

# The rise of mega distribution centers and the impact on logistical uncertainty

**ABSTRACT:** Between 1998 and 2005, employment in the U.S. warehousing industry grew at a compound annual growth rate of 22.23%, and the number of establishments increased at compound annual growth rate of 9.48%. Over this same period of time, the price for transportation fuels increased dramatically and became much more volatile. In this paper we examine the microeconomic and macroeconomic forces that have enabled such rapid growth in the warehousing industry. We also analyze structural change through employment and warehouse construction starts data and show that a new breed of warehouse has emerged – the mega distribution center, or mega DC. Mega DCs serve mega markets, which allows them to gain advantage through economies of scale and by employing push-pull supply chain strategies that decrease the uncertainty associated with forecasting market demand. Our geographical analyses suggest that this new breed of mega DC is attracted to locations that optimize access to multiple regional markets (and possibly national markets) at the expense of optimizing access to any single market. On average the length of the final leg of the supply chain becomes longer. Because the last leg must be made by truck — which is the least fuel-efficient mode of transport by far — the location requirements of this new breed of mega DC increase supply chain exposure to the related risks of rising and increasingly volatile fuel prices.

**KEYWORDS:** mega DCs, transportation vulnerability, fuel price volatility, warehousing

## 1. INTRODUCTION

In 1998, U.S. warehousing employment was 119,493. By 2006, the number of warehousing industry workers increased to 595,325. This represents a compound annual growth rate of 22.23%. By comparison, total U.S. employment grew at a compound annual growth rate of 1.3%. Across the economy, warehousing experienced stronger growth than most if not all other industries.

We define warehousing as those industries classified in 4931XX of the North American Industry Classification System (NAICS). This includes industries classified as general, refrigerated, and farm product warehousing and storage. This industry comprises establishments primarily engaged in

operating merchandise warehousing and storage facilities. These establishments generally handle goods in containers, such as boxes, barrels, and/or drums, using equipment, such as forklifts, pallets, and racks.

Warehousing is an essential element of the supply chain system. Warehousing establishments increasingly exist not as establishments to warehouse goods, but to transfer goods between vehicles. In some cases these goods are held for substantial periods of time, and in others, goods are held for only very short periods — only the time required to transit goods through the facility. Warehouses then, act as generators and attractors of freight activity. Their location determines the origin or destination of a large proportion of freight activity, and their locations, and trends in locations, should be well understood in order to understand transportation activity trends.

The current literature on the logistics of warehousing falls into three broad categories:

1. Methodological studies which identify idealized warehouse locations when transportation networks are optimized. These articles are typically found in the Operations Research literature, for example Ozsen, Coullard, and Daskin (2008).
2. Methodological studies which identify ideal supply chain characteristics when supply chain structure is optimized. These studies would consider the cost

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of inventory from warehousing and are typically found in the business literature, for example, Min and Zhou, (2002).

3. Studies which apply optimization tools to problems within warehouses or to warehouse design, for example Gue and Meller (2009).

Papers which describe the current geography of warehousing are limited. Two recent papers are of note, and very relevant to this research. Bowen (2008) highlights the growth of the warehousing industry during the period between 1998 and 2005, and shows that warehousing location preference is increasingly correlated with accessibility to roads and airports, but less so to rail terminals. Cidell (in press) shows that there is a dual warehouse structure, and that there is a tendency for both spatial concentration and dispersion. She notes that while historically warehouses have located close to the central business district, more recently there has been a suburbanization of the warehousing industry. Cidell approaches the question of geography much differently than we do. In her analysis of Gini coefficients, the base geography is defined as the CBSA (the U.S. Census Core Based Statistical Area), which refers collectively to metropolitan and micropolitan statistical areas. As such Cidell's analysis of Gini coefficients shows distribution within the CBSAs. Our analyses of geographic trends, by comparison, uses the nation as the base, and looks at three measures of distribution within the U.S.. That said, our research complements both Bowen's and Cidell's analyses in at least two ways:

1. We discover that the growth observed in warehousing is driven primarily by growth in the very large distribution center, or mega-DC (employing more than 100 workers in facilities greater than 500,000 square feet). These are the very large facilities that Cidell identifies as locating in suburban regions. A subset of these facilities serve much larger markets than the traditional warehouse, and therefore have a new geographic logic. We describe the factors that have encouraged and enabled their growth.
2. We explain how this logic increases vulnerability to variable and increasing fuel prices. This can be observed in Bowen's work through the weaker correlation with rail terminal facilities and stronger correlations with trucking accessibility.

Neither Cidell nor Bowen made an attempt to explain the economic logic underlying the much more rapid growth in large distribution centers (DCs). In our analysis we identify a sub-group of large DCs — those that serve multiple regional markets, or mega markets. We have dubbed this

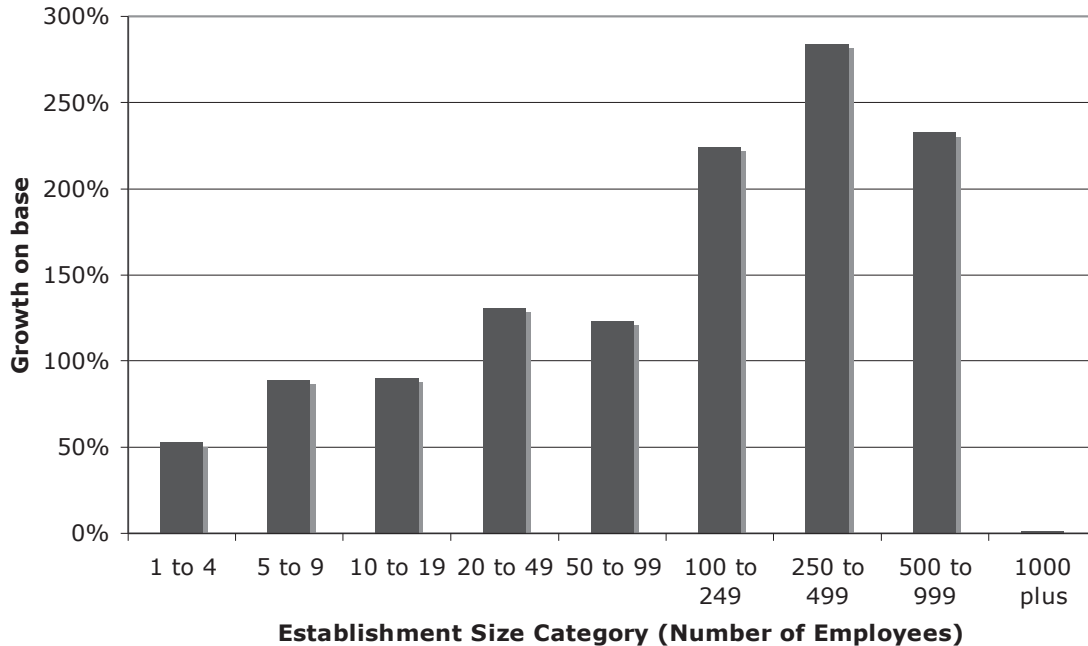
sub-group 'mega DCs' in reference not only to their size, but to the geographic extent of the market that they serve. Our analysis indicates that the mega DC strategy allows for economies of scale through serving larger market areas. This requirement increases the vulnerability of supply chains organized around the logic of the mega DC to rising fuel prices and rising volatility in fuel prices because the final leg of the supply chain is lengthened, and while the connection between the port and the distribution center *can* be made by train (a far more fuel efficient mode of transport), the final leg must be made by truck.

There has been some recent research that has considered the impact of increasing fuel prices on the structure of supply chains (Simchi-Levi, Nelson, Mulani, and Wright 2008). The research demonstrates how higher transportation cost alters the optimal number, location, and size of distribution centers. This work, however, work does not consider the impact of fuel price volatility — broadly defined as variable and less predictable price movements. While the cost of transportation fuels certainly impacts the optimal supply chain structure, so too does the stability of these prices. High and rising fuel price volatility implies high and rising uncertainty.

Sheffi (2007) makes qualitative consideration to the impact of uncertainty on supply chain structure (Sheffi, 2007). His seminal book identifies the vulnerabilities presented by lean supply chains, which depend on constant and predictable operations, however, Sheffi does not address the evolving logic of supply chains, nor does he address transportation fuel costs uncertainty in particular.

The analysis presented in this paper adds to the developing understanding of changing warehousing geography, supply chain structure, and the exposure these supply chains have to rising and increasingly volatile fuel prices. We highlight the importance of considering fuel price uncertainty in supply chain design, and the increased exposure of the freight distribution system to fuel price spikes.

This paper is organized into four sections. In the first section we provide evidence of the rise of mega DCs in the form of employment and warehouse construction data. In the second, we discuss the primary drivers and enablers of industry change. In the third section we analyze establishment data aggregated to the county and state levels. Our analysis shows that while many mega DCs locate in or in close proximity to major population centers, the new breed of mega DC prefers centralized locations that optimize access to multiple markets. The cost advantages gained through this strategy surmount the disadvantage of placing a DC in a location that is not optimum for delivery to any single regional market. In the fourth section, we present an analysis of diesel price volatility which suggests that supply chains organized around the mega DC-mega market logic are more exposed to



**Figure 1.** Relative Growth in the Number of Warehousing Establishments by Employment Category: 1998-2005 (Source: U.S. Census County Business Patterns).

rising fuel prices and rising fuel price volatility. Supply chains organized around the logic of the mega DC will experience proportionally higher cost increases than those not organized around this principle.

## 2. EVIDENCE OF THE RISE OF MEGA DCs

### 2.1 Growth in the Number of Establishments Categorized by Employment

The US Census Bureau publishes establishment-level data on employment, wages, and employment-by-establishment-size in the County Business Patterns database (CBP). County Business Patterns data are available in digital format beginning in 1998, and the latest year reported at the time data were gathered for this study was 2005. These years bookend the study period.

The data in Figure 1 reveal that — with the exception of the largest size category (warehouses employing more than 1,000 workers) — Mega DCs employing more than 100 workers grew in number at roughly double the rate of small and medium size establishments. When the nine categories shown in Figure 1 are aggregated into just two: mega DCs and other warehouses, we see that the number of other warehouses grew by 82.1% while mega DCs grew at by 238.5%.

### 2.2 Growth in Number of Establishments by Physical Plant Size

The growth characteristics revealed by the analysis of CBP data are validated by our analysis of a proprietary database of warehouse starts and completions created and maintained by ProLogis. In Figure 2 we see that completions roughly follow starts and that the strongest growth occurred between 1996 and 2001. In a related note in 1998, the price of transportation fuels fell below \$20/barrel (inflation adjusted) — its lowest level since 1973. This historic low bookends nearly a decade of steady price declines.

Like the CBP data, the ProLogis data indicate that growth rates were fastest among the largest warehouses when size is defined by the square footage of the facility rather than employment. When grouped by size a familiar trend emerges from the ProLogis data. We see in Figure 3 that both of the two largest size categories — 500K to 1M sq ft and those over 1M sq ft — grew as a share of total warehousing starts. In 1998, less than 5% of all warehouse starts were over 500,000 square feet. By 2006, warehouses larger than 500,000 square feet comprised nearly 25% of all starts. By contrast, small facilities experienced cyclical declines and medium size facilities remained relatively flat.

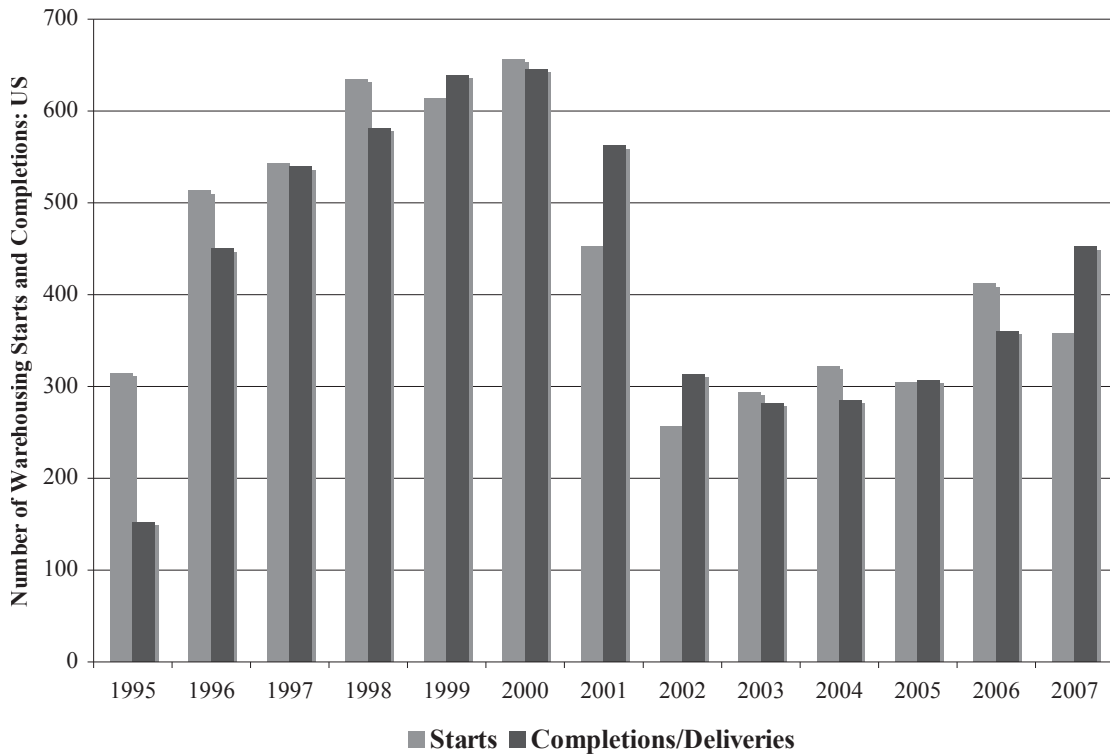


Figure 2. Warehousing Starts and Completions/Deliveries: 1995-2007 (Source: Prologis)

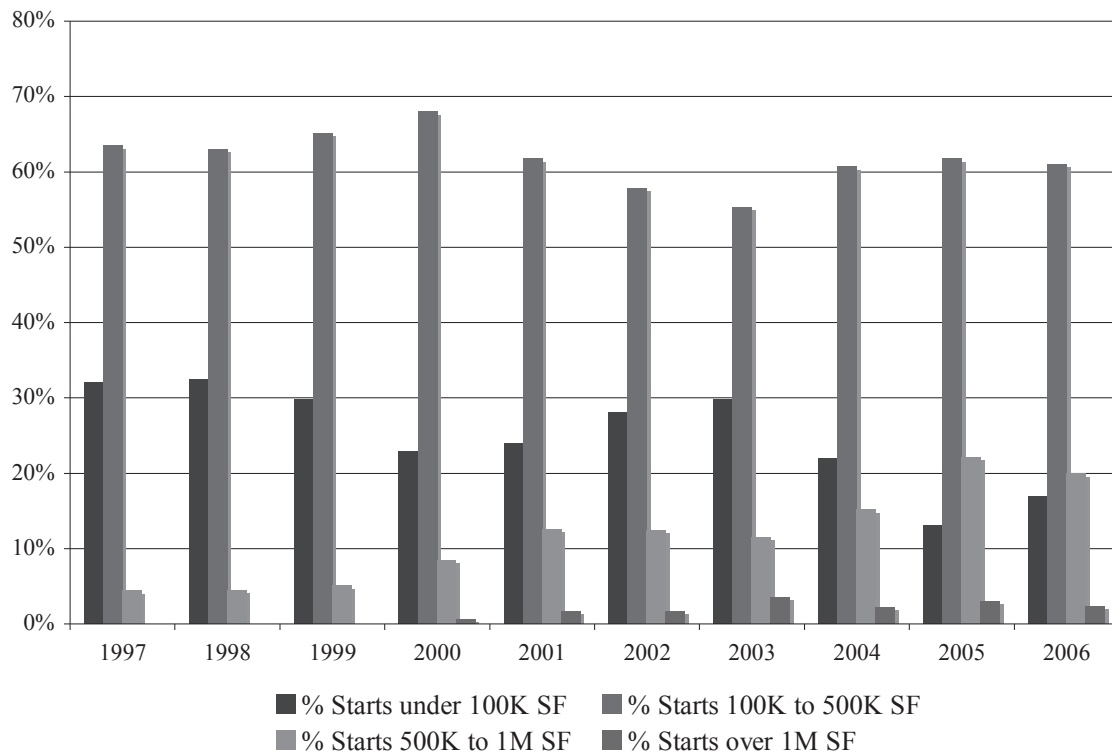


Figure 3. Warehousing Starts by Size Category: 1997-2006 (Source: Prologis).

### 3. DRIVERS AND ENABLERS OF INDUSTRY CHANGE

#### 3.1 Globalization: The driving force behind restructuring

Enabled by trade liberalization policies which emerged in the early 1980s, total U.S. trade grew at an accelerating rate over the last three decades. National income and product accounts data show that imports account for the majority of trade growth. In 1973, imports comprised 49.3% of all U.S. trade, but by 2006, imports accounted for 64.6% of total U.S. trade. Trade not only increased in absolute terms, growth in trade outpaced growth in GDP. The respective compound annual growth rates of total U.S. trade and GDP between 1976 and 2006 were 9.5% and 7.1% (U.S. Bureau of Economic Analysis). At these rates, it took just under 7 years for total U.S. trade to double, while it took just over 11 years for GDP to double. Like trade, flows of inward and outward foreign direct investment (FDI) have also grown rapidly. As a percentage of GDP, stocks of inward FDI rose from 6.8% to 13.5%, and stocks of outward FDI grew from 7.4% to 18.0% (United Nations Conference on Trade and Development).

These statistics on trade, GDP, and FDI indicate that the world economy not only grew, it underwent significant structural change during the study period. Statistics on trade and FDI reflect increasing regional specialization largely driven by international divisions of labor. While globalization is not solely responsible for the rise of mega DCs, offshoring and offshore outsourcing have lengthened supply chains, increased supply chain complexity, and greatly increased demand for transfer facilities. In addition, the physical networks carrying inputs along supply chains and goods from sites of final assembly to points of final consumption have become increasingly complex and require more sophisticated tools to manage. The effect is the geographic reorientation revealed in the statistics on trade, FDI, and GDP.

In addition to the systematic reduction and elimination of barriers to trade and investment, two other conditions underpin the process of globalization: steadily declining logistics costs and containerization.

Steadily declining logistics costs reduced the impact of transportation on overall cost. As a percentage of U.S. GDP, logistics expenditures declined from 13.5% in 1984 to 8.5% by 2003 (Andel 2007). Transportation costs make up the largest component of total logistics costs (61.5% in 2007), and the cost of transportation is strongly correlated with the price of transportation fuels. Simchi-Levi *et al.* show that a \$10 increase in the price of crude leads to a 24 cent increase in the per gallon price of diesel and a 4 cent per mile increase in transportation rates (Simchi-Levi, Nelson, Mulani, and

Wright 2008). Interestingly, as transportation fuels become more expensive, shippers increasingly seek economies of scale in shipping, and as a consequence, inventory carrying costs also increase.

While trucking is the most expensive mode of land transportation per ton mile, it is also the most flexible. The road network is much more expansive than the rail network, and unlike rail, trucks are not limited to strict time schedules. Persistently affordable fuel prevailed throughout much of the study period which culminated in 2005 (Figure 4). Low fuel prices and flexible schedules have allowed supply chains to organize around truck-based JIT delivery strategies despite the fact that trucking is more costly per ton-mile, and is especially sensitive to fuel price fluctuations.

The third major advance underpinning globalization is containerization. Whereas low fuel prices have minimized the line-haul costs of transportation, containerization has greatly reduced the labor costs associated with intermodal transfers. Containerization has also permitted cargo vessels and freight trains to realize economies of scale. Finally, containerization reduces the need to break shipments at the point of entry, and the location of these activities can now be located at sites that minimize cost (Levinson 2006). In short, containerization increased efficiency by lowering costs, but like all innovations, the benefits of containerization are subject to the law of diminishing returns.

#### 3.2 Factors Underlying the Rise of Mega DCs

Processes of globalization have manifested in new geographies of production which have transformed the logistics landscape. The volume of goods flows increased exponentially, and as a consequence so too has supply chain complexity. The main factors underlying the rise of mega DCs include the growth of big-box retail, industry mergers and consolidations, and emerging information technologies. These factors coalesce around the advantages gained through economies of scale and through the decreased uncertainty of predicting demand for mega markets as opposed to regional markets.

The rise of mega-DCs is not simply the result of the macro forces of globalization and the growth of world output; the recent trend has also been driven by industry consolidations and the microeconomics of big-box retailing where advantage is gained through economies of scale in production, sourcing, and distribution (Bonacich and Wilson 2008). The distribution needs of big-box retailers generate the incentive to build state of the art mega DCs rather than smaller regional DCs (Barnard 2008).

Larger facilities permit economies of scale in management. Supervisory and management costs are spread across a larger number of employees. Per employee overhead labor

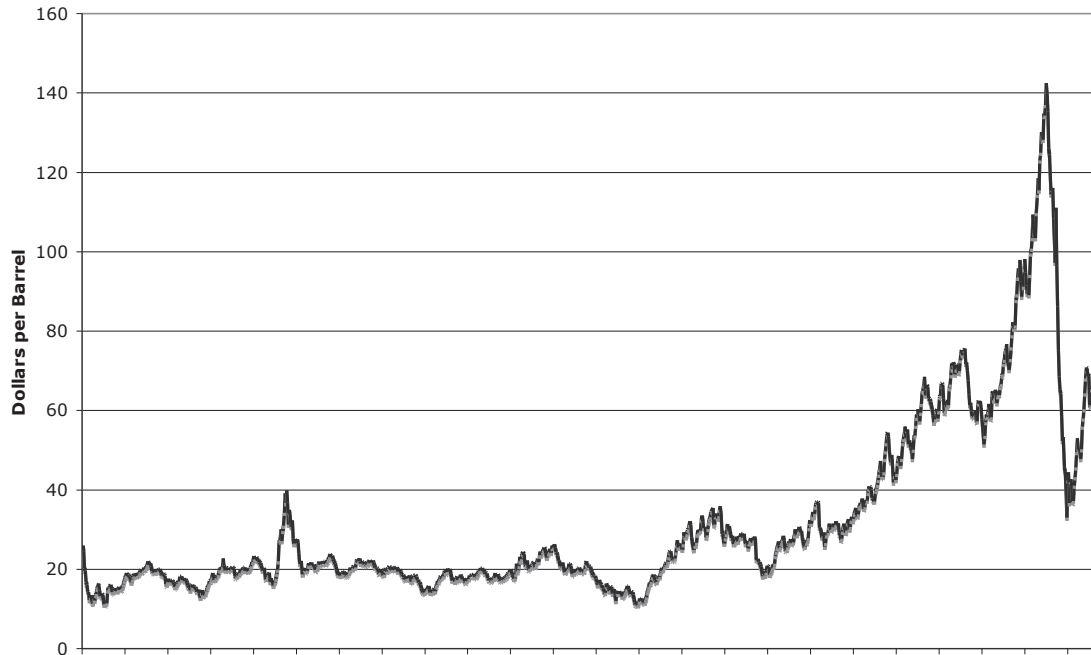


Figure 4. Weekly Cushing, OK WTI Spot Price: 1986-2009 (Source: U.S. Energy Information Agency).

expenses are thereby minimized. Our analysis of occupation employment statistics data published by the U.S. Bureau of Labor Statistics show that employee-to-management ratios grew by almost 300% over the study period. In 1998, the average warehouse manager was in charge of 12 employees. By the end of the study period, this number had grown to 32.

Larger warehouses are also able to handle the high volumes of traffic required to make 24-hour operations economically feasible. In turn, operating around-the-clock allows management to better schedule truck loading and offloading and reduce driver wait times. Extending the hours of operation also allows deliveries to be scheduled around times of typical highway congestion or to match port or rail operations hours.

### 3.3 Emerging Technologies

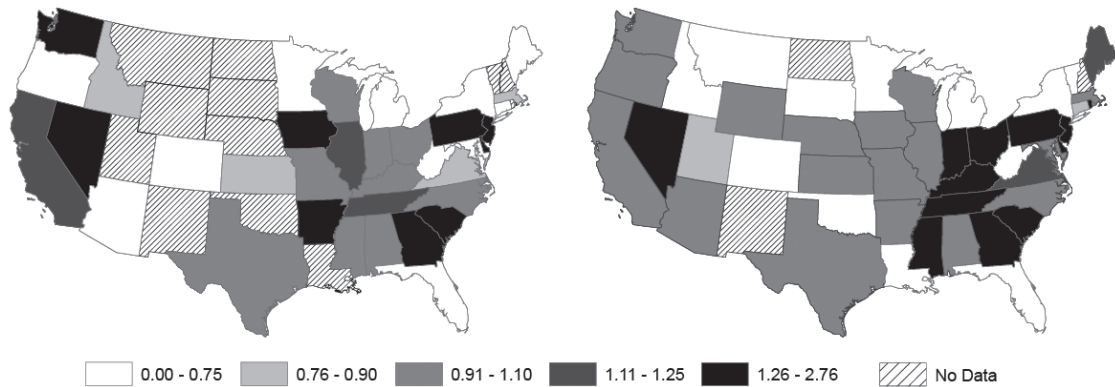
As a consequence of growth, outsourcing, offshoring, and consolidations, supply chains have become increasingly complex. This complexity has been further magnified by JIT delivery strategies, which decrease inventory carrying costs (International Workshop of Port Cities and Global Supply Chains 2007). In turn, both the temporal compression of the supply chain and the increase in its geographic complexity require the processing of greater amounts of information in shorter periods of time. New technologies have emerged to meet the demands of efficient management of substantial amounts of information.

The relationship between the drivers and enablers of structural and geographic change is largely self-reinforcing. So long as the savings accrued to economies of scale, flexibility, and international wage differentials continue to outweigh increased transportation costs, distance outsourcing and offshoring of production will persist. And so long as this situation persists, so will demand for technologies that increase a firm's ability to process information. In turn, increased information management capabilities will magnify the economies of scale bestowed on mega DCs and reinforce the economics that underlie growth in trade and FDI.

In addition to promoting economies of scale, increased velocity, streamlined management, and labor cost reductions, the growth in DC size makes it possible to serve larger market areas. Rather than predicting demand for smaller markets and having goods shipped to regional DCs, mega DC-based supply chains engage a much easier task: supply chain managers predict demand at a more aggregate level, then ship goods from the mega DC to producers and retailers on a JIT basis. As a consequence of the push-pull orientation, market demand predictions become more accurate.

## 4. GEOGRAPHIC IMPLICATIONS

Due to the emergence of mega DCs serving mega markets, it seems unlikely that the geographic pattern associated with the siting of new establishments will mimic earlier patterns. In order to test this hypothesis, a number of geographic



**Figure 5.** Warehousing Location Quotients by State: 1998 and 2005 (Source: U.S. Census County Business Patterns).

analyses were conducted. At the state level, location quotients were calculated for both 1998 and 2005, and a shift-share analysis was also conducted using data from those same years. The number of mega DCs was also mapped at the county level, and a global Moran's I statistical analysis was then used to determine whether mega DCs were evenly distributed, randomly distributed, or distributed in a clustered pattern. While a random pattern indicates that there was no underlying spatial logic, a clustered pattern indicates that tangible spatial assets attract mega DC investments.

#### 4.1 Warehousing Employment: State-by-State Comparison of Location Quotients

Location quotients (LQ) measure the relative concentrations of warehousing employment by state and offer a measure of competitive advantage. Location quotients are calculated by dividing the percentage of the total workforce employed in warehousing at the state level by the percentage of the workforce employed in warehousing at the national level. Values over 1.0 indicate that a state enjoys a competitive advantage, while values less than 1.0 indicate the opposite.

The map on the left in Figure 5 shows that in 1998 the states in the highest category — where location quotients are greater than 1.25 — were distributed evenly across the U.S.. The map on the right shows that a new geography had emerged by 2005. Competitive advantage had shifted to the corridor bounded by Indiana to New Jersey in the North and Mississippi to Georgia in the South. Within this band only 5 of 15 states are *not* in the highest category. Of them only one state is classified in the lowest category, three have relatively neutral LQs (.91 to 1.10), and Virginia, with a LQ of 1.21 only narrowly misses inclusion in the highest category.

Of the 35 states not located in this band, only two — Nevada and Rhode Island — are top performers. The final trend to note, is that in 1998, data were suppressed in eleven states in order to protect the privacy of individual respondents. By 2005, that number had dropped to only three. This trend reflects an increase in the number of warehouses in these states. When there are only a few warehouses, employment is recorded as a range rather than an absolute number in order to protect the privacy of the individual establishment. This decline reflects the overall growth of the industry.

#### 4.2 Warehousing Employment: State-by-State Comparison of Local Factors Components

Location quotients are useful metrics for comparing performance across areas. However, because location quotients are ratios of ratios, shifts in total local employment and total national employment impact the final value as much as shifts in industry-specific employment. In order to overcome this obstacle, a shift-share analysis was conducted using the same CBP data that were used to calculate the location quotients.

Shift-share analyses break growth/decline into three components: the national share component, the industry mix component, and the local factors component. We are only concerned with one: the local factors (LF) component. The LF component of growth is calculated by subtracting observed industry change over a specified time period at the national level from the observed industry change at the local level over the same time period. The LF component is a measure of shifts in competitive advantage. It can be expressed in relative terms (% growth) or absolute terms (number of jobs). Positive LF values indicate that a state gained competitive advantage whereas negative values indicate a loss of competitive advantage.



**Figure 6.** Location Quotients and Local Factors Components of Growth (Source: U.S. Census County Business Patterns database).

The shift share analysis indicates that competitive position was significantly advanced in eighteen states\*. These states added at least 20% more warehousing jobs than they would have added had warehousing employment in these states simply grown at the same rate as the nation on the whole. Ten of these states added at least twice as many warehousing jobs.

By plotting location quotients (1998) against local factors components (see Figure 6 below), we can simultaneously identify: 1) the states which enjoyed a competitive advantage in 1998, and 2) the states which have advanced their competitive position. The size of the proportional symbol reflects total warehousing employment in the state.

In a stable industry, one would expect a strong, *positive* relationship between location quotients and local factors values because states with a competitive advantage at the beginning of the study period should, by definition, find it easier than lagging states to advance their industry presence. Alternatively, as firms restructure and seek economies of scale made possible by emerging technologies and made

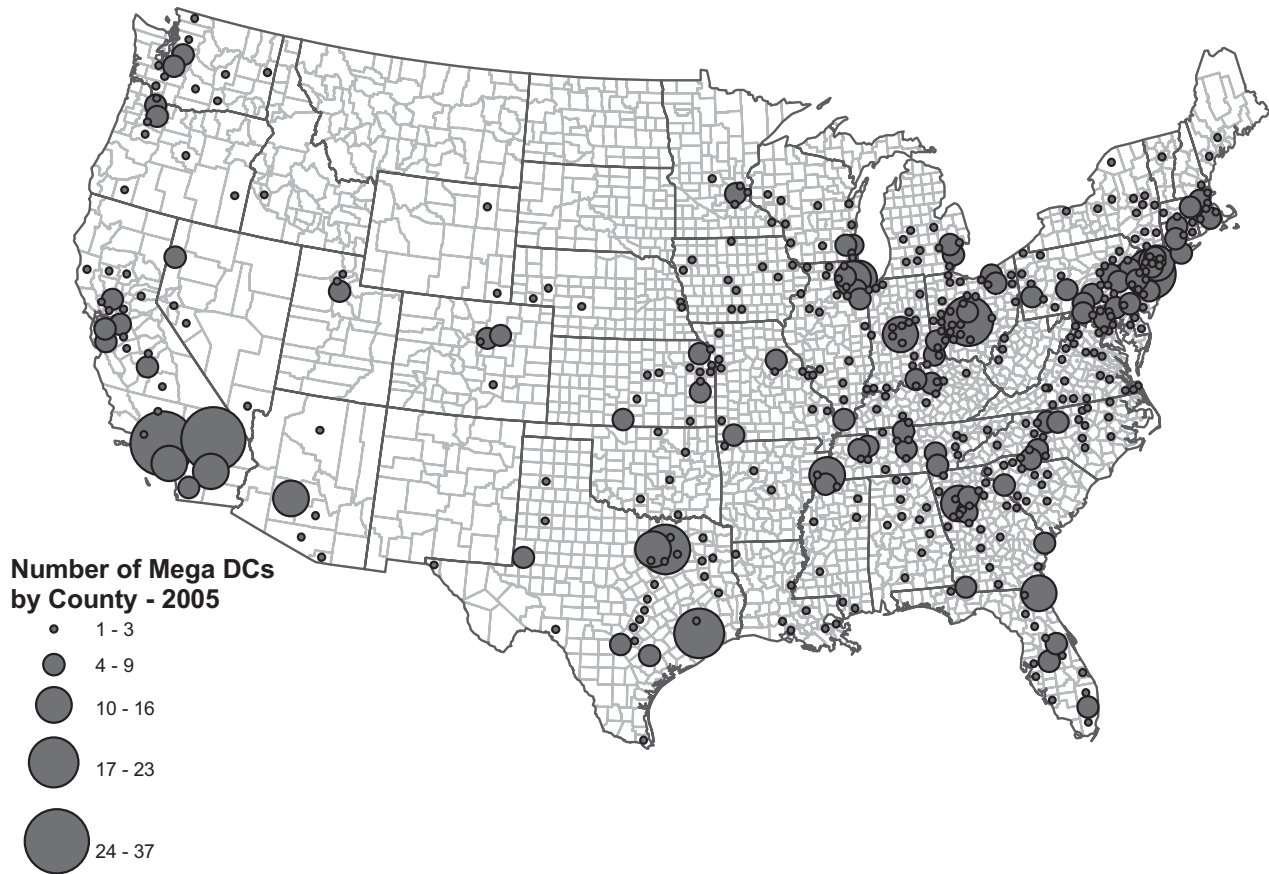
feasible by forces of globalization, we may expect to see a spatial reconfiguration where new establishments are located according to a new distribution logic. Figure 6 shows that the correlation coefficient between location quotients (1998) and local factors components is strong but *negative* ( $r = -0.59$ ). States with high location quotients were more likely to have lower local factors components than what we might otherwise have labeled 'less competitive' states.

What becomes clear from this analysis of location quotients and local factors components is that the *structural change experienced by the industry is associated with a new spatial logic*. If this were not the case, then we would expect to see a strong, *positive* correlation between the two indicators. Of interest to the argument presented here is that the port states of California, Washington, and New Jersey lost competitive advantage to interior states like Kentucky and Tennessee despite their proximity to both markets and points of entry.

### 4.3 County-by-County Comparison of the Growth of Mega DCs

While state level performance evaluations are an interesting indicator of macro trends and are useful for formulating state level policies, we conducted further analysis at the county level. By mapping the number of mega DCs by county (Figure 7), we are able to see that many are located in, or in close proximity to, major metropolitan centers. The

\* In order of greatest gains in the local factor component of the shift share analysis, the largest gainers are: Arizona (672.5%), Maine (514.9%), Connecticut (365.4%), Oregon (308.9%), Maryland (283.5%), Virginia (219.9%), Kentucky (215.6%), Indiana (183.1%), Tennessee (176.0%), Ohio (135.8%), West Virginia (79.9%), Florida (75.4%), Kansas (58.7%), Massachusetts (54.2%), Mississippi (51.3%), Georgia (35.2%), Michigan (34.5%), and Minnesota (20.5%).



**Figure 7.** Number of Mega DCs by County: 2005 (Source: U.S. Census County Business Patterns).

greatest number of Mega DCs are located in coastal counties of California and the Northeast. When statistics on mega DCs are normalized to total state employment — a proxy measure of population — however, these highly populated counties fall into the lowest category (Figure 8). By conducting a global Moran's I analysis on the population normalized index of mega DCs by county we are able to establish whether a phenomenon is randomly distributed, evenly distributed, or distributed in a clustered pattern.

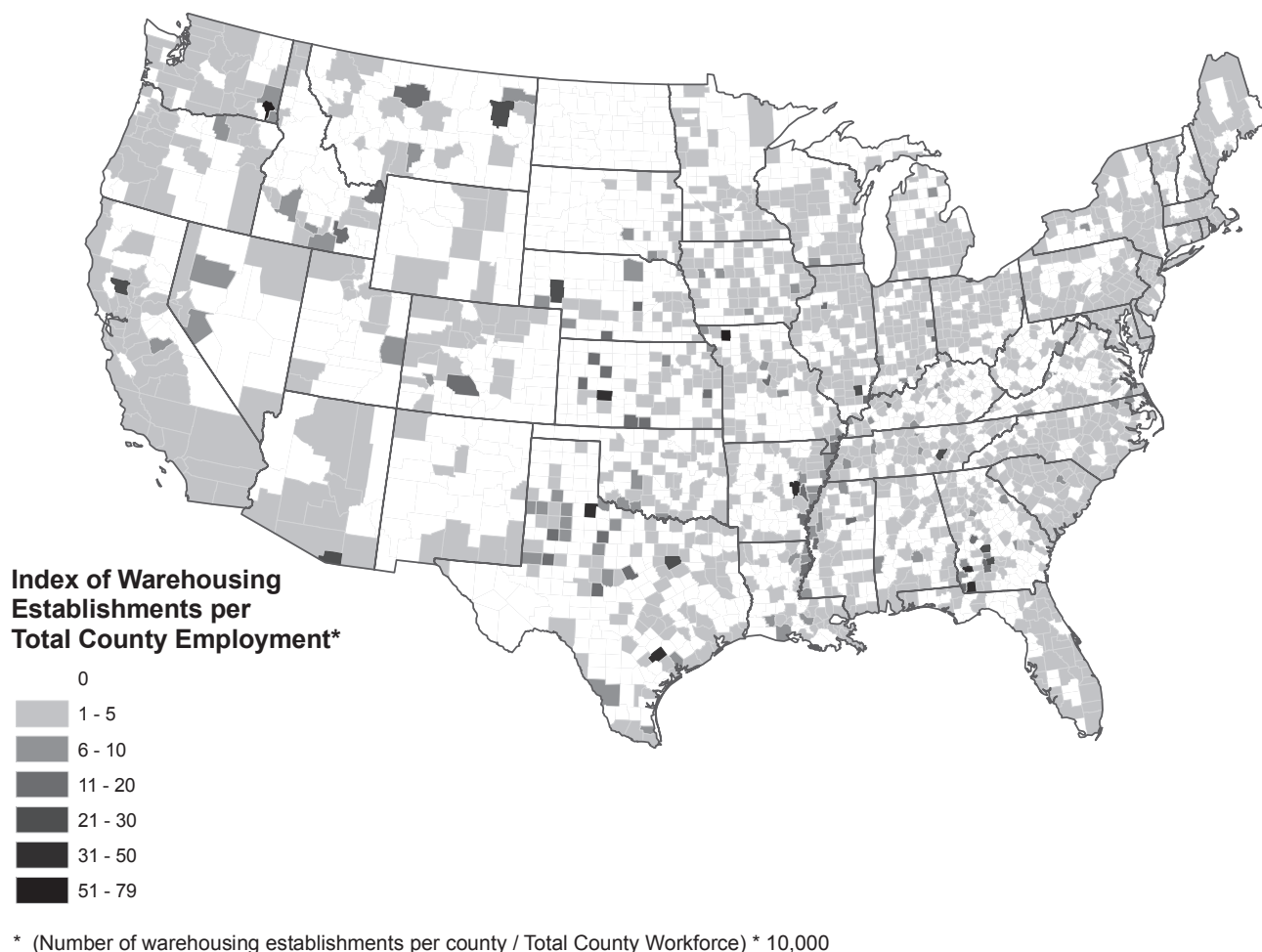
In a global Moran's I analysis, a z-score above 2.84 indicates a high degree of geographic clustering, while a value below  $-2.84$  indicates an even distribution. Z-scores near zero indicate a random pattern of distribution. When the analysis is run on the number of mega DCs normalized to total county employment, the product is a z-score of 8.4 (confidence level = .01). This analysis shows that mega DCs are strongly clustered, and there is less than a 1% probability that this pattern is the product of chance.

We see that much of the new growth in mega DCs is located in relatively remote counties like Shelby County, Tennessee and its neighbor, De Soto County, Mississippi. The population of these two counties combined is roughly

973,000. Despite the low population, 23 mega DCs are located there. By comparison, the population of King County, Washington was over 1.8 million in 2005, yet only seven mega DCs are located there. The pattern of new mega DCs echos this configuration. By example, 22 of the 23 mega DCs located in Shelby and De Soto Counties were established during the study period. To contrast these statistics with a similar county with much more immediate market access, we turn to Middlesex County, New Jersey. With a similar population (790,000), and an equal representation of mega DCs (23 in 2005), we note that only 16 of the mega DCs located there are newly established.

Through this geographic analysis, we see that the locations with high access to a single regional population center remain desirable. We also see, however, that a new breed of mega DC has emerged which optimize access to multiple regional markets. This finding affirms and complements both Bowen's and Cidell's implications of an emerging dualism in the U.S. warehousing industry.

From a line-haul cost perspective, this spatial restructuring has increased dependence on trucking as the last leg of the supply chain has become, on average, longer. Consequently,



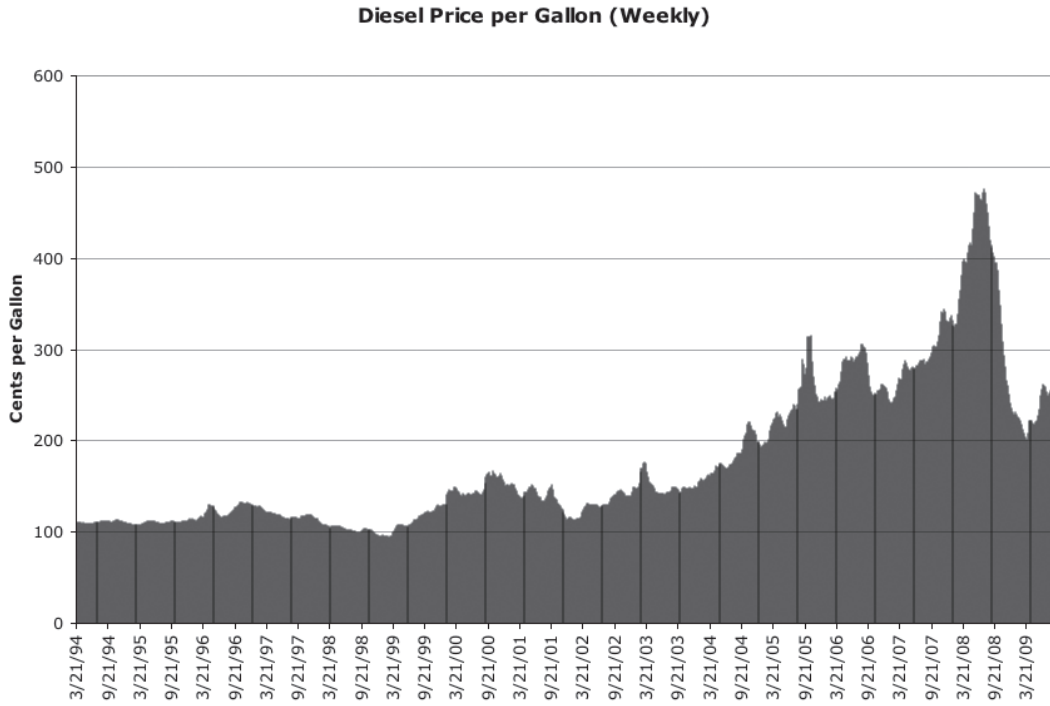
**Figure 8.** Index of Warehousing Establishments per Worker: 2005 (Source: U.S. Census County Business Patterns).

supply chains which have organized around the logic of the mega DC serving mega markets have increased their exposure to high and volatile fuel prices. In an effort to minimize costs (through economies of scale) and uncertainty associated with demand forecasting (through the creation of mega market areas), supply chains based on the logic of mega DCs have increased exposure to the uncertainty of fuel prices.

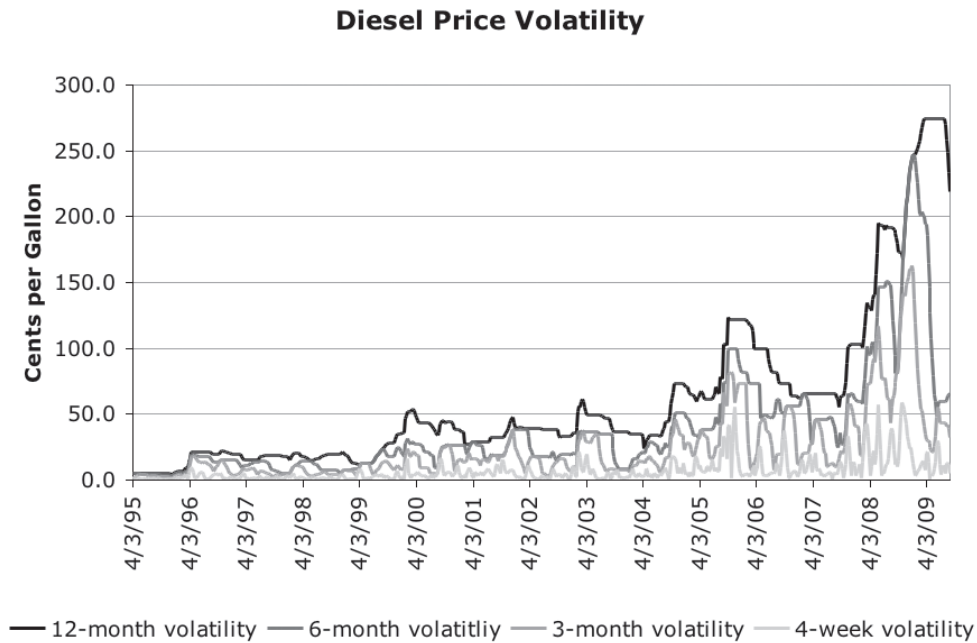
## 5. FUEL PRICES AND THE FUTURE OF MEGA DCs

Mega DCs serving geographically expansive markets began to emerge after more than a decade of persistently low and stable fuel prices (Figures 9, 10, and 11), and as noted earlier, the fastest period of mega DC growth occurred around the historic price trough of 1998-1999 when oil industry prognosticators talked of a world that was “awash with oil” which was likely to persist for decades (*The Economist* 1999).

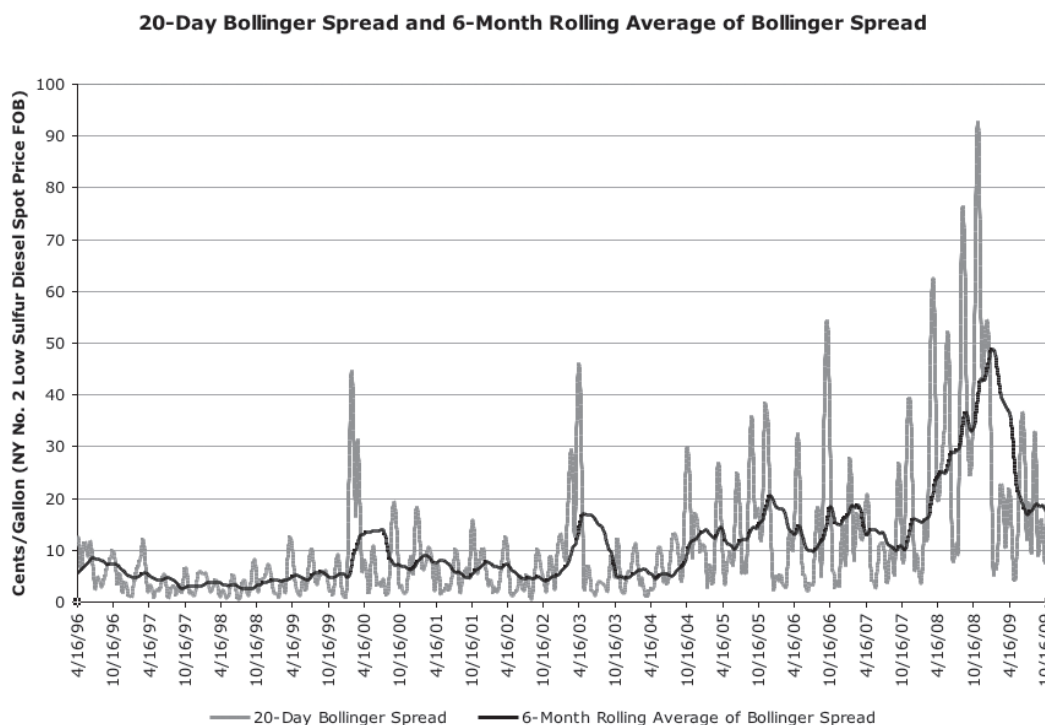
Simchi-Levi *et al* assert that “many of the current distribution strategies including JIT, quick and fragmented deliveries, and using one’s dedicated fleet are all based on the assumption of cheap oil” (Simchi-Levi, Nelson, Mulani, and Wright 2008). The price of diesel averaged just over one dollar per gallon between 1994 and 2000, then the price more than quadrupled, rising from \$1.14 in January 2002 to \$4.76 by July 2008. This price climb resulted in a real cost increase for trucking of 60 cents per mile. This equates to a compound annual growth rate of 24.6%. Since the price peak, the world economy has fallen into a serious recession. As economic output and trade has declined, so too did demand for — and consequently, the price of — both crude and its distillates (though other factors were also at work). By October the price for a gallon of diesel had fallen by \$1.10, and by November the price had fallen an additional dollar. The price eventually bottomed out at \$2.02 per gallon in March of 2009 before climbing back up 33.7% to \$2.70 per gallon by October of 2009.



**Figure 9.** Average Weekly Diesel Price Across the U.S.: 1994-2009 (Source: U.S. Energy Information Administration).



**Figure 10.** Diesel Price Volatility Expressed as The Maximum Move: 1995-2009. (Source: U.S. Energy Information Agency)



**Figure 11.** 20-Day Bollinger Spread and 6-Month Rolling Average of Bollinger Spread: 1995 - 2009 (source: U.S. Energy Information Agency)

The ‘maximum move’ is a simple measure of price volatility which is calculated by subtracting the minimum value from the maximum value for any defined time period. Using this measure, diesel price volatility was calculated using four different time periods to define the series (12 months, 6 months, 3 months, and 4 weeks). The results (Figure 10) show that volatility was very low between 1996 and 1999. During this period average 12-month and 6-month volatility was 15.1 cents and 10.1 cents, respectively. This period of stable prices came to an end in late 1999. Between 1999 and 2002, 12-month and 6-month volatility more than doubled to 36.2 cents and 23.0 cents, respectively. Then between 2004 and 2005, volatility more than doubled again — this time across all time periods. Between September 2007 and March 2009, 12-month volatility rose five-fold from 55.4 cents to 274.4 cents per gallon. In the three years between June of 2005 and June of 2008, 4-week volatility peaked higher than the highest peak in 12-month volatility 8 times.

Bollinger bands (Figure 11) offer a different measure of volatility. Bollinger bands are calculated by taking the difference between a high value (computed by adding two standard deviations to a rolling 20-day spot price average) and a low value (computed by subtracting two standard deviations from the rolling 20-day spot price). The Bollinger spread

represents the range required to account for roughly 95 percent of all daily prices over the previous 20 days. Hence, large Bollinger spreads reflect the amount of recent price volatility.

In Figure 11, two data series are shown: the Bollinger spread (the black line) and a 6-month rolling average of the Bollinger spread. From this data, four unique periods emerge. In chronological order, we see a very low period of volatility which lasted from April 1996 until December 1999. During this period, the Bollinger spread rarely broke 10 cents per gallon. Not only were diesel prices historically low, they were also relatively stable. This period was followed by a short period of significantly higher but declining volatility. Here we see a large spike (roughly 45 cents per gallon) followed by progressively smaller spikes of 20, 18, 16, and 12 cents each. During this period, the average on-highway price climbed from a low of slightly less than \$1.00 per gallon to a high of \$1.67 per gallon before falling back to \$1.16 per gallon. This equates to a cost increase of 8.5 cents per truck mile.

A second brief spike in price and volatility is associated with the lead up to the U.S. invasion of Iraq. During this period, the price climbed to \$1.75 per gallon before falling back to \$1.42 per gallon and the Bollinger spread spiked to 46 cents per gallon.

A third distinct period extends from early 2004 to September 2006. This period is characterized by high and variable volatility and a steady climb in the price of diesel. This period roughly equates to the point at which global supply of crude rather suddenly broke from a rising trend. Hamilton (2009) explains that the price run in crude resulted from a situation in which tightening supplies paired with inelastic OECD demand and rising emerging market demand, though other factors were also at play. As the price of crude rose, so too did the price of diesel – from roughly \$1.42 per gallon to \$3.03 per gallon. The impact on truck fuel costs of this jump was 27 cents per mile. The rise in price was not smooth, but rather punctuated by high and rising volatility.

A fourth period followed where the Bollinger spread climbed quickly to nearly 93 cents per gallon, meaning that at this time, the maximum and minimum per gallon diesel price fluctuated by *more than* 93 cents per gallon in *less than* three weeks. Over this period, prices nearly doubled from \$2.45 to \$4.72 per gallon (with the impact on truck fuel costs per mile of 75 cents per mile). Shortly after the spike, the economic crisis of 2008 drove the world economy into deep recession. Demand for crude declined along with economic output, and by March 2009, the price for a gallon of diesel fell to \$2.00. Despite the persistence of the recession and low diesel demand, prices had climbed back up to \$2.67 per gallon by August 2009, and volatility returned to a level 2 to 3 times greater than was experienced in the first period.

Even if prices stabilize near the current price of \$2.67 per gallon this figure is more than double the average price per gallon which prevailed between 1994 and 2004, when the new breed of DC, the mega DC serving mega markets, proliferated. Clearly, prices have become increasingly unpredictable, and price forecasts have become equally unreliable.

Unstable crude prices impact distribution strategies. In the short run, rising prices increase inventories as distributors seek economies of scale in individual shipments. In the long run, high prices *and* high volatility may shift advantage back to regional DCs as distributors capitalize on differentials in fuel efficiency across modes.

History has shown that during periods of economic growth, demand for transportation fuels climbs relentlessly. As demand increases, an increasing amount of transportation fuels will come from increasingly expensive unconventional sources and from conventional sources located in non-OECD regions. Under the most likely scenarios, a return to growth will eventually result in a further tightening of the world oil market. Not only will this put upward pressure on prices, our analysis shows that tight markets also greatly increase volatility as the price impact of even small or temporary supply constrictions is magnified. These disruptions can come in the form of intentional disruptions at any one

of the major supply chokepoints or through force of nature such as hurricanes Katrina and Rita. When spare capacity is tightened, inelasticities in demand drive prices up rapidly, and small supply disruptions will express themselves through rising volatility.

## 6. CONCLUSIONS

The interplay between emerging technologies and forces of globalization has permitted warehouses to grow in size and benefit from economies of scale. It has also allowed the optimization of push-pull supply chain strategies. Long-term demand forecasts are made for market areas served by mega DCs (push) allowing the final leg of the distribution network to be guided by demand within these mega markets (pull). By extending the geographic extent of the market area, uncertainty in demand forecasting is reduced. Through the application of new information technologies, velocity increases, and carrying costs are minimized. While uncertainty related to predicting market demand is minimized, the final leg of the supply chain becomes – on average – longer. Demands of just-in-time (JIT) delivery strategies require that trip scheduling from the mega DC to the site of final delivery be flexible, and therefore, the final leg of the supply chain must be made by truck – the most costly, energy intensive, and polluting form of surface transportation per ton-mile (Muller 1999).

In this paper we explain the changing structure of the warehousing industry, the micro- and macroeconomic logic underlying the rise of mega DCs, the geography of the emerging logistics landscape, and the role that inexpensive transportation fuels has played in this change process. We further show that rising fuel prices and high price volatility expose mega DCs serving mega markets to fuel price uncertainty, and higher costs when fuel prices rise. As such, rising prices and high volatility diminish the real and perceived advantages of organizing supply chains around the logic of the mega DC.

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