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WHAT’S DRIVING ENTREPRENEURSHIP AND INNOVATION IN THE TRANSPORT SECTOR?

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ABSTRACT

In this chapter we draw from existing literature and a range of statistics to describe economic, entrepreneurial and innovative activities in the transportation and warehousing sector of the U.S. economy. We suggest multiple avenues for future work, and argue for more research on the role of warehousing in particular. Recent trends suggest that the warehousing and storage subsector is experiencing rapid economic and technological changes, likely reflecting shifts in how consumers purchase goods. We also review several other recent innovations, including ride-sharing and autonomous vehicles, that are starting to affect this sector of the economy.

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1. Introduction

The transportation sector—including the movement and storage of physical goods and the movement of people—is an important contributor to the U.S. economy. It directly accounts for 3.2% of U.S. gross domestic product (GDP), and indirectly affects many other sectors (Figure 1). Personal transportation makes up a large portion of American consumption; according to the Bureau of Transportation Statistics, households spent an average of $9,737 on transportation in 2017, the second largest household expenditure category after housing.[1] Economists have highlighted the multiple ways in which transportation affects innovation and growth, including opening up geographically distant markets for entrepreneurs (Donaldson 2018), linking together people and thereby increasing the recombination of ideas (Agrawal, Galasso, Oettl 2017), sparking new innovations by the arrival of a new product (Sohn, Seamans, Sands 2019), and more.

Across the U.S. economy, firms are increasingly adopting new technologies, including artificial intelligence (AI), robots, sensors, and others, and the transportation sector is no different. For example, Uber bought autonomous trucking startup Otto for $680M in 2016[2] and Amazon bought warehouse robotics company Kiva for $775M in 2012.[3] While fully autonomous vehicles are still some ways off in the future—a topic we discuss later in this chapter—Kiva has led to dramatic changes in the way that Amazon organizes some of its fulfilment centers. Whereas in the past a human picker would go up and down aisles of shelving units to pick the order, now the Kiva robots bring the shelving units to a central location in which the human picker is located (CEA, 2016).

The costs associated with moving goods and individuals differ greatly. While the real cost of moving goods is 90% less than it was at the beginning of the 20th century, transporting individuals remains costly (Glaeser and Kohlhase 2004). In this chapter we review recent trends in the transportation sector and conduct deeper investigations into recent changes and innovations in the movement (and storage) of a) goods and b) people.

The key takeaways from this chapter include:

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[1] https://www.bts.gov/browse-statistical-products-and-data/transportation-economic-trends/tet-2018-chapter-6-household
[2] https://techcrunch.com/2016/08/18/uber-acquires-otto-to-lead-ubers-self-driving-car-effort-report-says/
[3] https://techcrunch.com/2012/03/19/amazon-acquires-online-fulfillment-company-kiva-systems-for-775-million-in-cash/

- Despite the rapid expansion of internet-enabled services and the digital economy, the importance of transporting physical goods has not diminished.
- In aggregate, the transportation sector has grown (20% employment growth over five years), but this average increase masks large differences in the composition of the transportation sector (rail and sea transport are down, couriers and warehousing are up).
- Transportation's share of value added in the economy has also increased (an absolute increase of 0.3% over five years).
- As such, warehousing and the automation contained therein (robots, autonomous vehicles, drones) will play a critical role in this increasingly important component of the transportation supply chain.

In the sections that follow we first describe what we currently know about the sector from prior academic research and aggregate government statistics. We then highlight recent innovations in the transportation and storage of goods, with a deep dive into the warehouse sector — an area of increasing activity. We then review existing work in the personal mobility domain, focusing on the impact of ride-sharing platforms and the potential for autonomous vehicles to transform the economy. How these new innovations affect the sector and the economy more broadly will ultimately depend on a variety of factors including government regulation, technological advancement, and customer demand. In our final section, we conclude and discuss opportunities for future work.

2. What Do We Know?

2.1. Prior Literature

Prior literature has highlighted the many ways in which transportation can affect innovation and economic growth. As the exchange of goods and services is contingent on the movement of materials and workers, transportation plays a key role in economic output. Investments in infrastructure and transportation technologies transform the urban landscape, and spur productivity growth and innovative activity.

Innovations in transportation infrastructure directly impact the spatial distribution of workers. Baum-Snow (2007) finds that the development of interstate highways contributed to the post-World War II sub-urbanization of the United States. Along with contributing to population shifts within cities, transportation influences the distribution of work across cities. Duranton and Turner (2012) estimate that a 10% increase in a city's initial stock of highways leads to a 1.5% increase in employment over a period of two decades. Taken together, these results indicate that transportation infrastructure has two distinct effects on input reorganization and growth: it can increase urban employment growth while also leading to population growth in surrounding areas (Redding and Turner 2015).

In addition to this work estimating the long-run effects of interstate highway development, other researchers have focused on the localized effects of within-city transportation infrastructure. In particular, studies have investigated the value of these transportation networks through estimating the proximal effects of subway line development on real estate prices. Billings (2011) finds that access to light rail transit increased single-family property values by 4%, and condominium values by 11%. Gibbons and Machin (2005) study the London subway network and find that homes near newly developed stations experienced price increases of around 9% relative to those unaffected by transportation changes. The authors compare the price effects of proximity to subway stations to the price estimates of other local amenities such as primary school performance and find that households seem to value transportation higher relative to other local factors.

Changes to the flow of people are accompanied with innovative activity; transportation's positive impacts on economic performance through worker movement are also the product of resulting positive knowledge externalities. Agrawal, Galasso, and Oettl (2017) find that the stock of regional highways increases inventive productivity not only through its labor agglomeration effects but also through improvements to knowledge flows—increasing output beyond that explained by the influx of new innovators. Perlman (2016) provides historical evidence that the 19th century "transportation revolution"—marked by the development of railroad networks—increased patenting activity through increased market access, among other covariates.

In addition to its impact on the geography of labor, transportation infrastructure serves as a catalyst to firm growth and productivity. Gains in accessibility to new roads lead to increases in the number of establishments, employment, and output per worker (Gibbons et al. 2019). Baum-Snow et al. (2017) further decompose the effects of highway growth on economic activity in China; they find that areas most proximal to dense highway networks show increased output, employment, and wages, and shift towards business services and manufacturing. Distal areas from these clusters demonstrate an opposite effect; they grow more slowly, and specialize in agriculture.

These economic benefits to transportation may rely on improvements to the transfer of physical goods. The development of colonial India's railroad system transformed agricultural trade; through decreasing the cost of transporting origin-destination products and increasing trade flows, this expansive change in transportation infrastructure increased per-capita agricultural incomes (Donaldson 2018). Additionally, economic gains to transportation may require sufficient ease of transporting capital along with goods. In examining the effects of railway access on economic growth, Banerjee, Duflo, and Qian (2012) find suggestive evidence that production factor immobility may limit the localized economic benefits to transportation infrastructure. These studies highlight the distinction between worker and capital flows; the regional benefits to government investment in transportation networks may be limited by the movement of physical production factors.

Historically, waterways have played a crucial role in determining market access, economic development, and innovation. Sokoloff (1988) finds evidence that navigable waterways explain early regional variation in patent activity across the United States. The author suggests that during the Industrial Revolution, areas like Southern New England and New York exhibited high growth in patenting due to increased access to low-cost river and canal transportation. The economic changes attributable to transportation infrastructure are persistent long after initial natural advantages afforded by geography become obsolete. Bleakley and Lin (2012) find that despite the decline in portage in the south-eastern United States, original portage cities remain denser than comparable regional counterparts, suggesting a degree of path dependence resulting from historical transportation activity.

More recent work has begun to focus on a more basic form of transportation infrastructure: the walkability of streets. In Roche (Forthcoming), the author examines how the physical layouts of street networks facilitate idea exchange amongst knowledge workers. The paper demonstrates that neighborhoods that are easier to traverse by foot also produce more patents (even after controlling for population and other density related measures) and are more likely to build upon geographically proximate knowledge inputs.

2.2. Basic Statistics

In the United States, the transportation sector (NAICS codes 48-49) contributes approximately 3% to U.S. GDP and comprises multiple sub-industries including air, rail, water, truck, pipeline, and passenger transport. It also includes couriers, messengering, warehousing, and storage businesses. Descriptive statistics of select sub-industries are presented in Table 1. Between 2013 and 2018 sector-wide employment grew by over 20% and real wages grew by 1.7%. However, this aggregate growth masks significant heterogeneity. Over the same period, rail and water transport saw 7% and 1% declines in employment, respectively. Conversely, the warehousing and storage (NAICS 493) and couriers and messengers (NAICS 492) sub-industries experienced the largest employment growth of all sub-industries with 59% and 33% employment, respectively. These two industries also saw real wage growth of 3% for warehousing and 15% for couriers and messengers. Providing a deeper understanding of the antecedents and consequences of this rapid growth in the warehousing sector will be an important point of focus for this chapter.

Figure 1 presents data on employment by transportation sub-industry over a longer time period. Using data from the BLS Current Employment Statistics (BLS CES) survey to provide employment by transportation sub-industry, we see that the growth in warehousing started in 2010. Drawing from Bureau of Economic Analysis data, Figure 2 plots value-added by transportation sub-industry, as a fraction of national GDP. We see that all transportation/warehousing industries make up an increasing share of aggregate economic activity, increasing from 2.8% in 2005 to 3.2% in 2018. Figure 3, using data from BLS CES, provides real average weekly earnings from 2006 onwards,[4] by transportation sub-industry. On average, wages in the industry appear relatively flat over this entire time period. However, there is some heterogeneity across sub-industries. These data suggest that as demand for transportation services increases, the industry is able to adjust relatively quickly at the margin by employing more individuals, such that wages do not rise much.

Figure 4 plots labor productivity by transportation sub-industry, measured with BLS's Annual Index of Labor Productivity. The figure shows changes in output per hour relative to 2007 levels. Most sub-industries appear to have relatively flat productivity, although air transport has increased steadily over the almost 30-year times series between 1990 and 2018. As such, the employment growth in the sector appears to not be a result of changes in labor productivity and instead may stem from broader changes in market structure (Combes and Lafourcade 2005).

[4] The BLS CES only publishes wage estimates at the industry level from 2006 onwards.

Figure 5 plots trends in the relative number of establishments by transportation sub-industry. The data come from the BLS Quarterly Census of Employment and Wages. The series are normalized to show establishment levels relative to 1990. While the number of establishments has increased in all sub-sectors, we find that growth in the Couriers and Messengers sub-industry outpaces that of all other sub-industries, followed by Warehousing and Storage.

Next we study two measures of innovative activity—patenting and venture capital investment. Figures 6 and 7 compare patent activity by transportation sub-industry over time. The data come from PatentsView. We find that from 1980 onwards, the number of vehicle-related patents outpaces the number of conveying, packing, storing, and other warehousing-related patents. Additionally, among less-frequently patented codes, non-rail land vehicle and aircraft-related patents outpace other categories, including those for ships and railways.

Figure 8 plots transportation-related funding over time (in U.S. Dollars). The data come from CrunchBase. We find that relative to other activities, funding for warehousing companies shows dramatic growth later in our timeframe. Whereas funding for autonomous vehicles (AV), shipping, and general transportation-related companies increases beginning in 2012, warehousing funding picks up in 2015 in our sample.

Finally, we consider adoption patterns from automotive technologies in the past. In Figure 9 we plot technology adoption s-curves for various automobile transmission technologies. Our data come from the United States Environmental Protection Agency (EPA). We define advanced transmission as having six or more gears. These data show that advanced transmissions were adopted by the majority of manufacturers faster than automatic transmission with lockup.

In Figure 10, we plot technology adoption s-curves for various engine technologies. These data come from the EPA. Variable valve timing (VVT) and gasoline direct injection (GDI) demonstrate considerable growth in production share. Multi-valve engines demonstrate a longer period of adoption, reaching around 90% of production share over a period of 37 years. Stop/start and turbocharged engines do not yet make up a majority of engine production in our timeline. The broad takeaway from Figures 9 and 10 is that new technologies can take many years before achieving widespread use, and there is heterogeneity across technologies. We keep these patterns in mind as we consider the potential effects of new technologies.

3. Moving and Storing Physical Goods

3.1. Literature

As noted, transportation's most aggregate industry classification (NAICS code 48-49) includes both transportation and warehousing-related activities. While transportation has received considerable interest from economists, warehousing has received less attention. One reason for this may be the larger impact that air and truck transport have in contributing to GDP (Figure 1) relative to warehousing and storage. Yet, over the past five years, growth in employment and in new establishments has been markedly higher in the warehousing sector than the overall transport sector (Table 1). In this section we examine this trend more deeply by exploring the changing role of warehousing and its interface with transportation and its relationship with the economy at large.

The effects of transportation on economic growth has been extensively documented in the economics literature and well summarized in Redding and Turner (2015). Much less has been written on the role of warehousing in the transport supply chain. One exception is a recent paper by Chava et al. (2019) where the authors find that when Amazon opens a fulfillment center in a county, employment levels at transportation and warehousing establishments in the same county grow by 2.1% while worker wages at transportation and warehousing establishments in the same county grow by 1.7%. This provides suggestive evidence of the complements that may exist between geographic co-location of warehousing/fulfillment centers of e-commerce players and local demand for additional transportation and warehousing services. It is unlikely, however, that the significant growth in warehousing employment is entirely attributable to the changing nature of retail. Figure 11 presents the warehousing employment plot first shown in Figure 1 alongside retail employment growth.

More broadly, as others have noted, there may have been a shift in consumer purchase behavior. For example, Lafontaine and Sividasan (2020) find marked growth in restaurant establishments and employment, which they attribute to an increase in consumer expenditure share for restaurant food. The authors also note that DoorDash and Instacart, two of the top delivery businesses, received substantial venture capital investments ($2.1B and $1.8B, respectively). As we indicate below, Instacart was the top hiring firm in the "transit and ground passenger" sector in 2017 and 2018 (Table 3). As another example, Relihan (2020) shows that consumers using online grocery delivery platforms change their consumption patterns by shifting time away from grocery shopping and toward visits to coffee shops. Relihan finds that early adopters of online grocery platforms reduce spending at grocery stores by 4.5% and increase spending at coffee shops by 7.6%.

Mandel (2020) points out that the shift from off-line retail purchases to online purchases requires a substantial change in the architecture of supply chains. Notably, firms like Amazon and Walmart that want to engage with consumers on a large-scale basis need to invest in warehousing to hold merchandise, fulfilment systems to organize and pack orders, delivery infrastructure to ship packages to customers, and a complementary returns infrastructure to handle orders that are sent back or dropped off at physical locations. Some of these functions need to be available at local levels, in order to serve customers quickly and efficiently, and others can be located far from customers.

3.2. Geography

The changes in employment documented in Table 1 vary by geography. The majority of warehousing employment growth has come in rural counties which have employment levels seven times higher than in 1990 (Figure 12). However, growth in warehousing employment is not solely a rural phenomenon. Urban counties have not grown at the same pace as rural ones, but employment levels are 3.5 times higher than they were in 1990. Indeed, Chava et al. (2019) note that Amazon opens fulfillment centers in counties with population densities 2.5 times higher than the average across all U.S. counties. This trend is also in line with growth of transportation companies, in particular truck transport. Figure 13 decomposes truck transport growth for establishments in urban and rural counties. As can be seen, truck transport employment growth follows similar patterns to those observed in Figure 12 but at a much smaller scale. Rural truck transport has increased by 40% from 1990 levels, while urban truck transport has increased by 25% from 1990 levels. The extent to which this increase in warehousing activity is a complement or substitute for long- and short-haul trucking is difficult to fully assess but time series data provide some suggestive relationships.

Figure 14 presents time series of warehousing and trucking employment relative to total US employment scaled to 1990 levels. As can be seen, general warehousing has increased the most wherein it has taken a 3.5 times larger share of US employment since 1990. Employment shares of used household and office goods moving as well as general freight trucking are unchanged since 1990. Conversely, couriers and express delivery services, and local messengers and local delivery employment are both up, with local messengers up significantly since 2015—a possible reflection of the increasingly important role e-commerce is playing in the retail industry. It may seem strange for us to observe such large increases in both urban-focused warehousing and transportation given the higher real estate costs of urban areas compared to rural ones. Yet, urban dwellers disproportionately make use of e-commerce retail and, as such, this demand pull has strongly affected the way in which technology is deployed and the impact it has had on entrepreneurial activity.

Figure 15 plots the changes in rank of the top counties employing warehouse and storage workers. There have been some notable shifts between 2007 and 2017, with Cook County (IL), Franklin County (OH), and Harris County (TX) experiencing drops in their rank and San Bernardino County (CA), Riverside County (CA), San Joaquin County (CA) and Dallas County (TX) experiencing rises in their rank. The results in Figure 15 mirror, at a broad level, an observation made by Michael Mandel (2018) that California and Texas have been among the biggest gainers in the shift to what he calls "consumer distribution" (e-commerce and brick and mortar retail).[5] Future research could investigate the causes and consequences of this shift.

3.3. Role of Incumbents and Entrants

Accompanying the change in economic activity for transportation and warehousing is an increase in startup activity. Much of this startup activity has been in logistics-focused firms attempting to reduce transport frictions and solving problems associated with delivering goods the 'last-mile.' One example is Fourkite, an e-commerce logistics company headquartered in Chicago that has received over $100M in venture backed funding through a Series C round of funding. Fourkite has built a supply chain platform alongside a predictive shipment arrival time algorithm to lower shipping times and costs. Technologies like these are enabling new forms of warehousing to develop in urban areas, often referred to as 'micro-fulfillment centers' that allow quicker delivery to urban customers. Another company that is working in the space of micro-fulfillment centers is Fabric. Founded in 2015, Fabric makes heavy use of robotics and small fulfillment centers in urban areas to fulfill order requests within an hour of purchase. They have raised $136M through a Series B venture round and are growing rapidly.

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[5] https://www.progressivepolicy.org/blog/the-geography-of-ecommerce-industries/

As Fabric has demonstrated, technology—both in the form of AI predictive algorithms and robotics—is playing a critical role in the development of these new warehousing forms. The company Nuro is focused on developing autonomous vehicles with the explicit purpose of delivering local goods and aiming to reduce the costs of the aforementioned last-mile delivery. They recently received $940M in financing from Softbank. While Nuro is one of the most high-profile startups in this space, a number of startups also exist including Startship Technologies, Marble, Boxbot, Robby Technologies, Kiwi Campus, Dispatch, and Unsupervised AI.[6] These technology trends may have divergent effects both for larger retailers continuing to vertically integrate into warehousing by operating ever more efficient fulfillment centers and the arrival of technology-enabled specialized micro-warehouses lowering the cost of developing viable e-commerce business models for fledging direct-to-consumer startups.

Another technology that has the potential to impact last-mile delivery is that of unmanned aerial vehicles, also sometimes referred to as drones. According to the CrunchBase database there are at least 329 drone startups operating in late 2019.[7] While some of these startups will undoubtedly not focus on logistics and transportation (and focus more on leisure applications, military, etc.), this figure may also undercount numerous companies that are still in 'dark mode.' Apart from startups, many incumbents are also increasingly thinking about the impact of drones to their businesses and a growing number of transportation companies have received clearance from the FAA to run pilot programs. As an example, in October of 2019, UPS's subsidiary UPS Flight Forward, Inc., was granted approval by the FAA to deliver medical packages by unmanned drone.[8] Not to be outdone, Amazon has launched a program named 'Prime Air' with the express intent of delivering items in under 30 minutes from purchase. In both of these instances, the geographic location of warehouses will continue to be critical as will advances in autonomous vehicle technologies. We examine the implications of improvements in the viability of autonomous vehicles on the transportation and warehousing sector next.

Despite all the excitement about new firms and technologies, it appears that most of the employment activity by firms in this sector is by established, incumbent firms. Table 2 uses data

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[6] https://news.crunchbase.com/news/robot-couriers-scoop-up-early-stage-cash/
[7] https://www.crunchbase.com/hub/drones-startups
[8] https://pressroom.ups.com/pressroom/ContentDetailsViewer.page?ConceptType=PressReleases&id=1569933965476-404

from job postings, collected by Burning Glass, to list the top five "courier and messenger" firms by year. The top three in each year are UPS, FedEx and DHL Express — this is no surprise, these are currently the dominant firms in the sector. Table 3, again using job posting data from Burning Glass, lists the top five "transit and ground passenger" firms by year. While most of the firms are engaged in transportation of people (covered in the next section), it is notable that in 2017 and 2018 the firm with the most listings was Instacart, a rapidly growing startup that specializes in same-day grocery store delivery.

Table 4 uses Burning Glass data to list the top five "warehouse and storage" firms by year. While the rank changes year to year, it is interesting to note that most of the top firms are the same each year. For example, Exel is in the top five each year except 2018. Exel is a subsidiary of DHL, one of the world's largest courier and messenger firms. As another example, Americold, the owner and operator of a network of temperature-controlled warehouses used for storage of fruits, vegetables, meats, dairy and other perishable products, is the top employer in 6 out of 9 years. Americold owned 160 such warehouses in the U.S. in 2019.[9]

4. Entrepreneurship and Innovation in the Movement of People

4.1. Introduction

As Section 3 demonstrates, the nature by which physical goods are moved and stored has changed significantly over the three decades. Yet, media focus and public attention has centered disproportionately on the movement of people. Figure 16 presents Google Trends data of internet search activity over the past 2 decades for the terms "Uber" and "Warehouse". As can be seen, warehousing has done little to change the attention (or internet query interest) of internet users, while interest in Uber and related ridesharing firms has grown significantly since the arrival of these services over the past ten years. This section will focus on the movement of people with a focus on personal mobility, the implications for autonomous vehicles, and provide a brief discussion on the externalities that will arise as a result of the increased movement of people due to entrepreneurship and innovation in the transportation sector.

[9] Americold Annual Report 2019, Form 10-K. Available: https://ir.americold.com/financials/sec-filings/sec-filings-details/default.aspx?FilingId=13971750

4.2. Personal Mobility

One of the biggest changes to personal mobility has been the rise of ride-sharing firms such as Lyft and Uber, particularly in certain urban areas. These firms differ from standard taxi firms in at least two ways. First, unlike a traditional taxi company that manages a fleet of taxicabs which either search for passengers on city streets or wait for a dispatcher to tell them where to go, ride-sharing firms rely on a digital application interface to manage the interaction between drivers and riders. Perhaps not surprisingly, then, ride-sharing is more popular among younger generations. According to the DOT's National Household Travel Survey (2019), Millennials are almost twice as likely to use ride-sharing services than Generation X or Baby Boomers.[10] In addition, ride-sharing firms rely on complex, dynamic pricing models to "manage" the number of drivers and riders. As such, the interactions between drivers and riders are similar to those in other two-sided market settings (Rochet and Tirole 2006, Parker and Van Allstyne 2005). Second, given the prominent role played by technology used by ride-sharing firms, they have argued that they should be regulated as technology firms and not as traditional taxi companies. This regulatory arbitrage has led to the seeming proliferation of ride-sharing services in a number of cities, arguably to the detriment of taxi companies. In some cases, cities have responded by banning ride-sharing altogether (Paik, Kang and Seamans 2019).

Recent research has sought to understand various economic and societal effects of these changes in personal mobility. To start, ride-sharing apps provide efficiency benefits. Cramer and Krueger (2016) attribute Uber drivers' capacity utilization rates premiums of 30-50% to the company's matching rates, larger scale, freedom from inefficient regulation, and flexible labor and pricing models. These technologies also show social benefits. For example, Greenwood and Wattal (2017) find evidence that ride-sharing has led to a decrease in vehicular fatalities associated with drunk driving. Burtch, Carnahan and Greenwood (2018) provide evidence that driving for ride-sharing firms may substitute for low-quality entrepreneurial activity. Gorback (2020) provides evidence that ridesharing's entry is associated with a doubling of net restaurant entry, and an increase in housing prices. A number of papers use incredibly rich and detailed data from ride-sharing firms to study other economic issues. For example, Cook et al. (2018) use ride-level data from a ride-sharing platform to study the determinants of gender earnings gap and Liu et al. (2018)

[10] https://nhts.ornl.gov/assets/FHWA_NHTS_Report_3E_Final_021119.pdf

compare taxi and ride-sharing ride-level data to study the extent to which digital monitoring via the ride-sharing platform reduces moral hazard on the part of drivers.

To study competitive effects of ride-sharing on traditional taxi businesses we consider how ride-sharing may affect taxi medallion sales. The 2016 *Economic Report of the President* (CEA 2016) shows that taxi medallion sales prices peaked in New York City in 2013 at over $1 million and in Chicago in 2013 at over $350,000. In Figure 17 we extend this analysis with updated data through 2018 and find that medallion prices in both cities have continued a dramatic decline. In New York, medallions are now below $200,000 and in Chicago below $50,000. These dramatic changes provide suggestive evidence that ridesharing has substituted for traditional taxi service in many cities. Berger, Chen, and Frey (2018) decompose the resulting labor market effects; they find that Uber's entry coincides with a 10% decrease in relative taxi earnings. However, the authors note that the supply and composition of the taxi labor market has remained largely the same. Additionally, research suggests that ridesharing may have spurred adaptive changes in product quality among taxi drivers; Wallsten (2015) finds that increases in Uber's popularity are associated with decreases in taxi customer complaints in New York and Chicago.

4.3. Autonomous Vehicles

Automation of driving can take multiple forms. The current standards for autonomous driving were developed by the Society of Automotive Engineers (SAE International). According to the standard, autonomous driving ranges from Level 0, with no autonomy, to Level 5, which is full automation (see Figure 18). Many vehicles sold today have features that would qualify as "Level 1" including park assist, lane assist and adaptive cruise control. A few vehicles claim to qualify as Level 2 or 3, including Tesla's vehicles, the Nissan Leaf and Audi A8.[11] Google's Waymo would be considered Level 4 or 5. No Level 4 or 5 cars are certified for use on regular roads.[12]

[11] https://www.pocket-lint.com/cars/news/143955-sae-autonomous-driving-levels-explained; https://techcrunch.com/2019/04/22/teslas-computer-is-now-in-all-new-cars-and-a-next-gen-chip-is-already-halfway-done/; https://www.forbes.com/sites/lanceeliot/2019/08/01/eyes-on-hands-off-for-nissans-propilot-2-0-rouses-level-3-self-driving-tech-misgivings/#60e628627558; https://www.wired.com/story/audi-self-driving-traffic-jam-pilot-a8-2019-availablility/

[12] https://crsreports.congress.gov/product/pdf/R/R45985

There is lots of excitement around autonomous vehicles (AVs). Some have referred to it as the "AI killer app".[13] However, there is lots of disagreement around how long it will take for AVs to become widespread, and also lots of uncertainty about the ultimate effect of AVs on the economy. On one hand, in 2018 Elon Musk predicted that there would be a Tesla driverless taxi fleet by 2020.[14] On the other hand, Chris Urmson, who was a DARPA challenge winner, head of Google's Waymo autonomous vehicle unit, and now CEO of a self-driving vehicle software company, argues it may take up to 30-50 years before widespread adoption of autonomous vehicles.[15] To put these predictions into perspective, recall from Figures 8 and 9 that historically widespread adoption of new innovations in the auto sector can take several decades, as automobiles are long-lived, durable assets. Ultimately, a number of factors will affect the timing of adoption, including technological development, consumer preferences and tastes, and regulatory landscape.

Researchers have begun to explore the economic and behavioral outcomes that may result from these technologies. Gelauff, Ossokina, and Teulings (2019) model two components of automation which lead to differing outcomes on population distribution: improved use of time during car trips, which lowers the cost of living at a distance from cities, and improved door-to-door public transit, which has the countervailing effect of lowering the costs of living in urban environments and may lead to increased population clustering within cities. Finding considerable welfare benefits resulting from these technologies, the authors suggest that these effects may lead to overall population shifts towards large, attractive cities at the expense of smaller urban, as well as non-urban, areas. Additionally, Kroger, Kuhnimhof, and Trommer (2019) project the adoption of autonomous vehicle technologies in the U.S. and Germany, and estimate that the introduction of AVs will increase vehicle traffic by 2-9%, as a result of new automobile user groups, as well as lower generalized costs of car travel. However, others have argued that the conversion of all drivers into passengers may result in a substantial reduction in travel costs and thus increase vehicle traffic substantially more (Duranton 2016).

4.4. Regulation

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[13] https://www.forbes.com/sites/chunkamui/2013/08/23/google-car-uber-killer-app/#2620f33d600a
[14] https://www.theverge.com/2019/4/22/18510828/tesla-elon-musk-autonomy-day-investor-comments-self-driving-cars-predictions
[15] https://www.theverge.com/2019/4/23/18512618/how-long-will-it-take-to-phase-in-driverless-cars

The speed of adoption of new technologies such as autonomous vehicles will depend in large part on federal rules and regulations. We highlight two notable developments in this section. One notable development on the regulatory landscape is the U.S. House and Senate nearing compromise language on legislation that would provide NHTSA with the authority to regulate AVs. This is significant as it would allow NHTSA to develop nationwide federal regulations for AVs, rather than allowing a patchwork of state-level AV regulations, which could slow down mass adoption. Federal regulation would provide clarity to a number of stakeholders, including car manufacturers and insurance companies, which should then lead to the development of AV vehicles and other technologies, and insurance products to complement these vehicles.

Another notable development is the FCC's recent announcement of its plan to split the use of the 5.9 GHz spectrum between unlicensed Wi-Fi and vehicle-to-vehicle (V2V) communications standards.[16] This spectrum, a 75mhz band, had initially been set aside for use for vehicle-to-vehicle communications in 1999, and NHTSA, car manufacturers and device manufacturers spent the ensuing two decades working on a standard for V2V communications. However, the standard that emerged, called DSRC, faced lots of resistance, including from a competing standard called C-V2V. Separately, Wi-Fi demands were growing, and the 5.9GHz spectrum was increasingly used for unlicensed Wi-Fi. A recent study by Rand Corporation estimates that the value of the consumer and producer surplus from using the entire band for Wi-Fi to be between $82.2 billion and $189.9 billion.[17] The FCC announced that 45mhz at the lower end of the band will be for Wi-Fi, the next 20 mhz for C-V2V, and the top 10mhz potentially for C-V2V or DSRC. While it is too early to predict the ultimate outcome, the FCCs announcement seems to throw a lot of weight behind the C-V2V standard. The upshot is that this may hasten resolution of what has been a standards battle. Resolving this uncertainty over standards should then lead to the development of AV vehicles and other technologies.

In addition, the federal government will also play a role in addressing any externalities that may arise from these new technologies. We discuss some of these externalities, and potential role for government to address them, in the next sub-section.

[16] https://www.reuters.com/article/us-usa-spectrum/u-s-regulator-proposes-splitting-auto-safety-spectrum-to-boost-wi-fi-idUSKBN1XU2BJ

[17] https://www.rand.org/content/dam/rand/pubs/research_reports/RR2700/RR2720/RAND_RR2720.pdf

4.5. Spillovers

Sections 4.2 and 4.3 highlight just two advances spurred by entrepreneurial entry and technological innovation and while ride sharing and autonomous vehicles certainly provide numerous benefits, they may, too, usher in costs and unintended consequences. These spillovers are discussed in more detail below starting with the effect of AV on jobs, followed by a broader discussion of ancillary spillovers that are unlikely to be properly priced.

4.5.1 Jobs

Scholars and pundits have speculated on a range of outcomes from autonomous vehicles, including lower transport costs due to fewer drivers, better fuel efficiency, and better safety. The effect on driving jobs has garnered lots of attention. For example, the *Guardian* reports that autonomous driving puts 2 million U.S. truck drivers at risk of losing their job.[18] However, as Gittleman and Monaco (2017) point out, there are a variety of types of drivers, and autonomous driving will affect some more than others. The use of autonomous vehicles is more likely for heavy and tractor trailer truck drivers (aka "long haul") rather than local delivery, given how difficult it would be to automate driving in a local or urban environment, and given all the other tasks associated with local delivery. According to analysis by Gittleman and Monaco, some of the other tasks performed by drivers include freight handling, paperwork and customer service. Gittleman and Monaco estimate that Level 4 automation may ultimately displace 300,000 to 400,000 drivers. But, the authors highlight that there are many practical limitations to automation. For example, they highlight that one of the important functions of a truck driver is to serve as a security guard for the freight.[19]

Expected benefits to autonomous trucking may need to be tempered in the event that the most likely application for autonomous trucking is in long haul and not local delivery. For example, most emissions and most accidents occur in urban environments (where local delivery is more common). Gately, Hutyra and Wing (2015) report that urban vehicle emissions account for 60% of total emission, and account for 80% of growth in emissions since 1980. In other words, the most polluted areas are potentially the very areas where there will be little penetration of

[18] https://www.theguardian.com/technology/2017/oct/10/american-trucker-automation-jobs
[19] The authors also cite an estimate of $175 million in losses to truck theft per year https://www.trucks.com/2016/01/29/truck-thefts-result-in-large-losses/

autonomous vehicles. The Insurance Institute for Highway Safety (IIHS) reports that most accidents occur in urban and local roads, not rural interstates, and that 67% of fatalities occur outside of the interstate system.[20] Again, the most dangerous areas are potentially the very areas where there will be little penetration of autonomous vehicles.

Ultimately the costs and benefits of autonomous trucking will likely depend on the shape of government regulation. For example, one could imagine that consumer fear of autonomous vehicles leads to regulations requiring humans to be in the cab of any autonomous vehicle, just in case the vehicle encounters unforeseen problems (in fact, in a 2018 survey 71% of U.S. drivers said they don't trust self-driving vehicles).[21] Such a regulation would attenuate any cost savings from replacing drivers. While the job displacement risk stemming from the arrival of autonomous vehicles is but one of the many consequences of the changes in transportation arising from new products and services, numerous other spillovers also arise as result.[22]

4.5.2. Congestion and Vehicular Accidents

The effect of increased vehicle traffic on congestion, pollution, and the rate of accidents will depend on the source of increased vehicle usage. On the one hand, ride sharing has been shown to lead to an increase in congestion[23] (and in turn pollution) in addition to an increase in accidents (Barrios, Hochberg, and Yi 2020). Autonomous vehicles (AVs), however, may overcome these negative externalities as AVs with improved response times (compared to humans) can more safely drive close together.[24] These safety improvements should, in turn, reduce fatalities, and assuming the increase in capacity is greater than the reduction in transport costs, reduce congestion as well (Duranton and Turner, 2011). Technologies that facilitate this vehicle-to-vehicle coordination, solutions that spread usage to off-peak hours, or improve passenger safety will all be important areas of both innovation and entrepreneurship. Policy makers will also need to strike the appropriate balance between usage patterns and how to allocate public space for various transportation modes.

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[20] https://www.iihs.org/topics/fatality-statistics/detail/large-trucks
[21] https://www.theverge.com/2018/5/22/17380374/self-driving-car-crash-consumer-trust-poll-aaa
[22] We thank our discussant, Gilles Duranton, for articulating many of these.
[23] As acknowledged by Chris Pangilinan, Uber's Head of Global Policy for Public Transportation, https://medium.com/uber-under-the-hood/learning-more-about-how-our-roads-are-used-today-bde9e352e92c
[24] https://www.economist.com/finance-and-economics/2018/01/20/why-driverless-cars-may-mean-jams-tomorrow

4.6. Long-run effects

Ultimately, the successful proliferation of new transportation technologies will affect the geographic distribution of economic activity but the impacts are likely to be heterogenous. As previously discussed, autonomous vehicles will reduce the costs of transport which in turn may reduce the need to live in proximity to one's place of work. This will have implications not only for the location of offices but also domiciles, with commuters potentially moving to cheaper areas far from city centers. On the other hand, the wide adoption of electric vehicles may reduce the costs associated with living in urban areas (e.g., pollution) as well as heighten the value of face-to-face interactions and thus may lead to more densification/urbanization. There are surely many other changes that will emerge from the unanticipated interactions between individuals and new transportation technologies. These long-run effects are sure to be large, but at present it is difficult to anticipate what equilibrium-level outcomes will look like, especially given the role that will be played by government regulators as indicated in the prior sub-section.

5. Conclusion

The transportation sector, which includes warehousing, plays a critical role in economic activity. In this chapter, we describe economic, entrepreneurial and innovative activities in this area of the U.S. economy. Recent trends suggest a shift underway in this sector, with warehousing playing an increasingly important role. Prior economic research has focused primarily on innovations affecting the movement of goods (e.g., building new roads or railways), and there has been comparatively little research on innovations in storing goods. Thus, one takeaway from this chapter is for economists to conduct more research on the role of warehousing in the economy.

We also highlight several new transportation technologies, including ride-sharing and autonomous vehicles. There is much speculation about how these technologies will affect the sector, and eventually the economy as a whole. We note that prior innovations in this sector experienced heterogeneous rates of adoption. We believe this lesson from history suggests we exercise much caution when speculating about the speed of adoption and impact of any new technology. Ultimately, the rate of adoption will depend on a range of factors including technological development, consumer preferences and tastes, and regulatory landscape.

We believe there are a number of areas for follow-on research including addressing the following questions:

- Which firms are adopting new technologies in this sector, what are barriers to adoption, if any, and what are the implications for the industrial organization of the sector?
- What accounts for the recent, rapid rise of employment in the warehousing sector? How much of this shift is attributable to online purchasing behavior or other shifts in consumer behavior?
- What is underlying the rapid growth in warehousing employment in certain geographies of the U.S.? What are the implications of this for the economic vitality of those regions that are gaining or losing employment in the sector?
- How much growth in the warehousing sector is coming from new firms versus established incumbents? If, as appears to be the case, most growth is from established firms, what entry barriers are new firms facing?
- How will autonomous vehicles affect employment and the economic geography of jobs?
- What are the implications of autonomous vehicles for congestion, pollution, safety, and other by-products?
- How will transportation technologies interact with existing information technologies and the existing digital infrastructure?

On the first point, we note that the U.S. statistical agencies can play a critical role in measuring the adoption and use of new technologies. The U.S. Census Bureau has started to collect data on firm-level adoption of robots (Buffington, Miranda and Seamans, 2018) and other new technologies such as machine learning, computer vision, and autonomous-guided vehicles. It appears that these technologies are primarily used by larger firms (Beede et al, 2020). This U.S. data will soon be available for researchers to study the impact of these technologies on workers, firms, communities and industries, including warehousing and transport. Consequently, the improved collection and increased availability of these data will play a critical role in answering many of the questions outlined in this chapter.

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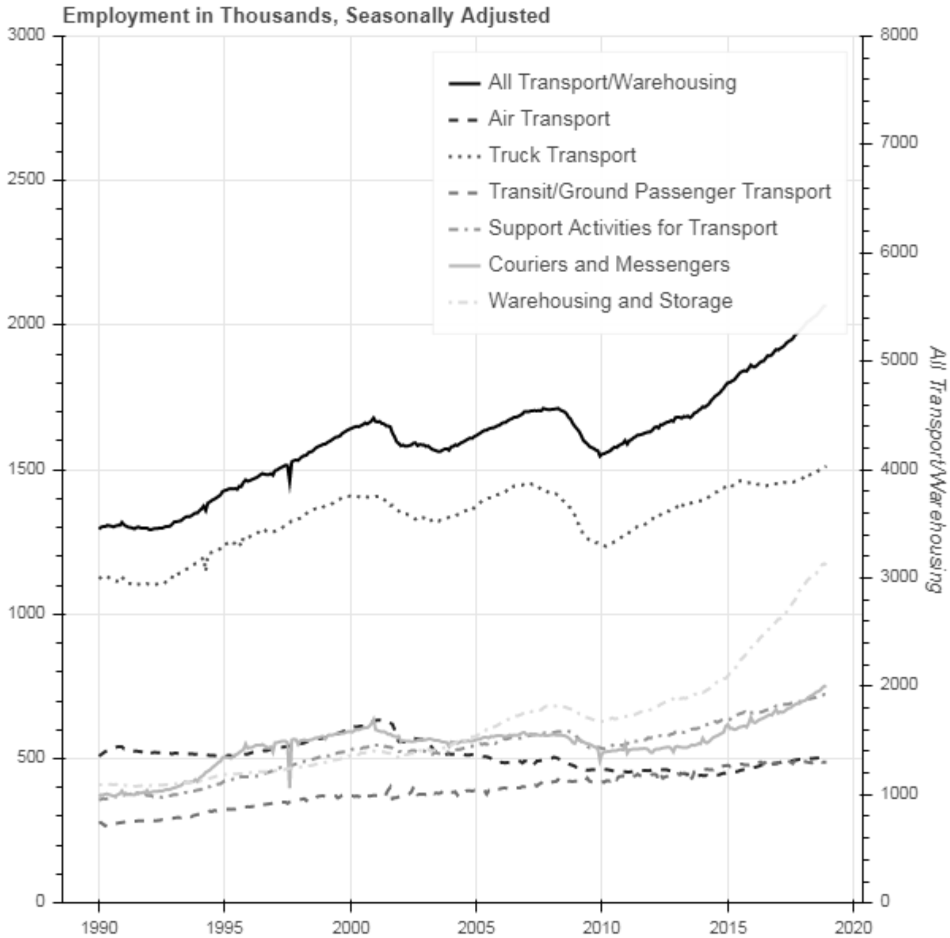
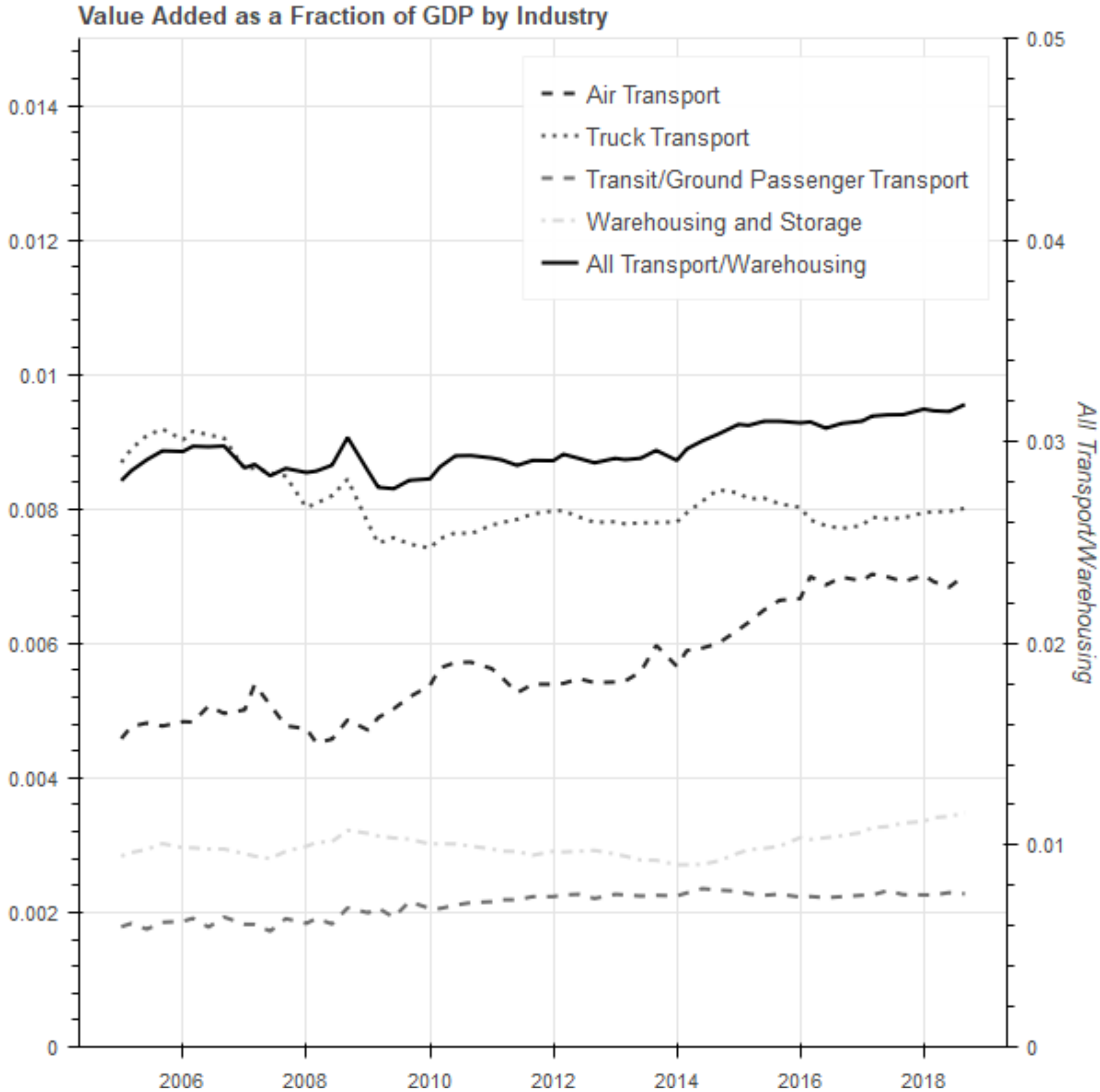
Figure 1. Employment by Transportation Sub-industries



Note: These data come from the Bureau of Labor Statistics Current Employment Statistics survey (BLS CES).

Figure 2. Value Added as a Fraction of GDP

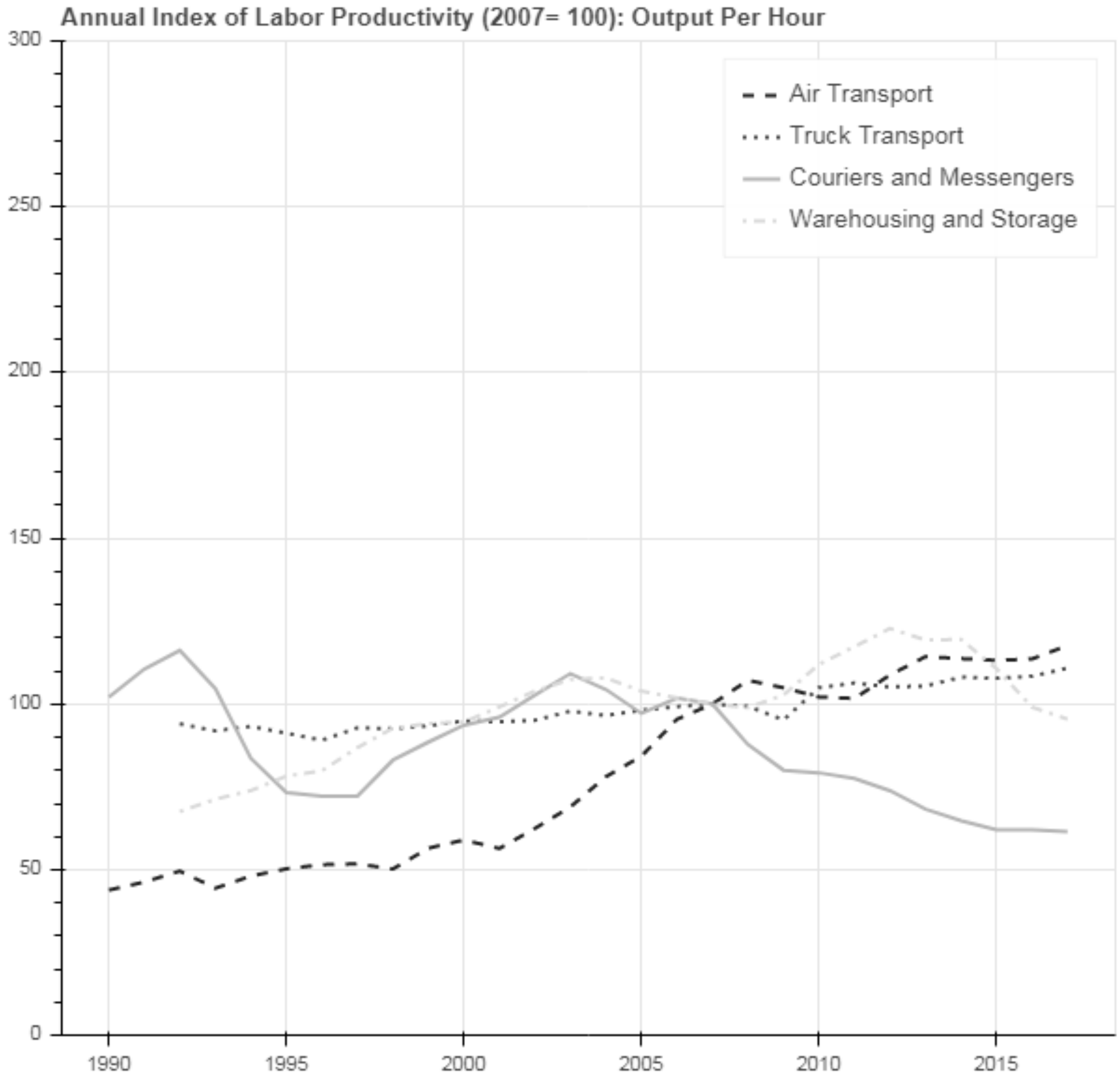


Note: These data come from the Bureau of Economic Analysis (BEA).

Figure 3. Real Average Weekly Earnings by Transportation Sub-industry

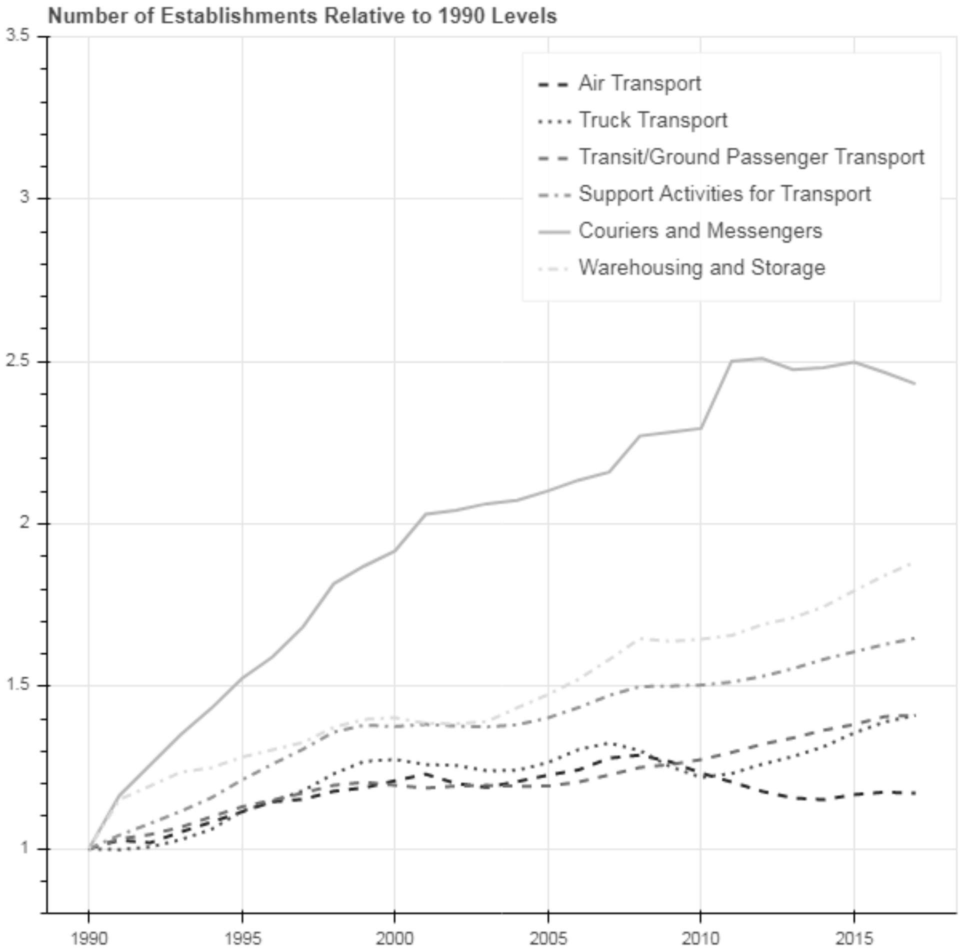
Note: These data come from BLS CES. We plot average weekly earnings by transportation sub-industry, adjusted for inflation using the CPI-U.

Figure 4. Labor Productivity by Transportation Sub-industry



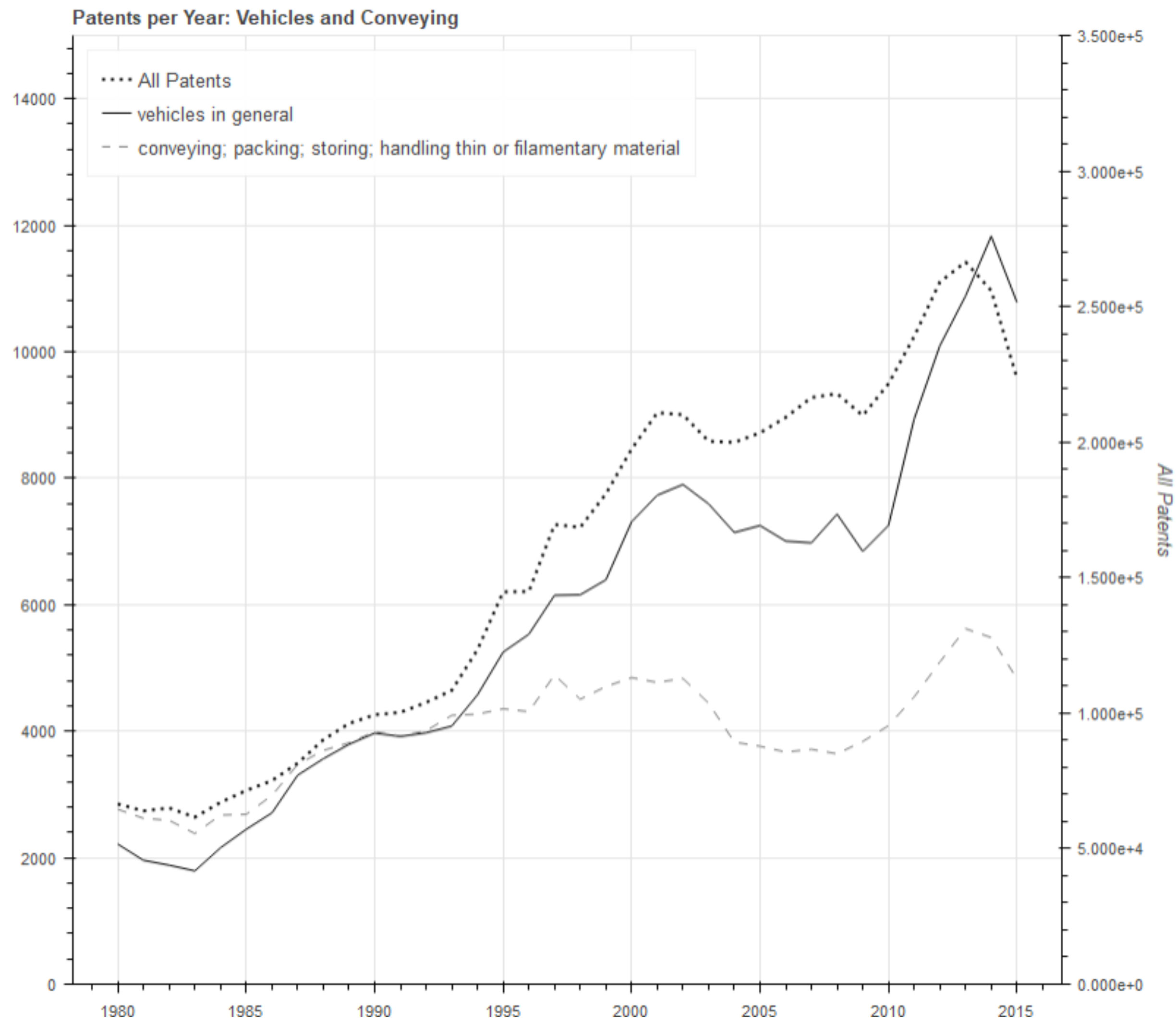
Note: These figures come from the BLS's Annual Index of Labor Productivity and show changes in output per hour relative to 2007 levels.

Figure 5. Growth in Establishments by Transportation Sub-industry



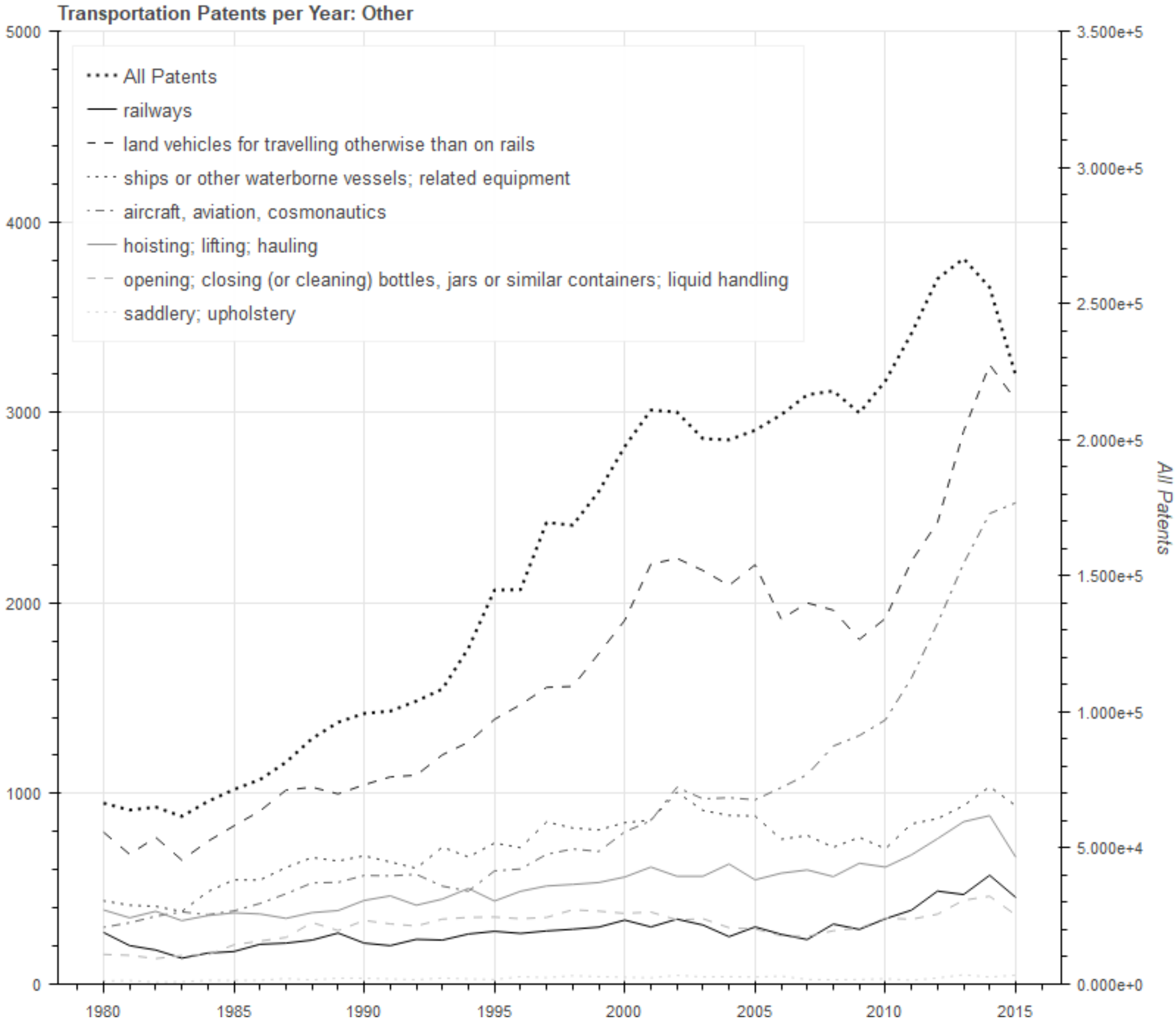
Note: These data come from the BLS Quarterly Census of Employment and Wages. The series are normalized to show establishment levels relative to 1990.

Figure 6. Patenting Activity: Vehicles in General and Conveying



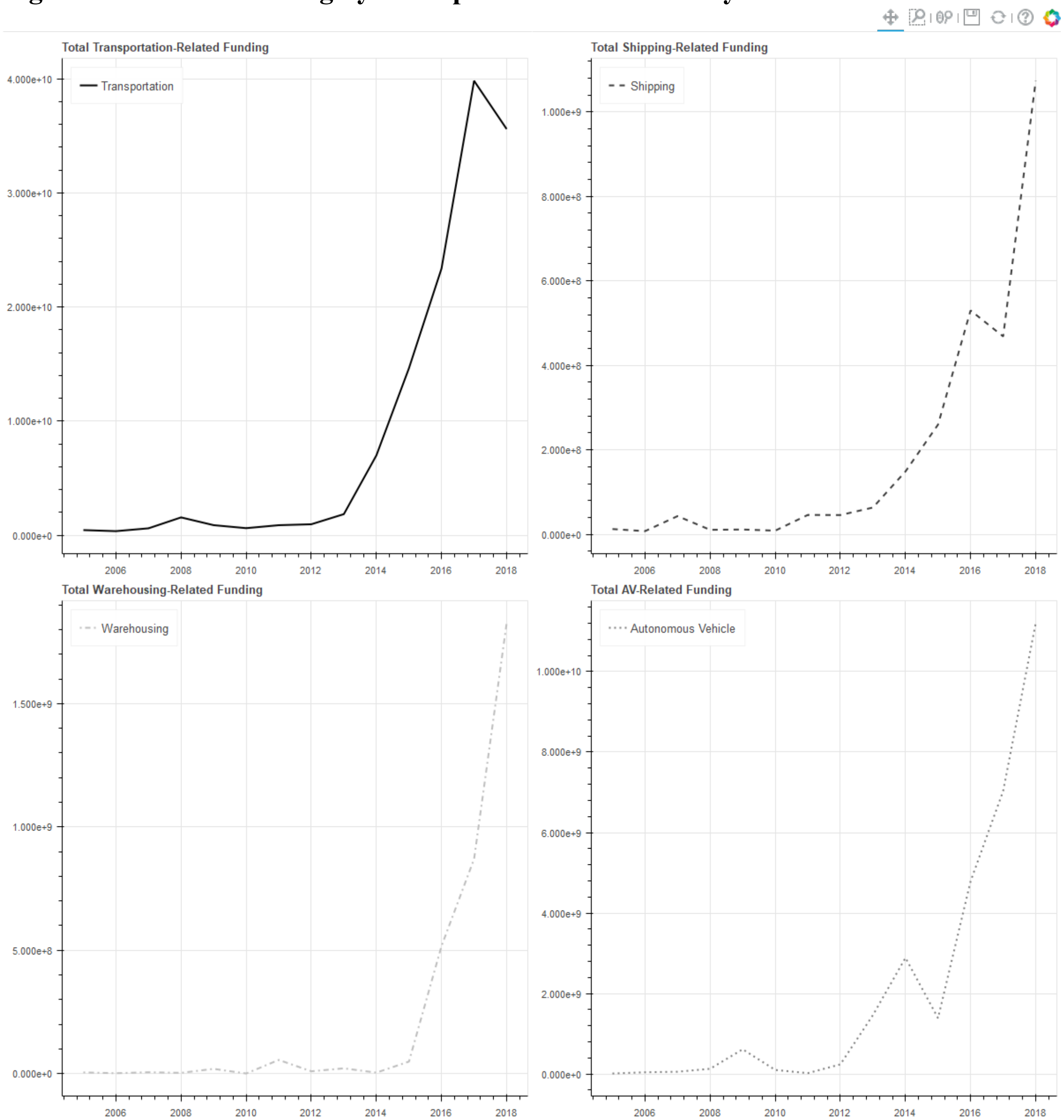
Note: These data come from PatentsView. We plot total patents per year for CPC codes B60 (vehicles in general) and B65 (conveying, packing, storing, etc.), as well as all patents.

Figure 7. All Other Transportation Patents



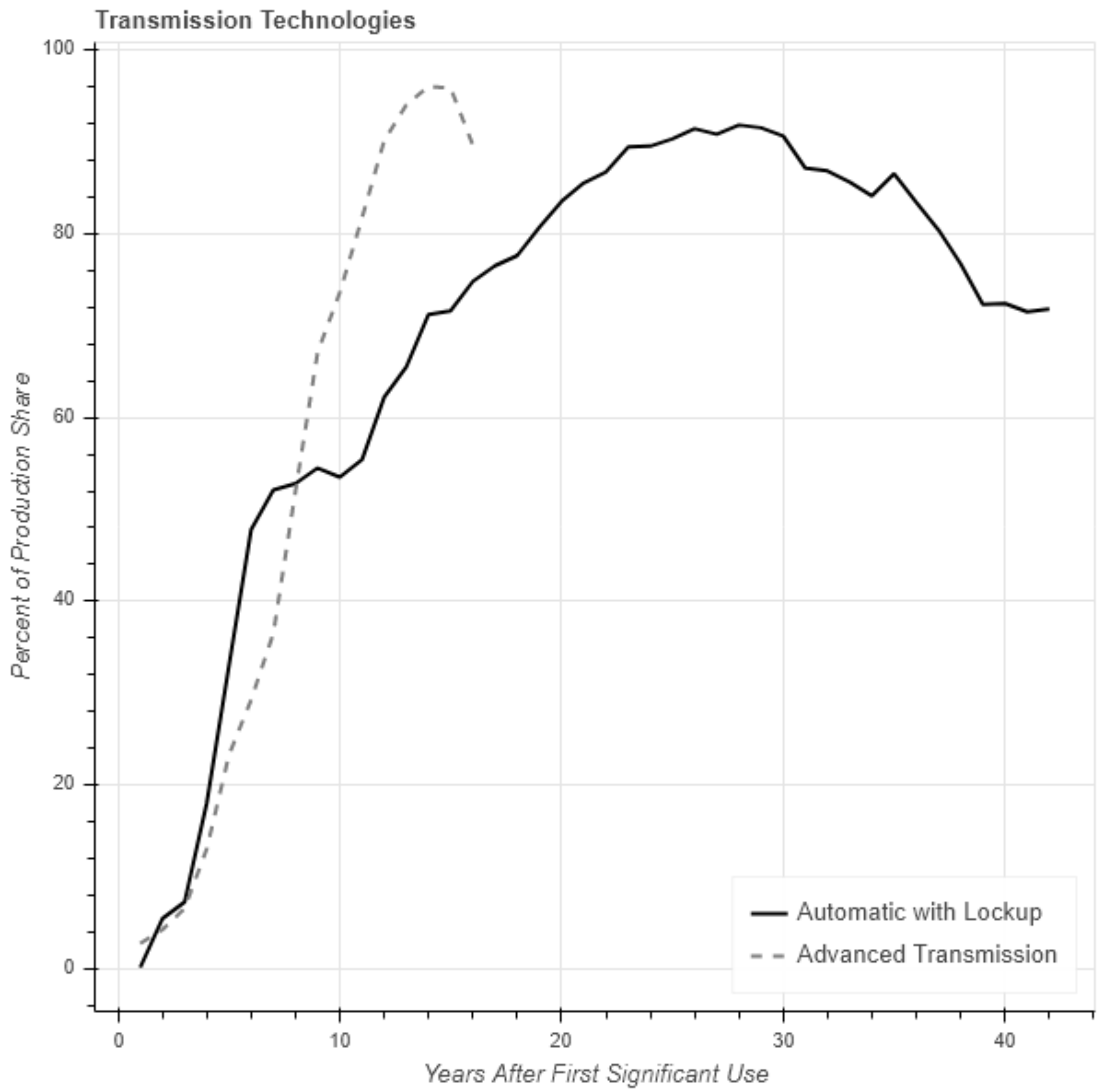
Note: These data come from PatentsView. We plot patents per year for the remaining transportation CPC codes (B60-B68), excluding vehicles in general and conveying/packing.

Figure 8. Venture Funding by Transportation Sub-industry



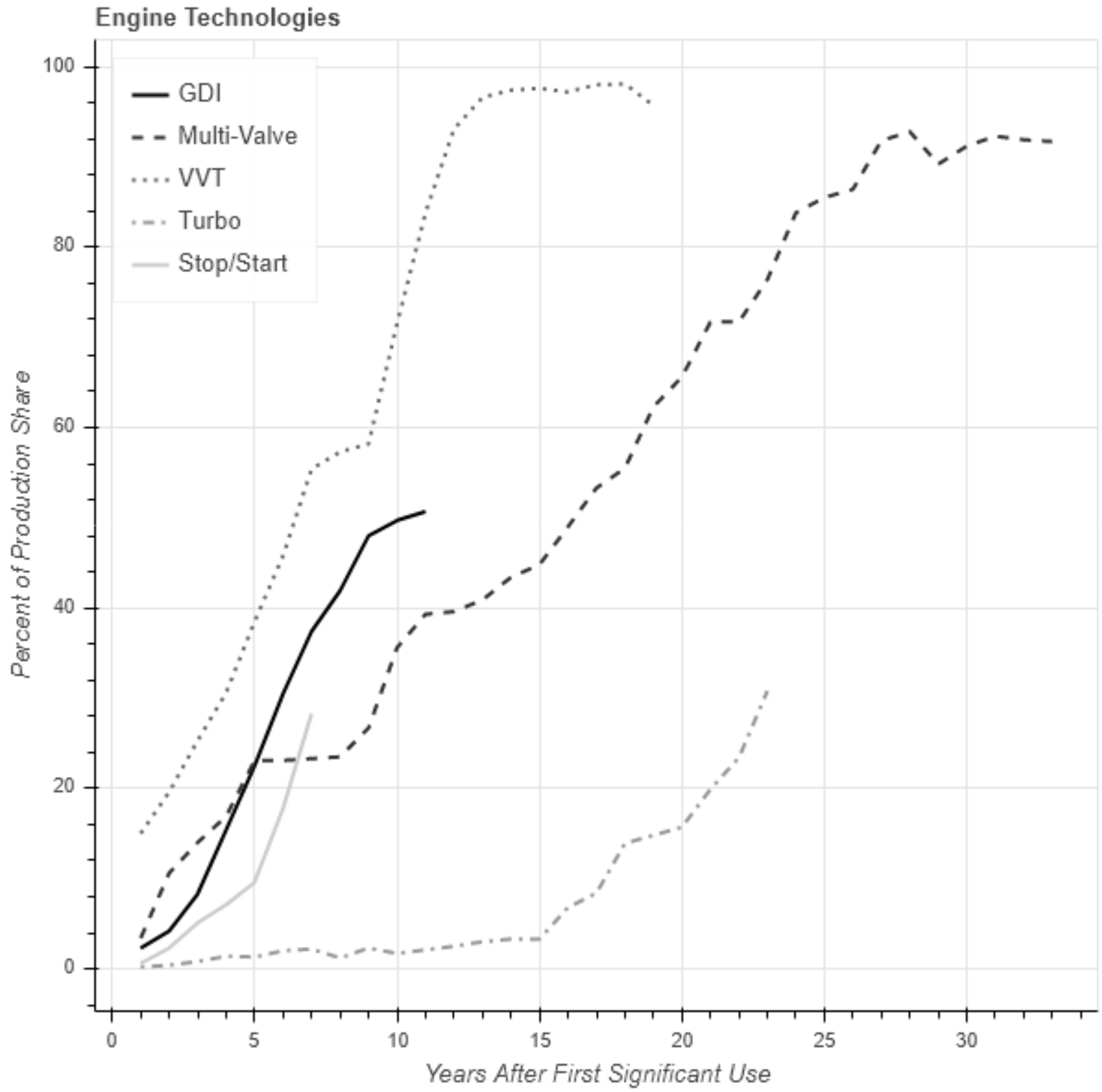
Note: These data come from CrunchBase. Figures report annual funding by company type; amounts are reported in US Dollars.

Figure 9. Automobile Transmission Technology Adoption



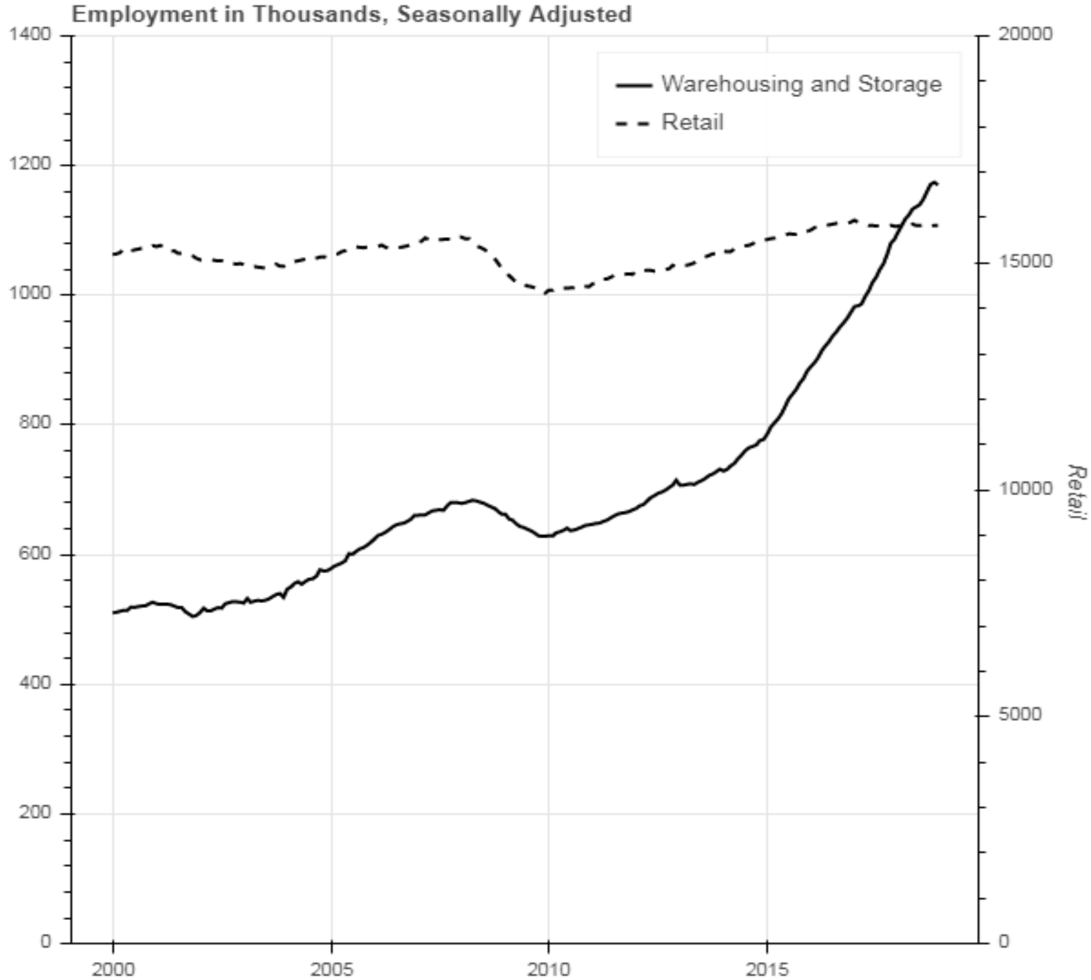
Note: These data come from the United States Environmental Protection Agency (EPA). We define advanced transmission as having six or more gears.

Figure 10. Automobile Engine Technology Adoption



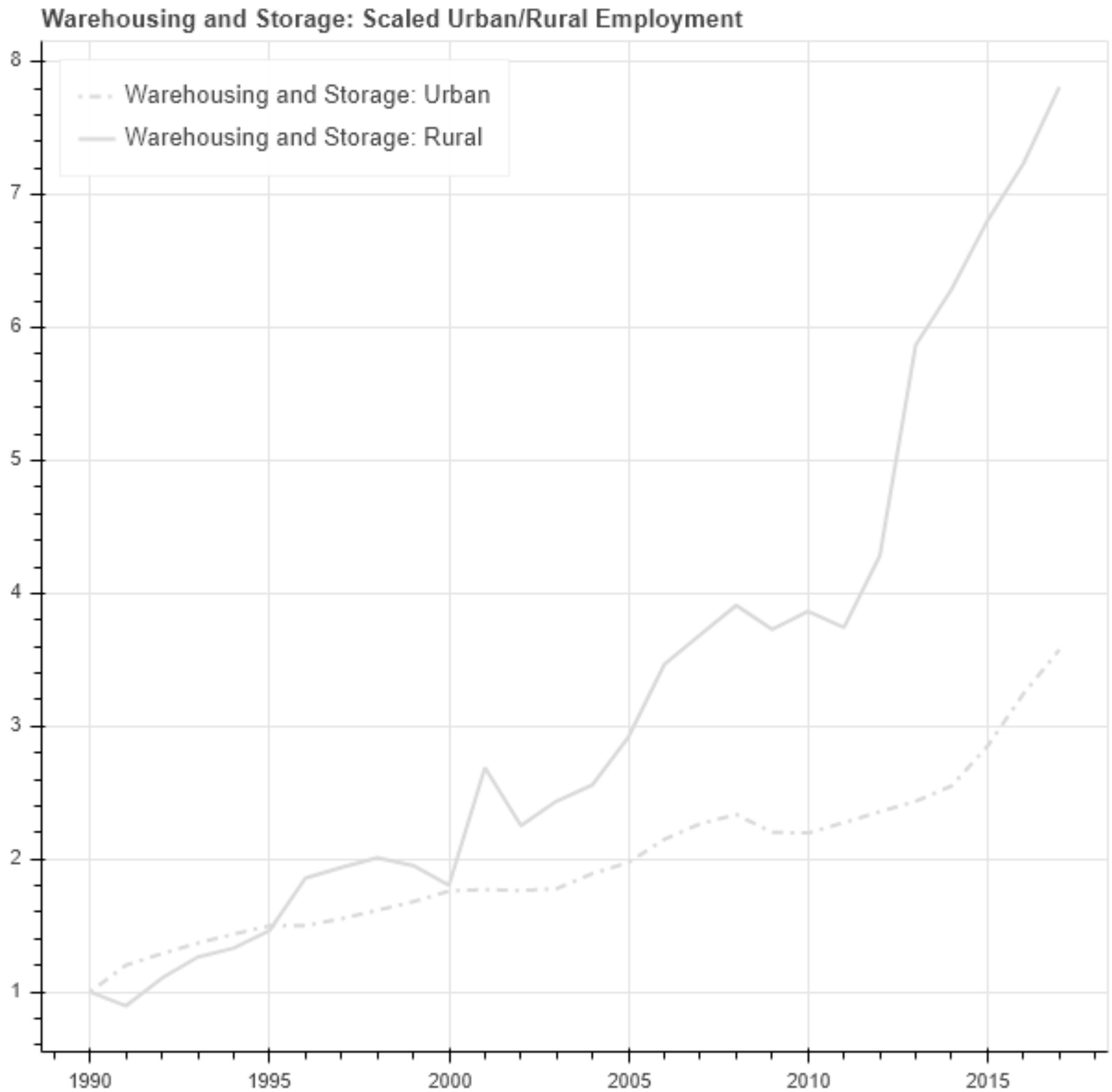
Note: These data come from EPA.

Figure 11. Retail and Warehousing Employment Over Time



Note: These data come from the BLS Current Employment Statistics.

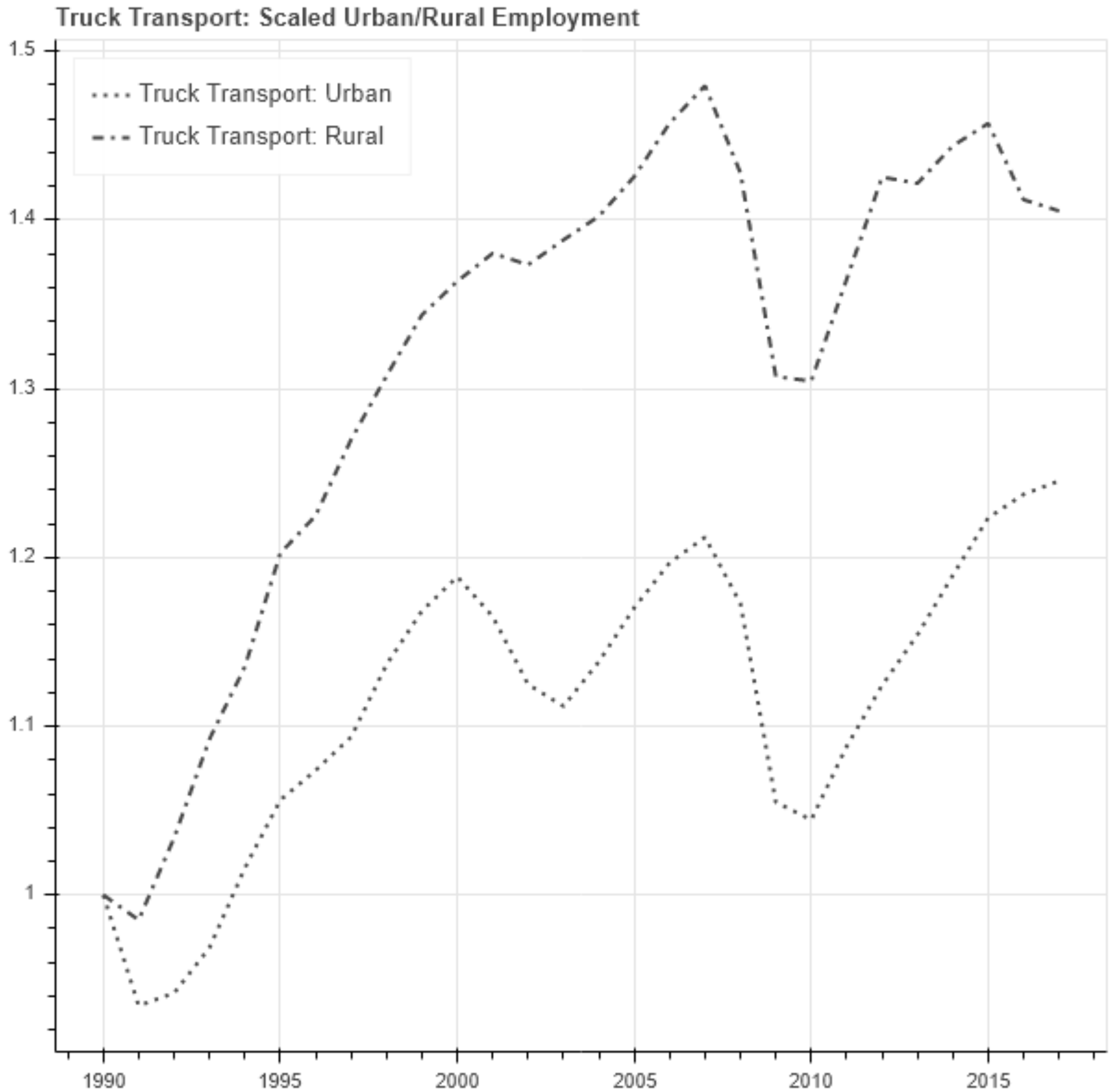
Figure 12. Warehouse Employment Growth: Urban vs. Rural



qcew_warehousing_and_storage_urbanrural_scaled.png

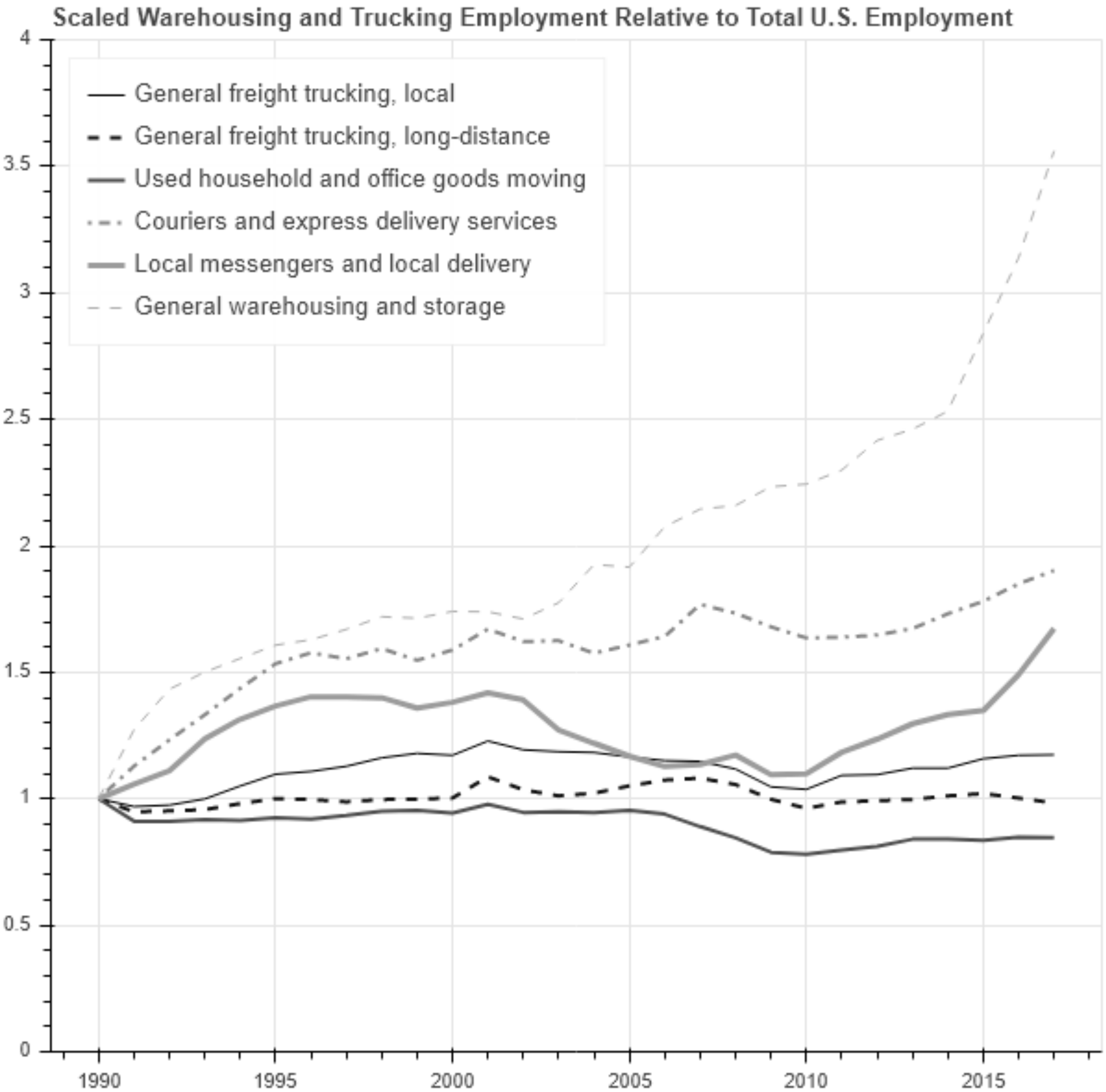
Note: These data come from BLS QCEW. Rural counties are defined as counties with more than half of their population living in rural areas as designated by the Census Bureau.

Figure 13. Truck Transport Employment Growth: Urban vs. Rural



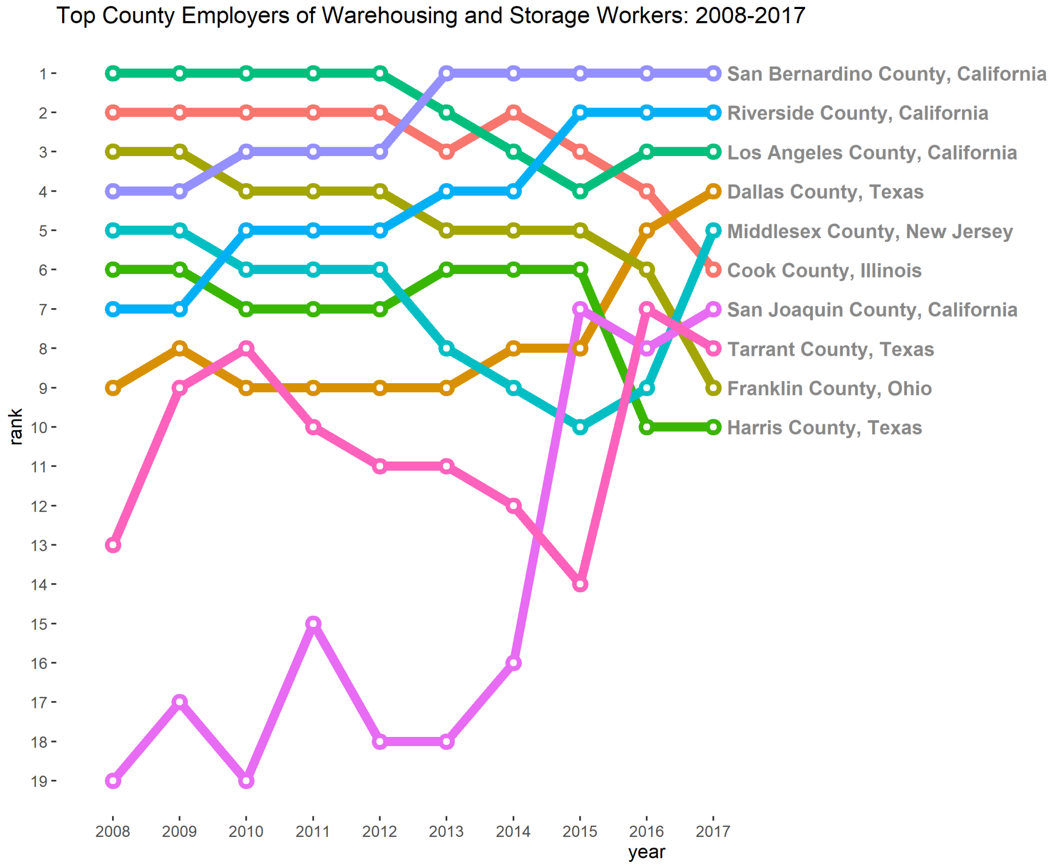
Note: These data come from BLS QCEW. Rural counties are defined as counties with more than half of their population living in rural areas as designated by the Census Bureau.

Figure 14. Increasing Importance of Warehousing Employment in the US



Note: These data come from BLS QCEW. We plot employment shares by transportation sub-industry (5-digit NAICS), normalized to 1990 levels.

Figure 15. Top County-level Employers: Warehousing and Storage



Note: These data come from BLS QCEW. Here is a bump chart plotting the county ranks in terms of raw (not per-capita) warehousing and storage employment. We include the top 10 counties in 2017 over a 10 year period (2008-2017).

Figure 16. Google Trends: Uber vs. Warehouse

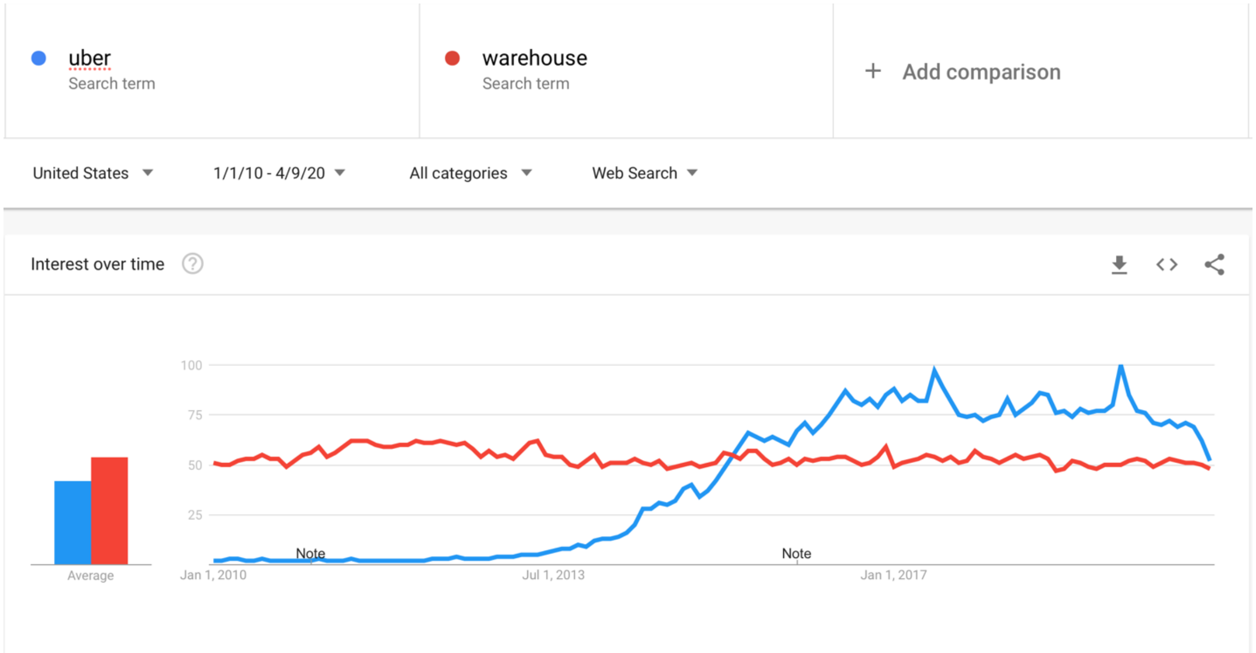
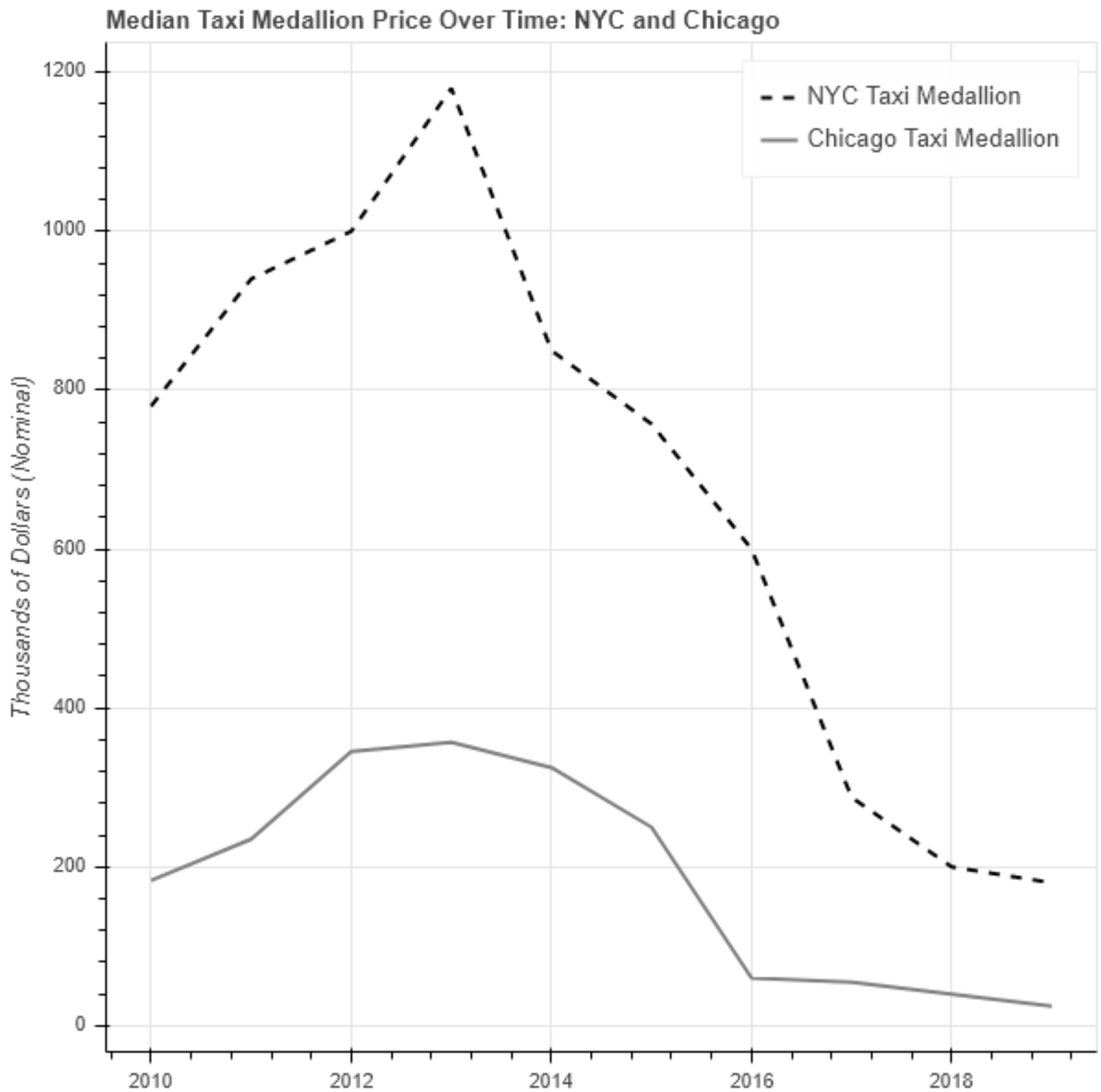
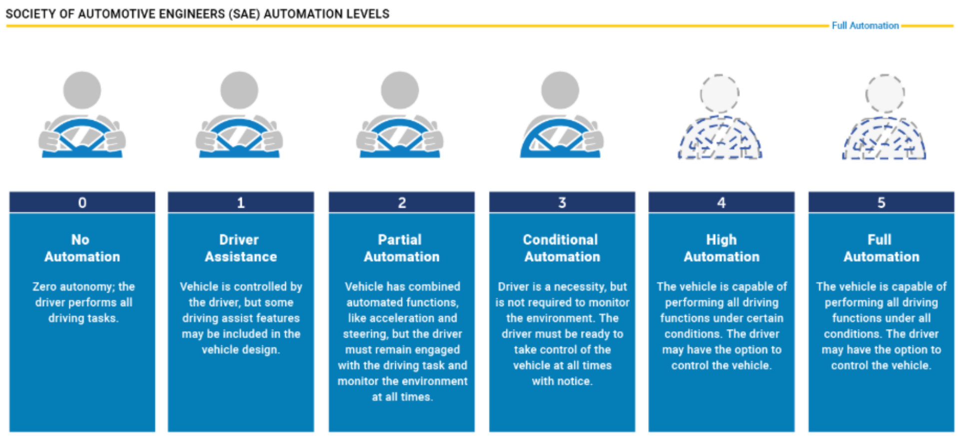


Figure 17. NYC and Chicago Taxi Medallion Prices



Note: These data come from the NYC Taxi and Limousine Commission, as well as the Chicago Department of Business Affairs and Consumer Protection.

Figure 18.



SOCIETY OF AUTOMOTIVE ENGINEERS (SAE) AUTOMATION LEVELS
Full Automation
0
No Automation
Zero autonomy; the driver performs all driving tasks.
1
Driver Assistance
Vehicle is controlled by the driver, but some driving assist features may be included in the vehicle design.
2
Partial Automation
Vehicle has combined automated functions, like acceleration and steering, but the driver must remain engaged with the driving task and monitor the environment at all times.
3
Conditional Automation
Driver is a necessity, but is not required to monitor the environment. The driver must be ready to take control of the vehicle at all times with notice.
4
High Automation
The vehicle is capable of performing all driving functions under certain conditions. The driver may have the option to control the vehicle.
5
Full Automation
The vehicle is capable of performing all driving functions under all conditions. The driver may have the option to control the vehicle.

Table 1: Industry Summary Statistics

Industry Title	NAICS Code	2018 Employment in Thousands	2018 Real Avg Weekly Wage	Five Year Employment Growth (2013-2018)	Five Year Real Wage Growth (2013-2018)
All Transport/Warehousing	48/49	5419.1	$940.0	20.3%	1.7%
Air Transport	481	501.4	$1,107.1	12.8%	1.2%
Rail Transport	482	214.3		-7.4%	
Water Transport	483	64.7		-0.9%	
Truck Transport	484	1491.3	$1,004.6	7.9%	0.7%
Transit/Ground Passenger Transport	485	487.4	$663.0	8.7%	8.7%
Pipeline Transport	486	48.6		9.3%	
Scenic/Sightseeing Transport	487	34.3		17.3%	
Support Activities for Transport	488	711.8	$955.5	18.9%	0.6%
Couriers and Messengers	492	725.5	$784.6	33.4%	14.9%
Warehousing and Storage	493	1139.9	$845.2	59.2%	3.5%

Note: These data come from BLS Current Employment Statistics. We omit the Postal Service, as well as wage data for rail, water, pipeline, and scenic/sightseeing transportation, as these aggregate data are not available from BLS CES.

Table 2: Top Couriers and Messengers Companies by Job Postings

	2010	2011	2012	2013	2014	2015	2016	2017	2018
1	UPS	UPS	UPS	UPS	UPS	UPS	UPS	UPS	UPS
2	FedEx	FedEx	FedEx	FedEx	FedEx	FedEx	FedEx	FedEx	FedEx
3	DHL Express	DHL Express	DHL Express	DHL Express	DHL Express	DHL Express	DHL Express	DHL Express	DHL Express
4	Republic Beverage	Republic Beverage	Midnite Express	Publisher's Circulation	Xpo Last Mile Inc	Spee Dee Delivery	Spee Dee Delivery	Spee Dee Delivery	Shipt
5	Courier	Courier	Republic Beverage	Ameriflight Incorporated	Spee Dee Delivery	Midnite Express	Midnite Express	Midnite Express	Ameriflight Incorporated

Notes: These data come from Burning Glass. We report the top 5 companies by number of job postings (NAICS 492). Burning Glass does not report employer data for every single job posting.

Table 3: Top Transit/Ground Passenger Transport Companies by Job Postings

	2010	2011	2012	2013	2014	2015	2016	2017	2018
1	MV Trans., Inc.	Firstgroup Plc	MV Trans., Inc.	MV Trans., Inc.	MV Trans., Inc.	Durham School Services	MV Trans., Inc.	Instacart	Instacart
2	Firstgroup Plc	MV Trans., Inc.	Firstgroup Plc	Veolia Trans.	Durham School Services	Uber	Amtrak	MV Trans., Inc.	MV Trans., Inc.
3	Veolia Trans.	Veolia Trans.	Westours Motor Coaches	First Student	Amtrak	Amtrak	Veolia Trans.	First Transit	Uber
4	Coach America	First Transit	Veolia Trans.	Firstgroup Plc	Veolia Trans.	MV Trans., Inc.	First Transit	Uber	First Transit
5	First Transit	Coach America	First Transit	Durham School Services	Firstgroup Plc	Veolia Trans.	Uber	Stock Trans.	Stock Trans.

Notes: These data come from Burning Glass. We report the top 5 companies by number of job postings (NAICS 485). Burning Glass does not report employer data for every single job posting.

Table 4: Top Warehousing and Storage Companies by Job Postings

	2010	2011	2012	2013	2014	2015	2016	2017	2018
1	Americold Logistics	Americold Logistics	Americold Logistics	Americold Logistics	Americold Logistics	Americold Logistics	Diversified Transfer Storage	Dematic	Dematic
2	Exel	Dematic	Dematic	Dematic	Exel	Exel	Americold Logistics	Americold Logistics	All My Sons Moving Storage
3	Dematic	Exel	After-market Tech. Corp,	Exel	Versacold Int. Corp.	Dematic	Dematic	Pure Storage, Inc	Life Storage, Inc
4	Document Storage Systems Inc.	After-market Tech. Corp.	Exel	After-market Tech. Corp.	Dematic	Diversified Transfer Storage	Exel	All My Sons Moving Storage	Pure Storage, Inc
5	Jk Moving Storage Inc.	Jk Moving Storage Inc.	Es3 Llc	Versacold Int. Corp.	Es3 Llc	Versacold Int. Corp,	Pure Storage, Inc	Exel	Americold Logistics

Notes: These data come from Burning Glass. We report the top 5 companies by number of job postings (NAICS 493). Burning Glass does not report employer data for every single job posting.