition between truck companies.

(5) *H5: The characteristics of the origin UA have a stronger impact on freight rates than the characteristics of destination UA.*

The most common incoterm in Japan is ‘Cost Insurance Freight’ (CIF), meaning the transport cost to the destination is usually included in the total (or final) price of the good. Therefore, the characteristics of the shippers’ UA would determine more the freight rates than the characteristics of consignees’ UA.

4. Data and geographic context

Japan provides an interesting area for studying the patterns of inter-urban freight rates for several reasons. First, its insular context and the extensive use of road transport imply less interference of transit flows and other modes. Second, the large size of the top three metropolitan areas, each covering several neighbouring prefectures, allows the analysis of freight flow movements at intra-metropolitan level. Last, but not least, this work has been made possible by the availability of two reliable data sources providing detailed information on the movements of cargo between prefectures in Japan.

4.1. Data: RCMS and CFS surveys

We use two complementary surveys to measure the freight flows and rates between the different levels of urban hierarchy Both were conducted by the Japanese Ministry of Land, Infrastructure, Transport and Tourism (MLIT)...: The, and The. The Regional Cargo Movement Survey (RCMS) is an exhaustive annual vehicle survey,

providing information on cargo movements (tonnes) by mode and type of goods, at the level of prefectures. The Commodity Flow Survey (CFS) is a shippers' survey conducted every 5 years recording cargo movements and freight rates paid by shippers. The CFS survey provides data on the activity of shippers during 3 days. In our analysis we used RCMS data for freight flows and CFS data for freight rates, for three time points: 2000, 2005 and 2010. .

4.2 Delimitation of urban areas and definition of hierarchical levels

Figure 1 displays a map representing the largest freight flows between prefectures based on the RCMS survey. It highlights the largest prefectures and the relationships over short distances, mainly along the Fukuoka-Tokyo manufacturing belt, which includes four major industrial areas (Tokyo, Nagoya, Osaka, and Fukuoka). It also confirms the metropolitan structures revealed by commuting, migrations, or firms' headquarters (Fujita and Tabuchi, 1997). Most of freight flows involve the prefectures around Tokyo area, which seem to constitute an urban system itself. Suburban prefectures are strongly interconnected with the core and between each other.

The map in Figure 2 represents the dominant freight flows. It provides an alternative view to the main flows (Figure 1) by highlighting the hierarchy between prefectures, even outside the top urban areas. According to this method (Nystuen and Dacey, 1961), a prefecture i is dominated by a prefecture j , (a) if the most important flow from i is emitted towards j , and; (b) if the sum of the flows received by j is greater than the sum of the flows received by i . While on the East freight movements are generally organised around large cities, on the West, the freight flows are less polarised. Again, the prefectures around Tokyo exhibit a complex hierarchical pattern with several levels, converging to the core. Paradoxically, the core of the Tokyo freight system is not dominated by Tokyo Prefecture, but by Yokohama (Kanagawa prefecture). This result,

possibly a counterintuitive, is related to a relative specialization of prefectures within Tokyo MA in freight flows of different scope. While Tokyo prefecture polarizes most of the - short-distance - flows of the neighbouring areas, Yokohama appears to be distant prefectures.

Based on the former maps and the definition of the Major Metropolitan Areas (MA) of the Statistics Bureau of Japan, data on freight movements were aggregated in five hierarchical levels. The first two levels (1 and 2) contain the three MAs of Tokyo, Osaka, and Nagoya. Suburban prefectures have been included when most of their municipalities belonged to one of the three Major Metropolitan Areas, whose definition rely on commuting patterns. A third level (3) is defined with the other prefectures containing core MAs of more than 2 million people: Fukuoka, Hiroshima, Shizuoka, and Miyagi. Additionally, all the other prefectures have been assumed to constitute another two groups (4 and 5) corresponding to the least intensively-urbanised levels of the hierarchy. Hokkaido and Okinawa, which are the islands in the far North and South of the country, were excluded from our analysis. The latter have very specific freight patterns resulting from their population size, surface, peripherality and lack of direct truck (road) connections with the two largest islands. Figure 3 presents the population of the prefectures in the five hierarchical levels, and the map in Figure 4 indicates their location.

5. Empirical analysis and discussion

5.1. Specifications

- a) For the sake of simplicity, in the regression analysis we try to explain freight rates as a function of the spatial organization of freight flows.. However, it is obvious that freight flows and freight rates are simultaneously determined.

Our starting point is the explanation of the spatial structure of the trade flows. As the distributions of manufacturing activities and population are typically stable across time, the demand for freight may be well-shaped in advance, suggesting that freight rates may be determined by a specific structure of trade flows. As discussed in Section 3, six hypotheses are to be examined by mainly concerning freight rates. However, it is necessary to understand the trends of freight flows, and hence, freight flows are estimated before freight rates. A preliminary analysis raised differences in the spatial organization of freight flows depending on their hierarchical structure. Therefore, two samples were used: one for vertical flows (either upward or downward), and another for horizontal flows, when the UAs of origin and destination belong to the same hierarchical level.

The following equation estimates the vertical and horizontal freight flows:

$$\ln Q_{rsct} = \alpha + \sum_{u=N} \beta_r \text{Class}_u + \gamma X_{rt} + \theta_t + \delta_c + \epsilon.$$

Q_{rsct} is the freight flow from the region (prefecture) r to s of commodity c at year t , Class is a categorical dummy variable of urban hierarchy discussed in Section 4 where the total number of categories is N , and X_{rt} is a vector of regional variables capturing the regional characteristics. Fixed effects in time (three-time points), θ_t , and commodity (**types of commodities), δ_c are also included.

On the determinants of freight rates, the equation to be estimated is written as follows:

$$\ln P_{rsct} = \alpha + \sum_{u=N} \beta_r \text{Class}_u + \sigma \ln Q_{rsct} + \gamma X_{rt} + \theta_t + \delta_c + \epsilon,$$

Where P_{rsct} is the freight rate from region r to s of commodity c at year t . Note

that there are restrictions of samples for vertical freight flows as $r \neq s$ and $N=20$, and for horizontal freight flows as $r=s$ and $N=5$, and total $N=25$ (=5 levels *5 levels). Table 1 summarises the statistics on freight flows and freight rates.

5.2 Regression results

Table 2 reviews a short version of the results on vertical freight flows and rates.. Appendix 1 presents the complete estimation results. To control for regional characteristics, we introduce the distance, and to characterize origins and destinations, we used the log of population and the log of per capita income..

The population sizes of origin and destination UAs largely determine freight flows. Log of per capita GDP of origin is positive and statistically significant, while the one of destination is negative and statistically significant. These are the most critical variables explaining the variations in freight flows.

After controlling for these factors, some other time-invariant factors can capture regional differences. We considered the OD pairs of the different levels of the urban hierarchy as dummies (results in Table 2). All these coefficients are different from the benchmark, which are the freight flows bounding from class 1 to class 3. From or to class 1, comparison of downward and upward reveals that upward flows are always larger. For class 2 and class 4, downward flows are larger, whereas upward flows are larger for class 3. Among these, the statistical significance remains at 1-2, 1-5, 2-3, and 4-5, depicted in the right column of Table 2. As we have a smaller coefficient size for flows from- and to- higher classes 1 and 2, these suggest that flows from- and to- class 3, 4, and 5 are large after controlling for the population size.

Freight rates are negatively correlated with freight flows, meaning that a 10%

increase in freight flows is associated with a 2.1% decrease in freight rates (see Appendix 1). This demonstrates the presence of economies-of-scale in truck transportation. This negative relation is substantial given the wide variations in freight flows among regions.

A further analysis of the results on the class dummies reveals that upward flows often have smaller coefficients. This means that after controlling for the population size and GDP of origins and destinations, t and the freight flows between o/d pairs, freight rates remain lower for upward flows. The differences between upward and downward are found for flows between 1-4, 1-5, 2-4, 2-5, and 3-5.

Table 3 presents the results for freight flows between UA belonging to a same level of the urban hierarchy. The freight flow is positively correlated with the population size from column (1). Namely, a 1% increase in the population size is associated with a 1.35% increase of freight flows. Column (2) shows negative relations between freight rates and flows. Instead of an all-in-one specification, an interaction term of the urban level with freight flow has been introduced. This result suggests that the extent of economies of scale is particularly important for class 1, and secondarily for class 2 [column (3)].

So far, the determinants of freight rates were explored, which revealed that freight flows explain the bulk of freight rate variations. An additional specification is searched to check the robustness of these arguments. All variables were converted to ratios (Table 4) to analyse the gaps in freight rates between back and front haul. They re-confirm the economies of density from the negative sign in the coefficient of the ratio of the log of freight flows. This means that a smaller gap in freight rates induces a larger gap in freight flows. Such a tendency may widen if the per capita GDP of the origin (of

numerator) is comparatively larger. Interestingly, road distance is not statistically significant, suggesting that the degree of distance economy may be symmetric for a pair of UA.

5.3 Results and discussion

H1: The longer the distance, the lower the freight rates

This relationship is statistically significant and explained by the fixed/variable cost composition of road transport. The share of fixed cost per tk is lower for flows conveyed over longer distances. The road distance is negatively correlated with freight rates, as per Appendix 1.

H2: The larger the UA, the higher the intra-urban freight rate

The nature of the cargo and its value explains this, which is different depending on the size of the city. Road congestion, which is highly dependent on the population density of the urban area, is usually higher in large metropolitan areas. Finally, yet importantly, labour costs and price index are also higher in large urban areas, which means that road transport companies should support higher costs, which are at least partly reflected in freight rates.

The regression analysis in Table 3 of column 3 does not verify this relationship. The intra-urban freight rates are surprisingly cheaper at the highest level of the urban hierarchy when controlling population and GDP per capita effects. This could result from a higher efficiency of truck transport markets in large urban areas.

The UAs at the top levels of the urban hierarchy have a larger population and higher per capita GDP. As there are positive correlations of freight flows with

population size and per capita GDP, and due to the presence of economies of scale, the resulting freight rates are not necessarily lower in the small UAs.

H3: Shipping downwards is more expensive than upwards

This relationship is mostly valid. Table 2 shows that the coefficients are mostly smaller for upwardflows. As the size of freight flows is controlled, these results suggest the presence of a matching problem where road transport companies find backhaul cargo for large urban areas easier as compared to smaller ones.

H4: The larger the flow, the lower the freight rates

This relationship is statistically significant and can be explained by economies-of-scale in transportation and a higher level of competition between truck companies.

H5: The characteristics of the origin UA have a stronger impact on freight rates than the characteristics of destination UA

This relationship is statistically significant. This may be related to the business characteristics in Japan, a country where shippers usually assume the transport costs until the establishment of the consignee (Cost, Insurance, and Freight). These variables are critical in determining freight rates.

6. Conclusion

Freight transport remains essential for urban growth and development in Japan, as well as in other countries. In this paper, we aimed to establish the impact of the spatial arrangement of freight flows on the ability of shippers to enjoy advantageous freight rates and turn this into a competitive advantage into the space economy. The uneven spatial patterns of freight rates observed in Japan suggest that urban areas are

not competing in equal terms to attract and maintain economic activities. Whereas much attention has been paid in the past to flow related aspects, particularly in the context of global trade, considering freight rates emphasises the often-neglected freight advantages of large urban areas. The latter was the core subject of this paper. This paper has analysed, for the first time, the relationship between freight rates and the position of urban areas within the Japanese urban hierarchy. The joint consideration of the size of the urban area and patterns of upward and downward flows provided a valuable framework for understanding inter-urban freight rates. The work has focused on reasons that may lead to freight rate differences and revealed that freight flows and distance largely determine the freight rates between urban areas. Beyond these two sources of explanation, other factors play non-negligible roles.

The differences in the size of the urban areas of origin and destination also influence freight rates, and hence, shipping cargo from small to a large urban area is cheaper than vice versa. This means that the firms located in small urban areas may benefit from lower freight rates when shipping cargo to other urban areas. Conversely, large urban areas may suffer from higher inter-urban freight rates. When there is a wide population gap between the urban areas of origin and destination, there is also a wide gap between the front haul and backhaul freight rates. This confirms the results of previous works and highlights the importance of efficiency issues in truck transport. Finally, other characteristics such as the economic performance of urban areas of origin and destination, measured by their GDP per capita, play a role in the formation of freight rates. The characteristics of the origin UA turned to be more important than those of the destination UA. This could be a regional specificity since Japanese shippers usually include transport costs in the price of the goods they sell (Cost, Insurance, and Freight). The application of this empirical framework to other regional contexts such the

US or France should provide more evidence to improve to our understanding of the determinants of freight rates.

The observed differences in intra-urban freight rates may have implications for the logistical policies of shippers². They suggest, on one hand, that shippers sending their cargo to other urban areas may be able to balance some of the intra-urban rates which can be particularly high in large urban areas. On the other hand, this compensation may be harder to achieve for shippers with a narrow (intra-urban) scope. Public authorities can decide on compensating shippers oriented to the intra-urban market for their potentially higher transport costs. This suggests the necessity for incorporating the spatial scope of firms' freight flows in the urban freight policies.

References

- Allen, J., Browne, M., & Cherrett, T. (2012). Investigating relationships between road freight transport, facility location, logistics management and urban form. *Journal of Transport Geography*, 24, 45-57.
- Ahlfeldt, G. M., Moeller, K., & Wendland, N. (2014). Chicken or egg? The PVAR econometrics of transportation. *Journal of Economic Geography*, 15(6), 1169-1193.
- Alexander, J. W., Brown, S. E., & Dahlberg, R. E. (1958). Freight rates: selected aspects of uniform and nodal regions. *Economic Geography*, 34(1), 1-18.
- Berry, B. J. (1966). *Essays on Commodity Flows and the Spatial Structure of the Indian Economy* (No. RP-111). Chicago Univ Ill Dept Of Geography.
- Chisholm, M. (1985). Accessibility and regional development in Britain: some questions arising from data on freight flows. *Environment and Planning A*, 17(7), 963-980.

² The authors are thankful to the reviewer who has raised this important point.

Chisholm, M. (1992). Britain, the European Community, and the centralisation of production: theory and evidence, freight movements. *Environment and Planning A*, 24(4), 551-570.

Cariou, P., & Wolff, F. C. (2006). An analysis of bunker adjustment factors and freight rates in the Europe/Far East market (2000–2004). *Maritime Economics & Logistics*, 8(2), 187-201.

Felton, J. R. (1981). The impact of rate regulation upon ICC-regulated truck backhauls. *Journal of Transport Economics and Policy*, 253-267.

Ferguson, D. C. (1972). Joint products and road transport rates in transport models. *Journal of Transport Economics and Policy*, 69-76.

Fujita, M., & Mori, T. (1996). The role of ports in the making of major cities: self-agglomeration and hub-effect. *Journal of Development Economics*, 49(1), 93-120.

Fujita, M., & Mori, T. (1997). Structural stability and evolution of urban systems. *Regional science and urban economics*, 27(4-5), 399-442.

Fujita, M., & Tabuchi, T. (1997). Regional growth in post-war Japan. *Regional Science and Urban Economics*, 27(6), 643-670.

Gonzalez-Feliu, J., Ambrosini, C., Pluvinet, P., Toilier, F., & Routhier, J. L. (2012). A simulation framework for evaluating the impacts of urban goods transport in terms of road occupancy. *Journal of Computational Science*, 3(4), 206-215.

Guerrero, D., & Proulhac, L. (2014). Freight flows and urban hierarchy. *Research in Transportation Business & Management*, 11, 105-115.

Hall, P., Hesse, M., & Rodrigue, J.-P. (2006). Reexploring the interface between economic and transport geography. *Environment and Planning A*, 38, p. 1401-1408.

Harris, C. D., & Ullman, E. L. (1945). The nature of cities. *The Annals of the American Academy of Political and Social Science*, 242(1), 7-17.

Holguin-Veras, J., Xu, N., Levinson, H. S., Paaswell, R. E., Mcknight, C. E., Weiner, R. D., ... & Ozmen-Ertekin, D. (2005). An investigation on the aggregate behavior of firm relocations to New Jersey (1990–1999) and the underlying market elasticities. *Networks and Spatial Economics*, 5(3), 293-331.

Hayashi, N., & Hino, M. (1988). Spatial patterns of the distribution system in Japan and their recent changes. *Geographical Review of Japan*, Series B., 61(1), 120-140.

Henderson, J. V. (1974). The types and size of cities. *American Economic Review*, 64(4), 640-656.

Janic, M. (2007). Modelling the full costs of an intermodal and road freight transport network. *Transportation Research Part D: Transport and Environment*, 12(1), 33-44.

Jeger, F., & Thomas, J. E. (1999). Les déterminants des prix du transport routier de marchandises. *Notes de synthèse du Service économique et statistique*, (123), 9-14.

Krugman, P. (1996). Confronting the mystery of urban hierarchy. *Journal of the Japanese and International Economies*, 10(4), 399-418.

Lawson, C., Holguín-Veras, J., Sánchez-Díaz, I., Jaller, M., Campbell, S., & Powers, E. (2012). Estimated generation of freight trips based on land use. *Transportation Research Record: Journal of the Transportation Research Board*, (2269), 65-72.

Ministry of Health, Labour and Welfare (2010) Summary Report of Basic Survey on Wage Structure (<http://www.mhlw.go.jp/toukei/index.html>)

Murayama, Y. (2000). *Japanese urban system* (Vol. 56). Springer Science & Business Media.

Nojiri, W., & Ishikawa, Y. (1994). Physical distribution studies in Japanese geography. *Progress in Human Geography*, 18(1), 40-57.

Nystuen, J. D., & Dacey, M. F. (1961). A graph theory interpretation of nodal regions. *Papers in Regional Science*, 7(1), 29-42.

O'Connor, K. (2010). Global city regions and the location of logistics activity. *Journal of Transport Geography*, 18(3), 354-362.

Plane, D. A., Henrie, C. J., & Perry, M. J. (2005). Migration up and down the urban hierarchy and across the life course. *Proceedings of the National Academy of Sciences*, 102(43), 15313-15318.

Pred, A. (1964). Toward a typology of manufacturing flows. *Geographical Review*, 54(1), 65-84.

Ravenstein, E. G. (1885). The laws of migration. *Journal of the statistical society of London*, 48(2), 167-235.

Sagers, M. J., & Green, M. B. (1985). The freight rate structure on Soviet railroads. *Economic Geography*, 61(4), 305-322.

Tanaka, K., & Tsubota, K. (2017). Directional imbalance in freight rates: evidence from Japanese inter-prefectural data. *Journal of Economic Geography*, 17(1), 217-232.

Ullman, E. (1941). A theory of location for cities. *American Journal of Sociology*, 46(6), 853-864.

Ullman, E. L. (1957). *American commodity flow*. Mimeo.

Zipf, G. K., 1949, Human Behaviour and the Principle of Least Effort. *Addison-Wesley, Cambody Mus. Am. Arch. and Ethnol. (Harvard Univ.), Papers, 19*, 1-125.

Figures

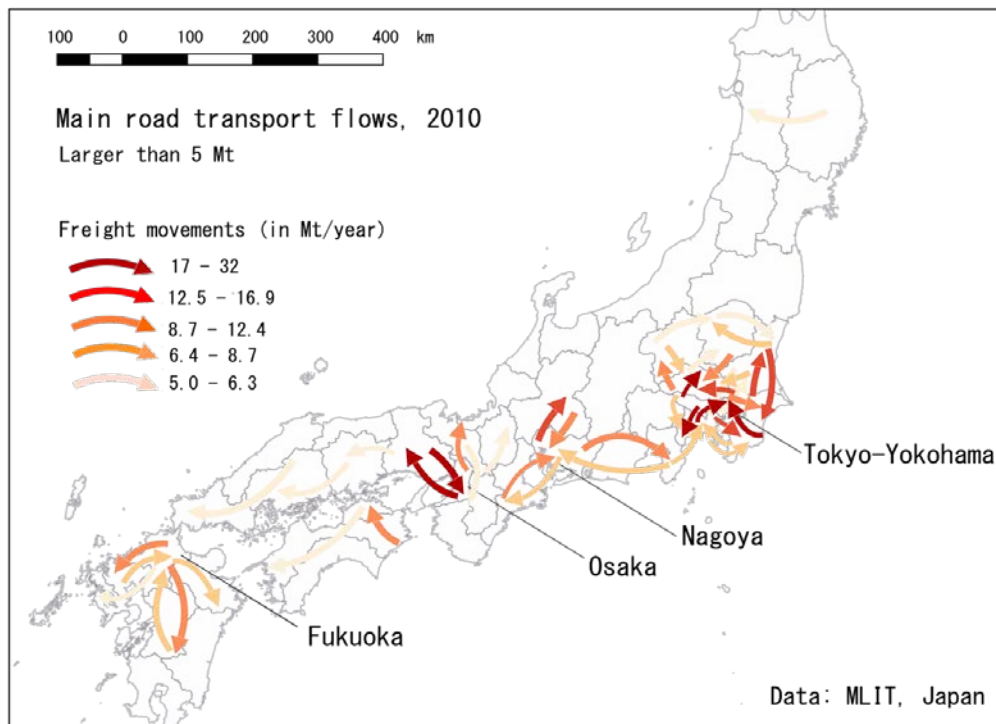


Figure 1. Main road transport flows.
Source: Authors. Data source: RCMS

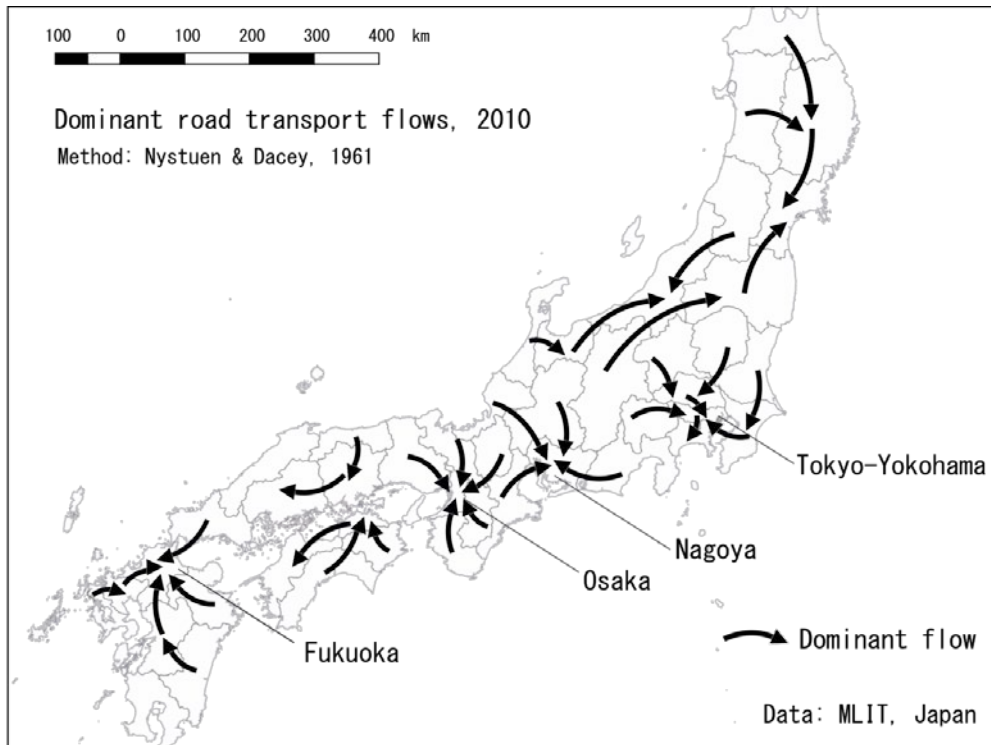


Figure 2. Dominant road transport flows (tonne-base).
 Source: Authors. Data source: RCMS

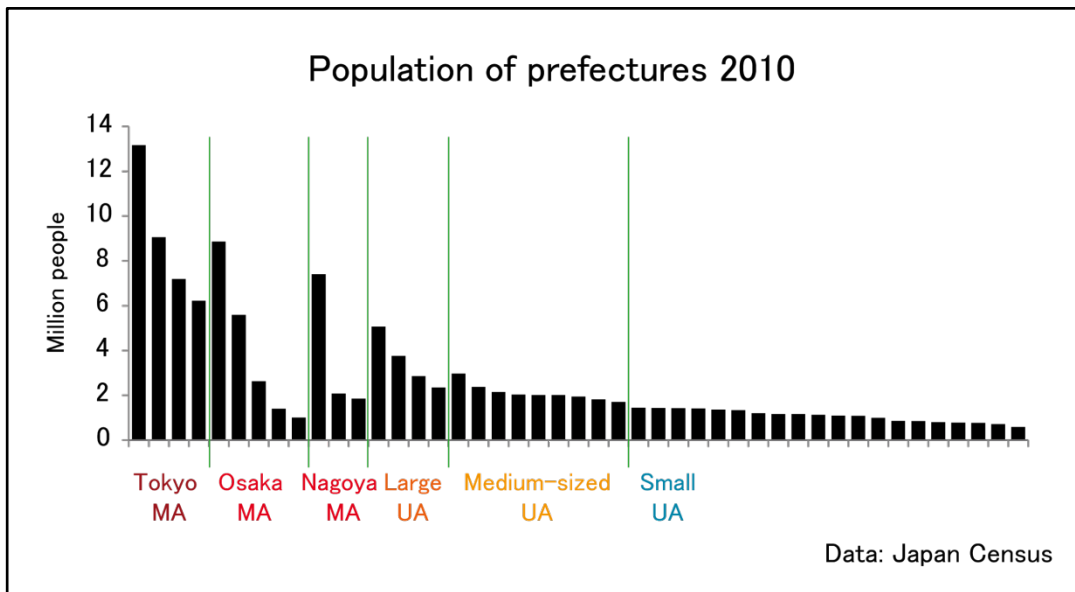


Figure 3. Population of prefectures of the five-level hierarchy.
 Source: Authors

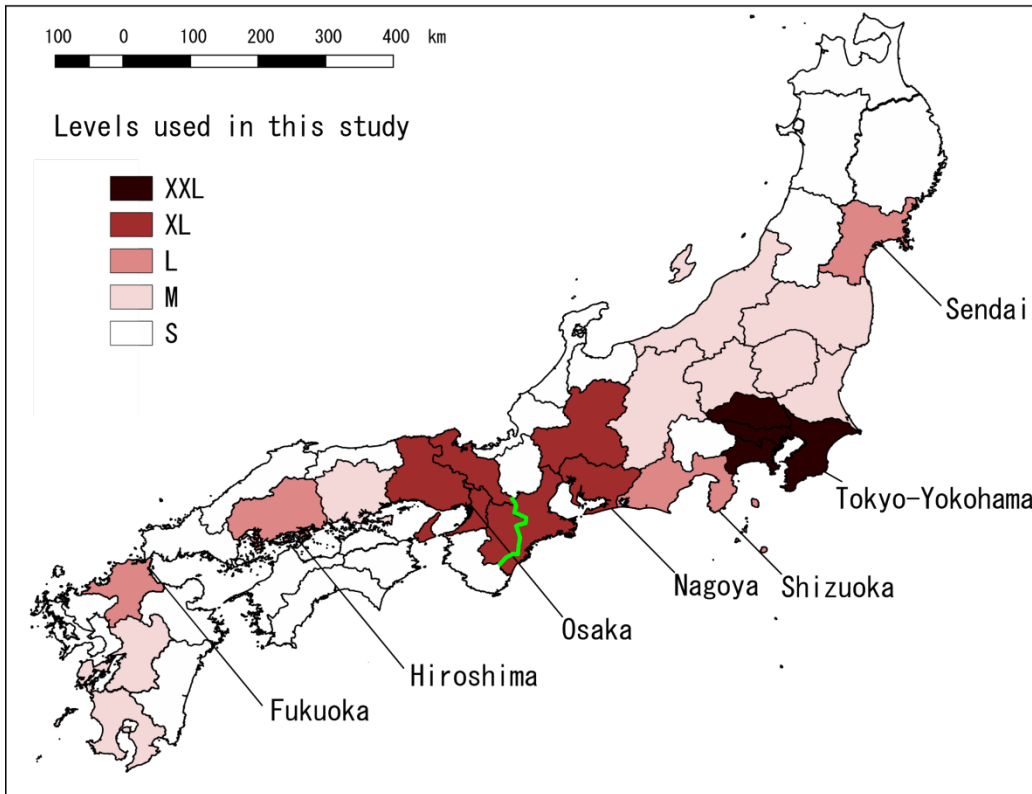


Figure 4. Location of the prefectures in the five-level hierarchy.
Source: Authors

Tables

Table 1. Summary statistics of freight flows and rates by direction between UA

Movements of freight	Log of freight flow			Log of freight rates		
	Mean	Std. Dev.	Freq.	Mean	Std. Dev.	Freq.
From 1 to 2	5.34	2.16	2,099	3.74	0.85	2,099
From 1 to 3	5.68	1.99	1,284	3.72	0.87	1,284
From 1 to 4	5.84	2.29	2,738	4.05	0.91	2,738
From 1 to 5	3.87	2.06	4,842	3.95	0.94	4,842
From 2 to 1	5.82	1.99	2,099	3.65	0.76	2,099
From 2 to 3	5.46	2.09	2,043	3.65	0.78	2,043
From 2 to 4	4.70	2.09	3,980	3.76	0.79	3,980
From 2 to 5	4.12	2.22	8,049	4.14	0.92	8,049
From 3 to 1	5.68	2.06	1,284	3.61	0.95	1,284
From 3 to 2	4.99	2.30	2,043	3.73	0.91	2,043
From 3 to 4	4.75	2.24	2,362	3.74	0.85	2,362
From 3 to 5	4.05	2.52	4,652	3.98	0.94	4,652
From 4 to 1	5.89	2.45	2,738	3.93	0.91	2,738
From 4 to 2	4.67	2.28	3,980	3.65	0.88	3,980
From 4 to 3	4.83	2.23	2,362	3.66	0.93	2,362
From 4 to 5	3.21	2.43	8,475	3.94	0.97	8,475
From 5 to 1	4.16	2.27	4,842	3.67	0.97	4,842
From 5 to 2	3.96	2.58	8,049	3.99	1.00	8,049
From 5 to 3	4.04	2.48	4,652	3.88	0.99	4,652
From 5 to 4	3.00	2.50	8,475	3.96	1.01	8,475
Total	4.26	2.48	81,048	3.88	0.95	81,048
Within 1	9.07	2.48	528	5.41	1.25	528
Within 2	8.60	2.55	881	5.17	1.24	881
Within 3	9.15	2.12	526	4.82	1.11	526
Within 4	8.24	2.46	1,114	4.95	1.21	1,114
Within 5	7.43	2.56	2,310	5.24	1.31	2,310
Total	8.12	2.58	5,359	5.14	1.27	5,359

Table 2. Upward and downward freight flows and freight rates

Dependent variable	Class	Class	Downward		Upward		Difference		
Freight flows	1	2	-1.271	***	-0.645	***	-0.626	*	
	1	3	0		0.086		-0.086		
	1	4	0.205		0.445	**	-0.240		
	1	5	-0.168		0.306		-0.474	***	
	2	3	0.552	***	0.012		0.540	***	
	2	4	0.504	***	0.503	**	0.001		
	2	5	0.485	**	0.399		0.086		
	3	4	1.053	***	1.181	***	-0.128		
	3	5	1.063	***	1.141	***	-0.078		
	4	5	1.097	***	0.849	***	0.248	***	
		Log of population (origin)				1.537	***		
		Log of population (dest.)				1.671	***		
		Log of per capita GDP (origin)				0.476	*		
	Log of per capita GDP (dest.)				-1.022	*			
Freight rates	1	2	-0.271	***	-0.283	***	-0.012		
	1	3	0		-0.127		-0.127		
	1	4	0.17	***	0.014		-0.156	*	
	1	5	-0.002		-0.296	***	-0.294	***	
	2	3	-0.183	***	-0.167	**	0.016		
	2	4	-0.16	***	-0.314	***	-0.154	***	
	2	5	0.038		-0.237	***	-0.275	***	
	3	4	-0.049		-0.145	*	-0.096		
	3	5	0.031		-0.12		-0.151	**	
	4	5	-0.123	*	-0.177	**	-0.054		
		Log of population (origin)				0.041	*		
		Log of population (dest.)				0.134	***		
		Log of per capita GDP (origin)				0.408	***		
	Log of per capita GDP (dest.)				-0.095				

Notes: Appendix 1 shows the complete results. The sample size is 17390, and the estimations include fixed effects in time and commodity. Robust standard errors are clustered at pairs of the origin-destination prefecture. The number of stars indicates the statistical significance at $p < 0.01$, $** p < 0.05$, $*$ and $p < 0.1$.

Table 3.:Horizontal freight flows and freight rates (The origin UA and the destination UA belong to the same hierarchical level)

	(1) Freight flows	(2) Freight rates	(3) Freight rates
Freight flow		-0.257*** (0.039)	
Freight flow x class 1			-0.337*** (0.073)
Freight flow x class 2			-0.265*** (0.055)
Freight flow x class 3			-0.253*** (0.059)
Freight flow x class 4			-0.200*** (0.052)
Freight flow x class 5			-0.262*** (0.046)
Class dummy: 2	0.643*** (0.226)	-0.097 (0.185)	-0.845 (0.902)
Class dummy: 3	1.192*** (0.208)	-0.327* (0.168)	-1.200 (0.833)
Class dummy: 4	1.123*** (0.260)	-0.296 (0.221)	-1.674** (0.787)
Class dummy: 5	1.048*** (0.352)	-0.125 (0.267)	-0.896 (0.744)
Log of population	1.352*** (0.171)	0.125 (0.141)	0.134 (0.139)
Log of per capita GDP	0.297 (0.450)	1.315*** (0.351)	1.316*** (0.355)
Constant	-14.181*** (4.093)	-4.399 (2.859)	-3.708 (3.102)
Year fixed effects	Yes	Yes	Yes
Commodity fixed effects	Yes	Yes	Yes
Observations	1,003	1,003	1,003
R-squared	0.708	0.494	0.496

Notes: Robust standard errors clustered by each prefecture are shown in parentheses. The number of stars indicates the statistical significance at *** p<0.01, ** p<0.05, * and p<0.1.

Table 4. Inter-freight market: Freight flows and freight rates (ratio)

	(1)	(2)
	Ratio of freight rates	Ratio of freight rates
Ratio of log of freight flow	-0.229*** (0.005)	-0.229*** (0.005)
Class dummy: 2	0.141 (0.151)	0.094 (0.162)
Class dummy: 3	-0.169 (0.134)	-0.261 (0.193)
Class dummy: 4	-0.774* (0.429)	-0.835* (0.438)
Class dummy: 5	-1.113** (0.556)	-1.066* (0.558)
Road distance		-0.009 (0.012)
Ratio of log of population	-0.439 (0.369)	-0.440 (0.369)
Ratio of log of per capita GDP	-0.438* (0.241)	-0.437* (0.241)
Constant	1.098* (0.567)	1.068* (0.568)
Origin fixed effects	Yes	Yes
Destination fixed effects	Yes	Yes
Year fixed effects	Yes	Yes
Commodity fixed effects	Yes	Yes
Observations	11,379	11,379
R-squared	0.269	0.269

Notes: Robust standard errors are clustered at pairs of the origin-destination prefecture. The Appendix presents detailed results. The number of stars indicates the statistical significance at *** p<0.01, ** p<0.05, * and p<0.1.

Appendix

Appendix 1. Complete results for Table 2

	(1)	(2)		(1)	(2)
	Freight flow	Freight rate			
Freight flow		-0.210*** (0.004)	Road Distance	-0.385*** (0.008)	-0.132*** (0.004)
Class dummy:1 to 2	-1.271*** (0.226)	-0.271*** (0.061)	Log of population (Origin)	1.537*** (0.064)	0.041* (0.024)
Class dummy:1 to 3			Log of per capita GDP (Origin)	0.476* (0.245)	0.408*** (0.083)
Class dummy:1 to 4	0.205 (0.206)	0.170** (0.066)	Log of population (Destination)	1.671*** (0.066)	0.134*** (0.026)
Class dummy:1 to 5	-0.168 (0.196)	-0.002 (0.063)	Log of per capita GDP (Destination)	-1.022*** (0.213)	-0.095 (0.084)
Class dummy:2 to 1	-0.645*** (0.209)	-0.283*** (0.067)	Constant	-37.959*** (2.614)	0.587 (0.941)
Class dummy:2 to 3	0.552*** (0.209)	-0.183*** (0.060)	Year Fixed Effect	Yes	Yes
Class dummy:2 to 4	0.504*** (0.191)	-0.160*** (0.060)	Commodity Fixed Effect	Yes	Yes
Class dummy:2 to 5	0.485** (0.190)	0.038 (0.065)	Observations	17,390	17,390
Class dummy:3 to 1	0.086 (0.225)	-0.127 (0.081)	R-squared	0.492	0.158
Class dummy:3 to 2	0.012 (0.203)	-0.167** (0.066)	Notes: Robust standard errors clustered at pairs of origin and destination are shown in parentheses, and the number of stars indicates the statistical significance at *** p<0.01, ** p<0.05, * and p<0.1.		
Class dummy:3 to 4	1.053*** (0.225)	-0.049 (0.075)			
Class dummy:3 to 5	1.063*** (0.221)	0.031 (0.072)			
Class dummy:4 to 1	0.445** (0.222)	0.014 (0.079)			
Class dummy:4 to 2	0.503** (0.200)	-0.314*** (0.065)			
Class dummy:4 to 3	1.181*** (0.236)	-0.145* (0.082)			
Class dummy:4 to 5	1.097*** (0.203)	-0.123* (0.068)			
Class dummy:5 to 1	0.306 (0.225)	-0.296*** (0.076)			
Class dummy:5 to 2	0.399* (0.219)	-0.237*** (0.077)			
Class dummy:5 to 3	1.141*** (0.234)	-0.120 (0.079)			
Class dummy:5 to 4	0.849*** (0.215)	-0.177** (0.072)			