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Why do warehouses decentralize more in certain metropolitan areas?

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ABSTRACT

Over the last decade, warehousing and distribution centers have decentralized to the urban peripheries where land is cheaper and readily available. This change in location patterns has been driven by the demand to build more modernized and larger facilities to accommodate an ever-increasing influx of freight. Since efficient freight movement is essential for the smooth functioning of metropolitan areas, decentralization should occur everywhere. However, this is not necessarily true. It is hypothesized that depending on the volume of goods movement and the spatial distribution of land prices, the extent of decentralization varies across metropolitan areas. This hypothesis is tested using 48 US metropolitan areas. Results provide robust evidence that high land prices push large warehouses away from central locations. When freight demand and land prices are not as high, the effect becomes insignificant. Indeed, not only is decentralization linked with large metro areas but also with very large warehouses.

1. Introduction

The purpose of this paper is to evaluate at the national level the factors that might explain warehousing decentralization. It is hypothesized that the variance across metro areas in freight activity and land price distribution explains the variance in decentralization. Results of descriptive analysis, hypothesis testing, and econometric models consistently show that warehousing decentralization is a function of freight activity and land prices. To be specific, it is closely linked with very large warehouses in large metro areas.

In recent decades, the logistics industry has prioritized throughput: moving large volumes of products through the supply chain as quickly, cheaply, and reliably as possible. This reorganization has resulted in a geographically-dispersed system of goods production at the global scale. At the sub-metropolitan level, larger and automated warehousing and distribution centers (W&D) have been built on the urban periphery, where land is cheaper and readily available, hence warehousing decentralization. These spatial shifts have been attributed to the rebalance of inventory and transportation costs: the gains from lower land prices, economies of scale, and automation outweigh the increase in transportation costs as warehouses move farther from the market.

Because efficient supply chains are essential for the smooth functioning of metropolitan areas, changes in scale and location of W&D should occur everywhere. However, this is not necessarily true. Recent literature has documented decentralization in Atlanta, Los Angeles, Paris, Tokyo, and Toronto (Dablanc and Ross, 2012; Dablanc et al., 2014; Dablanc and Rakotonarivo, 2010; Sakai et al., 2015; Woudsma et al., 2016). In Seattle, warehouses decreased the distance from their geographic center (Dablanc et al., 2014). Furthermore, according to Giuliano and Kang (2018), a case study of the spatial dynamics of the warehousing industry in four metropolitan areas in California between 2003 and 2013, not all major metro areas have experienced decentralization. In San Francisco, Sacramento, and San Diego, warehouses made marginal location changes. Los Angeles was the only place with significant changes in location. The authors explain that the difference may be attributed to the variance in the characteristics across metro areas, such as metro size, economic structure, and physical geography.

This paper expands the scope of analysis and evaluates at the national level whether the disparity in metro-level characteristics explains the difference in the extent of warehousing decentralization. In that regard, this study contributes to the theoretical understanding and empirical testing of the phenomenon. This paper is organized as follows. Section 2 reviews recent literature on how/why warehouses have changed location. Section 3 presents the research approach, measurements, and data. Section 4 presents results of descriptive and econometric analyses. In Section 5, this paper closes with conclusions and future research suggestions.

2. Literature review

2.1. Why should we care?

Over the last decade, various sources have documented the expansion of freight movement and linked industry sectors in the U.S. From

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2000 to 2011, the increase in foreign trade (U.S. dollars) was significant (40%), relative to the moderate increase in U.S. population (10%), employment (3%), and businesses (4%).[1] During roughly the same period, containerized trade volumes (TEU) increased by 44%, and domestic commodity shipments (U.S. dollars) increased by 29%.[2,3] Moreover, between 2003 and 2013, the warehousing sector in terms the number of establishments and employment increased by 15% and 33%, respectively.[4] These statistics indicate that the volume of goods shipped per capita increased nationally. Factors attributed to this trend are globalized trade, consumer demand shifts, just-in-time production, containerization, as well as advances in information, logistics, and transportation technology, and the restructuring of the logistics industry (Hesse and Rodrigue, 2004; McKinnon, 2009; Cidell, 2011).

Logistics restructuring has led to a spatial shift of warehousing facilities, which, in turn, has influenced the geography of freight movement in urban areas (Hesse, 2007). It has been argued that, if facilities are located farther from the urban center, this change may contribute to increased freight vehicle miles traveled (VMT) and associated negative externalities on society (e.g. GHG and criteria emissions, noise, congestion, increased fuel consumption, infrastructure damage, and environment justice) (Anderson et al., 2005; Andreoli et al., 2013; Crainic et al., 2004; Dablanc, 2013; Dablanc et al., 2014; Dablanc and Rakotonarivo, 2010; Dablanc and Ross, 2012; and USDOT, 2012; Wygonik et al., 2015). Cost savings from relocating may accrue to logistics businesses, while any external costs from increased vehicle miles are incurred by society at large (Hesse, 2006; Rodrigue et al., 2001). Two studies based on facility-level surveys documented that facility decentralization resulted in increased truck VMT (Dablanc and Rakotonarivo, 2010; Sakai et al., 2015). However, there are many operational aspects to consider at the facility level to accurately calculate the freight travel distance (Sakai et al., 2015). Some argue that the gains from operational efficiency might offset the negative externalities when shipment is consolidated through centralized logistics facilities (Kohn and Brodin, 2008). Moreover, new warehousing facilities are more energy-efficient (Dhooma and Baker, 2012). Therefore, the negative effects of decentralization remain uncertain.

There have been only a limited number of empirical evaluations of this impact because shipment data are scarce (Sakai et al., 2015). Rather, many studies have focused on analyzing the distribution of logistics facilities and the changes in W&D distribution over time to draw implications on freight VMT (Allen et al., 2012; Bowen Jr., 2008; Cidell, 2010; Dablanc and Ross, 2012; Dablanc and Rakotonarivo, 2010; Dablanc et al., 2014; Giuliano and Kang, 2018; Heitz and Dablanc, 2015; Sakai et al., 2015; Van den Heuvel et al., 2013; Woudsma et al., 2016). Aljohani and Thompson (2016) provides a thorough review of how W&D distribution has been quantified. Two studies examined national-level factors for W&D decentralization and concentration, such as access to transport infrastructure and a growing demand for high level throughput (Bowen Jr., 2008; Cidell, 2010). Another set of literature, mostly based on stakeholder interviews, investigated location factors logistics operators would consider when they choose a location for a facility (Jakubicek and Woudsma, 2011; Warffemius, 2007). Additionally, some research has evaluated the systematic factors that constitute warehousing rents (Buttimer Jr et al., 1997; Sivitanidou, 1996). Most of the past studies could not draw a definitive answer to the VMT question but rather have suggested several directions to proceed for future studies. Accordingly, understanding how and why the distribution of warehousing facilities has changed may be the first step to evaluate whether decentralization is a problem worthy of policy intervention.

2.2. Logistics restructuring and warehousing decentralization

Until recently, goods were produced and stored well ahead of customer demand and were infrequently shipped in larger volumes. These goods distribution activities happened in areas of a large metropolitan population (McKinnon, 1983). Inventory control was laborious because the process was not fully automated (Bowen Jr., 2008). However, logistics restructuring has changed these processes (McKinnon, 2009).

The primary goal of the restructuring was high throughput – to expand the capacity and velocity of goods transportation (Hesse, 2004; Rodrigue, 2008). Cidell (2011) stated, "Parts and products are not meant to sit on a shelf, but to be in constant motion along the supply chain until the final product reaches store shelves" (pp. 835). That is, the system has been restructured such that producers can transport a large volume of goods frequently and reliably (Bowen Jr., 2008; Cidell, 2011; Rodrigue, 2008; Dablanc and Ross, 2012).

The restructuring has been attributed to several factors. We are living in "a new distribution economy" that is dependent on how efficiently goods are produced and distributed via progressively more globalized systems (Hesse and Rodrigue, 2004, pp. 178; Lavassani et al., 2009; McKinnon, 2009). As customer demand has increased and diversified, producers have also reprioritized from supply-push to demand-pull production systems and compete based on time-saving operations (e.g. Just-In-Time production) (Bowen Jr., 2008; Lasserre, 2004). Moreover, major importers and big-box retailers have changed how warehouses are utilized (e.g. from storage to shipment consolidation and regional distribution) (Bowen Jr., 2008; Christopherson and Belzer, 2009; Dablanc and Ross, 2012). These changes in how/where goods are distributed and sold have largely been driven by the advances in information and logistics management technology and the concomitant rise of electronic commerce (Dablanc et al., 2011; McKinnon, 2009; Bowen Jr., 2008; Lavassani et al., 2009). This restructuring is a complex process that involves the spatial dispersion of the entire system of production and distribution (Hesse and Rodrigue, 2004; Lavassani et al., 2009; Rodrigue, 2008; Cidell, 2011). All of these above factors have contributed to logistics restructuring.

Over the past two to three decades, the logistics industry has expanded its facility capacity near intermodal terminals to maintain high throughput. However, this approach soon reached its limit due to development density, land constraints, and arterial congestion (Hesse, 2006; Cidell, 2010). For example, in many cases, major airports, seaports, and railways are in or near urban cores. To deal with these problems, warehousing and distribution centers have been relocated to the urban periphery – with its vast amounts of cheap land, large parcels, direct access to congestion-free highways, airport, and rail systems, as well as low-skilled and low-wage labor, and a supportive regulatory and business environment for logistics operations (Bowen, 2008; Christopherson and Belzer, 2009; Cidell, 2010; Cidell, 2011; Dablanc and Ross, 2012; Hesse, 2002, 2004, and Hesse, 2007; Hesse and Rodrigue, 2004; McKinnon, 2009; Notteboom and Rodrigue, 2005; Rodrigue, 2006; Slack, 1998). This logic for facility relocation applies to all major segments of the industry: warehousing, trucking, freight forwarding, and air-cargo service (Hesse and Rodrigue, 2004).

The rebalancing of logistics costs between inventory and transport has eased the relocation process (McKinnon, 2009). Most importantly, lower land prices offset the increased transport costs as these facilities locate farther from their market (McKinnon, 2009). Facility automation, feasible when operated on a large scale, further decreased per-unit inventory costs and enhanced maximum productivity (Bowen Jr., 2008). Moreover, owing to decreased transaction and per-ton-mile transport costs, logistics firms could make facility location decisions within a much greater distance range (Glaeser and Kohlhase, 2004; Hall et al., 2006; Rodrigue, 2004). These large, automated warehouses are "directly responsible" for decentralization (Dablanc and Ross, 2012, pp. 433). However, there have been very few empirical studies which focused on the *large* warehouses (Bowen Jr., 2008).

[1] Freight Facts and Figures 2013, USDOT Bureau of Transportation Statistics
[2] Total vessel calls in U.S. port, terminals and lightering areas report 2002–2012, U.S. Maritime Administration
[3] Of 2012 dollars, Commodity Flow Survey, 2002–2012.
[4] Warehouse definition derived from NAICS Sector 493 'warehousing and storage,' Economic statistics from the County Business Patterns 2003–2013.

3. Research approach

3.1. Conceptual framework – rationale behind decentralization

The purpose of this paper is to explore factors associated with warehousing decentralization in major U.S. metro areas. The metropolitan resident and business have a freight demand, which is correlated with the size of a population and industry. This demand is unobservable until producers and retailers fulfill it using logistics services, for which warehousing operators provide storage capacity. Warehouses and the logistics industry as a whole are profit-driven business entities who seek "productivity enhancing location attributes" (Sivitanidou, 1996, pp. 1262). According to the firm location choice literature, the location attributes, in conjunction with the warehouse characteristics (type, size, etc.), constitute the cost structure of selecting a location and influence the location choice (McFadden, 1974; McFadden, 2001).[5]

In this context, the variation across metropolitan areas is examined with a hypothesis that (Allen et al., 2012) the amount of freight activity and (Aljohani and Thompson, 2016) the spatial distribution of land prices jointly influence the extent of warehousing location change. First, freight activity is a function of population size. In very large metro areas, very high freight demand is present. Thus, a large freight volume is destined to/originating from the area. In this case, large-scale operation and facility automation may not be only feasible but also more sensible because it will decrease per-unit inventory costs. If so, considering land price and many other factors, a warehousing operator will build a new facility at an optimal location, therefore expanding a metro area's warehousing supply. As explained in the previous section, the recent trend is that large warehouses are built on the urban periphery where cheap land is readily available. Also, the recent logistics restructuring through the advancement of ICT has facilitated the spatial shifts (Hesse and Rodrigue, 2004; McKinnon, 2009; Cidell, 2011). The addition of these large warehouses over a period will eventually change their spatial patterns. Across metro areas, population size varies significantly. For instance, population decreases exponentially with respect to its size rank (Zipf's law; Gabaix, 1999). If this is the case, the demand for large warehouses would vary widely, hence a large variation in decentralization.

Moreover, freight activity is also correlated with a metro area's trade gateway function. Namely, major trade gateways transport a large volume of freight. Thus, the mechanism of location change is similar to the previous case in which substantial demand for goods movement results in large, automated facilities being built on the outskirts. Globalized supply chains have facilitated this process in a way that more goods are transported at the international scale (Hesse and Rodrigue, 2004). The variation in the size of freight activity across metro areas is also large in that relatively few metropolitan areas dominate in globalized supply chains – the ten largest container port systems accommodated 78% of all US container imports (in TEU, the Maritime Administration, 2015). The warehouses in these trade gateways are more likely to decentralize further.

Second, land prices vary not only across metro areas but also at the sub-metropolitan level. Land price is correlated with land demand, which can be approximated by population or employment density (Anas et al., 1998). As discussed earlier, population size varies widely across metro areas, hence population density varies as well (Gabaix, 1999). Furthermore, both population and employment are not uniformly distributed within a metro area. Rather, the densities in the urban core (whether mono- or poly-centric) are significantly greater than those in the suburbs or the exurbs (Giuliano and Small, 1991; Giuliano et al., 2015). As suggested in the urban economics literature, this spatial distribution of densities can be consistently quantified (Clark, 1951; McDonald, 1989; Anas et al., 1998). If so, how the distribution of densities influences the extent of decentralization can be systematically tested. In this paper, employment density is used as a proxy for land prices.

In sum, the variance across metro areas in the vectors of *freight demand* and *land price distribution* explains the variance in decentralization. Here, it is worth noting again that the fundamental driver of decentralization is the unquantifiable process of logistics restructuring to transport large volumes of goods quickly, cheaply and reliably. Thus, it is first tested how much the variation in *freight demand* across metro areas, jointly with the *land price distribution*, explains variation in *decentralization* (cross-section, Eq. 1). Furthermore, there may be some cases in which a significant increase in *freight demand* resulted in logistics restructuring and consequential warehousing decentralization. Examples include a significant increase in population, a drastic change in consumption patterns, a relocation of expansive manufacturing complexes, or construction of major intermodal terminals (world-class seaport, air hub, railyard, and canal). Thus, it may be also evaluated whether the change in the *freight demand* and *land price distribution* explains the variation in *decentralization* (time series, Eq. 2). However, because of data problems, time series models are not estimated. The issues are explained more in detail in Section 4.2. General models are:

$$\Delta D_i = f(F_i, L_i) \text{ Cross} - \text{section} \quad (1)$$

$$\Delta D_i = f(\Delta F_i, \Delta L_i) \text{ Time} - \text{series} \quad (2)$$

Where in metro area i;
Δ denotes change over time;
ΔD = change in warehousing distribution (decentralization);
F = vector of freight demand;
L = vector of land price distribution.

To test the linear relationship, ordinary least squares (OLS) estimation is used. The unit of analysis is a metro area, and 48 major US metro areas are used in the models.

3.2. Study area, measurement, and data

3.2.1. Study area

Table 1 and Table 2 list 48 US metropolitan areas with their population and employment statistics – 42 of which are Combined Statistical Areas (CSAs) and six of which are Metropolitan Statistical Areas (MSAs). The MSA is a metropolitan statistical area with either one or multiple counties that have at least one urban core with a minimum population of 10,000. A CSA consists of either a single or multiple neighboring MSAs with a significant level of economic interactions quantified by commuting patterns. The CSAs and MSAs are delineated by the Office of Management and Budget.[6] In this study, 48 metro areas are drawn from the Commodity Flow Survey (CFS, see Section 3.2.4 for details) regions, which are consistent with CSA/MSA boundaries. Those metro areas with suppressed freight flow information are excluded. Across metro areas, population size in 2000 varies considerably from 22 million in New York to 0.9 million in Tucson. The median population of all 48 metro areas is 2.06 million, and employment 0.94 million.

A preliminary analysis documented a non-linear relationship between decentralization and population size. Thus, 48 metro areas are divided into two groups: Group 1 Large metro areas (size rank #1–22) and Group 2 Small metro areas (size rank #23–48). This arbitrary division is based on the scatter plot of decentralization and metro size (see Fig. 2). Later in the regression models, to account for the unobservable heterogeneity between the large and small metro areas, a metro-size dummy interaction variable is used.

[5] Whether a warehousing facility is owned by a logistics business or is leased, its location fulfills a tenant's profit maximization objectives. If a facility at a location does not fit any supply chain strategies (e.g. obsolete technology, small size, increased land rent or more stringent regulation), the facility of this location will not be utilized and close down.

[6] http://www.census.gov/population/metro/data/glossary.html

Table 1
Large metro areas ($N = 22$) and their population (2000) and employment (2003).

Rank	Short Name	Type	Full Name	Pop. 2000 (Million)	Emp. 2003 (Million)
1	New York	CSA	New York-Newark, NY-NJ-CT-PA	22.24	9.22
2	Los Angeles	CSA	Los Angeles-Long Beach, CA	16.37	6.43
3	Chicago	CSA	Chicago-Naperville, IL-IN-WI	9.47	4.16
4	Washington DC	CSA	Washington-Baltimore-Arlington, DC-MD-VA-WV-PA	7.98	3.13
5	San Francisco	CSA	San Jose-San Francisco-Oakland, CA	7.66	3.32
6	Boston	CSA	Boston-Worcester-Providence, MA-RI-NH-CT	7.63	3.53
7	Philadelphia	CSA	Philadelphia-Reading-Camden, PA-NJ-DE-MD	6.69	2.89
8	Dallas	CSA	Dallas-Fort Worth, TX-OK	5.57	2.56
9	Miami	CSA	Miami-Fort Lauderdale-Port St. Lucie, FL	5.48	2.06
10	Detroit	CSA	Detroit-Warren-Ann Arbor, MI	5.46	2.24
11	Houston	CSA	Houston-The Woodlands, TX	4.88	2.10
12	Atlanta	CSA	Atlanta-Athens-Clarke-Sandy Springs	4.78	2.25
13	Seattle	CSA	Seattle-Tacoma, WA	3.78	1.65
14	Cleveland	CSA	Cleveland-Akron-Canton, OH	3.58	1.54
15	Phoenix	MSA	Phoenix-Mesa-Scottsdale, AZ	3.25	1.41
16	San Diego	MSA	San Diego-Carlsbad, CA	2.81	1.12
17	St. Louis	CSA	St. Louis-St. Charles-Farmington, MO-IL	2.77	1.26
18	Pittsburgh	CSA	Pittsburgh-New Castle-Weirton, PA-OH-WV	2.75	1.14
19	Denver	CSA	Denver-Aurora, CO	2.63	1.23
20	Portland	CSA	Portland-Vancouver-Salem, OR-WA	2.55	1.04
21	Tampa	MSA	Tampa-St. Petersburg-Clearwater, FL	2.40	0.99
22	Orlando	CSA	Orlando-Deltona-Daytona Beach, FL	2.19	0.97
Median				4.83	2.08

Table 2
Small metro areas (N = 26) and their population (2000) and employment (2003).

Rank	Short Name	Type	Full Name	Pop. 2000 (Million)	Emp. 2003 (Million)
23	Kansas City	CSA	Kansas City-Overland Park-Kansas City, MO-KS	2.12	0.99
24	Columbus	CSA	Columbus-Marion-Zanesville, OH	2.07	0.94
25	Cincinnati	CSA	Cincinnati-Wilmington-Maysville, OH-KY-IN	2.05	0.94
26	Indianapolis	CSA	Indianapolis-Carmel-Muncie, IN	2.03	0.95
27	Milwaukee	CSA	Milwaukee-Racine-Waukesha, WI	1.94	0.93
28	Charlotte	CSA	Charlotte-Concord, NC-SC	1.87	0.93
29	Salt Lake City	CSA	Salt Lake City-Provo-Orem, UT	1.85	0.77
30	San Antonio	MSA	San Antonio-New Braunfels, TX	1.71	0.65
31	Virginia Beach	CSA	Virginia Beach-Norfolk, VA-NC	1.67	0.62
32	Las Vegas	CSA	Las Vegas-Henderson, NV-AZ	1.56	0.75
33	New Orleans	CSA	New Orleans-Metairie-Hammond, LA-MS	1.53	0.58
34	Nashville	CSA	Nashville-Davidson–Murfreesboro, TN	1.49	0.71
35	Raleigh	CSA	Raleigh-Durham-Chapel Hill, NC	1.46	0.67
36	Greensboro	CSA	Greensboro–Winston-Salem–High Point, NC	1.41	0.64
37	Louisville	CSA	Louisville/Jefferson County–Elizabethtown–Madison, KY-IN	1.32	0.58
38	Grand Rapids	CSA	Grand Rapids-Wyoming-Muskegon, MI	1.31	0.57
39	Buffalo	CSA	Buffalo-Cheektowaga, NY	1.25	0.50
40	Austin	MSA	Austin-Round Rock, TX	1.25	0.55
41	Birmingham	CSA	Birmingham-Hoover-Talladega, AL	1.22	0.49
42	Greenville	CSA	Greenville-Spartanburg-Anderson, SC	1.22	0.52
43	Rochester	CSA	Rochester-Batavia-Seneca Falls, NY	1.16	0.46
44	Albany	CSA	Albany-Schenectady, NY	1.12	0.41
45	Dayton	CSA	Dayton-Springfield-Sidney, OH	1.09	0.45
46	Richmond	MSA	Richmond, VA	1.06	0.49
47	Tulsa	CSA	Tulsa-Muskogee-Bartlesville, OK	1.02	0.41
48	Tucson	CSA	Tucson-Nogales, AZ	0.88	0.31
Median				1.44	0.60

3.2.2. *Warehousing decentralization: changes in distribution over time*

ZIP Code Business Patterns (ZBP) for 2003 and 2013 are the main data sources. 2003 is the earliest year from which the ZBP datasets have become consistent after two rounds of industry code revision in 1997 and 2002.[7] 2013 is the latest available data year when this study was conducted. The Business Register, the source of employer and establishment information in the ZBP, maintains records of each known establishment with paid employees located in the U.S. An "establishment" is defined as "a single physical location at which business is conducted, or services or industrial operations are performed."[8] Every business with an EIN (Employer Identification Number) with at least one employee is included. The ZBP provides the number of establishments by

[7] The industry code changed from SIC to NAICS in 1997, and the NAICS was revised in 2002. SIC (Standard Industrial Classification); NAICS (North American Industry Classification System)

[8] CBP, Census Bureau (http://www. census. gov/econ/cbp/)

employee size classes at the 6-digit industry code level.[9] The spatial unit of the ZBP is the United States Postal Service (USPS) ZIP Codes, which are derived primarily from the businesses' physical addresses. To identify warehouses, the NAICS 493 (warehousing and storage) is used which includes facilities that store goods and/or provide logistics services.

In Giuliano and Kang (2018), the authors define multiple spatial measures to quantify warehousing distribution consistently. One of these calculates the average distance to the central business district (CBD) from each warehouse in a metropolitan area. The decentralization argument has focused on the spatial shift of warehouses from the urban core to the periphery (Aljohani and Thompson, 2016). Accordingly, the CBD is used as a benchmark to measure the distribution. In this paper, because of the ZIP Code-level dataset, the CBD is defined as the centroid of the ZIP Code with the highest employment density of a metro area. The calculation is based on the Euclidean distance between ZIP Code centroids. This distribution is calculated by metro area as follows:

$$W\&D\ distribution = \frac{\sum_{j=1}^{N} d_j * e_j}{E} \tag{3}$$

Where,

d_j = distance to the CBD from ZIP Code j (j = 1, 2, …, N); e_j = number of W&Ds in ZIP Code j; E = sum of e_j.

Therefore, decentralization in metro area *i* is calculated as the difference in distribution from *t-1* and *t*:

$$\begin{aligned} Decentralization_i &\equiv Changes\,(\Delta)\ in\ distribution_{i,t-1\ to\ t} \\ &= Distribution_{i,t} - Distribution_{i,t-1} \end{aligned} \tag{4}$$

3.2.3. Spatial distribution of land prices

According to the urban economics literature, the spatial distribution of land prices is approximated by the negative exponential curve of employment density (Clark, 1951; McDonald, 1989; Anas et al., 1998).

$$D(x) = D_0 * e^{-G*x+u} \tag{5}$$

Where

D(x) = employment density at distance x from the CBD; D_0 = peak employment density at the CBD (x = 0); x = distance from the CBD; G = density gradient; u = error term.

The logarithm transformation of Eq. 5 yields a simple linear equation with a slope, *G*, and an intercept, *log(D₀)*. The estimated *density gradient*, $\widehat{G}$, and *peak density*, $\log(\widehat{D_0})$, are used to describe the spatial distribution of land prices. The calculation is based on the ZBP datasets for 2003.

$$log(D(x)) = log(D_0) - G*x + u\ (as Y = a - bX) \tag{6}$$

Fig. 1 illustrates how the variance in density gradients and peak densities influences the extent of decentralization. As discussed, employment density is a proxy for land price and is the measurement for illustration. A mono-centric urban structure is assumed. The left side presents two exponential curves of two different metro areas A and B that have the same gradient (0.08) but different peak density values (7.5 for A and 6.5 for B). Assume a) the optimal land price for a new warehouse is 200 and b) warehousing operators look for an ideal location from the CBD and outward into the periphery. The land price on the A line reaches 200 at approximately 28 miles from the CBD, whereas on the B line it is 15 miles. This difference implies that controlling for the density gradient, warehouses in a metro area with a higher peak density will decentralize more to reach the optimal price than those with a lower peak density. Thus, *peak density* is positively correlated with decentralization. The right side of Fig. 1 again presents two exponential curves of two metro areas C and D that have an identical peak density (7.0) yet different gradients (0.12 for C and 0.06 for D). In order to reach the land price of 200, warehouses on the C line will have to move less than those on the D. This implies that, controlling for peak density, warehouses in a metro area with a higher density gradient will decentralize less to reach the optimal level. Thus, *density gradient* is negatively correlated with decentralization.

3.2.4. Freight demand

As discussed, freight flow is a proxy for the demand for warehouses to operate on a large scale, and greater freight flows are correlated with more decentralization. The Commodity Flow Survey (CFS) 2002 is the data source. All domestic inbound and outbound freight volumes (in million tons) are calculated, which do not duplicate domestic flows originating from and destined to the same area. The Bureau of Transportation Statistics publishes the CFS data every five years. The CFS provides the origins and destinations of freight flow by value (USD) and weight (tonnage) by mode of transportation at the metropolitan and state levels. The data source is shipper-based surveys. The CFS 2002 does not include international trade portions, as all CFS flows originate from and are destined to a domestic region. An alternative data source for international trade is the Freight Analysis Framework (FAF) datasets – a refined version of the CFS. However, the FAF 2002 is available only at the state level. Because all imported freight will be transported either to the same region or to other domestic regions, all imports are accounted in the CFS; this also applies to exports.

As a proxy for freight demand, *the change in the number of large W&Ds* is also used. It is one of the outcomes of the logistics restructuring to transport large *freight flows*. The metro areas with greater freight flows are more likely to have large W&Ds built therein, and these facilities are more likely to have been established in more distant locations, hence more decentralization. The threshold of 100 employees or more is set for large warehouses to calculate how many of these large facilities are in each metro area for both 2003 and 2013. Employment might not be perfectly correlated with a facility's floor area. For instance, a product picking-and-packing facility might hire more employees per unit area than a regional distribution center. However, because the floor area information is not available at the national level, employment is used as a proxy. ZBP does not provide employment but establishment counts by nine employee size classes. Further tests were carried out on the case with the size threshold of 50 employees or more, and the results are available from the author.

Table 3 presents the summary of W&D size statistics of the 48 US metropolitan areas. Approximately 9.9% of W&Ds in 2003 and 11.5% in 2013 are large W&Ds. Compared to the 14% increase in the number of all W&Ds, these large W&Ds expanded much significantly. Table 4 summarizes the dependent variable and all explanatory variables.

4. Results

Results are presented in two parts. First, I describe how the extent of warehousing decentralization differs across metro areas. I also conduct multiple hypothesis tests regarding the distribution and location change of warehouses. Second, I present the results of econometric model estimations.

4.1. Descriptive statistics and hypothesis testing

4.1.1. W&D decentralization in 48 U.S. metropolitan areas

Table 5 presents the summary statistics of decentralization by metro size. The mean and median decentralization in all metro areas is 1.06 and 1.07 miles, respectively. The standard deviation is large (2.23), and is even larger (2.73) for Group 2. Of the 48 metro areas, warehouses in New Orleans decentralized the most (6.50 miles farther from the CBD), whereas those in Tucson substantially centralized (6.75 miles closer to

[9] Employee size classes are: 1–4; 5–9; 10–19; 20–49; 50–99; 100–249; 250–499; 500–999; and > 1000 employees

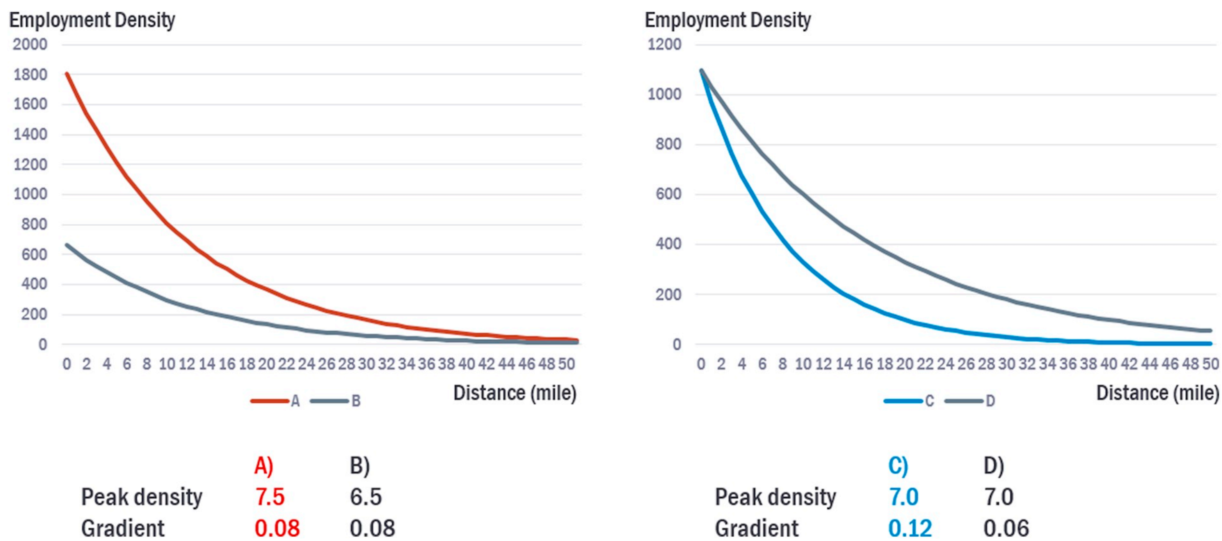

Fig. 1. Illustration of density gradient and peak density measures.

Table 3
W&D size distribution in 48 US metropolitan areas, 2003–2013.

N of W&Ds	2003		2013		From 2003 to 2013	
	N	% share	N	% share	N change	% change
Total	7901	100.0%	9011	100.0%	1100	14.0%
By employee size classes (summarized)						
1–49 employees	6429	81.4%	7183	79.7%	754	11.7%
50–99	688	8.7%	797	8.8%	109	15.8%
100–249	474	6.0%	636	7.1%	162	34.2%
> 250	310	3.9%	395	4.4%	85	27.4%

the CBD).

Fig. 2 presents the scatter plot of metro size (population) in logarithm with base ten and decentralization in miles. The population of ten million in log is seven, and one million in log is six. The labels (#1–48) represent the size rank in Tables 1 and 2. The distribution is clearly distinguished between the two groups. At approximately 6.34 (2.2 million in population), the scatter pattern changes. It is noticeable that population size – a proxy for freight demand – has a positive correlation with decentralization for Group 1 (Corr. = 0.65). The relationship is not significant for Group 2 (Corr. = 0.28).

Below are results of three hypothesis tests. The first hypothesis (H1) is that the 48 metro areas, as a whole, did experience statistically significant warehousing decentralization. The *t*-test rejected the null hypothesis that the mean of decentralization by metro area is equal to zero. The second (H2) is that warehouses in Group 1 did decentralize significantly more than those in Group 2. However, the t-test did not reject the null that the mean of the change is equal to each other. The statistics in Table 5 and the scatter plot in Fig. 2 all support this result. The third hypothesis (H3) is tested in each metro area that from 2003 to 2013 warehouses did decentralize significantly. The null hypothesis is by ZIP Code the distribution in 2003 is equal to that in 2013. Results are in Table 6. Of the 48 samples, a total of seven, not only large metro areas (Los Angeles, Chicago, Atlanta, Detroit) but also several small ones (Milwaukee, Las Vegas, and New Orleans), experienced significant W&D decentralization.[10]

4.1.2. Distribution and decentralization of Large W&Ds

Now I turn the focus to the location change of large warehouses, which hire 100 or more employees. In order to minimize the bias originating from the small sample number, only 24 metro areas with at least ten large warehouses in both 2003 and 2013 are used. Fig. 3 presents the scatter plot of population size and decentralization of large warehouses. A green marker is for larger ones, and a gray marker otherwise. So, the metro label appears twice. Overall, in almost all metro areas, large warehouses decentralized more than small ones. It can also be seen that, with respect to the unit change in population size, the variance of large warehouse decentralization is greater than the variance of small ones'.

Below are results of four more hypothesis tests. The fourth hypothesis (H4) is that the pattern of large warehouses shows more dispersal than that of small ones in 2003 and 2013 separately. If land-intensive businesses are sensitive to high land price, large and small facilities will be allocated differently, hence different distribution patterns. If the demand for large warehouses changes over time, there would also be changes in the distribution between 2003 and 2013. Table 7 presents the results. In 2003, the null hypothesis was not rejected in 16 of the 24 metro areas. Whereas in 2013, in more than half of the samples, the null was rejected, hence large warehouses were significantly farther from the CBD. Over the period, in Los Angeles, Boston, Philadelphia, Dallas, Houston, Atlanta, and Charlotte, the distribution of large warehouses has become distinctively different from that of small ones. In two metro areas, Columbus and Phoenix, their distribution has become more similar.

The fifth hypothesis test is that large warehouses decentralized more than small warehouses across metro areas (H5). The t-test rejected the null that the mean of large ones' decentralization is equal to that of small ones'. Table 8 presents the summary statistics. Notwithstanding the large standard deviation, the mean of large warehouses' decentralization is much greater than that of smaller ones'.

The sixth hypothesis (H6–1) is that the extent of decentralization of large warehouses in large metro areas is greater than that in small metro areas (H6–1). If land prices are higher in large metro areas, large warehouses will relocate to the outskirts to a greater extent than they would do in small metro areas. Similarly, it is tested if small warehouses are sensitive to land price (H6–2). The *t*-test rejected the null H6–1, but not the null H6–2. There is indeed a difference between large and small metro areas in the extent of large warehouses' decentralization, which is not the case for small warehouses.

Seventh, it is evaluated whether the location changes of large warehouses reach significance. The null hypothesis is that the

[10] Detailed statistics of the number, distribution, and decentralization of W&Ds are available from the author.

Table 4
Definition and data source of variables.

Variables	Definition	Data source
W&D decentralization	Changes in warehouse distribution from 2003 to 2013 quantified as the average distance from the CBD to warehouses	ZIP Code Business Patterns 2003 and 2013
Change in large warehouses	The net change in the number of warehouses with 100 or more employees	ZIP Code Business Patterns 2003 and 2013
Density gradient	Estimated $\widehat{G}$ in Eq. 6	ZIP Code Business Patterns 2003
Peak density	Estimated $\log(\widehat{D_0})$ in Eq. 6	ZIP Code Business Patterns 2003
Freight flow	All domestic freight flows in million tons	Commodity Flow Survey 2002

Table 5
Summary statistics of decentralization by metro size.

Variable	Group	N	Mean	Median	SD	Min	Max
Decentralization 2003–2013 (miles)	All metro areas	48	1.06	1.07	2.23	−6.75 Tucson	6.50 New Orleans
	Group 1 (Rank #1–22)	22	1.10	1.25	1.49	−1.81 St. Louis	3.66 Miami
	Group 2 (Rank #23–48)	26	1.02	0.60	2.73	−6.75 Tucson	6.50 New Orleans

Group 1 (Rank #1–22) in Orange; Group 2 (Rank #23–48) in gray; (N = 48).

distribution at the ZIP Code level in 2003 is equal to that in 2013. Results are in Table 9. Of the 24 metro areas, Los Angeles, Chicago, Boston, and Phoenix have experienced significant distribution changes over the ten-year period. Large warehouses did not change location significantly in small metro areas.

4.1.3. Decentralization and freight flow

Lastly, it is evaluated whether *freight flow* is correlated with decentralization. This time, I compare among quartile groups delineated by freight volume. Table 10 presents summary statistics. The 4th quartile has the largest freight volume. Due to the small sample size, no formal comparison of the mean between the quartile groups has been made. However, given the large variances of all four groups relative to their means, it is hard to claim the mean of any one group is greater than the others. Rather, as shown in Fig. 4, the non-linear relationship

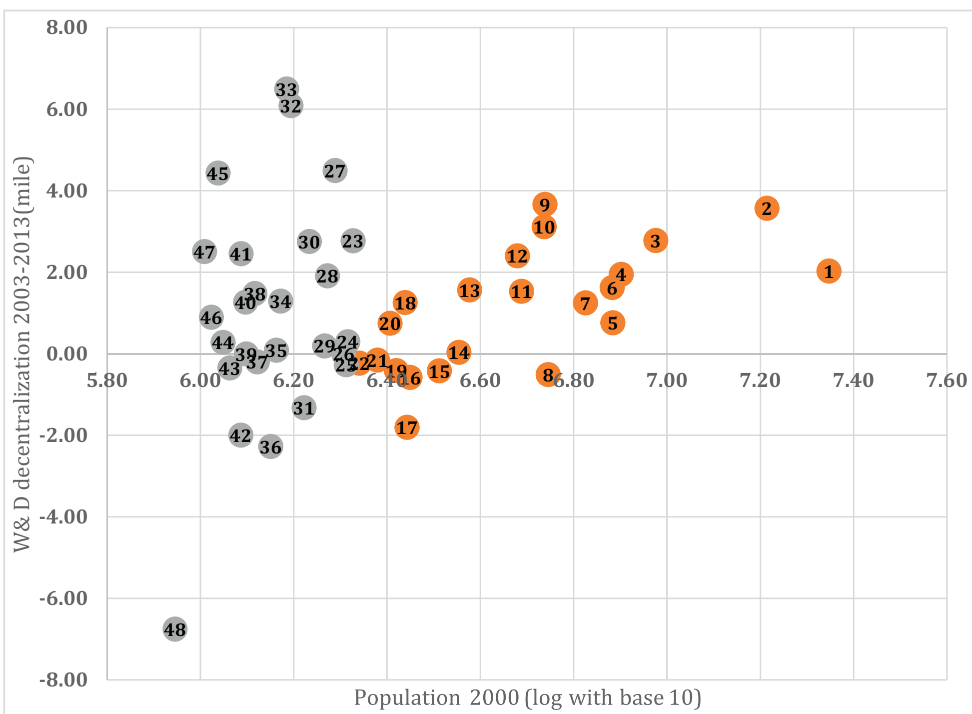

Fig. 2. Scatter plot of W&D decentralization and 2000 population.

Table 6
Decentralization by significance and by metro size.

Decentralization	Group 1 – Large metro areas	Group 2 – Small metro areas
Significant	Los Angeles, Chicago, Atlanta, Detroit	Milwaukee, Las Vegas, New Orleans
Not significant	New York, Washington-DC, Boston, San Francisco, Dallas, Philadelphia, Houston, Miami, Seattle, Phoenix, Cleveland, Denver, St. Louis, Pittsburgh, San Diego, Portland, Orlando	Tampa, Indianapolis, Charlotte, Kansas City, Columbus, Cincinnati, Salt Lake City, San Antonio, Nashville, Raleigh, Austin, Louisville, Greensboro, Virginia Beach, Grand Rapids, Richmond, Greenville, Buffalo, Birmingham, Rochester, Tulsa, Albany, Dayton, Tucson

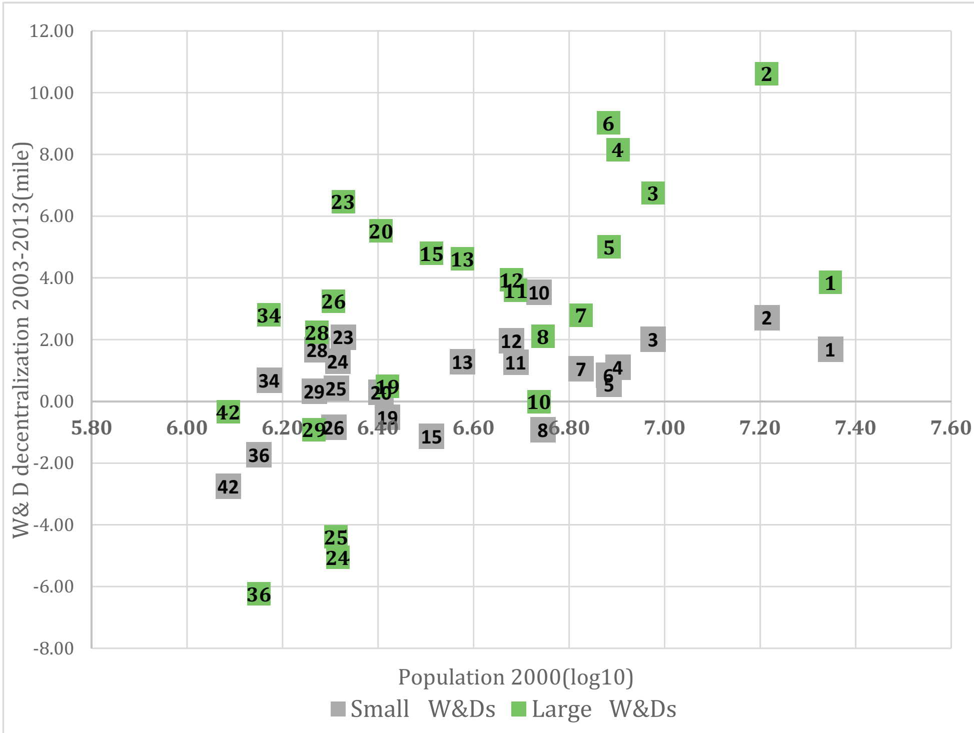

Fig. 3. Scatter plot of decentralization of large/small W&Ds and 2000 population. *Only those metro areas with at least ten large W&Ds in 2003 and 2013 (N = 24).*

Table 7
Comparison of the distribution of large and small W&Ds.

Test results	In 2003	In 2013
Large W&Ds are significantly farther from the CBD	New York, Chicago, Washington-DC, San Francisco, Columbus, Nashville, Greenville (*N* = 7)	New York, Los Angeles, Chicago, Washington-DC, San Francisco, Boston, Philadelphia, Dallas, Houston, Atlanta, Charlotte, Nashville, Greenville (*N* = 13)
Not different	Los Angeles, Boston, Philadelphia, Dallas, Detroit, Houston, Atlanta, Seattle, Denver, Portland, Kansa City, Cincinnati, Indianapolis, Charlotte, Salt Lake City, Greensboro (*N* = 16)	Detroit, Seattle, Phoenix, Denver, Portland, Kansa City, Columbus, Cincinnati, Indianapolis, Salt Lake City, Greensboro (*N* = 11)
Large W&Ds are significantly closer to the CBD	Phoenix (N = 1)	–

Excluded metro areas are: Miami, Cleveland, San Diego, St. Louis, Pittsburgh, Tampa, Orlando, Milwaukee, San Antonio, Virginia Beach, Las Vegas, New Orleans, Raleigh, Louisville, Grand Rapids, Buffalo, Austin, Birmingham, Rochester, Albany, Dayton, Richmond, Tulsa, and Tucson.

is again existing – positive correlation where trade volume is high; not so clear otherwise. The freight volume is in logarithm with base 10.

4.2. Model results

In this section, I present econometric model results. Table 11 shows the summary statistics of the explanatory variables. From 2003 to 2013, 247 large warehouses were added to 48 metro areas – 5 per metro area on average. The change is correlated with metro size. Atlanta, followed by Los Angeles, Chicago, Dallas, and Miami, gained the most, while Austin lost the most. The distribution of freight flows is highly skewed: the top five trade gateways (Chicago, Houston, Los Angeles, New York, and New Orleans) transported 36% of all freight volume (in million tons). Thus, a logarithm form is used. The density gradient and peak densities are estimated figures from the density gradient estimation (Eq. 5). The *density gradient* has an inverse correlation (−0.36) with population, whereas the *peak density* has a positive correlation (0.52). For example, large metro areas with polycentric urban centers and small metro areas without a significant urban core have gentle density gradients (e.g. bottom 5: Seattle, Miami, Las Vegas, Los Angeles, and Virginia Beach). Moreover, large metro areas, as expected, have urban cores with very high peak densities (e.g. top 5: Chicago, New York, Los Angeles, San Francisco, and Detroit).[11] Densities (a proxy for the land price) in large metro areas are significantly high in their urban cores and decrease at a lesser rate per-unit-distance from the center. In small metro areas, not only is the peak much lower but it also decreases at a greater rate. These differences should drive what I documented in the last section – more spatial shifts in large metro areas.

Table 12 presents the pairwise correlation between the explanatory variables and decentralization by size group. Again, the statistics suggest a non-linear relationship in that the correlation coefficients are significantly different between the two groups, particularly for the variables: *change in large warehouses, density gradient*, and *peak density*. Freight flow is moderately correlated with decentralization in all groups. Table 13 shows the pairwise correlation among the explanatory variables. *Freight flow* is correlated with *the change in large W&Ds* and *peak density*, which is reasonable, because all three variables are partially a function of metro size. All other variables have a moderate level of correlation.

[11] The estimated peak density of Chicago is very slightly greater than that of New York.

Table 8
Summary statistics of decentralization by W&D size.

Variable	Group	N	Mean	Median	SD	Min	Max
Decentralization 2003–2013 (miles)	Large W&Ds (Emp. ≥100)	24	2.88	3.42	4.24	−6.23 Greensboro	10.62 Los Angeles
	Small W&Ds (Emp. 〈100)	24	0.70	0.95	1.45	−2.75 Greenville	3.53 Detroit

Table 9
Decentralization of large W&Ds by significance by metro size.

Decentralization	Group 1 – Large metro areas	Group 2 – Small metro areas
Significant	Los Angeles, Chicago, Boston, Phoenix	–
Not significant	New York, Washington-DC, San Francisco, Philadelphia, Dallas, Detroit, Houston, Atlanta, Seattle, Denver, Portland	Kansa City, Columbus, Cincinnati, Indianapolis, Charlotte, Salt Lake City, Nashville, Greensboro, Greenville

Excluded metro areas are: Miami, Cleveland, San Diego, St. Louis, Pittsburgh, Tampa, Orlando, Milwaukee, San Antonio, Virginia Beach, Las Vegas, New Orleans, Raleigh, Louisville, Grand Rapids, Buffalo, Austin, Birmingham, Rochester, Albany, Dayton, Richmond, Tulsa, and Tucson.

Table 10
Decentralization by freight flow quartile groups.

Variable	Freight flow	N	Mean	Median	SD
Decentralization 2003–2013 (miles)	4th quartile	12	1.80	1.78	2.16
	3rd quartile	12	1.31	1.41	1.31
	2nd quartile	12	0.77	0.55	1.75
	1st quartile	12	0.33	0.04	3.23

Of the models laid out in the research approach, time series models are not estimated, because a) the change from 2003 to 2013 in the estimated density gradients and peak densities is marginal (corr. = 0.997 and 0.991, respectively) and b) the geography delineation of the 2012 CFS is neither consistent nor comparable with that of the 2002 CFS. Hence, results of the cross-section model are presented. The cross-section model cannot examine the exact period when W&D decentralization occurred (e.g. if it was early in 2003 or late in 2013) or the exact factors directly contributing to the location change. A preliminary analysis showed that the period of significant W&D decentralization is not uniform across the 48 metro areas. Rather, this paper focuses on the variation in the explanatory variables across metropolitan areas. The cross-section model is run twice using decentralization of all warehouses (Model 1) and that of large warehouses as dependent variables separately (Model 2). For all warehouse model runs, a metro-size dummy interaction is incorporated to account for the non-linearity (Small = 1, if Group 2; Small = 0, otherwise). There are no priors on empirical testing of the factors for W&D decentralization. Hence, all variables are included, and stepwise results are presented. In order to compare the effect size across variables, standardized coefficients are used. The final model is:

$$\Delta D_{2003-2013} = \beta_0 + \beta_1 Flow_{2002} + \beta_2 Large\ W\&D_{2003-2013} + \beta_3 Gradient_{2003} + \beta_4 Peak_{2003} + \beta_5 S{*}Flow_{2002} + \beta_6 S{*}Large\ W\&D_{2003-2013} + \beta_7 S{*}Gradient_{2003} + \beta_8 S{*}Peak_{2003} + \beta_9 S + \varepsilon \tag{7}$$

Where,
ΔD = change in W&D distribution (decentralization); Flow = freight flow; Large W&D = change in the number of large warehouses; Gradient = density gradient; Peak = peak density; S = small metro area dummy; and ε = an error term.

Results of all warehouse models are shown in Table 14. Given the small sample size (*N* = 48), the model offers a reasonable level of explanatory power (R^2 = 0.431, Step 3). Moreover, as expected, the statistical significance of the estimated parameters varies between large and small metro areas. For Step 1, *freight flow* for large metro areas (Group 1, when Small = 0) is significant and has expected signs. With one standard deviation (SD) increase in *freight flow* in large metro areas, decentralization increases by 0.354 SD. For Step 2, the inclusion of *change in large W&Ds* alters the size and significance of *freight flow* variables: *freight flow* becomes insignificant, whereas Small**freight flow* becomes significant. *Change in large W&Ds* in large metro areas is significant and positive, whereas, in small metro areas, it is not different from zero (0.272–0.324). As documented in the previous hypothesis testing and summary statistics, the correlation between freight demand measures and decentralization differs between large and small metro areas. In large metro areas, decentralization increases by 0.272 SD with a net increase (1 SD) of large warehouses. In small metro areas, decentralization also significantly increases as *freight flow* increases.[12] For Step 3, despite the inclusion of land price measures, results of freight demand measures do not change. The correlation between land price measures and decentralization is significant and as expected. Generally speaking, a steeper density gradient results in less decentralization, whereas a higher peak density leads to more. When the absolute values of the standardized coefficients are compared, the variance in *density gradient* influences the variance in decentralization the most (−0.524).[13] Again, the correlation between land price measures and decentralization differs between large and small metro areas. In sum, the distribution of land prices with respect to the rate of decrease by the unit distance from the center is a critical factor in large metro areas. I surmise that land prices are already relatively high for warehousing operations in most large metro areas. A recent report from Cushman and Wakefield, a commercial real estate services company, documented that warehousing development has been the strongest in primary markets (the Inland Empire near Los Angeles,[14] Chicago, Dallas, Houston, and New Jersey) and the largest growth in rents has been in markets with constrained land supply (Cushman and Wakefield, 2015). Thus, decentralization was inevitable. In small metro areas, land prices are not as high, hence decentralization is primarily a function of *freight flow*.

The results for large warehouse models (N = 24) in Table 15 are consistent with the previous results. Results of Steps 1 and 2 are very similar. Regardless of the inclusion of *changes in large W&Ds*, freight flow remains significant and positive. In Step 3, when land price

[12] In the small metro area-only model, which I did not present here, the standardized coefficients of freight flow are 0.616 in Step 2 and 0.545 in Step 3. Full results are available upon request.

[13] In small metro areas, freight flow is the most explanatory variable.

[14] The Inland Empire is an area with intense warehousing activity in San Bernardino and Riverside counties in the Los Angeles region.

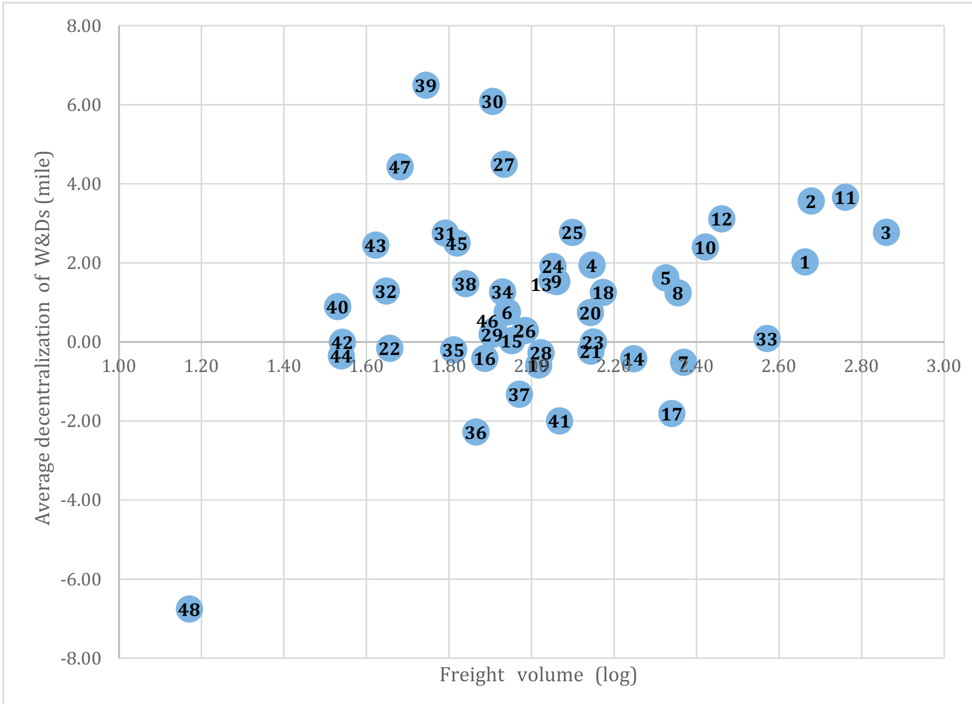

Fig. 4. Scatter plot of W&D decentralization and 2002 freight flow.

Table 11
Summary statistics of explanatory variables.

Explanatory variables	N	Mean	Median	SD	Min	Max
Freight flow (million ton)	48	151.53	100.25	146.99	14.82 Tucson	724.00 Chicago
Change in large W&Ds	48	5.15	3	6.80	−3 Austin	32 Atlanta
Density gradient ($\hat{G}$)	48	0.09	0.09	0.03	−0.01 Seattle	0.18 Austin
Peak density ($\widehat{D_0}$, log)	48	7.02	7.22	0.96	3.50 Seattle	8.69 Chicago

Table 12
Pairwise correlation of explanatory variables with decentralization.

Explanatory variables	All metro areas (N = 48)	Group 1 Rank #1–22 (N = 22)	Group 2 Rank #23–48 (*N* = 26)
Freight flow (million ton)	0.41**	0.46*	0.56**
Change in large W&Ds	0.24+	0.62**	−0.01
Density gradient ($\hat{G}$)	−0.06	−0.48*	0.11
Peak density ($\widehat{D_0}$, log)	0.22	0.19	0.32

** *P* < .01.
* *P* < .05.
\+ *P* < .1.

measures are included, the *change in large W&Ds* reaches significance with a size of effect (0.256) similar to the previous model (Model 1 Step 3). The effect size of *density gradient* is consistent with the previous model, whereas that of *peak density* increased substantially (e.g. from 0.259 in Model 1 Step 3 to 0.581 in Model 2 Step 3). This result shows that the decentralization of large warehouses is certainly influenced by the high land prices in the urban core, which pushes large facilities to be established on the outskirts.

Table 13
Pairwise correlation between the explanatory variables.

Explanatory variables (N = 48)	Freight flow	Change in large W&Ds	Density gradient	Peak density
Freight flow (million ton)	1.00			
Change in large W&Ds	0.54**	1.00+		
Density gradient ($\hat{G}$)	−0.16	−0.20	1.00	
Peak density ($\widehat{D_0}$, log)	0.57**	0.31*	0.35*	1.00

** P < .01.
* P < .05.
\+ P < .1.

Table 14
Results of model estimation: Model 1 (all warehouses).

W&D Decentralization 2003–2013	Model 1 Step 1		Model 1 Step 2		Model 1 Step 3	
	Std. β	Sig.	Std. β	Sig.	Std. β	Sig.
Freight flow	0.354+	**	0.126		0.046	**
ΔLarge W&Ds			0.272	*	0.214	**
Density gradient					−0.524	**
Peak density					0.259	**
Small*Freight flow	1.500		2.379	*	2.283	*
Small*ΔLarge W&Ds			−0.324	*	−0.300	*
Small*Gradient					0.517	
Small*Peak density					0.503	
Small	−1.277		−2.018	*	−2.646	*
Constant	.		.		.	
R^2	0.293		0.357		0.431	
N	48		48		48	

** P < .01.
* P < .05.
\+ P < .1.

Table 15
Results of model estimation: Model 2 (large warehouses).

W&D Decentralization 2003–2013	Model 2 Step 1		Model 2 Step 2		Model 2 Step 3	
	Std. β	Sig.	Std. β	Sig.	Std. β	Sig.
Freight flow	0.402	**	0.303	+	−0.156	
ΔLarge W&Ds			0.165		0.256	+
Density gradient					−0.566	*
Peak density					0.581	*
Constant	.			.	.	
R^2	0.162		0.179		0.381	
N	24		24		24	

** P < .01.
* P < .05.
+ P < .1.

5. Conclusions and future research

Several studies have examined warehousing decentralization in urban areas worldwide. Only a handful of US metro areas have been explored separately. Yet few studies have tested such location changes at the national level and empirically examined what has led to their relocation. The current understanding is that the recent restructuring of globalized supply chains has resulted in increased demand for larger and automated warehouses. To fulfill this demand, many facilities have been built on the urban periphery; hence, warehouse decentralization. However, because not every metro area participates in global supply chains, decentralization has not occurred everywhere. Dablanc et al. (2014) theorize that decentralization is a problem of very large metropolitan areas. In this research, it is hypothesized that the variation in characteristics across metro areas has resulted in differences in the extent of decentralization.

I focused on two factors: 1) variation in land price distribution and 2) variation in freight demand. These two factors are exogenous, yet they both influence decentralization at the same time. Because there are no priors regarding this phenomenon, I began with descriptive analyses and hypothesis testing of warehousing distribution and decentralization in 48 US metro areas. ZIP Code-level datasets of 2003 and 2013 were used.

I drew the following observations. First, over this ten-year period, warehouses did decentralize at the national level. The extent of decentralization in large metro areas (size rank #1–22) was not significantly greater than that in smaller ones (size rank #23–48). Second, significant decentralization occurred in seven metro areas – Los Angeles, Chicago, Atlanta, Detroit, Milwaukee, Las Vegas, and New Orleans. Third, the correlation between decentralization and metro size, a proxy for the land price, was non-linear. With the rank order from large to small metro areas, the extent of decentralization decreased linearly until the population reached approximately 2.2 million. Beyond this point, the relationship was not significant. Fourth, the correlation between *freight flow* and decentralization was similarly non-linear. Fifth, nationally, large warehouses (100 or more employees) decentralized more than small ones (fewer than 100 employees) did. Also, large warehouses decentralized to a greater degree in large metro areas than they did in small metro areas. However, this pattern was not documented in the case of small warehouses. Lastly, large warehouses decentralized significantly in Los Angeles, Chicago, Boston, and Phoenix.

I further evaluated the linear relationship between decentralization and two explanatory measures – freight demand (*freight flow* and *change in large warehouses*) and land price (*density gradient* and *peak density*) – at the metropolitan level with stepwise OLS models. Decentralization of large warehouses was also evaluated separately. I summarize the results as follows. Most importantly, descriptive scatter plots, correlation statistics, and the significance of estimated parameters with dummy interactions, all of these factors, suggest that the effect of freight demand and land price on decentralization is indeed significant and non-linear. Furthermore, *density gradient* across large metro areas, controlling for all other factors, had the greatest impact on decentralization. Namely, the extent to which employment density decreases with respect to a unit distance increase from the CBD is most significantly correlated with the extent of W&D decentralization. *Peak density* and *changes in large W&Ds* had almost half of this effect size. When the decentralization of large warehouses was considered, *density gradient* and *peak density* were equally influential. Employment density, as a proxy for land demand and prices, in general, explains the changes in warehouse location at the national level. However, this real estate market may be specific. The effect of actual logistics land prices and warehouse rents on the variation in warehouse location choice at the regional level merits further investigation.

The results of the hypothesis testing and linear models provide robust evidence for the theory that freight and land demand influences decentralization. Large freight demand increases the feasibility of scale operation and automation, which will substantially increase the facility size and land consumption. High land prices, or the spatial concentration of land demand, push land-intensive businesses away from central locations. When these demands are not sufficiently high, the effect becomes insignificant. Indeed, decentralization is, as Dablanc et al. (2014) stated, linked with very large metro areas. However, it is also associated with very large warehouses.

Conversely, these models can only partly explain the decentralization in small metro areas. Land prices in central locations of small metro areas might not be high enough to provide warehousing operators with a sufficient incentive to relocate to the exurbs. Rather, decentralization in small metro areas is mainly a function of *freight flow* – an incentive to consolidation and scale operation. There also may be some unobserved effects. I suspect two location-specific factors: (Allen et al., 2012) land use/zoning regulations and (Aljohani and Thompson, 2016) proximity to intermodal terminals (e.g. airports, seaports, and railways). Depending on the facility function, logistics operators will prioritize different location factors, because different warehouses play different roles in a supply chain. For example, a regional distribution center of a global freight distributor would prioritize access to cargo service airports, railways, and highways much more than access to the urban center, whereas a fulfillment center of an online shopping company would prioritize instant access to their local market. Thus, employment might not be the best proxy for facility size, even though the size division of warehouses was made based on the currently available information. The facility location choice logic will likely differ, hence their location patterns. An empirical investigation of (Allen et al., 2012) the changes in warehouse location choice over time and (Aljohani and Thompson, 2016) the variation in location choice with respect to various types of warehousing facilities may provide more substantive evidence for how and why warehouses have decentralized.

More information is necessary to provide a definitive answer to the inquiry concerning whether warehousing decentralization will lead to more truck vehicle miles traveled (VMT). Many factors – spatial or operational – contribute to changes in truck VMT. If so, an evaluation at the sub-metropolitan level of the introduction of state-of-the-art warehouses and the changes in the geography of urban freight movement may be the natural choice for future research.

Acknowledgement

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