TRAFFIC CONGESTION, POLYCENTRICITY, AND INTRA-URBAN FIRM LOCATION CHOICES

A nested logit model for the Los Angeles metropolitan area

Abstract

This study empirically investigates traffic congestion effects on agglomeration through the lens of firm location decisions. A discrete choice model is applied to examine new establishments' location choices within the Los Angeles metropolitan area. Employment centers are defined as the choice set to explore the nature and role of intra-urban agglomerations. The results show that metro-wide congestion negatively affects the location choices of firms in the high-order office-related activities, while local congestion have positive impacts on those firms' location decisions. In contrast, firms in production-related activities are positively influenced by regional congestion but are negatively affected by local congestion levels.

JEL CLASSIFICATION

C5, C8, R3, R4

1. INTRODUCTION

Traffic congestion has been intensively studied in transportation research. Many empirical studies focus on the causes, social consequences, and policy solutions of traffic congestion, while the economic costs of traffic congestion are evaluated in the most direct way. For example, the estimation of the economic value of time is the key issue in measuring the extra costs for transport system users due to congestion delays (e.g., Goodwin, 2004; Lomax, Schrank, and Eisele, 2012). Except for the immediate costs for transport users, Sweet (2011) suggests that traffic congestion also causes second-order impacts to the economy that extend beyond the transportation system. However, not many empirical studies examine the wider impacts of congestion because it is difficult to identify how businesses, individuals, and land use patterns respond or adapt to traffic congestion (Sweet, 2011).

Traffic congestion, like land rents and pollution, is an important source of diseconomy in agglomeration research. The view that the tradeoff between congestion costs and agglomeration benefits explains the structure and growth of cities and regions has been repeated in many agglomeration theories (e.g., Fujita and Mori, 2005; Richardson, 1995). While the positive benefits of agglomeration economies have been intensively examined in empirical studies (see Melo, Graham, and Noland 2009 for a complete review), the negative effects of traffic congestion have only been examined in a few studies (e.g., Boarnet, 1997; Graham, 2007; Hymel, 2009). One major reason is the endogeneity of traffic congestion to the economy, in that congested locations may also be economically robust places with high growth potentials (Downs, 1992; Taylor, 2002; Hymel, 2009). How to unravel the costs of congestion from the potential benefits of agglomeration remains an important issue in empirical studies.

This paper aims to contribute to the empirical literature by directly testing the trade-off between the two effects at the sub-metropolitan level from the perspective of individual firms' location behavior. Specifically, this study focuses on the location choice of new establishments among employment centers within the Los Angeles metropolitan area and tests whether congestion costs are incorporated in firm location choice. Drawing on the theories of industrial location and agglomeration, the central hypothesis is that traffic congestion reduces the accessibility advantages and agglomeration benefits of employment centers within a metropolitan area, and reduces the probability of these centers being chosen by firms, all else equal. By focusing on the location choices of new businesses, all locational attributes can be considered as exogenous, so that the costs of congestion and the benefits of agglomeration can be examined and evaluated separately.

Although it is not the first time that the wider economic impacts of traffic congestion have been examined, this study adds to the literature by using a discrete choice framework to explain how congestion costs affect firms to choose one location over another within a metropolitan area. Past studies of the congestion effects usually apply aggregate frameworks. For example, they use the aggregate production function at the county (Boarnet, 1997), metropolitan (e.g., Hymel 2009; Sweet 2013), or state/provincial level (e.g., Broersma and Dijk, 2008; Montolio and Solé-Ollé, 2009) to examine the effects of traffic congestion on aggregate economic outcomes such as productivity levels (Boarnet, 1997), the growth rate of total factor productivity (e.g., Broersma and Dijk, 2008; Montolio and Solé-Ollé, 2009), or the growth rate of total employment (Hymel 2009; Sweet 2013). These studies do not examine individual firms' decisions. However, the individual perspective can be important because it is not counties or metropolitan areas, but individual firms and households that are actually responding to congestion costs. Also, by focusing on firm location at the intra-metropolitan scale, we are able to look at congestion effects on urban spatial structure, which has not been explicitly examined in previous studies.

This study also sets it apart from the existing empirical work by testing the differential effects of congestion on firms of different industrial sectors. In theory, it is often predicted that some sectors valuing face-to-face interactions and proximity to other businesses more (e.g., service sectors) are more likely to endure congestion costs than others (e.g. manufacturing, wholesale and retail trade sectors). This prediction has seldom been tested (for an example, see Graham 2007). Using a detailed classification of industrial sectors and differentiating them by their preference for large agglomerations, this study provides more insights in whether and to what extent firms' spatial responses to congestion depend on the value they place on economies of proximity.

The structure of this paper is as follows. Section 2 summarizes the theoretical basis of this paper and reviews some empirical evidence on the possible impacts of congestion on firms. Section 3 develops a nested logit model of discrete choice that accounts for the correlation in unobserved factors between alternative locations and permits a hierarchical location decision process. Section 4 describes the data and the construction of key explanatory variables, while Section 5 presents the estimation results. The study concludes with a summary of the findings and discusses the remaining questions for future work.

2. LITERATURE REVIEW: TRANSPORT, TRAFFIC CONGESTION, AND FIRM LOCATION

This section reviews relevant theories of industrial location, agglomeration economies, and urban structure that focus on individual firms' location choices. The purpose is to identify the general role that transport has, and the possible impact that traffic congestion has on firm location, especially within an urban context. Related empirical studies in transportation analysis are also discussed to derive the implications of congestion effects on individual firms' location behavior.

Theoretical basis

Traditionally, transport costs play a key role in industrial location theory. In Weber's (1929) classic triangle problem, the optimal location of an individual firm would be the one that minimizes the total transportation costs to input suppliers and to customers. When input factors are allowed to substitute each other, the optimal location becomes the profit-maximization one and this would not overlap with the transport-minimization location (Moses, 1958; Alonso, 1967; Khalili, Mathur, and Bodenhorn, 1974). Further theoretical developments of firm location choices in a transportation-network space suggest that when transport rates decrease with distance, the optimal location would be market sites, nodes on the network with a high degree of centrality, or junction points for mode transfers, depending on their relative locations on the network and the transport cost functions (Louveaux, Thisse, and Beguin, 1982).

While the traditional industrial location theory explains the location choices and patterns of firms, the effects of agglomeration economies are not included (Brown, 1979; Stahl, 1987; McCann and Sheppard, 2003). Tracing back to Marshall's (1920) economic analysis, theories of agglomeration economies suggest that individual firms benefit from proximity to other firms because of intermediate input sharing, labor-market pooling, and knowledge spillover effects. It can be directly derived from agglomeration theories that transportation can enhance the agglomeration effects by substituting for spatial proximity and increasing the connectivity between firms and workers in the cluster (Melo, Graham, and Noland, 2010; Graham and Melo, 2011).

Other theoretical works suggest that proximity can be advantages or disadvantages, depending on the nature of the activities, the output market and the input suppliers (Hoover and Giarratani, 1971). If the activity is output-oriented, the outputs are standardized and the markets are dispersed, firms would avoid being proximate to each other in order to have a "market area" of its own and minimize competition (Hoover and Giarratani, 1971; Mejia-Dorantes, Paez, Vassallo, 2012). Competition for local inputs and/or dispersed tradable inputs would also discourage firm concentration (Hoover and Giarratani 1971). On the other hand, if the outputs (or inputs) are differentiated and the customers(or suppliers) are concentrated in a few locations, firms will tend to cluster in order to benefit from shopping externalities(or input sharing) (Hoover and Giarratani 1971). This clustering advantages not only accrue to firms of a single activity, but also to firms of related activities, including specialized suppliers, customers and other general service activities (Hoover and Giarratani 1971). Thus, the location of firms is jointly determined by agglomeration and dispersion forces.

The recent development of the new economic geography (NEG) theory explains how transportation costs influence the balance of agglomeration and dispersion forces (Krugman 1991a, 1991b, 1996; Fujita, Krugman, and Venables, 2001). In a review of previous NEG modeling, Fujita and Mori (2005) summarize that firms will tend to agglomerate only when the transport costs of the final differentiated outputs are moderate: when transport costs are high, firms will tend to disperse over space to serve dispersed local demands from the workers in the traditional sector. When transport costs are low, high land rents in the cluster and the resultant high labor costs will be the dominant driving forces for firms to disperse (Fujita and Mori, 2005). Their market potential function approach suggests that the propensity of a single firm to locate in an agglomeration (or a city) is determined by: i) the labor cost advantage of dispersed locations, ii) the market size of the city, iii) accessibility to the market in the city, and iv) the intensity of competition for differentiated products in the city (Fujita and Mori, 2005). Thus, firms will tend to locate away from the agglomeration due to the lower competition intensity and labor costs in lower density locations.

Transport costs and rates are assumed to be exogenous in industrial location theories and the NEG modeling. However, in reality, transport costs vary over space and time because of traffic congestion, which occurs when the travel demands exceed the transportation network capacity. Since the demand for travel is derived from the need for interactions between economic agents, the aggregate results of firms' and residents' location decisions will also affect transport cost outcomes (e.g., Solow, 1972; Tauchen and Witte, 1983; Mun and Yoshikawa, 1993; Anas and Kim, 1996; Wheaton, 2004). In other words, the transport cost may be endogenous to firm location decisions because of the limited transportation supply. Moreover, firms not only benefit from spatial interactions with each other through exchanges of information and inputs, but also suffer from the costs of traffic congestion associated with these interactions (e.g., Tauchen and Witte, 1983; Mun and Yoshikawa, 1993).

The endogeneity of transport costs and traffic congestion has been introduced in some theoretical models of intra-urban firm locations (e.g., Tauchen and Witte, 1983; Mun and Yoshikawa, 1993; Anas and Kim, 1996; Anas and Xu, 1999; Wheaton, 2004; Anas and Buyukeren, 2013). These models assume that the location choices of firms/households and land rents are simultaneously determined with the travel-time matrix and congestion patterns on the road network (e.g., Tauchen and Witte, 1983; Mun and Yoshikawa, 1993; Anas and Kim, 1996; Anas and Xu, 1999; Wheaton, 2004). Resorting to the numeric solution, some models suggest that compared with the scenario without congestion, the accessibility advantage is diminished, and firms are more likely to decentralize and disperse over space (e.g., Tauchen and Witte, 1983; Mun and Yoshikawa, 1993; Anas and Kim, 1996). Some models also suggest that the higher initial density of a location, the greater the density loss in the presence of endogenous congestion; the model results are that the natural accessibility advantage of a central location will be diminished the most, and may even be cancelled out (e.g., Mun and Yoshikawa, 1993; Tauchen and Witte, 1983).

In sum, the location choice of a firm results from the tradeoff among transport costs to markets, labor force, other intermediate inputs. Changes in the transport rate will change the relative attractiveness of different input factors and final demands as well as the relative strength of agglomeration and dispersion forces. Traffic congestion increases an individual firm's travel costs and shifts its bid-rent curve, making those locations connected by congested routes less profitable for the firm.

Possible impacts of traffic congestion on firms

Possible impacts of traffic congestion on firms' operation and production have been examined in some transportation analyses and can be summarized in terms of two aspects (Weisbrod, Vary, and Treyz, 2001, 2003; Sweet, 2011). First, analogous to transportation improvements, traffic congestion directly increases costs for existing travel by causing travel-time delays and unreliability (Sweet, 2011). According to the study by the Economic Development Research Group (2005), traffic congestion not only increases workers' commuting costs, but also increases firms' time costs for business-related trips that are subject to schedule requirements. On the one hand, firms in those production-related industries such as manufacturing, transportation, and wholesale trade may have to adjust their schedules, increase their inventories, or deploy extra vehicles and crews to reduce the uncertainties and delays in scheduled deliveries (Economic Development Research Group, 2005; Weisbrod and Fitzroy, 2008). On the other hand, firms engaged in office-related activities or local services industries may also be adversely affected by congestion because of possible delays in business meetings and conferences as well as increased access costs for their services trips (Economic Development Research Group, 2005).

Second, by reducing the efficiency in the flow of goods, people, and information between locations congestion effects may extend beyond the existing travel and further reduce the agglomeration and accessibility advantages of a location. In particular, firms' relative ease of access to specialized workers and suppliers within a given travel time may decrease due to traffic congestion, and firms may have to substitute those inputs with others that do not match their production needs (Weisbrod, Vary, and Treyz, 2001, 2003). The size of the output delivery market served by firms would also shrink (Weisbrod, Vary, and Treyz, 2001, 2003).

In sum, by directly increasing firms' operation costs and indirectly reducing their access to markets, traffic congestion adversely impacts business' productivity and locations' competitiveness for retaining and attracting economic activities. Thus, firms may avoid choosing congested areas or those areas connected by congested routes when opening new businesses.

3. A MODEL OF INTRA-METROPOLITAN FIRM LOCATION CHOICE

Based on the literature review, two basic hypotheses are developed: (i) firms are less likely to be attracted to traffic-congested locations, all else being equal; (ii) firms in industrial sectors that benefit more from agglomeration economies will be less responsive to congestion costs, all else equal. Traffic congestion is included in the location choice model and its effects firms' choice probabilities of locations are directly estimated.

Discrete Choice Analysis and Nested Logit Model

Following the pioneering work of McFadden (1974), this study uses a discrete choice framework to model the intra-metropolitan firm location: individual new businesses are assumed to weigh production costs and potential revenues over space and choose from the available alternatives that maximize their potential net profits. This approach is consistent with the "Weber" tradition of industrial location theory that emphasize profit maximization for the location choices of rational firms (Guimaraes, Figueiredo, and Woodward, 2004; Arauzo-Carod, Liviano-Solis, and Manjón-Antolín, 2010). Moreover, the location decisions are assumed to be separated from other considerations (such as the decision to run a business or the choice of business size) and each firm is considered to be a price taker of all markets. By focusing on new businesses, the inertial behavior of firm migration due to high moving costs is avoided, so that different locational effects may be separated and compared. This is especially important for evaluating the effects of congestion costs, which can be simultaneously determined with existing land-use and employment patterns, but can be considered as exogenous in the eyes of new businesses. As discussed later, the location pattern of new firms and existing firms do not differ significantly from each other, so that the conclusions of congestion effects on new firm locations might also be extended to firm location decisions in general.

Following the profit-maximization assumption, each firm i attaches an expected profit to each alternative location j consisting of an observed component and a random unobserved component:

(1) $$\pi_{ij} = X_j\beta + \varepsilon_{ij},\ i = 1, \dots N; j = 1, \dots J$$

where X_j is the vector of the observed location-specific variables and ε_{ij} is the unobserved locational characteristics. Firm i would choose location j if the expected profit achievable at location j is greatest, so that the probability yields

(2) $$P_{ij} = \Pr\left(\pi_{ij} > \pi_{il},\ i = 1, \dots N; l \neq j, l = 1, \dots J\right)$$

If the random component is independently and identically distributed (i.i.d.) with a type I extreme value distribution, the conditional logit model is used and the probability that a given firm i choose location j is given by following form (McFadden, 1974):

(3) $$P_{ij} = \frac{\exp(\pi_{ij})}{\sum_{l=1}^{J} \exp(\pi_{il})}$$

The coefficients of (3), β, would be estimated with the maximum likelihood method.

Most firm location choice analyses apply the conditional logit model (Arauzo-Carod, Liviano-Solis, and Manjón-Antolín, 2010). A major property of the conditional logit model is the "independence of irrelevant alternatives" (IIA). That is, how an individual firm chooses between two locations is independent of the availability or attributes of other alternative locations. This assumption, however, can be too restrictive when the number of alternatives in the choice set is large (Quigley, 1985). In location choice models, especially at the intra-metropolitan scale where the available alternative locations are spatially close to each other, the independence of the unobserved factors among nearby spatial alternatives is very unlikely to be held, thus violating the IIA property (Bernasco, 2010). Moreover, the error term of the profit function can be non-identically distributed in spatial choice if the variance of an unobserved variable is different across alternatives (Bhat, 1995). For example, if business amenity is an unobserved locational characteristic, its value may vary greatly between central city locations and suburban locations so that the random components for the two types of locations will have different variance.

To cope with the violation of IIA property, the nested logit model has been developed to partially relax the IIA assumption by partitioning the alternatives into homogeneous nests and allowing the random components to have the same correlation within a nest, but maintain independence across nests (McFadden, 1978). The error term have identical variances within a nest, but have different variances across nests. In other words, choice alternatives within the same nest still retain the IIA property (Williams, 1977; McFadden, 1978).

In a nested logit model, the expected profit function is composed of a term constant for all alternatives within a nest and a term specific to each alternative:

(4) $$\pi_{ijk} = Z_k\alpha + X_{jk}\beta + \varepsilon_{ij},\ j = 1, \dots J_k$$

where Z_k is a vector of variables associated with nest k and X_{jk} is a vector of variables specific to alternative j in the nest k. The nested logit model assumes that ε_{ij} exhibits the type I extreme value distribution, so that the probability of individual firm i choosing location j at nest k takes the following form (see Cameron and Trivedi 2010:512):

(5) $$P_{kj} = P_k \times P_{j|k} = \frac{\exp(Z_k\alpha + \tau_k I_k)}{\sum_{m=1}^{K}\exp(Z_m\alpha + \tau_m I_m)} \times \frac{\exp(X_j\beta/\tau_k)}{\sum_{l=1}^{J_k}\exp(X_l\beta/\tau_k)}$$

(6) $$I_k = \ln\{\textstyle\sum_{l=1}^{J_k}\exp(X_l\beta/\tau_k)\}$$

where I_k is called the "inclusive value" that describes the expected maximum utility of the members of nest k, and τ_k is the estimated coefficients of the inclusive value and is called the "dissimilarity parameter". The utility maximization theory restricts that the dissimilarity parameters be between 0 and 1 (Williams, 1977). Thus, the estimation of dissimilarity parameter can be used to test whether a nesting structure is acceptable and whether the IIA assumption is violated in the conditional logit framework (Quigley, 1985; Christiadi and Cushing, 2007). Moreover, the value of 1-τ_k^2 represents the correlation coefficient of the error terms within the nest (Quigley, 1985; Heiss 2002). If τ_k is equal to 1, the error term are statistically independent and the IIA assumption holds across all spatial alternatives, making a nesting structure unnecessary (Quigley, 1985). By contrast, if the dissimilarity parameter is equal to 0, the spatial units within a nest can be viewed as perfect substitutes to each other and the choice of a nest will depend only on the common characteristics of the nest (Quigley, 1985).

Definition of Choice Sets

Previous studies on intra-metropolitan firm location usually use constant-boundary administrative units such as zip code areas as spatial alternatives (e.g., Charney, 1983; Shukla and Waddell, 1991). Waddle and Shukla (1993), instead, use employment centers as the basic spatial unit to explore the role of intra-urban agglomerations and the polycentric nature of metropolitan areas. This study follows Waddell and Shukla's (1993) method and defines employment centers as the choice set for the following reasons.

First, as explained by the NEG theory, the existence of employment centers is a result of the trade-off between agglomeration economies and diseconomies within metropolitan areas (Giuliano et al. 2011; Agarwal, Giuliano, and Redfearn, 2012). Empirical studies also show that employment centers are the "right unit" to analyze agglomeration effects because they act persistently as magnets of intra-urban growth (Giuliano and Redfearn, 2009; Redfearn, 2009; Redfearn, 2014). Second, based on the definition of employment centers, the component spatial units within each center are relatively homogeneous in terms of, for example, minimum density, or employment/population ratios. Previous empirical studies also show that the employment centers differ from each other in terms of size, industrial composition, and other spatial characteristics (Giuliano and Small, 1991; Giuliano and Redfearn, 2009). This provides sufficient heterogeneity among spatial alternatives as required by discrete choice analysis. Third, employment centers are predicted in theory to be widely separated from each other to avoid being in the "market shadow" of each other (Hoover and Giarratani, 1971; Fujita and Mori, 2005), which may diminish the spatial correlation problem at the micro-geographic level. In sum, defining employment centers as the choice set allows us to examine the nature of intra-metropolitan agglomeration and polycentric structure through a micro-economic approach.

4. DATA AND MODEL SPECIFICATION

This study uses the Los Angeles region as the study area, which has been considered as the most congested region in the U.S. for the past 30 years. The Los Angeles CSA (Combined Statistical Area) includes the five counties of Los Angeles, Orange, Riverside, San Bernardino, and Ventura.

The primary data used here is the National Establishment Time Series (NETS). The NETS database provides establishment-level information such as address, geographic coordinates, employment, sales, and establishment categories, and follows the lifecycle of establishments over time by assigning a unique D-U-N-S number to each establishment that is not allowed to change (Walls and Associates, 2008).[1] An establishment in the dataset is defined as a standalone firm, a headquarters, or a branch or division (Walls and Associates, 2008). A new business only enters into the database when it is confirmed as having started doing business (Walls and Associates, 2008). As suggested by Kolko and Neumark (2008), a key strength of the NETS data is that it distinguishes true birth and death from establishment relocations, which fits well with the study purpose.

The NETS dataset for the Los Angeles region is extracted from the California dataset for the years 2000 to 2005, with the year 2000 set as the base year for measuring the locational variables. Focusing on the intra-metropolitan scale, new businesses are defined as all types of newborn establishments. All the self-employed standalone firms (employment size = 1) and all the "cottage firms" with less than three employees (and residence-based) are excluded because they would generate little demand for space, and their locational behavior would be more likely to be footloose. The agriculture (SIC1 = 1 or NAICS2 = 11) and mining (SIC1 = 2 or NAICS2 = 21) sectors are also excluded in advance because these firms are more likely to be resource-oriented and may not fit well with our model of urban firm location. Based on the definition, there were 399,527 new-born establishments in the region in the 2001–2005 period, associated with 2,102,718 new jobs.

Employment Centers and the Nesting Pattern in a Nested Logit Model

The classic method of employment center identification by Giuliano and Small (1991) is applied in this study. The establishment-level NETS data are matched to the 2000 census tract boundaries, and the 10 jobs per acre density/10,000 total jobs cutoff (referred to as a "10/10" center) is used to identify the employment centers in the base year. Using the 2000 employment data of NETS, forty-seven 10/10 centers are identified, accommodating 132,285 new establishments in the 2001–2005 period. The geography of the centers is illustrated in Figure 1, with the centers ranked by employment size.

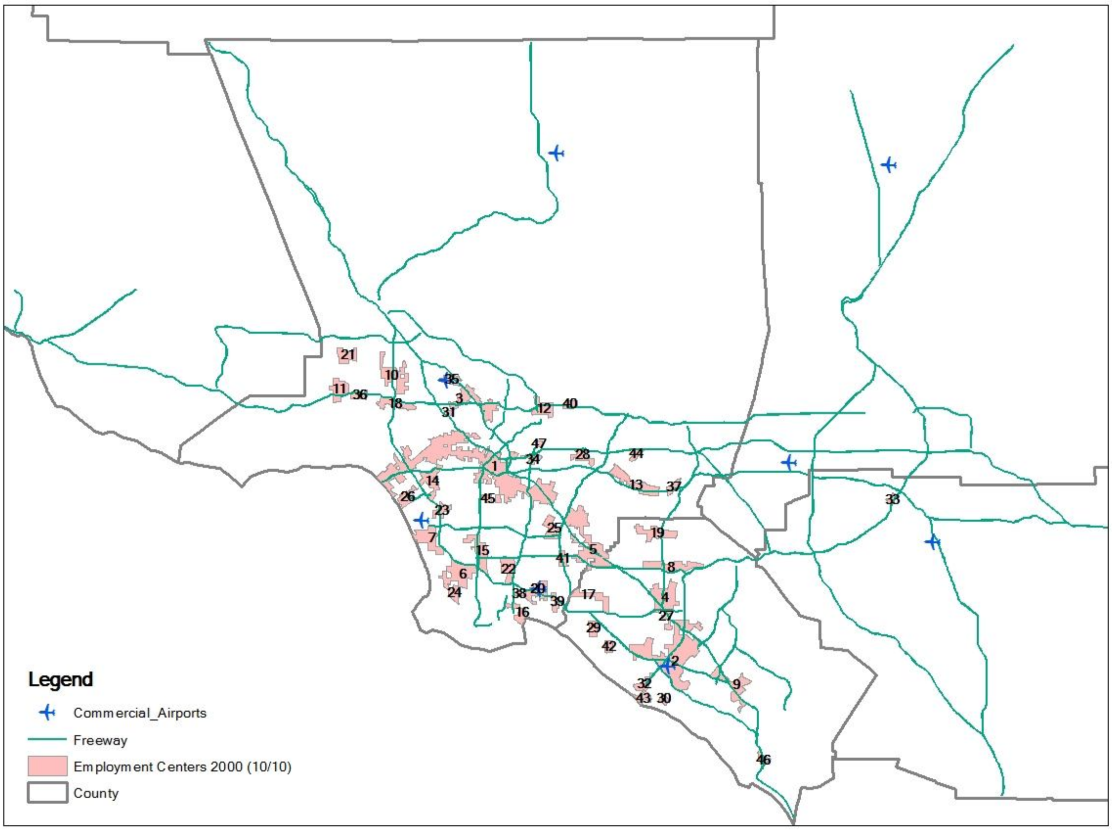

FIGURE 1: Spatial distribution of employment centers identified in 2000 (10/10 criterion).

The development of the nesting structure is an important step in a nested logit model application. There are different ways to define nests of employment centers with similar or homogeneous characteristics. One simple nesting strategy is based on the spatial proximity of alternatives. By partitioning nearby location alternatives into the same nest, correlation of the error terms within a nest is accounted for.[2] However, as discussed earlier, spatial correlation among employment centers may not arise because in theory clustering of economic activities are likely to occur at multiple distant places to access the market as much as possible (Agarwal, Giuliano, and Redfern, 2012). This is consistent with what we observe in Figure 1, where employment centers are shown to be spatially distant from each other. Distances between pairs of employment centers are calculated and the summary statistics are indicated in Table 1. Given that more than 85 percent of centers pairs are more than 10 miles away from each other, the correlation of the error term among employment centers is expected to be weak.

TABLE 1: Summary statistics of distance between pairs of centers (mile)

	mean	sd	p5	p10	p15	p50	p90	p95
Distances	24.05	13.45	6.14	8.37	10.07	21.69	42.89	50.37

Another way to define a nesting structure is based on locational attributes, assuming that there is higher degree of substitution among alternatives with similar characteristics. In this case, the utilities of employment centers with similar size or functions are expected to be highly correlated with each other. This is because employment centers within a metropolitan area are "analogous to the system of cities in a larger regional economy" (Anas, Arnott, and Small, 1998: pp. 1427). Previous studies find that the rank-size rule describes the size distribution of centers within a metropolitan area, suggesting a clear hierarchy of functions among the employment centers in a region (Giuliano and Small, 1991; Giuliano et al., 2007; Giuliano and Redfearn, 2009). There is also some evidence that the economic roles of centers are also closely correlated with the size of centers. For example, production-related activities, such as manufacturing, transportation, and whole trade sectors are relatively concentrated in smaller centers, while office-related activates are concentrated in both small and large centers (Giuliano and Small, 1991; Giuliano and Redfern, 2009). The behavioral implication of this hierarchical structure is that employment centers of different size types can be treated differently in the location and investment decisions of firms and centers of similar size are more likely to be substitutes to each other. Thus, defining a nesting pattern based on the size category of centers helps in exploring the intra-regional hierarchy from the perspective of individual firms' location behavior. It also helps in investigating the presence of correlation in unobserved factors among centers in the same size category. Because centers of competing size are likely to be mutually repulsive in space (Hoover and Giarratani, 1971), spatial correlation among centers of similar size may not arise. Instead, unobserved factors that are not yet captured by the employment size variable, such as business environment and cultural amenity, may be common among centers of similar size.

Observed from Figure 1, employment centers in the Los Angeles region vary in size and there are a few very large and many smaller centers. Table 2 summarizes the basic characteristics of centers by size category. The largest center (the core center)—the corridor starting from Santa Monica through Los Angeles downtown to Los Angeles East—accommodates more than 1.15 million jobs, taking more than 32 percent of all jobs within centers. The second largest center—the Santa Ana-Costa Mesa corridor centered at the Orange County Airport have more than 0.43 million jobs that take more than 12 percent of jobs within centers. Obviously, the top two centers tower above other centers in terms of the scale of agglomeration. Centers 3 to 6 have more than 100,000 jobs each and Centers 7 to 15 have more than 50,000 jobs each. The two groups together take account for about 45.5 percent of jobs within centers. The subsequent smaller centers (Centers 16 to 47) have less than 50,000 jobs each. Clearly, the size distribution of employment centers in the Los Angeles region exhibits a hierarchical structure.

TABLE 2: The number and employment share of centers by size category

Size Category	Number of centers	Total Number of Employment	Share of employment within centers (%)
10,000 - 20,000	17	245,281	7.0
20,000 - 50,000	15	508,775	14.6
50,000 - 100,000	9	639,045	18.3
100,000 - 200,000	4	519,505	14.9
200,000 - 500,000	1	428,769	12.3
>500,000	1	1,150,264	32.9
Total	47	3,491,639	100

Based on the above discussion, firm location choices among employment centers can be conceptualized as a two-tier decision process: first, individual firms choose a subset of centers with similar characteristics; they then choose a particular center only from the group they have selected in step 1. However, the full information maximum likelihood estimation is applied here to obtain efficient and consistent estimates of all coefficients in Equation (5) (Hensher, 1986). This implies that individual firms will still have some probability of choosing any centers outside the chosen nests. Since economic theory does not provide guidance on the appropriateness of a nesting pattern, it must be determined econometrically (Chattopadhyay, 2000). That is, the distance threshold used to define "nearby" employment centers as well as the size ranges used to categorize "similar" employment centers must be found econometrically. The appropriateness of different nesting structures is further discussed in section 5.

Choice of Industrial Sectors

In the 2001–2005 period, the percentage of new establishments that chose to locate within the centers was 33.1 percent, while the share of employment centers in the total employment of new establishments was slightly higher (about 36.8 percent). Not all firms value the agglomeration benefits associated with centers and their responses to congestion costs may also differ. Aiming at examining the nature and role of employment centers, this study chooses those sectors that are spatially concentrated within centers. To examine this, the location quotient (LQ) for each industrial sector in all center locations is calculated as each sector's share of new establishment counts in center locations divided by the sector's share of new establishment in the region. If the centers' LQ for a sector is larger than 1.1, the sector is considered to have a higher concentration in center locations than in the whole region. This LQ threshold restricts that those chosen sectors already favor the centers, which allows us to focus on the location choices among employment centers, based on the fact that the center locations have been chosen.

Table 3 (in the appendix) indicates the number of new establishments, associated employment counts, and the LQs for all the NAICS3 sectors (or NAICS4 sectors for the professional services sectors) in center and non-center locations. In the study period, the total new establishments counts of those sectors meeting the LQ threshold is 45,563 and the total employment of those establishments is 267,787. To examine if the location pattern of new firms across center and non-center locations is significantly different from the location pattern of existing firms, LQs for existing firms of all detailed sectors in center and non-center locations are also calculated and t-tests are run to test the equality of the means for LQs. The results show that the difference in the means of LQs in center locations between new firms and existing firms is less than 0.03, while the t-statistic is not significant at any level of significance ($t_{190} = 0.71$). Similarly, the difference in the means of the LQs in non-center locations is −0.01 and is not significant either ($t_{190} = -0.67$). This result implies that the location decisions of new firms are representative of the location decisions of all firms in the study period.

To efficiently run the discrete choice model, those chosen sectors not only show a pattern of concentration in centers but also have at least 1,320 new establishments locating in centers (see the highlighted rows in Table 3).[3] This threshold for the sample size is chosen to ensure that dependent variable is not zero and that there are at least 30 respondents per spatial alternative, so that parameters in the expected profit function can be reliably estimated.[4]

Figure 2 illustrates the LQs of center and non-center locations for new establishments in those selected sectors. The table and the figure indicate that sectors concentrating in centers include a variety of economic activities. However, most of the chosen sectors are office-related activities, such as the information, financial and insurance, and professional service sectors. Other activities such as manufacturing and retail sectors in general show a dispersed pattern to be insulted from competition.

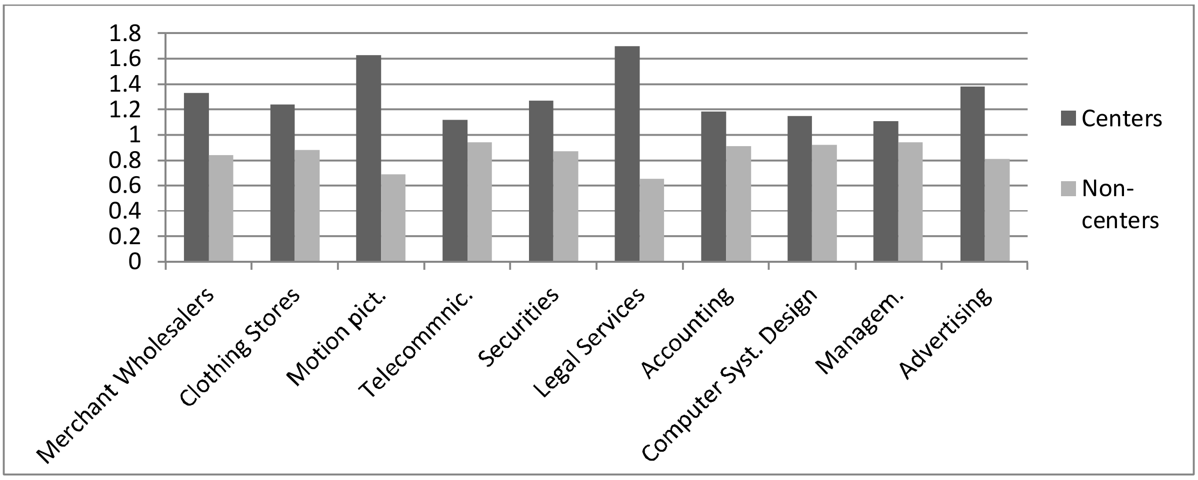

FIGURE 2: Spatial concentration pattern of chosen sectors across center and non-center locations.

To examine how firms in different sectors value the benefits of locating in large agglomerations differently, and to predict their sensitivities to congestion costs and delays, the LQs for each sector in the largest two centers are calculated and other centers. It is expect that those sectors more concentrated in the top two centers would benefit more from agglomeration economies. Figure 3 shows the results with all sectors ranked by the LQs in the two largest centers and categorized into 3 groups based on their LQs in the two largest centers. Three groups of industries are defined to describe the differences in the level of concentration between large and small centers across different sectors (see Figure 3).

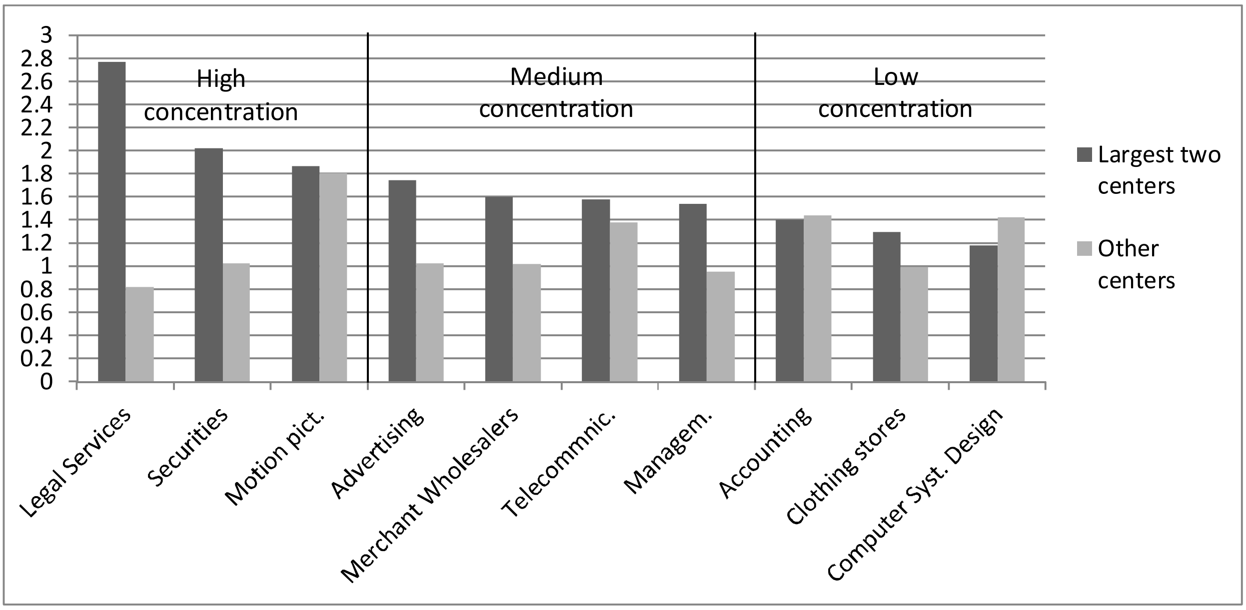

FIGURE 3: Spatial concentration pattern of chosen sectors across centers of different size.

The three "high-concentration" sectors are all office-related activities, including legal service, securities, and motion pictures sectors. These sectors are the so-called high-order office activities that rely heavily on frequent contacts with outside customers and suppliers in their "production" processes, including formal face-to-face meetings (Ihlanfeldt and Raper, 1990) and less formal face-to-face contacts between employees of different firms (Coffey, Drolet, and Polèse, 1996). Large employment centers are more likely to provide such inviting business environments for these office firms (Coffey, Drolet, and Polèse, 1996; Shearmur and Coffey, 2002). Thus, these sectors are expected to be more likely to endure congestion delays as long as the savings in interaction costs within centers outweigh costs of delays in accessing workers and other businesses within and surrounding centers.

The three "medium-concentration" sectors include three office-related activities and one production-related sector. The only chosen production-related sector, the merchant wholesalers sector (non-durable goods), may have a large share of its production costs taken by transport costs of goods because of its role as an intermediate between the manufacturing and retail sector. As implied by the theory, wholesalers can benefit from co-locating with each other to share transport and storage capacity and save repair and maintenance costs, and other operation costs (Heuvel et al., 2013). However, given the importance of shipments and scheduled deliveries in production-related activities, firms in these sectors are expected to avoid centers having long delays to destinations at the local scale as well as the regional scale.

The "low concentration" group includes three office-relative activities and one retail sector. The LQs for these sectors in the top two centers are lower than 1.5. Compared with the three "high-concentration" office-related activities, the accounting and computer system design sectors may have a lower need for face-to-face interactions. The only retail sector selected here—the clothing and clothing accessories stores—may be driven to concentrate in large centers due to consumers' demands for differentiated products. Firms in the "low concentration" group are expected to benefit least from agglomeration economies and be sensitive to congestion delays at the regional scale or within centers.

Construction of Variables

Firms' expected profit in an employment center is specified as a linear function of center-specific variables, which can be grouped into seven types of variables: (i) congestion delays at the regional scale, (ii) congestion delays within centers, (iii) accessibility to labor force/other businesses at the regional scale, (iv) urbanization/localization economies within centers, (v) access to regional transportation infrastructure, (vi) land use characteristics within centers, (vii) labor quality within centers. All the explanatory variables describe center-level characteristics as specified in Equation (4). Except the congestion variables, most of factors are usually included in empirical studies of intra-metropolitan firm location studies (e.g. Erickson and Wasylenko, 1980; Ihlanfeldt and Raper, 1990; Shukla and Waddell, 1991; Waddell and Ulfarsson, 2003; Arauzo-Carod and Viladecans-Marsal, 2009) and are included here as important control variables. The summary statistics of all the explanatory variables are included in Table 4 (in the appendix).

To quantify the level of traffic congestion, this study applies travel time-related measures. This is because the impacts of traffic congestion on firm behavior are mainly through travel-time delays, which directly increase transport costs and indirectly reduce locations' accessibility advantages. The measure of travel-time delays in accessing metro-wide labor force and other businesses derives from the "delay rate" measure of congestion in transportation engineering studies that was originally used to measure the differences in the travel rate between congested and uncongested conditions for specific road segments or trips (Lomax et al., 1997). To convert the trip-based measure into a location-based measure, this study uses the average delay rate for all possible trips from each location to all other locations that are within a certain distance boundary as a measure of the average congestion level for a location i:

(7) $Delay\ Rate_i = \frac{1}{n}\sum_j^n[(T_{ij}\ at\ AM\ Peak - T_{ij}\ at\ Night\ Period)/Dist_{ij}]\ ,\ Dist_{ij} < Dist_{boundary}$

where n is the total number of tracts that are accessible to location i within distance boundaries, and T_{ij} under different scenarios is the network travel time between focal location i and any other location j within the travel-distance threshold. The morning (AM) peak is used as the congested condition because it is "nearly uniform, consistent and predictable" (Lomax et al., 1997), while the night period is used as the free-flow or benchmark condition because it is usually easily identifiable by travelers as a desirable or acceptable condition. For each pair of locations (i and j), T_{ij} for AM peak/Night period is the shortest-path travel time on the network for each period; within each census tract i, T_{ii} is estimated as the average travel time for all road segments (excluding limited-access highways) within each census tract for each period. The transportation network data is obtained from the Southern California Associations of Governments (SCAG) base-year network files for the Regional Transportation Plan (RTP) of 2004, which estimated the travel time and speed of each highway/arterial link from the contemporary land use pattern and validated the estimations by comparing them with the actual average daily traffic counts across a set of screen lines.[5] For each employment center, the congestion level of its peak-density tract is used to represent the regional congestion experienced by the employment center. The distance boundary is set as 12 miles, which is the average commuting trip length according to the 2001 National Household Travel Survey (NHTS). This distance threshold is chosen because journey-to-work trips take up a much larger proportion of the total number of personal trips than work-related trips do, which implies metro-wide congestion costs imposed on firms are more likely to be through workers' commuting time delays that yield higher wages and labor costs.[6]

Similar to the regional congestion measure, within-center congestion is also measured by the "delay rate" that captures to what extent within-center trips are delayed:

(8) $$Delay\ Rate_{inner\ i} = \frac{1}{m}\sum_{a,b}\left[\frac{T_{a,b}\ at\ AM\ Peak - T_{a,b}\ at\ Night\ Period}{Dist_{a,b}}\right], a, b \in \{Center\ i\}$$

where a and b represent component tracts of employment center i, $T_{a,b}$ is the network travel time between a and b for different periods, and m is the total number of routes within centers.[7] This measure proxies for the efficiency of within-center trips most likely to be associated with face-to-face contacts between firms, such as short-distance trips for business meetings, conferences, or consulting services. The local and regional congestion variables show a weak correlation of 0.39, indicating that the two variables measure congestion costs at different spatial scales.

Access to the labor force, customers, and suppliers are also important theoretical inputs for firm location choice. Here accessibility variables are included to describe the potential of the markets and are hypothesized to increase the probability of a location being chosen. The cumulative opportunity form is used to measure access to potential workers and other related businesses:

(9) $$LFAcc_i = \sum_j Labor_j,\ where\ Dist_{ij} < Dist_{boundary}$$

(10) $$BizAcc_{i,m} = \sum_j Emp_{j,m},\ where\ Dist_{ij} < Dist_{boundary}$$

where the labor force ($Labor_j$) is proxied by the whole working-age (18–65) population and the total employment in the same industry m ($Emp_{j,m}$) is used as objective opportunities for business access. The data on the population and households at the census-tract level come from the 2000 U.S. Census of the Population. This form of accessibility measure considers all opportunities available within certain thresholds as equally important (Handy and Niemeier, 1997). This measure is used instead of the gravity-based accessibility measure (Hansen 1959) because spatial-decay effects are captured by congestion variables. Consistent with congestion measures, the 12-mile distance threshold is used for both of the two measures. Similarly, the accessibility levels of the peak-density tract for each employment center are used to proxy for the center's accessibility.

Besides the accessibility advantages, firms are hypothesized to favor those centers showing large urbanization benefits, which is proxied by employment size ($EmpSize$) and the total employment density of each center ($EmpDen$). However, high employment density would also proxy for high land rent or high competition among firms that might drive away new firms (Giuliano et al., 2011). Thus, the sign of the density variable is an empirical question: a positive sign may indicate the existence of density-related agglomeration benefits, while a negative sign may suggest high land costs or intense competition among firms. In addition to urbanization effects, centers concentrated with economic activities in a specific sector are hypothesized to attract new firms in the same sector. This localization effects is measured by the percentage of each center's employment in the same industrial sector ($InduShare$).

Two measures of access to regional transportation infrastructure are also included in the model. First, straight-line distance to the nearest highway ramp ($DistHwy$) is included to test if highways provide additional benefits besides facilitating market access for firms (Holl, 2004). Second, straight-line distance to the airport is also controlled to represent the proximity to inter-regional transport facilities, which have been proven to play significant roles in determining employment location in previous studies (Button et al. 1995; Cieślik, 2005a, 2005b; Egeln, Gottschalk, and Rammer, 2004).

Land use characteristics of each center are measured by the percentage of a center's land that has been developed into related land use types (Per_LU). This variable could either imply the amount of available rental space for a particular use or a constraint on future development for the same use type (Erickson and Wasylenko, 1980). Thus, the sign of this variable is expected to be either positive or negative. The data source is SCAG's region-wide land use (LU) dataset for the survey year of 2001. Land use is categorized into three broad types—industrial and transportation use, office use and commercial use—which are assigned to production-related activities (e.g., manufacturing, wholesale trade), office-related activities (e.g., information, finance and insurance, and professional services) and retail activities, respectively.

Finally, the quality of the local labor force is represented by the percentage of the population over 25 with at least a bachelor's degree for each center (Per_baplus). This variable reflects the availability of local human capital and wage level.[8] As summarized by

Arauzo-Carod, Liviano-Solis, and Manjón-Antolín (2010), firms may tend to choose those locations with workers potentially having higher human capital, or they may avoid these locations because of higher wage levels. Since high human capital individuals are more attracted to neighborhoods with good public services such as good schools and safe streets, this variable is also a proxy for the local amenity effects (Glaeser, Kolko, and Saiz, 2001). Moreover, in neighborhoods with larger share of highly educated population, residential land prices are also likely to be higher, which may increase general land costs and reduce the likelihood that a firm chooses a particular center. Thus, the influences of this factor are expected to be either positive or negative, depending on the industrial sectors studied.

5. EMPIRICAL RESULTS

This paper aims to examine the impacts of congestion delays on the location choices of firms in different industrial sectors. Both of the two ways to construct the hypothesized nesting structures (see discussions in section 3) are exercised. First, to test for the possible spatial correlation among the error terms, employment centers are grouped based on their geographic locations so that each center within a nest is within a certain distance threshold of at least one other center within the same nest. The 5th percentile value (6.14 miles) and 10th percentile value (8.37 miles) of distances between pairs of centers are used as distance thresholds, which yield 11 and 8 clusters of employment centers, respectively. However, the maximum likelihood estimation results of the two nesting specifications indicate that the estimated inclusive value parameters are either insignificantly different from 1 or greater than 1, implying that nesting structures based on the geographic proximity of centers is inappropriate here (results not shown).[9]

The second nesting strategy categorizes employment centers based on their employment size. Different size cutoffs, including 20,000, 50,000, 100,000, 200,000, and 500,000, are used and their different combinations generate various nesting patterns with different number of nests. After experimenting with different nesting patterns, the final chosen pattern categorizes all employment centers into three groups based on employment size ranges:{(less than 50,000), (50,000-200,000), (greater than 200,000)}. Figure 4 describes the chosen nesting specification. Table 5 shows the results of the nested logit model with the chosen nesting structure for each industrial sector. Consistent with utility maximization, all the dissimilarity parameters fall between 0 and 1. The likelihood ratio (LR) tests in Table 5 also lead to a strong rejection of the IIA assumption among all the choices. Compared with the results of the conditional logit model (see Table 6 in the appendix), the nested logit models yield higher likelihood values and the coefficients for all variables in Table 5 are much smaller in magnitude. Thus, violating IIA may lead a conditional logit model to produce biased estimates and exaggerate the effects of locational factors.

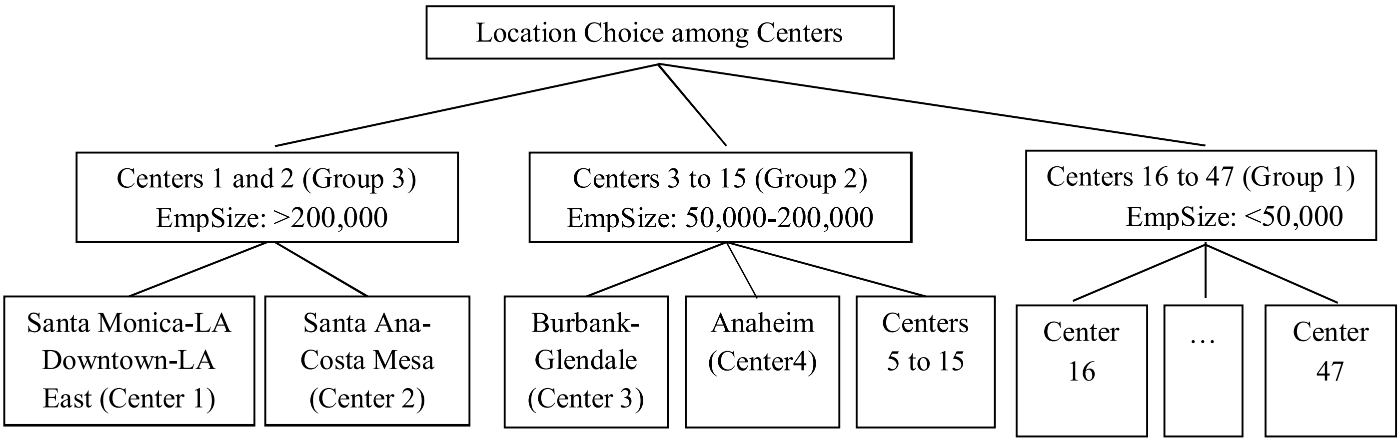

FIGURE 4: Nesting structure for firm location choices among centers.

Recall that the dissimilarity parameter also measures the correlation of the error term among the employment centers. The Wald tests show that the coefficients τ_1, τ_2 and τ_3 are all significantly different from 1, signifying that some unobserved factors associated with the scale of agglomeration are not captured by the employment size variable. Although the estimated inclusive value parameters vary across the results for different industrial sectors, there is a general trend that the parameters are smaller in Group 1 and Group 2 than in Group 3. This means that the degree of similarity is higher among alternative centers in the small-size group (less than 50,000 jobs) and in the medium size group (50,000-200,000 jobs) than in the large size group (more than 200,000 jobs).

TABLE 5: Estimation results of the nested logit model for firm location choices, 2001-2005

	Legal Serv.	Securities	Motion Pict.	Advertising	Merchant Wholesaler	Telecomm.	Managem.	Clothing Stores
Center-Specific Variables								
EmpSize	0.0117***	0.0109***	0.0213***	0.0125***	0.0156***	0.0109***	0.00791***	0.0164***
	(27.67)	(29.97)	(46.89)	(18.56)	(32.35)	(16.19)	(14.78)	(42.23)
EmpDen	7.3E-04***	1.08E-04	-9.84E-04	3.23E-04	-6.19E-04**	-4.49E-04	2.44E-05	-2.14E-04
	(7.07)	(1.02)	(-1.83)	(1.83)	(-2.73)	(-1.94)	(0.31)	(-1.14)
InduShare	4.63E-04***	0.00122***	0.00182***	5.54E-04***	0.00271***	2.19E-04	2.47E-04***	5.6E-04***
	(5.63)	(5.92)	(4.01)	(3.39)	(8.57)	(1.11)	(3.74)	(4.58)
BizAcc_NAICS2	2.56E-04**	4.62E-04***	0.0062***	1.49E-04	1.71E-04	3.36E-04*	2.79E-04***	9.29E-04***
	(2.94)	(4.41)	(9.33)	(0.88)	(0.71)	(2.05)	(3.39)	(3.53)
DelayRate	-4.85E-04***	-1.05E-04	-0.00196***	-4.31E-04**	0.00158***	1.13E-04	-2.86E-04***	-1.08E-05
	(-5.30)	(-1.09)	(-3.97)	(-2.58)	(5.22)	(0.80)	(-3.81)	(-0.05)
DelayRate_inner	7.57E-04***	3.65E-04**	4.92E-04	5.52E-04*	-5.06E-04*	-4.28E-05	9.212E-05	-3.62E-04**
	(5.89)	(2.90)	(1.09)	(2.15)	(-2.54)	(-0.27)	(1.02)	(-3.07)
DistHwy	-5.21E-04***	-4.1E-04***	1.31E-04	-1.79E-04	4.34E-04**	-1.10E-04	-2.81E-04***	-2.22E-04
	(-7.69)	(-5.04)	(0.35)	(-1.35)	(2.59)	(-0.96)	(-4.84)	(-1.76)
DistAP	3.67E-05	1.07E-04	0.00223***	-1.02E-04	0.00148***	1.09E-04	6.69E-05	0.00112***
	(0.51)	(1.35)	(5.13)	(-0.72)	(7.81)	(0.96)	(1.18)	(5.82)
Per_LU	6.82E-05	-4.28E-04***	-0.00175**	-5.48E-04**	-5.54E-04**	-1.71E-04	-1.06E-04	4.46E-04*
	(1.03)	(-4.10)	(-3.11)	(-3.22)	(-2.73)	(-1.05)	(-1.71)	(2.37)
Per_baplus	1.98E-04**	4.63E-04***	0.0043***	6.09E-04***	-7.95E-04***	6.08E-04***	2.89E-04***	6.856E-05
	(2.79)	(4.67)	(7.58)	(3.84)	(-3.29)	(4.28)	(4.44)	(0.57)
Dissimilarity Parameters								
τ_1	0.0236***	0.0279***	0.0835***	0.0236***	0.0643***	0.0224***	0.0138***	0.0403***
(Centers 16 to 47)	(5.17)	(8.44)	(9.93)	(5.17)	(9.31)	(5.49)	(6.38)	(6.71)
τ_2	0.107***	0.129***	0.127***	0.107***	0.118***	0.0945***	0.0778***	0.112***
(Centers 3 to 15)	(6.44)	(11.89)	(11.68)	(6.44)	(8.94)	(5.15)	(5.64)	(14.43)

τ_3 (Centers 1 and 2)	0.604*** (14.47)	0.721*** (25.21)	0.437*** (22.47)	0.604*** (14.47)	0.439*** (25.12)	0.522*** (13.45)	0.591*** (14.03)	0.369*** (29.10)
N	163372	328483	221417	71816	269545	77221	104199	285995
N_chooser	3476	6989	4711	1528	5735	1643	2217	6085
Log-Likelihood	-8116.7	-13966	-6791.4	-3658.5	-12781	-4151.4	-5959.7	-12918.6
Likelihood ratio statistic ($\chi^2(10)$)	770.7	921.4	2522.8	348.2	1419.4	268.3	219.4	1958.4
Likelihood ratio statistic ($\chi^2(3)$)	481.4	524.3	337.6	159.9	544.9	254.9	293.5	420.3
Wald Test: τ_k=1								
Group 1, $\chi_1^2(1)$	3.60E+05	86471.7	11888.4	45711.9	18370.6	57233.2	2.10E+05	25563.9
Group 2, $\chi_2^2(1)$	12185.8	6428.9	6492.1	2909.1	4485.7	2436.3	4460.2	13089.8
Group 3, $\chi_3^2(1)$	91.0	95.0	837.2	90.0	1026.7	151.2	94.3	2474.8

t statistics in parentheses; * p<0.05, ** p<0.01, *** p<0.001
Standardized coefficients are reported for all the explanatory variables

We now discuss the estimated coefficients of the nested logit models, starting with the congestion effects. Table 5 suggests that congestion delays at the regional scale have negative and significant influence on centers' attraction for new firms in most sectors. This is consistent with existing empirical evidence that congestion delays increase firms' costs indirectly by increasing workers' commuting costs and/or costs for other business-related trips. However, it is found that firms in different sectors respond differently to regional congestion delays. To further indicate the magnitude of regional congestion effects, the average marginal effects of regional congestion delays are computed based on the results in Table 5. That is, the effect of a one unit change in the congestion variable associated with a specific employment center on the probability that a firm chooses that center or an alternative center from the choice set. The estimated average marginal effects of regional congestion at Center 1 and Center 2 on the choice probabilities for the two centers are shown in Figure 5.

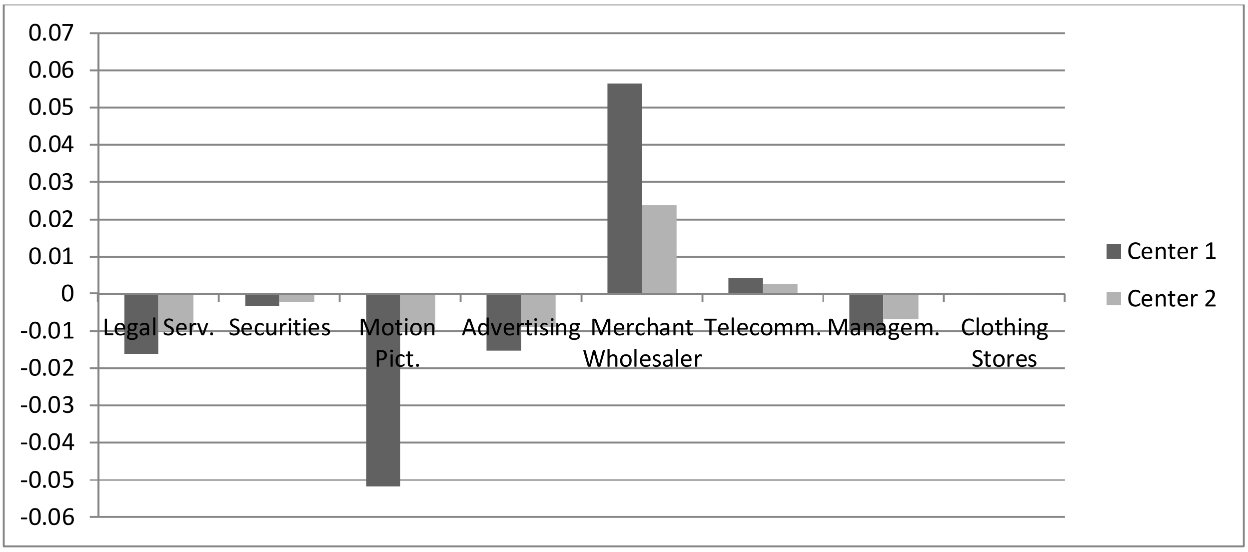

FIGURE 5: (Own-center) average marginal effects of change in regional congestion in Centers 1 and 2.

Figure 5 illustrates that firms in high-order office activities are in general more sensitive to regional congestion delays in their location choices. Among those sectors, the locations of motion picture firms are mostly affected that one standard deviation increase in the regional congestion delays (= 0.12 minutes per mile) for Center 1 and Center 2 is predicted to decrease the choice probability for Center 1 by 0.052 and Center 2 by 0.01. Legal service firms and advertising firms rank second and third, respectively, in terms of their responsiveness to regional congestion delays. Firms in the management sector, though belonging to the "low-concentration" group, are also significantly affected by regional congestion delays. Other office-related firms and the clothing stores seem to be less affected by regional congestion delays and the coefficient for the variable are not statistically different from zero (see Table 5). Since journey-to-work trips take a large share of the total number of personal trips and might be most relevant to the metro-wide congestion effects on firms, this result implies that regional access costs for labor-force are less important for firms in these sectors.

Another interesting finding is that regional congestion delays have positive and significant effect on the location choices of firms in the non-durable goods wholesale trade sector. For example, one standard deviation increase in congestion delays increase the choice probability associated with Center 1 by 0.056 and Center 2 by 0.024. The positive association between regional congestion delays and centers' attraction to new wholesalers may correspond to the corridor of I-5 Freeway starting from downtown LA to the intersection of I-5 and S-91 Freeway (see Figure 6 in the appendix), which has a higher level of congestion, but also accommodates centers with high concentration of wholesale trade activities. This result to some extent reflects a reversed causality story that a higher concentration of wholesale trade firms at those locations contributes to the higher levels of congestion there.

The coefficients for measures of congestion delays within centers ($Delayrate\_inner$) are also of great interest here. Similarly, we find differential effects of local congestion delays on the location choices of firms in different sectors. To illustrate this, the average marginal changes in the choice probability for Center 1 and Center 2 with respect to one standard deviation change in local congestion delays within the two centers are also computed, using the results in Table 5.

Figure 7 indicates that local congestion delays seem to have positive and significant effect on location choices of firms in high-order office-related activities. For example, one standard deviation increase in local congestion delays (= 0.15 minutes per mile) within Center 1 increase legal service firms' choice probability for the center by 0.02, advertising firms' choice probability by 0.015 and motion picture firms' choice probability by 0.01, all else being equal. This result implies that local congestion levels might proxy for some unobserved locational advantages associated with employment centers, such as the intensity and frequency of economic interactions among businesses that are attractive to those firms relying on face-to-face interactions with suppliers and customers. Figure 7 also shows that the other two office-sectors benefiting less from agglomeration economies are also less affected by local congestion delays and the estimated coefficients for the variable are not significant at 5 percent level of significance for the two sectors (see Table 5). Firms in the non-durable goods wholesale trade sector and the clothing store sector are significantly negatively affected by congestion delays within centers, as expected.

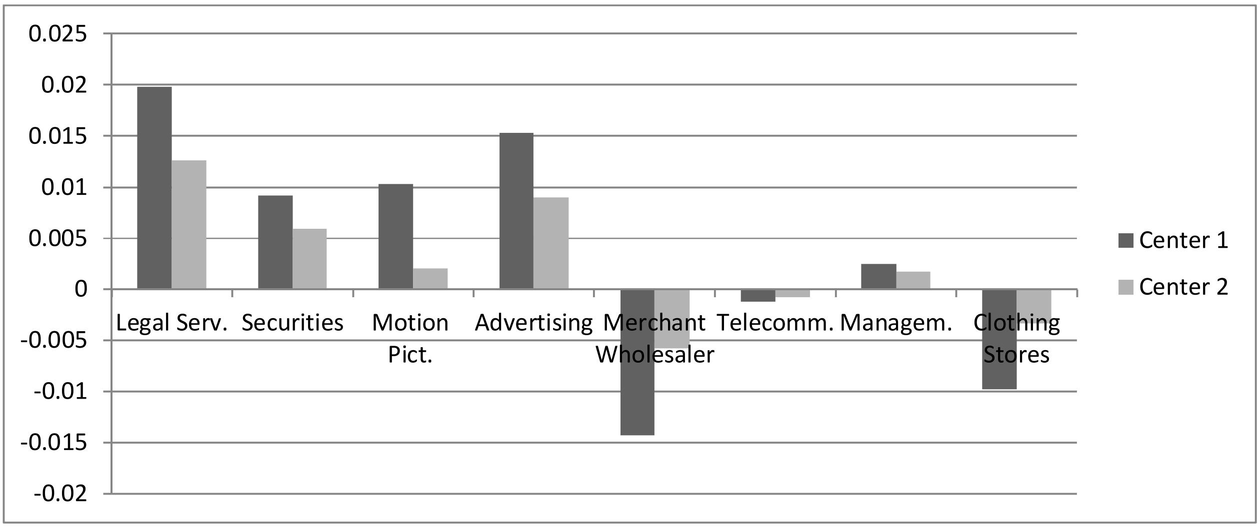

FIGURE 7: (Own-center) average marginal effects of change in local congestion in Centers 1 and 2.

The second group of variables measure the cumulative sum of workers or employment in the same NAICS2 sectors accessible within 12-mile distance on the road network. Since the two types of accessibility variables are highly correlated with each other, the logit models are estimate using the two groups of variables separately. The results in Table 5 suggest that the effects of access to other related businesses are positive and significant for most of sectors. Firms in the motion pictures sector are most sensitive to access to other business. The wholesale trade sector and the advertising sector are the only two sectors do not exhibit any preference to locate in centers with better metro-wide business accessibility. The regressions using labor force accessibility variables yields similar results and the estimated coefficients for all other variables do not change very much in terms of magnitude and significance. Thus these results are not reported here.

The employment size of centers is positively and significantly associated with location choices of all firms. Observed from the standardized estimated coefficients, the size variable shows the strongest effect among all the center-specific factors on the location choices of firms. However, the employment density of centers only has a positive and significant association with the location of legal service firms. The association is negatively significant for non-durable goods wholesalers and is not significant for other firms. The results imply that all being equal, the negative effects of employment density, such as those associated with high land costs and intense competition between firms offset the positive effects of density associated with local agglomeration benefits in the location choices of firms in most sectors.

Localization economies, measured by $InduShare$, have positive and significance influence on the location of all firms except those in the telecommunication sector. Interestingly, the telecommunication sector do have positive and significant estimated coefficients for the $BizAcc$ variable, implying that telecommunication firms value access to other related businesses at the metro-wide scale rather than at the local scale (i.e. within the same center).

Transport-access effects are measured by distance to a highway intersection and distance to the nearest airport. The estimated coefficients for $DistHwy$ suggest that the probability of a center being chosen by firms in legal services, securities, and management sectors decreases with increasing distance from the nearest highway ramp, while firms in the non-durable goods wholesale trade tend to locate away from centers closer to highways. Firms in other sectors exhibit no preference for centers with better highway access. Positive and significant coefficients for the $DistAP$ variable are found in the regression results of motion pictures, wholesaler, and clothing store sectors. These results suggest that disamenities effects associated with access to inter-regional transportation facilities dominate the location choices of firms in the three sectors.

In terms of land use characteristics, the results suggests that centers with large share of office use tend to drive away firm in securities, motion pictures, and adverting sectors. For other office-related activities, the proportion of developed office land within centers is not relevant. New non-durable goods–wholesalers tend to avoid those centers having a large percentage of land area developed into industrial uses. This result implies that industrial land use in general may not fit the needs of specific production-related activities and may even constrain further development of industrial activities. However, positive and significant association are found between center's share of commercial land use and the location of new clothing stores, implying that commercial land use may provide inviting business environments for this sector.

Finally, results related to the labor-quality variable (Per_baplus) suggest that firms in all the office-related activities favor centers with a larger percentage of highly educated worker residents. However, as a production-related industry, the wholesale trade sector seems to avoid those centers with high labor quality due to the possible high wage rates or land rents. The location choices of clothing stores among employment centers are not significantly affected by local human capital levels.

6. CONCLUSION

This study examines whether or not congestion-induced travel-time delays influence the intra-metropolitan firm location decisions, using a nested logit model of firms' choices among the employment centers. The model accounts for regional congestion delays, local congestion levels and other center-specific factors, as well as the difference between large centers and small centers. The results of the model appear to support our hypotheses that congestion delays matter for firm location choices and firms of different industrial sectors respond differently to congestion delays, depending on how they value agglomeration economies at the regional scale and the local scale. Firms specialized in most of high-order office activities are sensitive to metro-wide congestion delays, which are likely to increase these firms' operation costs by increasing access costs to labor force at the regional scale. However, these sectors may also have high requirements for face-to-face interactions with other business so that their choice probabilities for centers increase with congestion levels within centers. Firms in other office-related activities are not responsive to congestion delays at the local scale. Firms specialized in the wholesale trade sector are attracted to those centers having long travel delays to other destinations within the region, but show strong aversion to those centers with high levels of local congestion delays. The clothing store firms are not sensitive regional congestion delays, but also tend to avoid those centers having high local congestion levels.

These results could be useful for urban policy makers finding ways to influence the location pattern of different activities and enhance the strength of existing agglomerations. For example, within a metropolitan area, high levels of congestion at the local scale may drive away firms in production-related sectors and retail sectors, while long commuting delays that many employment centers have for office workers may drive away firms in high-order service activities. This study thus supports public efforts to mitigate congestion delays at both the regional scale and local scale to influence the future development pattern of different activities.

In summary, this study contributes to the literature on agglomeration economies and on intra-metropolitan location choices by directly examining the tradeoff between congestion costs and agglomeration economies at the intrametropolitan scale. By looking at the location choices of new establishments and defining employment centers as the choice set, the case study of Los Angeles suggested a way to distinguish the congestion effects from the agglomeration benefits at the regional scale and the local scale. The nested logit model provides a useful tool to model the intrametropolitan firm location in a polycentric region like Los Angeles where the size and function of centers follow a hierarchical structure. The usefulness of the nested logit model in accounting for the heterogeneity and correlation between alternative locations and avoiding biased estimates for the Los Angeles region implies that a similar modeling framework may also be applied for analysis of intra-urban firm location in other metropolitan areas.

Given that there exist remarkable differences in the degree of polycentricity among metropolitan areas (Lee 2007), whether the model results of the Los Angeles region can be generalized to other urban regions will be an interesting question. Although polycentric employment structure is not a unique feature of the Los Angeles region (Lee, 2007), the uniqueness of Los Angeles is the existence of a number of employment centers with different "packages" of characteristics from which firm can choose. It is plausible to expect that in other metropolitan areas where the agglomeration in the CBD is more dominant among the centers, firms will have relatively fewer options in their location choices, so that congestion costs may play a less significant role in intrametropolitan firm location decisions.

Moreover, as predicted by theory, internal spatial structure of urban areas will be reshaped to adjust to traffic congestion in the long run (Richardson, 1988). Thus, another interesting question is to explore the causal link between congestion costs and the spatial dynamics of urban areas. Previous empirical studies suggest that metropolitan spatial structure is "path dependent" and largely affected by the geographic and historical context as well as the industrial structure of metropolitan areas (Lee, 2007), implying a small role of congestion costs might be playing in the formation, growth and changes of employment centers within an urban area. However, given that changes in metropolitan spatial structure result from the accumulated locational responses of firms and households, the causal impacts of congestion-agglomeration tradeoffs may be further explored by, for example, tracking the spatial mobility behavior or the growth and productivity of individual establishments over time, which might provide different insights about the importance of congestion costs in urban form than the results from a cross-sectional model in this study.

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Appendix

TABLE 3: Spatial Concentration pattern of different industries (2001-2005)

NAICS Code	Industry Title	Center			Non-center location		
		Est	Emp	LQ	Est	Emp	LQ
	Utilities (NAICS2=22)						
221	Utilities	80	1,699	0.81	218	2,306	1.09
	Construction (NAICS2==23)						
236	Construction of Buildings	958	7,564	0.68	3,303	18,464	1.16
237	Heavy and Civil Engineering Construction	1,562	5,563	1.09	2,759	9,707	0.95
238	Specialty Trade Contractors	2,752	13,341	0.67	9,628	37,152	1.16
	Manufacturing (NAICS2=31-33)						
311	Food Manufacturing	497	4,382	0.91	1,160	6,144	1.05
312	Beverage and Tobacco Product Manufacturing	50	395	0.95	109	1,163	1.02
313	Textile Mills	158	2,373	1.82	104	1,218	0.59
314	Textile Product Mills	103	1,098	1.23	149	887	0.88
315	Apparel Manufacturing	860	9,668	1.73	638	3,131	0.64
316	Leather and Allied Product Manufacturing	70	388	1.36	86	1,886	0.82
321	Wood Product Manufacturing	110	671	0.75	335	2,373	1.13
322	Paper Manufacturing	55	1,667	0.98	115	1,838	1.01
323	Printing and Related Support Activities (Printing)	1,132	6,094	1.14	1,863	6,559	0.93
324	Petroleum and Coal Products Manufacturing	26	272	1.06	48	2,410	0.97
325	Chemical Manufacturing	289	4,896	1.26	401	3,697	0.87
326	Plastics and Rubber Products Manufacturing	131	3,960	1.08	234	4,779	0.96
327	Nonmetallic Mineral Product Manufacturing	95	1,379	0.76	281	3,353	1.12
331	Primary Metal Manufacturing	67	1,190	1.19	103	1,134	0.91
332	Fabricated Metal Product Manufacturing	649	6,058	1.06	1,200	7,217	0.97
333	Machinery Manufacturing	380	4,338	1.06	704	4,982	0.97
334	Computer and Electronic Product Manufacturing	671	16,337	1.28	915	23,544	0.86
335	Electrical Equipment, Appliance, and Component Manufacturing	128	1,461	0.95	277	3,710	1.02
336	Transportation Equipment Manufacturing	175	6,114	0.93	391	7,945	1.03

337	Furniture and Related Product Manufacturing	263	2,440	0.95	573	3,320	1.02
339	Miscellaneous Manufacturing	788	6,174	0.99	1,609	9,224	1.00
	Wholesale Trade (NAICS2=42)						
423	Merchant Wholesalers, Durable Goods	5,963	32,464	1.08	10,751	47,686	0.96
424	Merchant Wholesalers, Nondurable Goods (Merchant Wholesalers)	5,735	25,323	1.33	7,306	28,225	0.84
	Retail Trade (NAICS2=44-45)						
441	Motor Vehicle and Parts Dealers	1,450	6,622	0.68	4,957	23,512	1.16
442	Furniture and Home Furnishings Stores	1,459	5,177	0.89	3,470	11,209	1.05
443	Electronics and Appliance Stores	1,562	6,455	0.99	3,225	11,940	1.01
444	Building Material and Garden Equipment and Supplies Dealers	769	4,472	0.87	1,892	10,762	1.06
445	Food and Beverage Stores	2,154	9,140	0.76	6,390	31,267	1.12
446	Health and Personal Care Stores	1,438	5,906	0.93	3,224	15,419	1.03
447	Gasoline Stations	319	1,339	0.55	1,438	6,569	1.22
448	Clothing and Clothing Accessories Stores (Clothing Stores)	6,085	20,340	1.24	8,701	28,689	0.88
451	Sporting Goods, Hobby, Book, and Music Stores	1,723	6,960	0.97	3,647	12,885	1.02
452	General Merchandise Stores	261	1,941	0.64	965	14,222	1.18
453	Miscellaneous Store Retailers	2,896	9,180	0.82	7,736	23,550	1.09
454	Nonstore Retailers	242	2,498	0.85	618	4,206	1.07
	Transportation and Warehousing (NAICS2=48-49)						
481	Air Transportation	43	357	1.24	62	769	0.88
482	Rail Transportation	13	235	1.03	25	118	0.98
483	Water Transportation	17	249	1.09	30	372	0.95
484	Truck Transportation	610	3,331	0.70	2,030	10,021	1.15
485	Transit and Ground Passenger Transportation	320	3,100	0.91	739	5,071	1.04
486	Pipeline Transportation	5	342	0.94	11	292	1.03
487	Scenic and Sightseeing Transportation	7	143	0.81	19	59	1.09
488	Support Activities for Transportation	1,514	8,296	0.95	3,293	13,825	1.02
491	Postal Service	17	961	0.52	81	6,512	1.24
492	Couriers and Messengers	209	7,992	0.98	437	7,229	1.01
493	Warehousing and Storage	301	4,450	1.22	444	5,653	0.89
	Information (NAICS2=51)						
511	Publishing Industries (except Internet) (Publishing)	1,059	7,900	1.31	1,385	6,156	0.85
512	Motion Picture and Sound Recording Industries (Motion pict.)	4,711	27,588	1.63	3,998	12,419	0.69
515	Broadcasting (except Internet)	190	6,298	1.32	245	3,736	0.84

517	Telecommunications (Telecommnic.)	1,643	12,059	1.12	2,783	12,171	0.94
518	Internet Service Providers, Web Search Portals, and Data Processing Services	540	5,898	1.23	787	6,806	0.89
519	Other Information Services	126	426	1.15	204	1,198	0.92
	Finance and Insurance (NAICS2=52)						
522	Credit Intermediation and Related Activities	3,743	26,082	1.06	6,960	40,780	0.97
523	Securities, Commodity Contracts, and Other Financial Investments and Related Activities (Securities)	6,989	19,566	1.27	9,659	23,963	0.87
524	Insurance Carriers and Related Activities	2,393	10,996	0.98	4,980	18,387	1.01
525	Funds, Trusts, and Other Financial Vehicles	294	2,447	1.10	511	1,991	0.95
	Real Estate and Rental and Leasing (NAICS2=53)						
531	Real Estate	8,256	26,592	1.09	14,719	47,789	0.96
532	Rental and Leasing Services	1,242	4,956	0.88	3,029	9,692	1.06
533	Lessors of Nonfinancial Intangible Assets (except Copyrighted Works)	46	869	1.62	40	221	0.70
	Professional, Scientific, and Technical Services (NAICS2=54)						
5411	Legal Services	3,476	14,828	1.70	2,705	13,002	0.65
5412	Accounting, Tax Preparation, Bookkeeping, and Payroll Services (Accounting)	1,551	8,019	1.18	2,416	9,390	0.91
5413	Architectural, Engineering, and Related Services	1,228	12,311	1.09	2,168	11,584	0.95
5414	Specialized Design Services	698	3,003	1.14	1,148	5,581	0.93
5415	Computer Systems Design and Related Services (Computer Syst. Design)	1,323	11,002	1.15	2,146	12,013	0.92
5416	Management, Scientific, and Technical Consulting Services (Managem.)	2,217	18,702	1.11	3,793	22,819	0.94
5417	Scientific Research and Development Services	472	3,221	1.18	732	6,035	0.91
5418	Advertising and Related Services (Advertising)	1,528	8,159	1.38	1,813	7,139	0.81
5419	Other Professional, Scientific, and Technical Services	492	4,564	1.09	869	5,776	0.95
	Management of Companies and Enterprises (NAICS2=55)						
551	Management of Companies and Enterprises	1,268	3,126	1.55	1,201	4,173	0.73
	Administrative and Support and Waste Management and Remediation Services (NAICS2=56)						
561	Administrative and Support Services	9,634	48,463	0.83	25,429	104,083	1.08
562	Waste Management and Remediation Services	202	1,426	0.77	586	3,043	1.11

Educational Services (NAICS2=61)							
611	Educational Services	948	11,808	0.82	2,528	42,666	1.09
Health Care and Social Assistance (NAICS2=62)							
621	Ambulatory Health Care Services	10,128	47,666	1.01	20,160	86,664	1.00
622	Hospitals	177	4,934	1.23	259	5,184	0.89
623	Nursing and Residential Care Facilities	163	3,797	0.51	802	13,683	1.24
624	Social Assistance	1,740	9,869	0.74	5,373	27,533	1.13
Arts, Entertainment, and Recreation (NAICS2=71)							
711	Performing Arts, Spectator Sports, and Related Industries	1,612	9,332	1.28	2,183	11,060	0.86
712	Museums, Historical Sites, and Similar Institutions	120	440	0.94	264	723	1.03
713	Amusement, Gambling, and Recreation Industries	1,081	5,539	0.89	2,588	14,701	1.05
Accommodation and Food Services (NAICS2=72)							
721	Accommodation	360	9,866	0.94	791	12,672	1.03
722	Food Services and Drinking Places	2,844	33,248	0.82	7,612	84,055	1.09
Other Services (except Public Administration) (NAICS2=72)							
811	Repair and Maintenance	2,754	12,211	0.67	9,625	28,695	1.16
812	Personal and Laundry Services	3,331	11,903	0.74	10,280	30,215	1.13
813	Religious, Grantmaking, Civic, Professional, and Similar Organizations	3,617	12,604	0.80	10,053	39,019	1.10
Public Administration (NAICS2=92)							
921	Executive, Legislative, and Other General Government Support	120	7,804	1.14	198	9,483	0.93
922	Justice, Public Order, and Safety Activities	117	11,081	0.71	382	20,175	1.14
923	Administration of Human Resource Programs	79	3,320	1.06	147	9,306	0.97
924	Administration of Environmental Quality Programs	22	1,410	0.57	94	4,630	1.21
925	Administration of Housing Programs, Urban Planning, and Community Development	32	2,743	0.85	82	1,827	1.08
926	Administration of Economic Programs	50	5,360	0.96	108	2,341	1.02
927	Space Research and Technology	8	89	1.34	10	35	0.83
928	National Security and International Affairs	49	512	0.85	126	4,015	1.08

TABLE 4: Summary statistics of explanatory variables

	Variable	Description	Expected Sign	Mean	Std. Dev.	Min	Max
Urbanization Effects	EmpSize	Total employment of each center (,000 jobs)	(+)	74.29	173.557	11.407	1150.264
	EmpDen	Total employment per land area (jobs per acre) for each center	(+/-)	19.53	9.22	10.86	59.18
Localization Effects	InduShare42	Percent of center employment in the wholesale trade sectors (NAICS2=42)	(+)	7.61	5.97	0.1	22.26
	InduShare51	Percent of center employment in the information sectors (NAICS2=51)		5.62	9.17	0.07	60.6
	Indushare52	Percent of center employment in the finance and insurance sectors (NAICS2=52)		5.38	5.24	0.46	25.32
	InduShare54	Percent of center employment in the professional services sectors (NAICS2=54)		8.59	6.03	0.78	26.31
Traffic Congestion	DelayRate	Average of travel time delays (in minutes) per mile for all possible trips within 12 miles of each center's peak tract	(-)	0.47	0.12	0.16	0.68
	Delay Rate_inner	Average of travel time delays (in minutes) per mile for all possible trips within each center	(-)	0.30	0.16	0	0.69
Accessibility (within 12 miles)	BizAcc42	Cumulative sum of employees in the wholesale trade sector (NAICS2=42) (,000 jobs)	(+)	81.258	35.569	15.5	178.708
	BizAcc51	Cumulative sum of employees in the information sector (NAICS2=51) (,000 jobs)	(+)	52.776	47.716	6.775	179.372
	BizAcc52	Cumulative sum of employees in the finance and insurance sector (NAICS2=52) (,000 jobs)	(+)	56.040	28.011	10.007	117.335
	BizAcc54	Cumulative sum of employees in the professional service sector (NAICS2=54) (,000 jobs)	(+)	94.581	53.057	15.263	228.472
	LFAcc	Cumulative sum of potential workers (,000 workers)	(+)	1250.8	482.904	287.738	2396.28
Transport Access	DistHwy	Distance to the nearest highway ramp (miles)	(+/-)	0.51	0.38	0.003	1.62
	DistAP	Distance to the nearest commercial airport (miles)	(-)	8.56	5.08	0.44	19.4

Land Use	Per_indutrans	Percent of center area developed into industrial or transportation use	(+/-)	26.16	20.14	0.13	67.35
	Per_office	Percent of center area developed into office use	(+/-)	4.66	4.38	0	25.25
	Per_comm	Percent of center area developed into commercial use	(+/-)	14.27	7.36	3.08	43.48
Labor Quality	Per_baplus	Percent of center population over 25 and with at least bachelor's degree	(+/-)	17.93	11.33	0	51.65

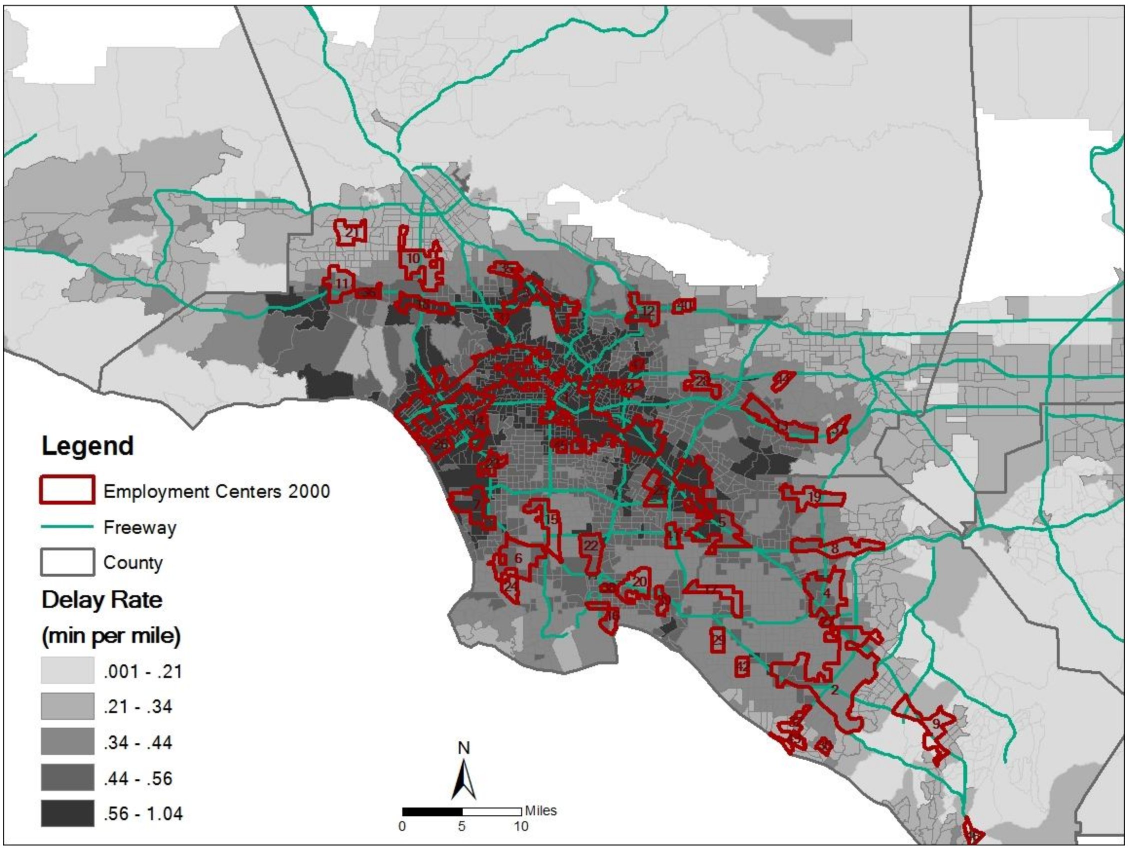

FIGURE 6: Spatial pattern of congestion delays (measured by Delay Rate, 12-mile boundary used).

TABLE 6: Estimation results of the conditional logit model for firm location choices, 2001-2005

	Legal Serv.	Securities	Motion Pict.	Advertising	Merchant Wholesaler	Telecomm.	Managem.	Clothing Stores
EmpSize	2.404***	3.123***	2.261***	3.081***	4.250***	3.717***	2.782***	4.102***
	(20.52)	(39.21)	(4.42)	(17.16)	(39.49)	(22.95)	(20.17)	(35.25)
EmpDen	1.701***	-2.623***	0.161	-0.698	-0.269	-2.873***	-1.500***	-1.300***
	(5.91)	(-10.89)	(0.18)	(-1.49)	(-1.17)	(-6.55)	(-4.21)	(-4.41)
InduShare	2.459***	3.638***	1.966**	2.224***	2.989***	2.721***	2.340***	0.108
	(12.30)	(20.46)	(2.70)	(6.66)	(15.40)	(6.17)	(9.69)	(0.54)
BizAcc_NAICS2	0.347	1.674***	2.329***	0.524	-0.311	-0.0232	1.127***	1.192***
	(1.18)	(8.63)	(4.29)	(1.23)	(-1.29)	(-0.06)	(3.50)	(3.81)
DelayRate	-2.292***	-1.663***	-0.480	-2.037***	0.494	-0.562	-1.809***	-0.141
	(-7.40)	(-8.12)	(-0.99)	(-4.73)	-1.8	(-1.45)	(-5.69)	(-0.45)
DelayRate_inner	5.944***	4.670***	1.637**	5.084***	1.074***	3.556***	4.170***	1.351***
	-18.91	(24.72)	(3.15)	(11.60)	(5.19)	(9.69)	(13.00)	(7.17)
DistHwy	-0.918***	-0.222	-0.263	0.220	-0.451**	-0.261	-0.838***	-0.0103
	(-4.68)	(-1.68)	(-0.57)	(0.82)	(-2.64)	(-0.96)	(-3.90)	(-0.06)
DistAP	-2.710***	-2.989***	0.0574	-2.629***	0.0161	-1.935***	-2.187***	0.927***
	(-13.39)	(-20.22)	(0.11)	(-8.63)	(0.11)	(-7.33)	(-9.98)	(5.74)
Per_LU	2.467***	1.850***	-2.479***	1.403***	-0.137	2.505***	2.379***	2.170***
	-11.64	(11.43)	(-3.46)	(4.22)	(-0.66)	(7.48)	(9.57)	(7.86)
Per_baplus	-0.762***	-1.199***	4.329***	-0.112	-1.450***	-0.0583	-0.880***	-0.326
	(-3.41)	(-8.27)	(10.05)	(-0.33)	(-6.08)	(-0.16)	(-3.47)	(-1.75)
N	163372	328483	221417	71816	269545	77221	104199	285995
N_Chooser	3476	6989	4711	1528	5735	1643	2217	6085
pseudo R-sq	0.38	0.34	0.62	0.37	0.41	0.32	0.29	0.44
Log-Likelihood	-8357.4	-17854.1	-6960.2	-3738.5	-13053.4	-4278.9	-6106.4	-13133.8
Likelihood ratio statistic ($\chi^2(10)$)	10051.4	18109.1	22355.7	4289.1	18054.4	4093.8	4858.7	20588.7

t statistics in parentheses; * p<0.05, ** p<0.01, *** p<0.001;
Standardized coefficients are reported for all the explanatory variables.

NOTES

[1] The D-U-N-S number means the "Data Universal Numbering System" established by Dun and Bradstreet (D&B) in, 1963. Source: http://www.dnb.com/content/dam/english/dnb-data-insight/duns_number_overview_2011.pdf

[2] The nested logit model has two disadvantages in solving the spatial correlation problem (Bernasco 2010): (1) the correlation of the error terms within a nest is set to be equal; (2) spatial correlation across nests is ignored. To fully address the spatial correlation issue, a generalized nested logit model (GNL) by Wen and Koppelman (2001) can be used by generating a paired nested structure to account for the correlation between pairs of neighboring alternatives. See detailed discussions in Bhat and Guo (2004).

[3] Some sectors also fit these standards but are not chosen because by comparing the NETS dataset with the County Business Pattern (CBP) dataset, I found that employment shares in these sectors at the NAICS2 level for the entire Los Angeles region are undercounted (e.g. NAICS2 = 55) or over-counted (e.g. NAICS2 = 71) in the NETS dataset by more than 20%.

[4] This restriction is derived from McFadden (1984) that "sample sizes which yield less than thirty responses per alternative produce estimators which cannot be analyzed reliably by asymptotic methods (pp. 1442)".

[5] Source: SCAG, 2003 Model Validation Summary Final Report

[6] The NHTS defines work-related trips as those trips for "attending business meetings" and "other work-related trips." According to the, 2001 NHTS' "Day Trip File for Public Use," the total number of journey-to-work trips (Code = 11) is 47,475, while the total number of trips for "attending Business meetings" (Code = 13) and "other work-related trips" (Code = 14) is 1,316 and 11,692, respectively.

[7] Assuming employment center i has k census tracts, the total number of trips is calculated as $C_k^2 + k = \frac{k(k-1)}{2} + k$, which is the total number of pairs of tracts within i plus the total number of component tracts of the center.

[8] Based on the 2000 U.S. Census data, a high correlation of 0.77 is observed between the mean earnings of individuals and the proportion of highly educated population (*Per_baplus*) at the census tract level. At the center locations, the correlation between the two variables is higher ($\rho^2 = 0.88$).

[9] I also followed Bhat and Guo (2004) and experimented the generalized nested logit model, which applies a "paired nested structure" to account for the spatial correlation between pairs of employment centers that are within a certain distance threshold to each other. The two distance thresholds (6.14 miles and 8.37 miles) yield 41 and 108 nests, respectively. However, the GNL model is computationally burdensome and continually failed to converge.