What's Driving Entrepreneurship and Innovation in the Transport Sector?*

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Abstract: In this chapter we draw from prior literature and a range of statistics to describe economic, entrepreneurial and innovative activities in the transportation sector. Analysis of recent trends suggest that warehousing is playing an increasingly important role; we argue for more research on the role of warehousing in particular. We also review several new technologies, including autonomous vehicles, drones and robots, that are starting to affect transportation and warehousing.

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1. Introduction

The transportation sector—including physical warehousing as well as the shipment of goods—is an important facet of the U.S. economy. It directly accounts for 3.2 percent of U.S. gross domestic product (GDP), and indirectly affects many other sectors (Figure 1). Economists have highlighted the multiple ways in which transportation can affect 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.

New technologies, including artificial intelligence (AI), robots, sensors, and others, are increasingly being adopted throughout the economy, and the transportation sector is no different. For example, Uber bought autonomous trucking startup Otto for $680M in 2016.[1] As another example, Amazon bought warehouse robotics company Kiva for $775M in 2012.[2] These robots have 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).

In this chapter we review recent transportation sector trends. We conduct a deeper look at warehousing—a segment of the transportation sector that has seen a dramatic increase in activity—and consider ways in which these changes in both transportation and warehousing affect the movement of both goods and individuals.

The key takeaways from our review include:

- 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).

[1] https://techcrunch.com/2016/08/18/uber-acquires-otto-to-lead-ubers-self-driving-car-effort-report-says/
[2] https://techcrunch.com/2012/03/19/amazon-acquires-online-fulfillment-company-kiva-systems-for-775-million-in-cash/

- 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 know about the sector from prior academic research and from aggregate government statistics. We then highlight recent innovations in the warehousing and trucking sectors, including robots, autonomous vehicles and drones, discussing their potential economic and public policy implications. We also review existing work in the personal mobility domain, focusing on the impact of ride-sharing platforms on various economic and societal outcomes. 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 distinct effects on input reorganization and growth—causing a degree of outward population shift amid prevailing urban employment growth (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 labor agglomeration effects but also through improvements to knowledge flows—increasing output beyond that explained by the influx of new innovators. Perlman (2016) shows 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 be in part contingent 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 market expansions through increased access to low-cost river and canal transportation allowed areas like Southern New England and New York to exhibit high growth in patenting activity during the Industrial Revolution. The economic changes attributable to transportation infrastructure are persistent beyond initial natural advantages afforded by geography. 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 is comprised of 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 employment for the sector as a whole grew by over 20% and saw real wages grow by 1.7%. However, this aggregate growth masks significant heterogeneity. Rail and water transport saw a 7% and 1% decline, respectively, in employment over the same period. 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 2 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 1 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 percent in 2005 to 3.2 percent in 2018.

Figure 3, using data from BLS CES, provides real average weekly earnings from 2006 onwards,[3] by transportation sub-industry. Wages appear to increase until the financial crisis in 2009, then decrease, and then slowly start to recover starting in 2013. While employment levels were clearly heavily impacted by the financial crisis of 2009, employment levels recovered after the trough of 2010, while wage growth has lagged.

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. Examining warehousing and storage on the other hand, we see that although employment has more than doubled between 2010 and 2018 (Figure 2) and real wages have increased at twice the rate of the entire transportation sector as a whole, labor productivity increased to 120% of 2007 levels in 2012 but in 2018 have reverted to 2007 levels.

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

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

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. Warehousing

3.1. Literature

Transportation's most aggregate industry classification (NAICS code 48-49) includes both transportation and warehousing. While transportation has received considerable interest from economists, warehousing has received less attention by economists. One reason for this may be the larger impact that air and truck transport have in contributing to GDP (Figure 1) than warehousing and storage. Yet, growth in employment and in new establishments has been considerably higher in the warehousing sector than the transport sector. In this section we examine this trend more deeply by exploring the changing role of warehousing and its interface with transportation as it affects 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 appears to provide some 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 2 alongside retail employment growth.

3.2. Geography

Of additional interest, is a finding in Chava et al. (2019) that Amazon opens fulfillment centers in counties with population densities 2.5 times higher than the average across all U.S. counties. While the majority of employment growth has come in rural counties which have employment levels seven times higher than in 1990 as can be seen in Figure 12, 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. 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 much smaller scales. 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. 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.

3.3. New Technologies

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 highprofile startups in this space, a number of startups also exist including Startship Technologies, Marble, Boxbot, Robby Technologies, Kiwi Campus, Dispatch, and Unsupervised AI.[4] 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.[5] 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. Figure 15 provides a plot of the frequency in which the term 'drone' appears in SEC filings by fiscal quarter. While this may appear futuristic, 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.[6] 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.

4. Autonomous vehicles

4.1. Overview

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

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

full automation (see Figure 16). 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.[7] Google's Waymo would be considered Level 4 or 5. No Level 4 or 5 cars are certified for use on regular roads.[8]

There is lots of excitement around autonomous vehicles (AVs). Some have referred to it as the "AI killer app".[9] 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.[10] 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.[11] 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. 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

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7 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/

8 https://crsreports.congress.gov/product/pdf/R/R45985

9 https://www.forbes.com/sites/chunkamui/2013/08/23/google-car-uber-killer-app/#2620f33d600a

10 https://www.theverge.com/2019/4/22/18510828/tesla-elon-musk-autonomy-day-investor-comments-self-driving-cars-predictions

11 https://www.theverge.com/2019/4/23/18512618/how-long-will-it-take-to-phase-in-driverless-cars

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.

4.2. Regulation

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. 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.[12] 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.[13] 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.

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

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

4.3. Economic effects

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.[14] 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 includes 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.[15]

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 autonomous vehicles. The Insurance Institute for Highway Safety (IIHS) reports that most accidents occur in urban and local roads, not rural interstates, and that 32% of fatalities from large trucks occur on interstates.[16] Again, the most dangerous areas are potentially the very areas where there will be little penetration of autonomous vehicles.

[14] https://www.theguardian.com/technology/2017/oct/10/american-trucker-automation-jobs

[15] 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/

[16] https://www.iihs.org/topics/fatality-statistics/detail/large-trucks

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).[17] Such a regulation would attenuate any cost savings from replacing drivers.

5. Personal Mobility

One of the biggest changes to personal mobility has been the rise of ride-sharing firms such as Lyft and Uber. These firms differ from standard taxi firms in at least two ways. First, unlike a traditional taxi company that manages a fleet of taxicabs and 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. 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. 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. 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) 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.

[17] https://www.theverge.com/2018/5/22/17380374/self-driving-car-crash-consumer-trust-poll-aaa

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.

6. 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 sector. 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 focus more attention warehousing.

We also highlight several new technologies, including autonomous vehicles, drones and robots, that are starting to affect this sector. 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

References

Agrawal, A., Galasso, A., & Oettl, A. (2017). Roads and Innovation. *The Review of Economics and Statistics*, *99*(3), 417–434. https://doi.org/10.1162/REST

Banerjee, A., Duflo, E., & Qian, N. (2012). On the Road : Access to Transportation Infrastructure and Economic. *NBER Working Paper*, (17897).

Baum-Snow, N. (2007). Did Highways Cause Suburbanization? *The Quarterly Journal of Economics*.

Baum-Snow, N., Henderson, J. V., Turner, M. A., Zhang, Q., & Brandt, L. (2018). Does investment in national highways help or hurt hinterland city growth? *Journal of Urban Economics*, *000*(September 2017), 103124. https://doi.org/10.1016/j.jue.2018.05.001

Billings, S. B. (2011). Estimating the value of a new transit option. *Regional Science and Urban Economics*, *41*(6), 525–536. https://doi.org/10.1016/j.regsciurbeco.2011.03.013

Bleakley, H., & Lin, J. (2012). Portage and path dependence. *Quarterly Journal of Economics*, *127*(2), 587–644. https://doi.org/10.1093/qje/qjs011

Burtch, G., Carnahan, S., & Greenwood, B. N. (2018). Can you gig it? An empirical examination of the gig economy and entrepreneurial activity. *Management Science*, *64*(12), 5497-5520.

Chava, S., Oettl, A., Singh, M., & Zhang, L. (2019). Creative Destruction? Assessing the Impact of E-Commerce on Employees at Brick-and-Mortar Retailers. Working Paper.

Cook, C., Diamond, R., Hall, J., List, J. A., & Oyer, P. (2018). The gender earnings gap in the gig economy: Evidence from over a million rideshare drivers (No. w24732). *National Bureau of Economic Research*.

Donaldson, D. (2018). Railroads of the Raj. *American Economic Review*, *108*(4–5), 899–934. https://doi.org/10.2307/1251838

Duranton, G., & Turner, M. A. (2012). Urban growth and transportation. *Review of Economic Studies*, *79*(4), 1407–1440. https://doi.org/10.1093/restud/rds010

Gately, C. K., Hutyra, L. R., & Wing, I. S. (2015). Cities, traffic, and CO2: A multidecadal assessment of trends, drivers, and scaling relationships. *Proceedings of the National Academy of Sciences*, *112*(16), 4999-5004.

Gelauff, G., Ossokina, I., & Teulings, C. (2019). Spatial and welfare effects of automated driving: Will cities grow, decline or both? *Transportation Research Part A: Policy and Practice*, *121*(October 2017), 277–294. https://doi.org/10.1016/j.tra.2019.01.013

Gibbons, S., Lyytikäinen, T., Overman, H. G., & Sanchis-Guarner, R. (2019). New road infrastructure: The effects on firms. *Journal of Urban Economics*, *110*(January), 35–50. https://doi.org/10.1016/j.jue.2019.01.002

Gibbons, S., & Machin, S. (2005). Valuing rail access using transport innovations. *Journal of Urban Economics*, *57*(1), 148–169. https://doi.org/10.1016/j.jue.2004.10.002

Gittleman, M., & Monaco, K. (2017). Truck-Driving Jobs: Are They Headed for Rapid Elimination?. *ILR Review*, 0019793919858079.

Greenwood, B. N., & Wattal, S. (2017). Show Me the Way to Go Home: An Empirical Investigation of Ride-Sharing and Alcohol Related Motor Vehicle Fatalities. *MIS quarterly*, *41*(1), 163-187.

Kröger, L., Kuhnimhof, T., & Trommer, S. (2019). Does context matter? A comparative study modelling autonomous vehicle impact on travel behaviour for Germany and the USA. *Transportation Research Part A: Policy and Practice*, *122*(April 2018), 146–161. https://doi.org/10.1016/j.tra.2018.03.033

Liu, M., Brynjolfsson, E., & Dowlatabadi, J. (2018). *Do digital platforms reduce moral hazard? The case of Uber and taxis* (No. w25015). National Bureau of Economic Research.

Paik, Y., Kang, S., & Seamans, R. (2019). Entrepreneurship, innovation, and political competition: How the public sector helps the sharing economy create value. *Strategic Management Journal*, *40*(4), 503-532.

Parker, G. G., & Van Alstyne, M. W. (2005). Two-sided network effects: A theory of information product design. *Management science*, *51*(10), 1494-1504.

Perlman, E. (2016). *Connecting the Periphery: Three Papers on the Developments Caused by Spreading Transportation and Information Networks in the Nineteenth Century United States*.

Redding, S. J., & Turner, M. A. (2015). Transportation Costs and the Spatial Organization of Economic Activity. In *Handbook of Regional and Urban Economics* (1st ed., Vol. 5). https://doi.org/10.1016/B978-0-444-59531-7.00020-X

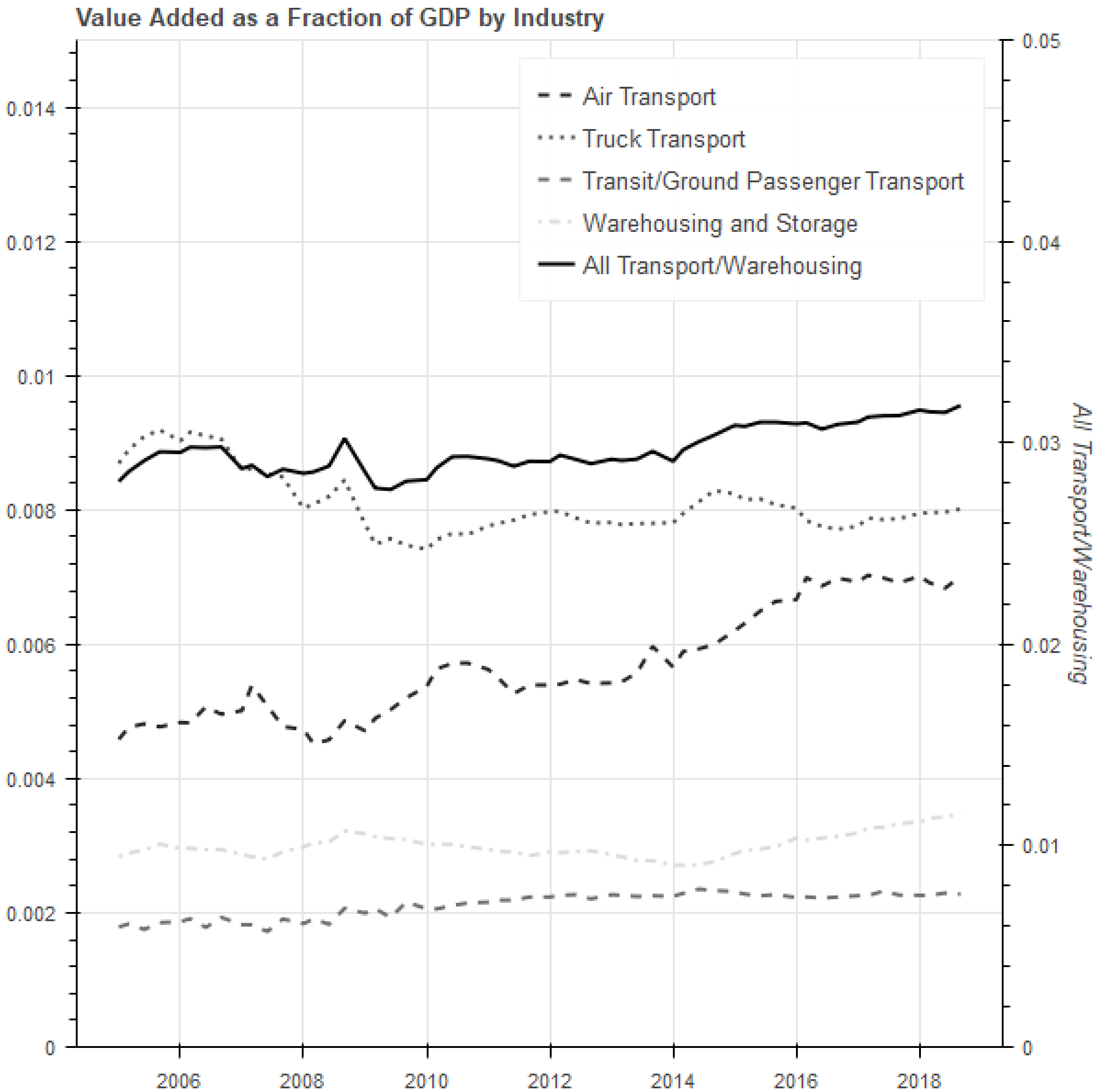
Roche, MP (Forthcoming). Taking Innovation to the Streets: Microgeography, Physical Structure and Innovation. *The Review of Economics and Statistics*.

Rochet, J. C., & Tirole, J. (2006). Two- sided markets: a progress report. *The RAND journal of economics*, *37*(3), 645-667.

Sohn, E., Seamans, R., & Sands, D. (2019). Technological Opportunity and the Locus of Innovation: Airmail, Aircraft, and Local Capabilities. NYU Stern working paper.

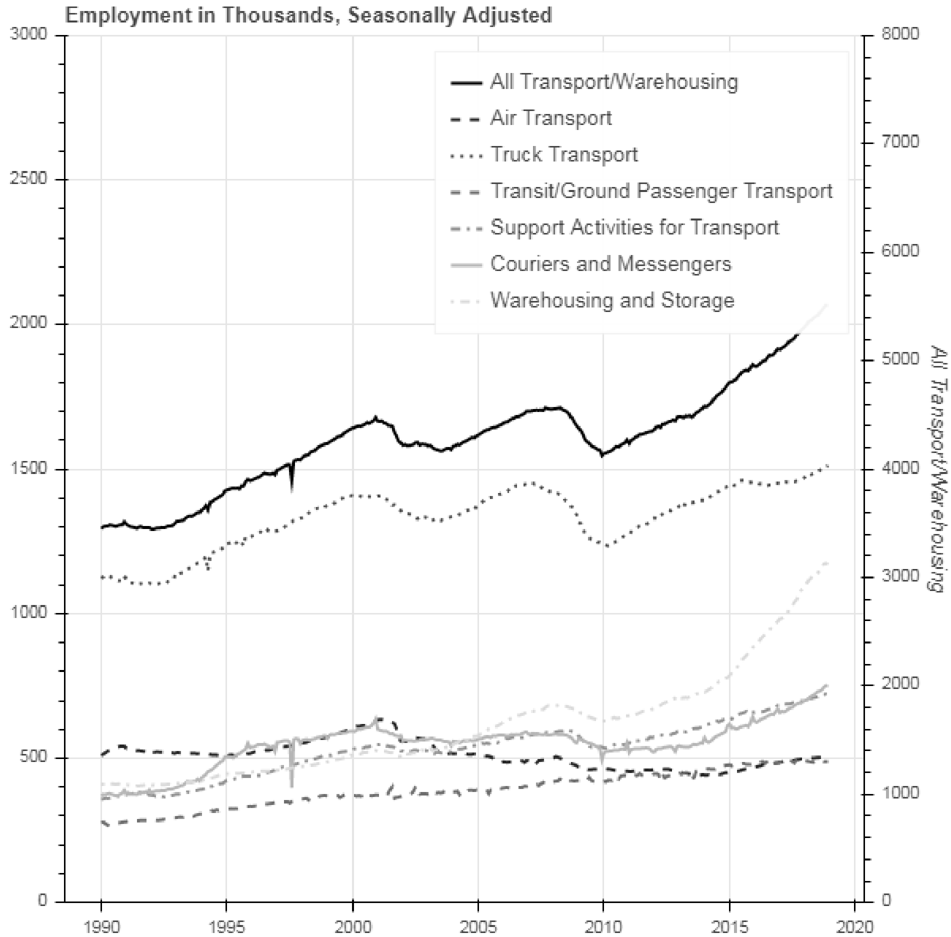
Sokoloff, K. L. (1988). Inventive Activity in Early Industrial America: Evidence from Patent Records, 1790-1846. *NBER Working Paper*, (2707).

Figure 1. Value Added as a Fraction of GDP



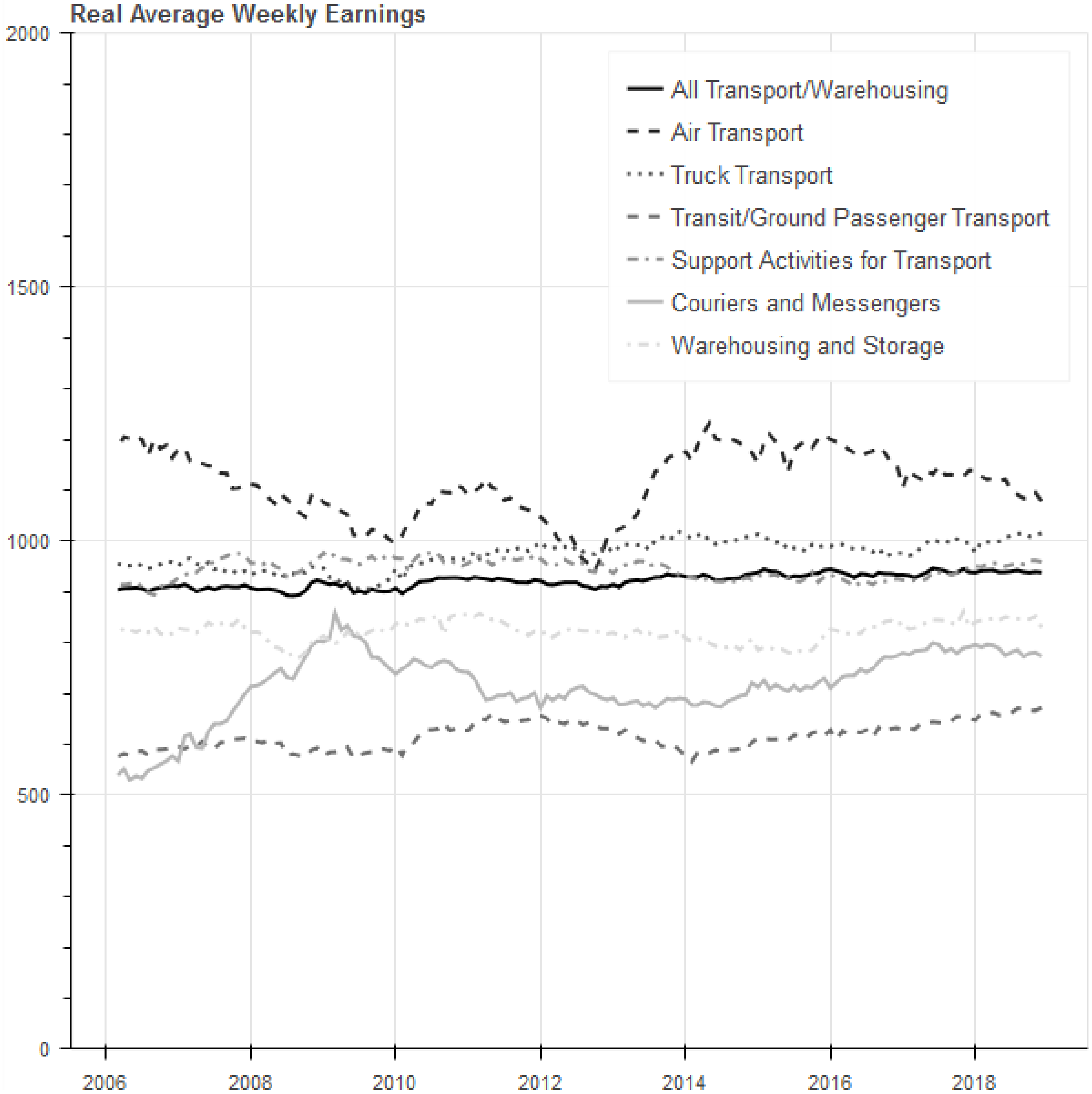
Note: These data come from the Bureau of Economic Analysis (BEA).

Figure 2. Employment by Transportation Sub-industries



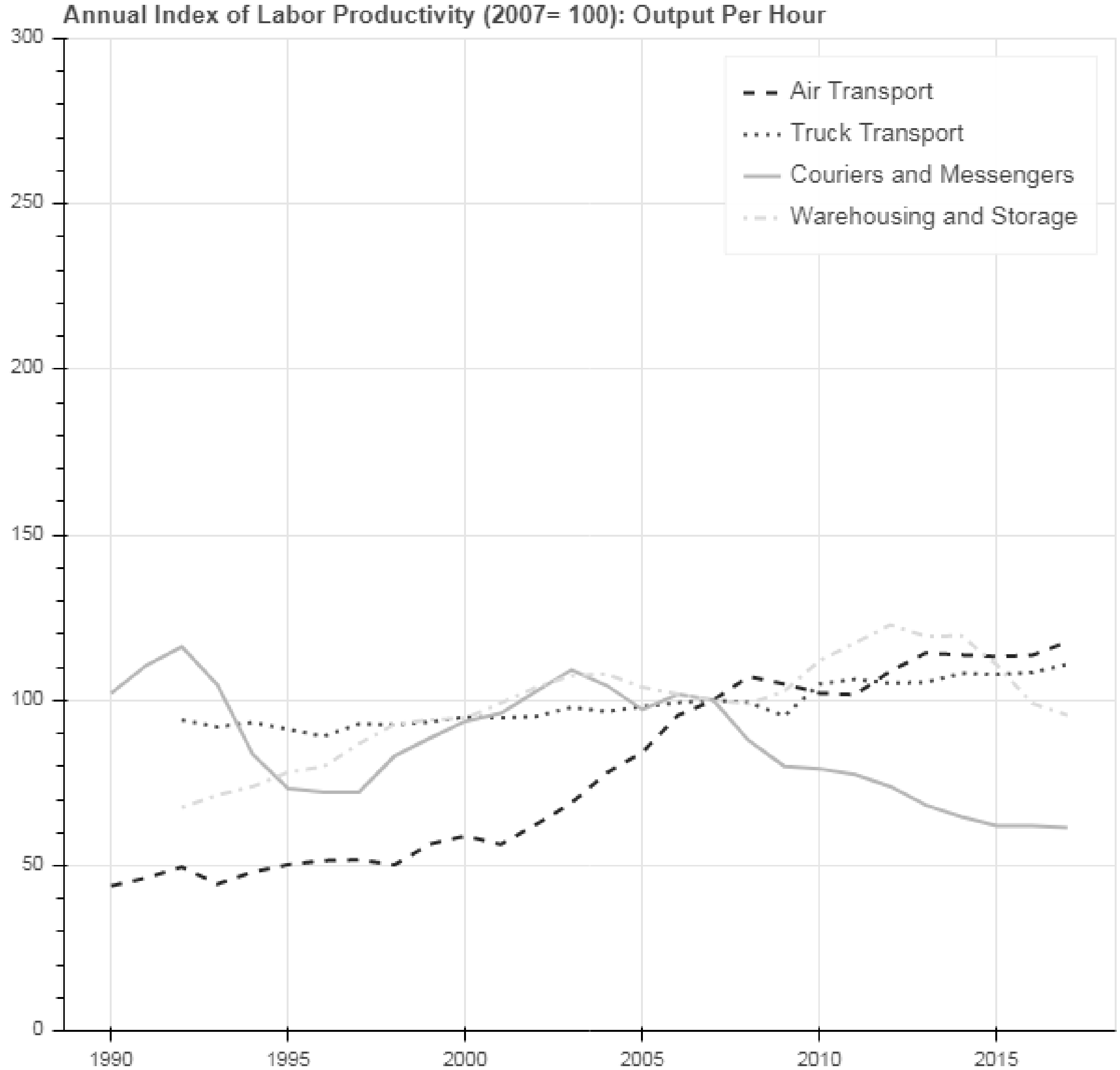
Note: These data come from the Bureau of Labor Statistics Current Employment Statistics survey (BLS CES).

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



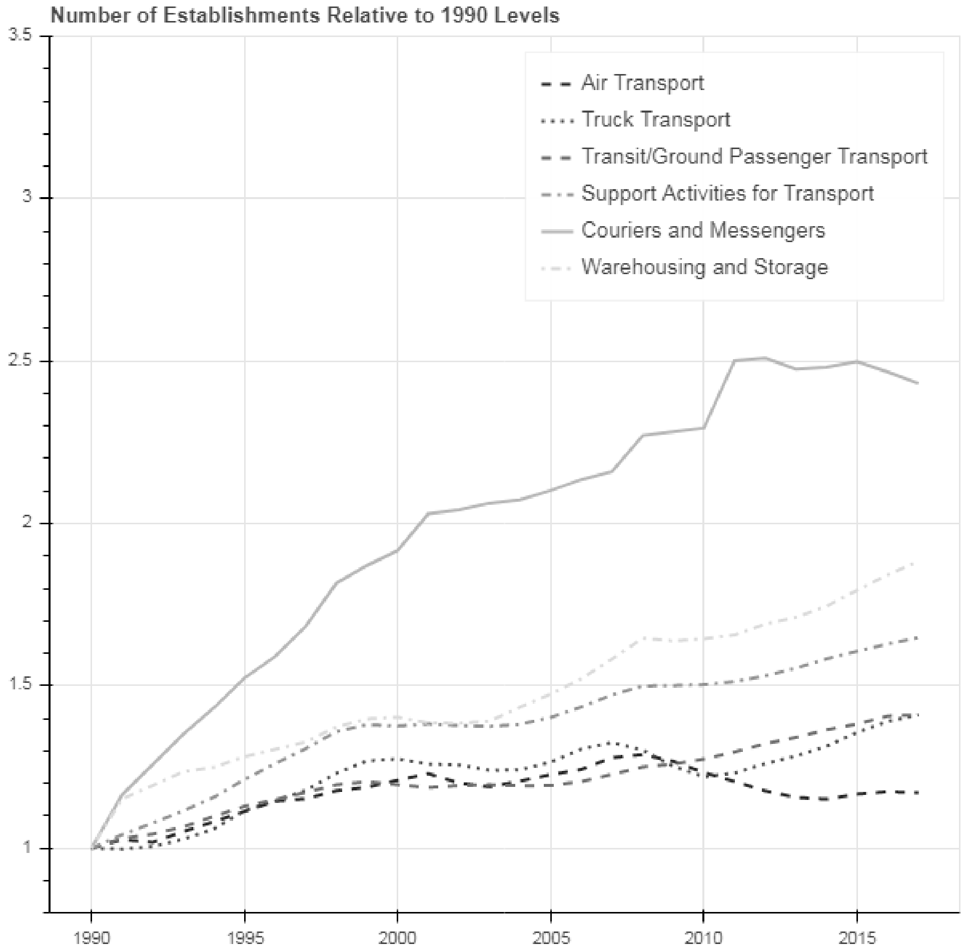
Note: These data come from BLS CES. We plot average weekly earnings by transportation sub-industry, adjusted for inflation using the CPI-U.

Figure 4. Labor Productivity by Transportation Sub-industry



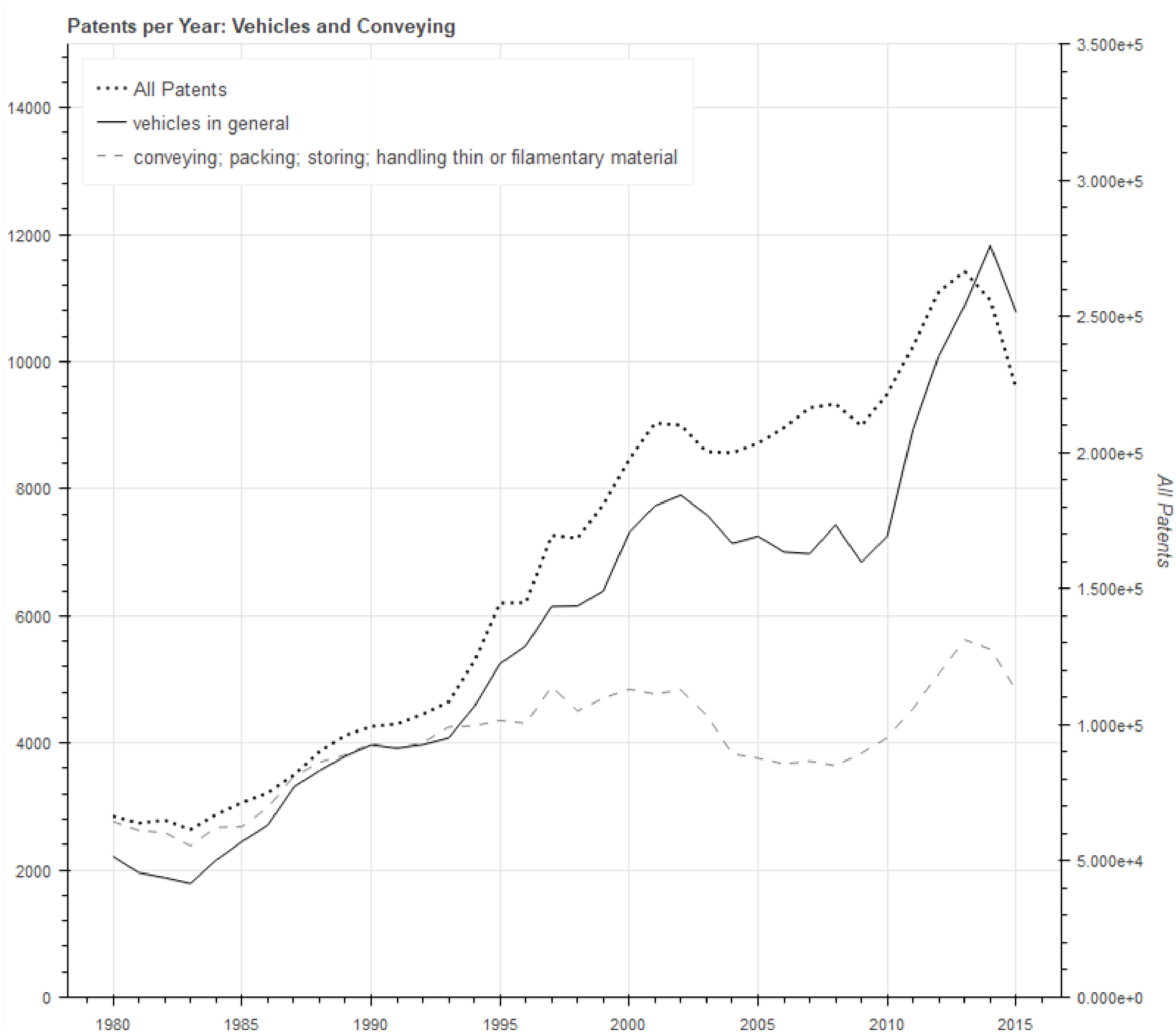
Note: These figures come from the BLS's Annual Index of Labor Productivity and show changes in output per hour relative to 2007 levels.

Figure 5. Growth in Establishments by Transportation Sub-industry



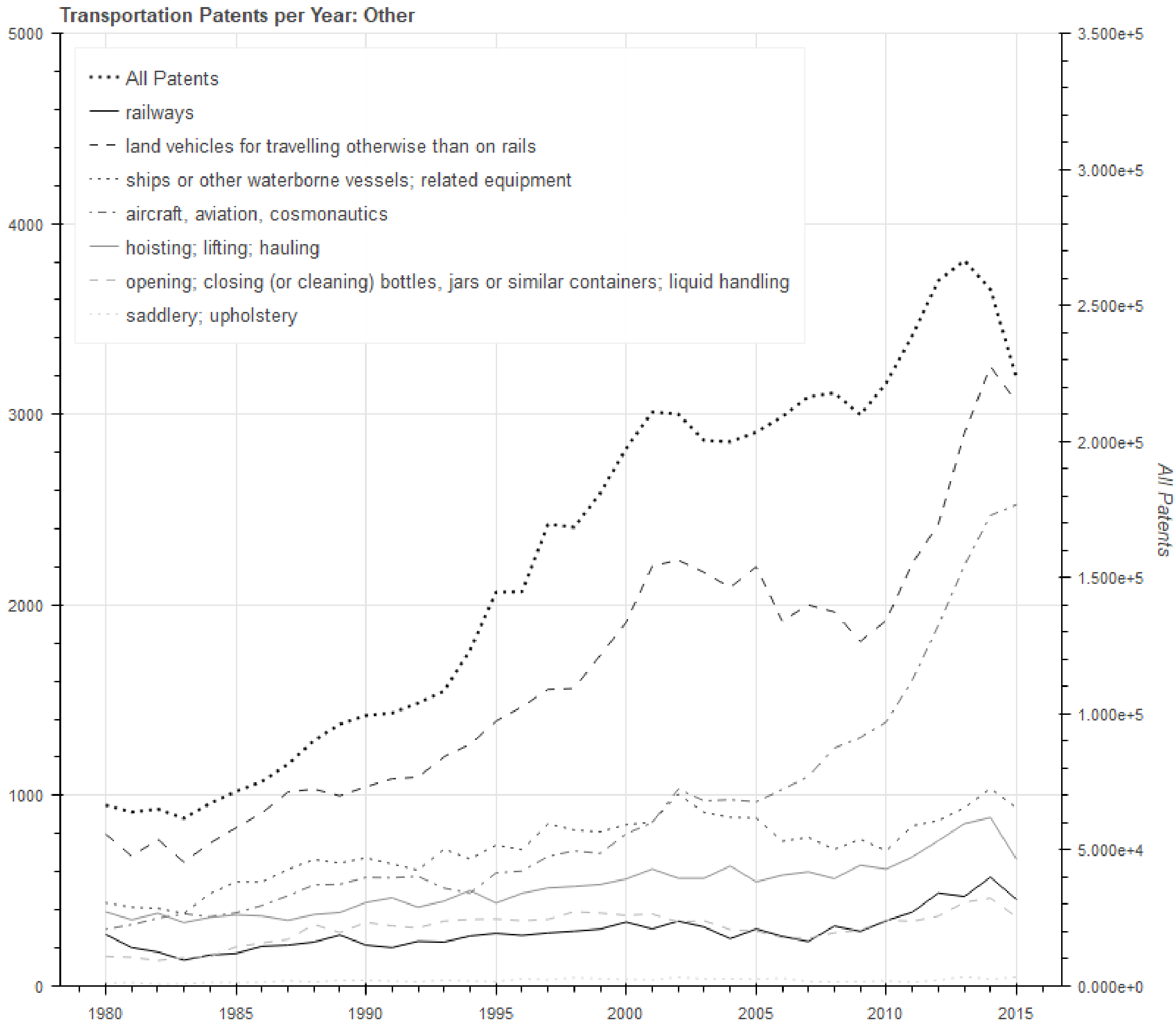
Note: These data come from the BLS Quarterly Census of Employment and Wages. The series are normalized to show establishment levels relative to 1990.

Figure 6. Patenting Activity: Vehicles in General and Conveying



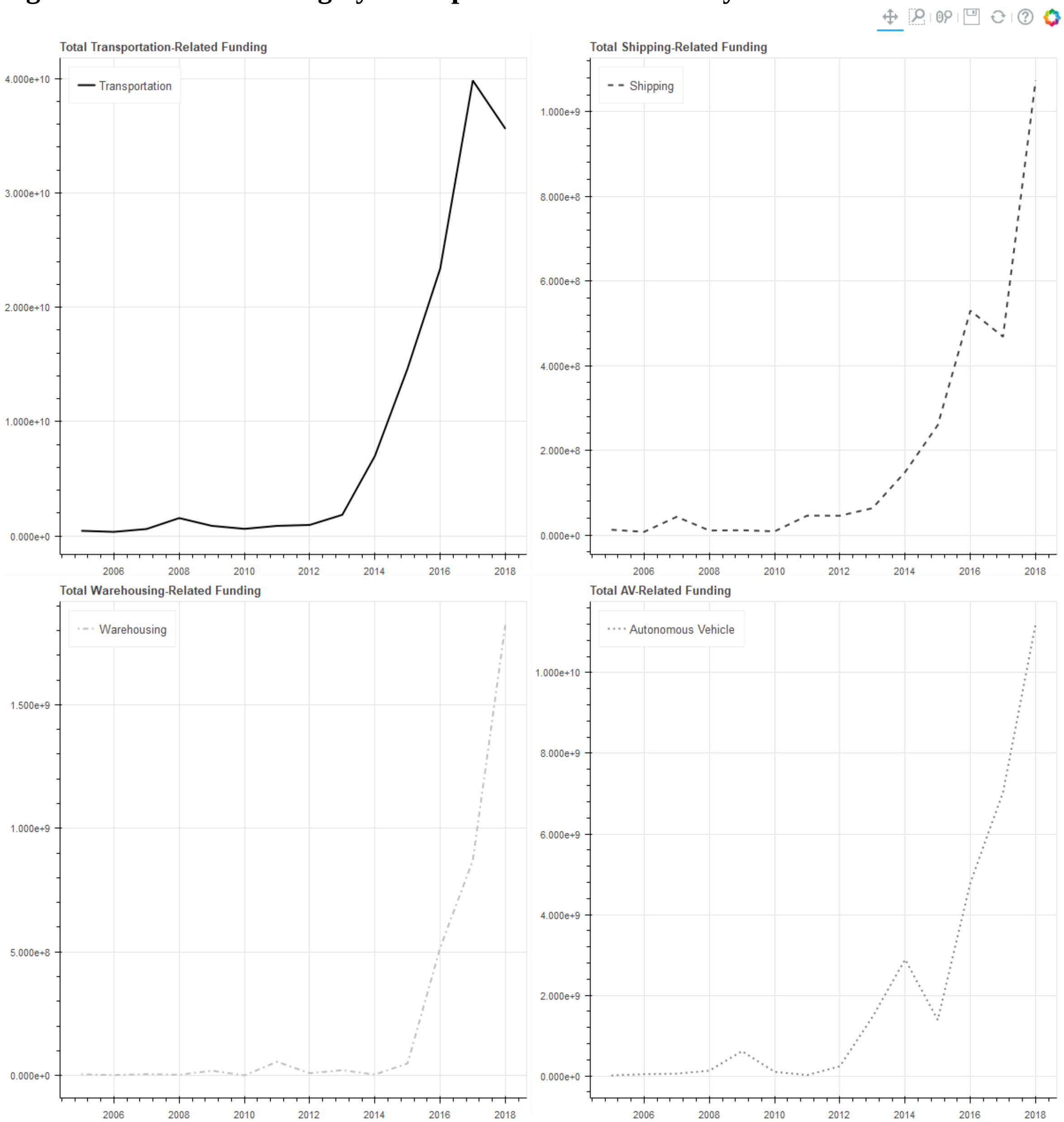
Note: These data come from PatentsView. We plot total patents per year for CPC codes B60 (vehicles in general) and B65 (conveying, packing, storing, etc.), as well as all patents.

Figure 7. All Other Transportation Patents



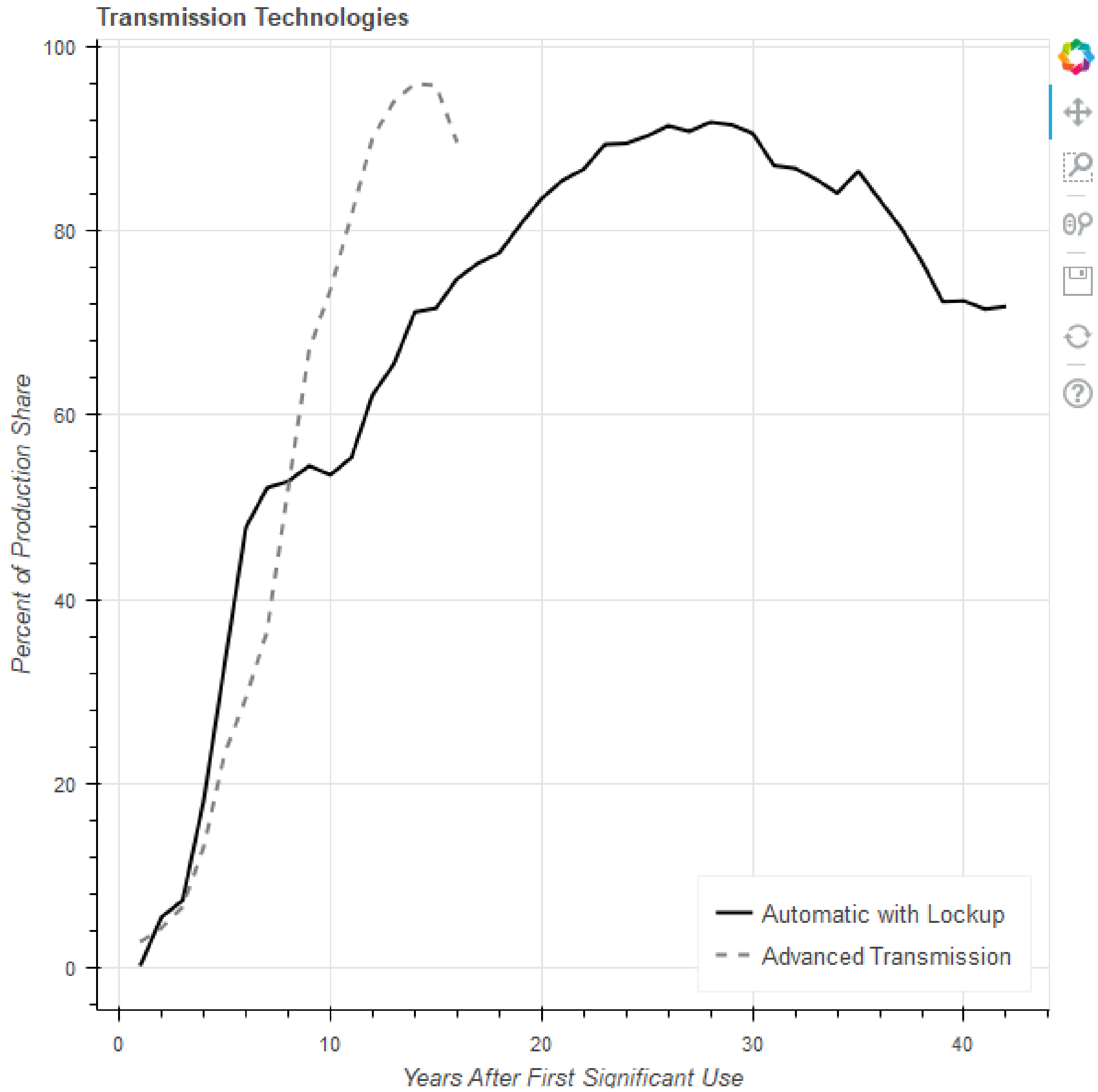
Note: These data come from PatentsView. We plot patents per year for the remaining transportation CPC codes (B60-B68), excluding vehicles in general and conveying/packing.

Figure 8. Venture Funding by Transportation Sub-industry



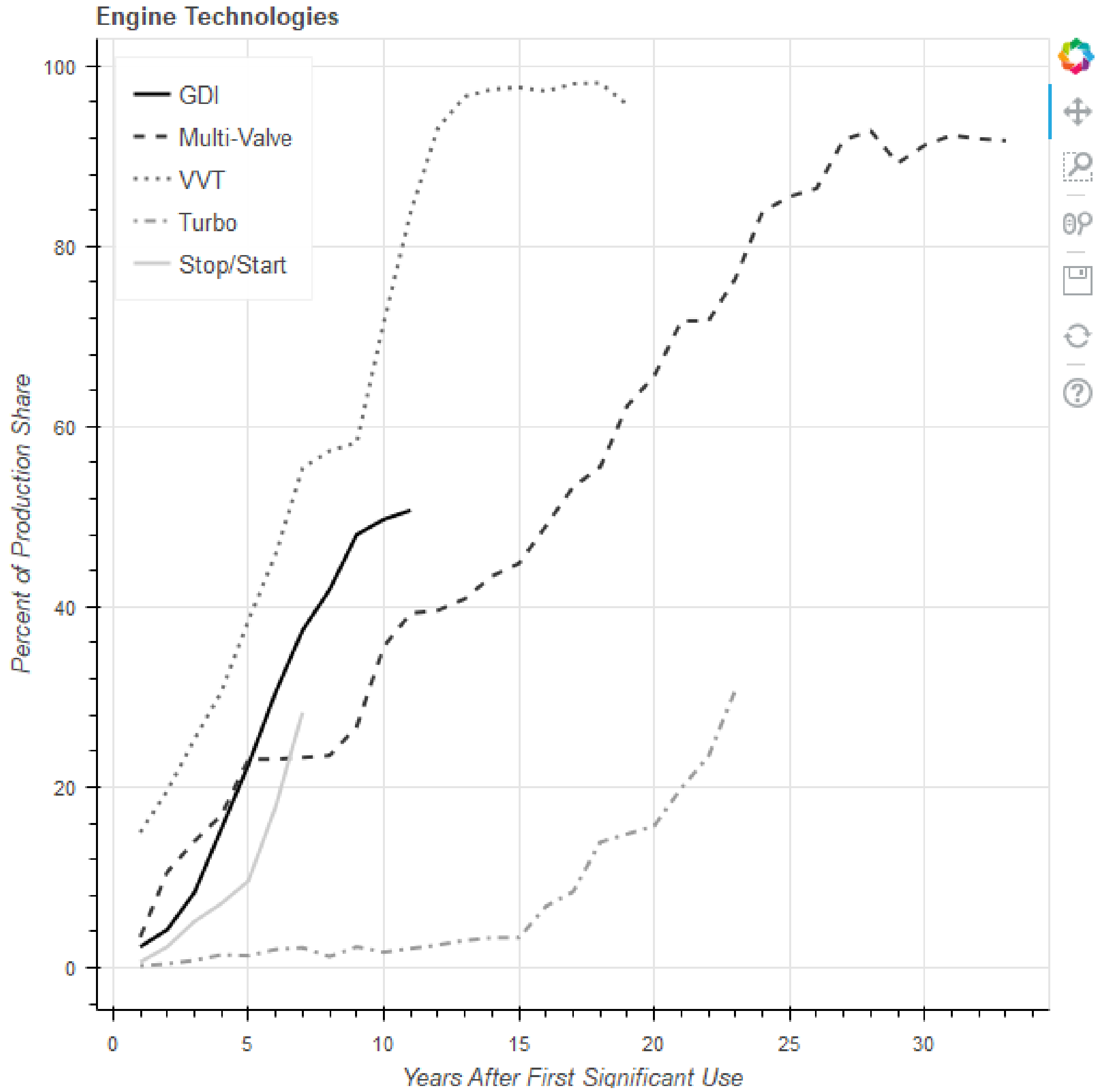
Note: These data come from CrunchBase. Figures report annual funding by company type; amounts are reported in US Dollars.

Figure 9. Automobile Transmission Technology Adoption



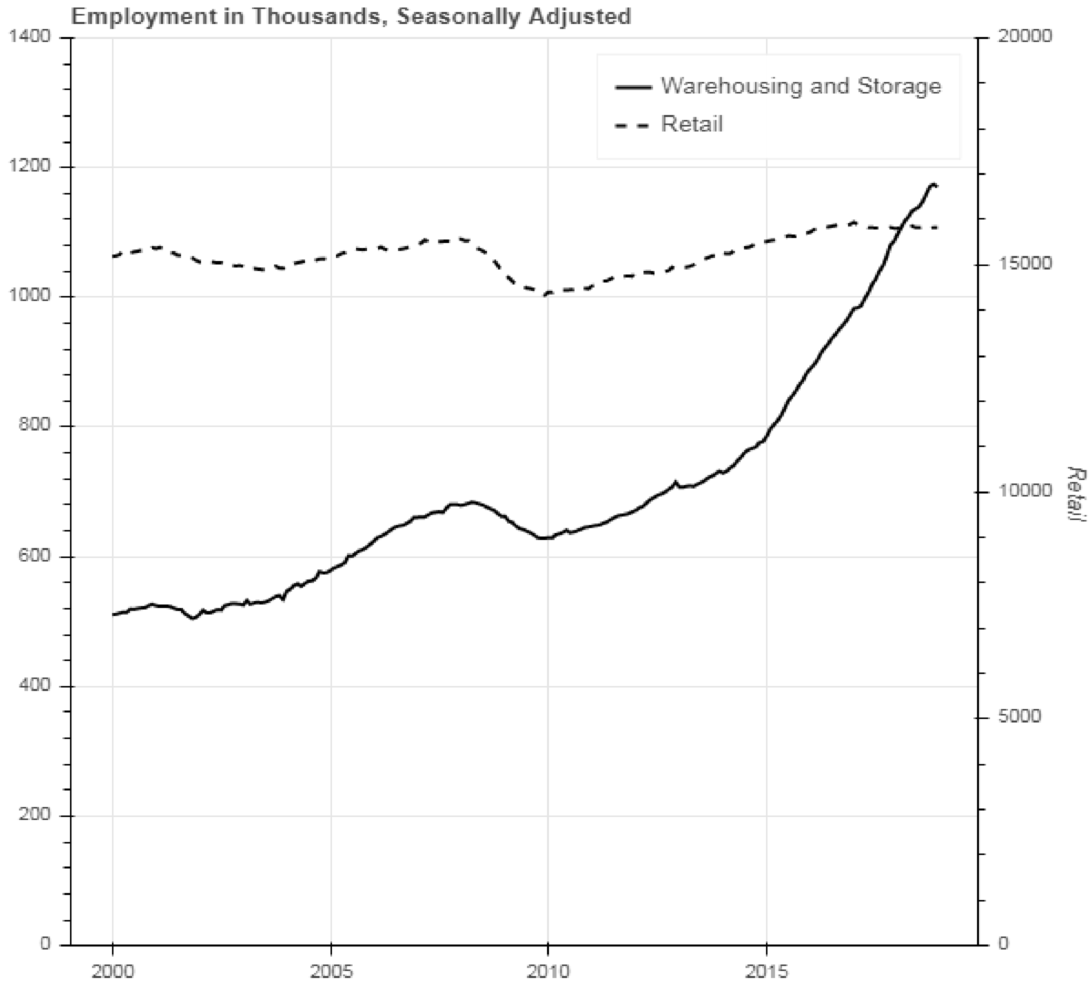
Note: These data come from the United States Environmental Protection Agency (EPA). We define advanced transmission as having six or more gears.

Figure 10. Automobile Engine Technology Adoption



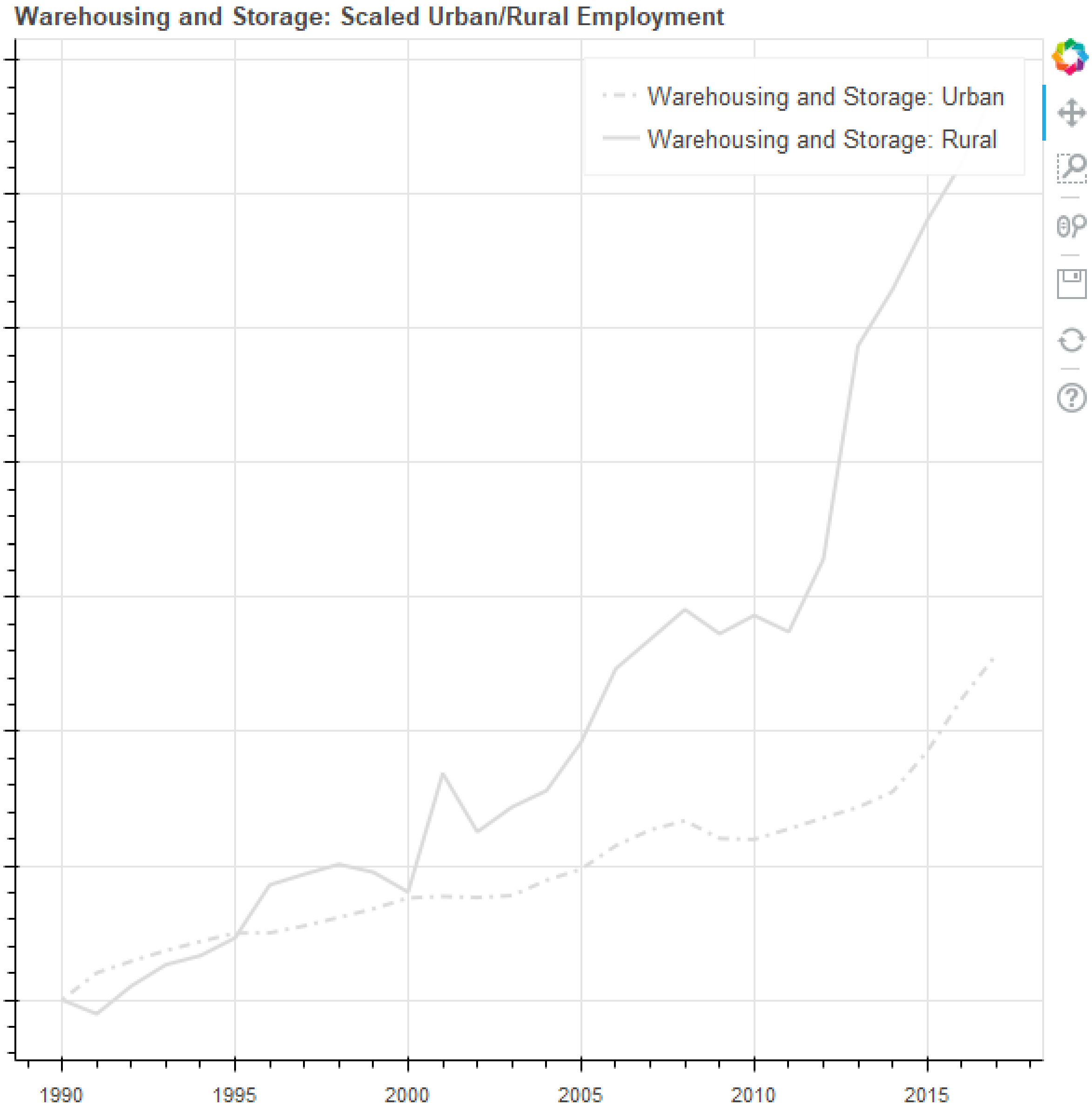
Note: These data come from EPA.

Figure 11. Retail and Warehousing Employment Over Time



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

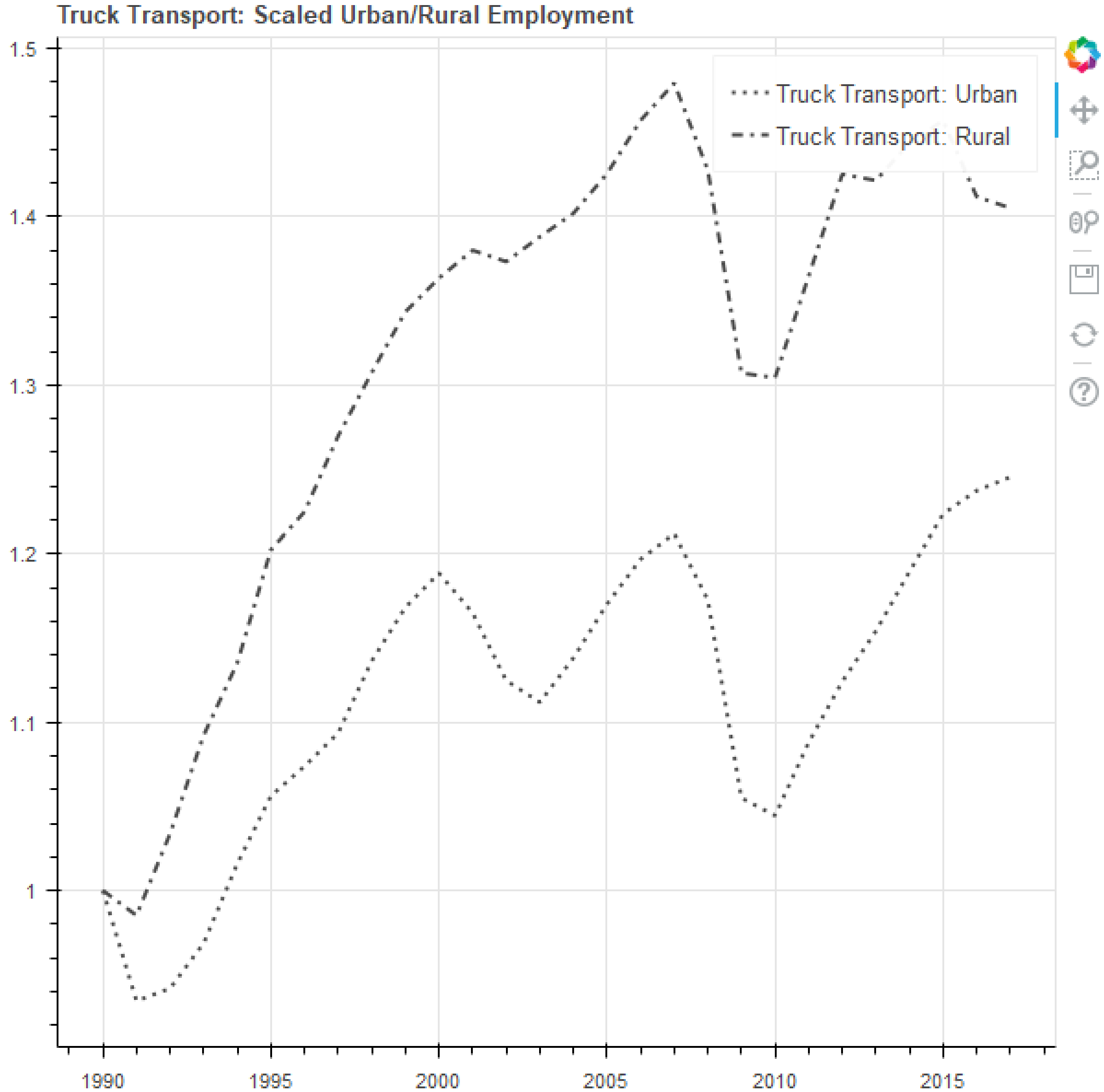
Figure 12. Warehouse Employment Growth: Urban vs. Rural



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

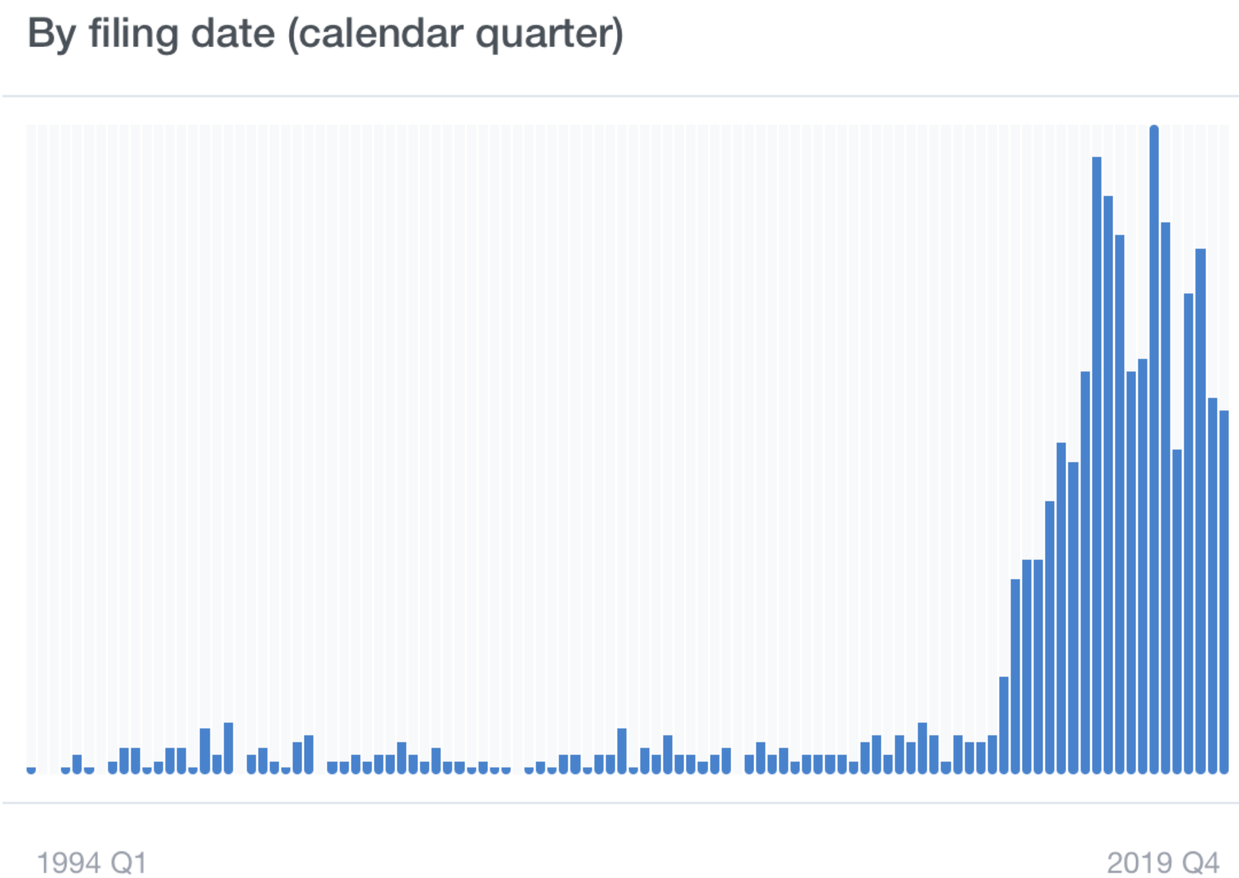


Note: These data come from BLS QCEW. Rural counties are defined as counties with more than half of their population living in rural areas as designated by the Census Bureau.

Figure 14. Increasing Importance of Warehousing Employment in the US

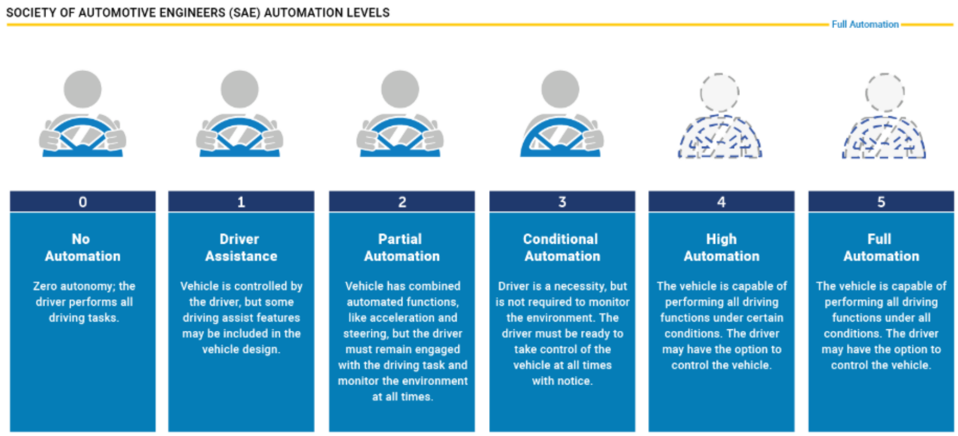
Note: These data come from BLS QCEW. We plot employment shares by transportation sub-industry (5-digit NAICS), normalized to 1990 levels.

Figure 15. Mentions of "Drone" in 8K and 10Q filings



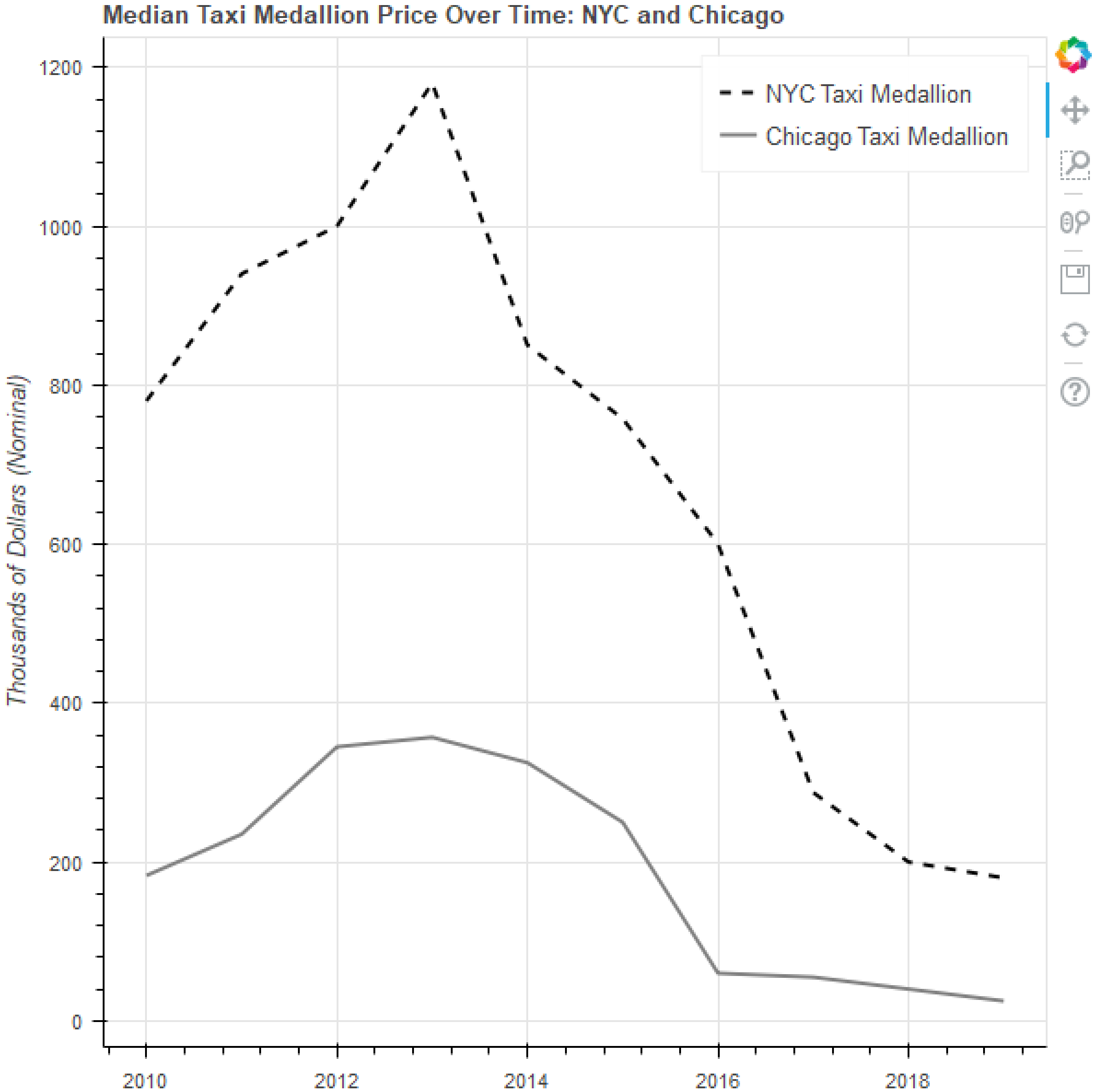
Source: Dokoh.com, Eighty-Five Technologies Inc.

Figure 16.



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.

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.

Table 1:

Industry Title	NAICS Code	2018 Employment in Thousands	2018 Real Avg Weekly Wage	Five Year Employment Growth	Five Year Real Wage Growth
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.