RESEARCH BRIEF

Warehousing, Trucking, and Technology: The Future of Work in Logistics

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Executive Summary

Twenty years ago, U.S. distribution networks were built to deliver products in bulk to retail stores. Today, large parts of distribution networks are built to deliver individual items to home residences. The shift has been driven by technology, working through e-commerce, and recently reinforced by the COVID-19 pandemic.

This brief describes how technology has affected three supply chain industries—warehousing and storage, general and specialized freight trucking, and freight transportation arrangements (i.e., freight brokers and third-party logistics providers).

In many future-of-work studies, technology operates only on the supply side of the market, replacing people in the production of goods and services. In the case of logistics, technology also works on the demand side of the market. By enabling e-commerce, internet technology has sharply increased the demand for two kinds of logistics services:

- The warehouse industry, built around bulk packaging, now handles huge numbers of individual items, such as a bottle of hand sanitizer or a single toy.

- The trucking industry, built around large shipments to distribution centers and retail stores, must now make many more small deliveries to individual homes.

Greater reliance on logistics has increased demand for the services of the freight transportation arrangements industry—more efficient scheduling, in-transit updates on shipment status, and handling of shipping paperwork.

The high demand for warehousing and trucking has also stimulated work on cost-reducing innovation, including varieties of warehouse automation and the development of autonomous trucks that can run on interstate highways. In practice, however, these innovations have either not yet come to market or are only slowly being adopted.

If we think of logistics employment as a tug of war between job gains from e-commerce and job losses from automation, thus far job gains are winning decisively. In eight to ten years, however, automation will likely be significantly stronger, both reducing the total number of jobs and shifting the mix of remaining jobs toward technicians, analysts, and other skilled occupations.

The challenge is to design labor market policies that handle automation-induced transitions better than current policies have handled the collapse that comes when manufacturing jobs suddenly leave a local labor market. In designing policy, the automation case begins with two advantages. Where manufacturing plant shutdowns are often sudden, the automation described in this brief is proceeding relatively slowly; and where manufacturing plant shutdowns are highly concentrated in particular communities, warehousing and trucking jobs are dispersed throughout the country.

KEY FINDINGS

- Between 2000 and 2019, the output of the general freight trucking industry (as measured by the U.S. Bureau of Labor Statistics) increased by roughly 20%. One-quarter of the increase came from more drivers: 1.62 million in 2000 compared with 1.75 million in 2019. Three-quarters of the increase represented a more efficient *use* of trucks—for example, fewer long-distance deliveries where the truck would make the return trip empty, less time spent waiting at a loading dock to pick up an order, and so on.

- Much of the gain in trucking efficiency came from firms in freight transport arrangements—truck brokers and third-party logistics providers—who increasingly used digital tools to improve load matching and scheduling, to change routes in emergencies, and to automatically process paperwork.

- The killer app in trucking—a commercially viable autonomous truck that travels on interstate highways—is at least a decade away.

- More limited automation, including automated truck platooning, will start to cost some truck driver jobs before the decade is out.
- Between 2000 and 2019, the output of the warehousing and storage industry (as measured by the U.S. Bureau of Labor Statistics) increased by 157% (sic). All of this increase came from a labor force that had grown from 438,000 in 2000 to 1.1 million in 2019. Despite substantial discussion of warehouse automation, the output per hour of warehouse workers was no higher in 2019 than in 2000.
- A closer look at output per hour in warehousing shows it increased by about roughly 20% between 2000 and 2014 but declined thereafter. This rise and decline is the result of several factors including:
    - Warehouses were slow to take up the most advanced automation equipment in part because it requires major restructuring of the warehouse.
    - From 2014 to 2019, rapid increases in e-commerce caused warehouse hiring to grow faster than 10% per year, much of it in older, un-automated warehouses.
- About 30% of warehouse workers are classified as laborers who move and pack materials by hand. In 2018, they averaged $12.64 per hour (including those persons who worked at Amazon warehouses at $15.00 per hour).
- As warehouse and trucking automation evolve, the jobs at greatest risk are filled by workers whose education did not go beyond high school.
- All three industries raise the possibility that only the biggest firms can afford to develop advanced technology—a process that may be adding to current trends toward greater market concentration among a few firms.

POLICY RECOMMENDATIONS

- Develop employer-community college consortia to expand access to career education. These programs, like the private sector equivalents - Amazon's Career Choice and Walmart University - would be directed at preparing low-wage logistics workers for better jobs that are under less threat from automation.
- Use local economic development incentives as a way to encourage new warehouses to set a higher-than-market minimum wage and to cooperate with local career education consortia.
- Adopt a federal mileage tax on autonomous trucks to fund a program administered by the states, which would provide a safety net for truck drivers displaced by automation and help

them transition into other occupations. One version of such a tax is currently under development by the International Brotherhood of Teamsters.

KEY REMAINING QUESTION

- To what extent is technology adding to the current trend toward market concentration in a few large firms?

Section 1: Introduction

Twenty years ago, only professionals discussed logistics, consumer products purchased by mail required long delivery waits, and warehouse workers were invisible to the public. Today, a Google search for "supply chain" produces 1.8 billion links, many warehouse workers are designated essential workers, and e-commerce firms often apologize if delivery takes more than two days.

Logistics presents an unusual example of how technology changes work. We normally think of technology operating through the supply side of the market, replacing people in the production of goods and services. In logistics, we will see examples of supply side replacement, but to this point they are swamped by technology's impact on the demand side of the market: internet technology enabling the growth of e-commerce and the increase in logistics jobs required to pack and deliver orders.

To make sense of these developments, we undertook an examination of three industries that together account for more than half of logistics employment: warehousing and storage, general and specialized freight trucking (hereafter, "freight trucking"), and freight trucking arrangements (i.e., truck brokers, third-party logistics providers). Our analysis is based on interviews with warehouse automation suppliers, distribution center managers, managers in both established logistics companies and digital startups, and academics who study trucking. We have drawn on reports from the trade press (e.g., *Modern Materials Handling, Inbound Logistics, DC Velocity, SupplyChainDive)* and the business press (*Wall Street Journal*). We have also drawn on research papers from the National Bureau of Economic Research, and we have utilized data from both the U.S. Census and the U.S. Bureau of Labor Statistics.

The resulting research brief summarizes how technology is changing a central part of the U.S. economy.

A final comment: While this brief does not focus on retail sales workers, increased e-commerce has increased logistics employment and has reduced retail sales employment below what it otherwise would have been. In 2000, the retail trade industry employed 15.3 million persons and employment had been growing at 1.5 percent per year since 1990. If retail trade employment had continued to grow at that rate, it would have stood at 17.5 million in 2019. In fact, retail trade employed 15.6 million persons in 2019, a difference of 1.9 million persons.The average workweek for retail trade employees has been roughly stable at 30 hours per week (rather than the normal 40 hours). As a rough approximation then, we can say that retail trade jobs are roughly 1.5 million full-time jobs below what we might have expected. E-commerce is not the only cause of this shortfall, but the number should be kept in mind when considering logistics employment.

Section 2: An Overview of Three Industries

Prior to the COVID-19 pandemic, warehousing and storage, freight trucking, and freight trucking arrangements accounted for 3.1 million jobs. The number represents one out of every 50 jobs in the economy or about one-quarter as many jobs as in U.S. manufacturing.

To sharpen this picture, Table 1 classifies most of these jobs by the U.S. Bureau of Labor Statistics' NAICS[1] industry classification. Warehousing and storage (NAICS 49311) employed 1.13 million persons, including packers and material movers, managers, mechanics, and a small but growing number of analysts and data scientists. Across all occupations, warehousing employees earned an average of $792 per week, a 4% decline from earnings in 2000 (earnings comparisons are adjusted for inflation[2]).

Hired freight truck drivers—those who work for firms—can be classified into three broad groups:

- Local delivery services, including home deliveries, account for 29% of all truck-driving jobs (NAICS 484110, 484220).
- Long-distance truckload (TL) carriers account for 30% of driving jobs (NAICS 484121).
- Long-distance less than truckload (LTL) carriers represent 15% of driving jobs (NAICS 484122).

TL and LTL carriers both move goods among factories, distribution centers, and retail stores. A TL carrier moves a single, full trailer shipment to a single destination, while an LTL carrier moves multiple shipments to multiple destinations in the same run.

In addition to truck drivers who work for firms, there are an estimated 300,000 owner-operator drivers—both TL and LTL—who are not counted in NAICS industry surveys but are listed in Table 1.

In 2019, TL drivers averaged $1,004 per week and LTL drivers averaged $1,164 per week. Both figures are 10% higher than they were in 2000. Local drivers averaged $985 per week, a 10% decline from 2000. Owner-operator drivers earned a roughly estimated $1,000 per week. All these earnings figures should be interpreted with caution. Most truck drivers—employees and owner operators—are paid by the mile or by the job, not by the hour. Time spent stopped in a traffic jam or waiting for an order at a loading dock is not paid time. The result is that drivers (including owner operators) often spend far more than 40 hours per week working for their pay.[3]

In addition to driving jobs, 240,000 persons worked in freight transportation arrangements: primarily truck brokers who connect shippers to TL carriers and third-party logistics providers (3PLs) who connect shippers to TL and LTL carriers and provide multiple other services (see Section 5). Employees in this industry averaged $1,217 per week, a 14% increase from 2000.

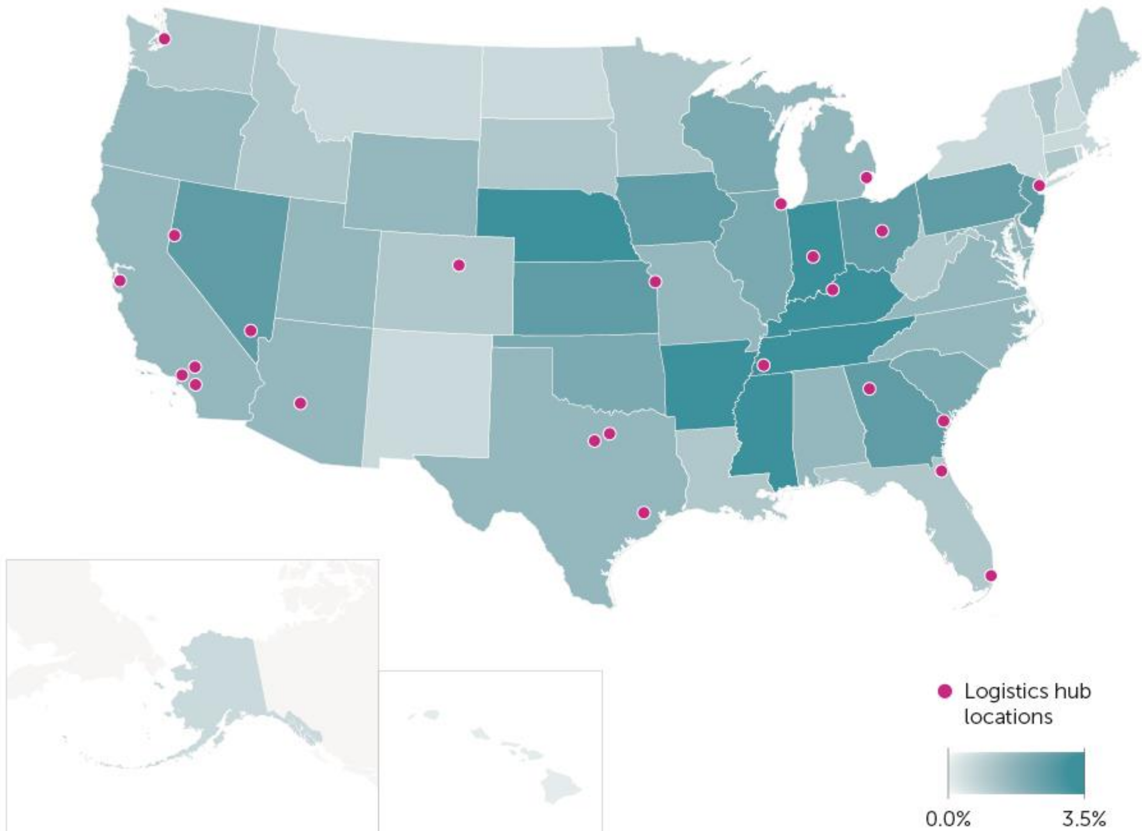
Table 1. U.S. Employment and Labor Productivity in Trucking and General Warehousing and Storage

NAICS CODE OCCUPATIONAL TITLE	2000	2019	% CHANGE IN EMPLOYMENT	2019 AV. WEEKLY WAGE	% CHANGE AV. WEEKLY EARNINGS
NAICS 484110—General freight trucking, local	249,577	272,020	9.0%	$985	-11.4%
NAICS 484121—General freight trucking, long distance (TL)	550,923	526,942	-4.4%	$1,004	8.7%
NAICS 484122—General freight trucking, long distance (LTL)	225,404	263,078	16.7%	$1,164	11.2%
NAICS 484220—Other specialized trucking, local	190,561	238,313	25.1%	$1,076	-13.1%
NAICS 484230—Other specialized trucking, long-distance	109,348	139,692	27.7%	$1,153	-4.1%
Estimated—Owner-Operator (TL) and (LTL) Drivers	??	300,000	??	$1,000?	??
NAICS 488510—Freight transportation arrangement	181,907	239,794	31.8%	$1,217	14.4%
Freight Trucking Employment (total)	**1,509,720**	**1,981,858**	**31.3%**		
NAICS 49311—Warehousing and Storage	438,313	1,130,503	157.9%	$792	-4.2%
Freight Trucking + Warehousing and Storage Employment	**1,948,033**	**3,112,361**	**59.8%**		

Source: NAICS related data from the U.S. Bureal of Labor Statistics.
Estimates for Owner-Operatior Drivers from conversations with industry experts.

Like much of the nation's economic activity[4], many warehousing and trucking jobs are located near metropolitan areas, including concentrations in Southern California, South Florida, Northeast Illinois, New Jersey–Pennsylvania, Seattle–Tacoma–Bellevue, Dallas-Ft. Worth, and Houston.

Figure 1. Warehousing, Storage, and General Freight Trucking Employment as a % of Total Employment

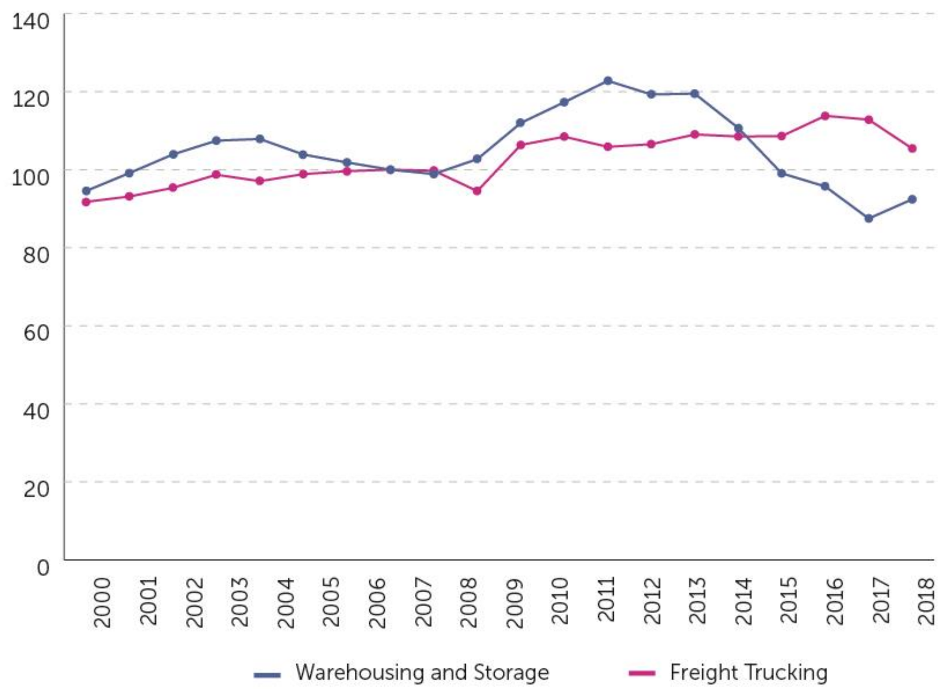


For most of the past two decades, however, employment in both industries has grown relatively faster in rural rather than urban counties.[5] Rural expansion reflects a combination of delivery network design, efforts by rural and exurban counties to attract economic activity, and efforts by warehouse developers to find low-wage workers and open land.[6] Over the last 30 years, many rural counties have lost manufacturing jobs that employed men and women whose education stopped at high school. Two-thirds of employees in trucking and warehousing have not gone beyond high school, making these industries attractive rural development targets. At the same time, rural counties offer warehouse operators open space for large structures and a supply of workers with limited alternative opportunities.

Most recently, the pandemic may be stimulating a different kind of expansion in which big distributors, including Amazon, are creating a limited number of fulfillment centers in vacated retail space in urban shopping malls.[7] At first glance, the expansion logically follows the shift of retail spending from brick-and-mortar stores to online purchases. But this expansion faces obstacles—including opposition from other shopping mall tenants—and will, at best, take time to develop.

As a final piece of this overview, Figure 2 displays one measure of productive efficiency for both warehousing and storage and freight trucking, the index of output per hour of work from 2000 to 2019.[8]

Figure 2. Index of Output per Hour in Warehousing and Storeage and in Freight Trucking (2007=100)



Source: https://www.bls.gov/lpc/tables_by_sector_and_industry.htm

Between 2000 and 2012, output per hour of work in warehousing and storage rose by more than 20%. It then declined after 2014, leaving the productivity measure slightly lower in 2019 than it had been in 2000. In 2019, the total output of warehousing and storage was roughly 2.3 times as large as it had been in 2000, with essentially all of the increased output due to increased employment. These figures raise an obvious technology question: Given the extensive discussion of warehouse automation, how could output per hour decline after 2014?

Between 2000 and 2019, output per hour of work in freight trucking increased in a more regular pattern by a little less than 1% per year—a total growth of 14.8%. Over these years, total hours of labor increased by 4.2%, and so trucking output, the product of these two factors, increased by roughly 20%. These figures also raise a technology question: Was the increased efficiency in trucking due primarily to more efficient trucks or the more efficient *use* of trucks (e.g., fewer long deliveries where a truck had to return empty)?

We provide tentative answers to both technology questions in the sections that follow.

Section 3: Logistics, Technology, and E-Commerce

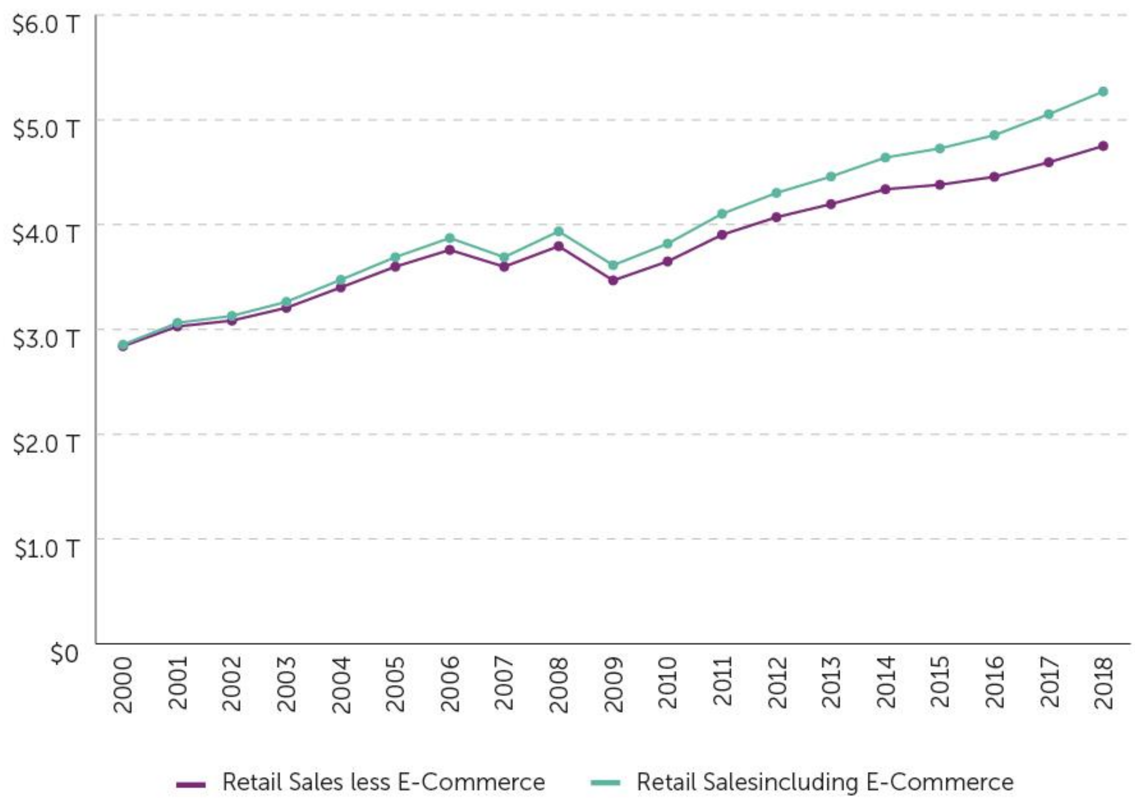
In 1979, CompuServe (now part of America Online) became the first service offering email to subscribers' home computers.[9] In 1984, CompuServe announced another first—the Electronic Mall—where CompuServe subscribers could browse in product categories, including hardware, gardening, records, books, travel services, and magazines. CompuServe subscribers received an explanatory letter including these instructions:

> *To order an item in the Mall, simply press the letter "O" followed by the item to be ordered. The order is placed in a personal file for you. You can either continue shopping the store or exit, at which time an order form automatically appears that adds your charges and provides options for paying the merchant. You can order as many items as you like in any individual store before checking out.*[10]

By 1995, both Amazon.com and eBay.com had processed their first transactions; but, as late as 2001, internet purchases remained a novelty—1.1% of all retail sales (see Figure 3).

Internet access and e-commerce continued to mature in parallel. In 2010, well over half of the population had always-on, broadband internet connections. By 2017 (well before the pandemic stimulated online orders), e-commerce represented roughly 9% of all retail sales and almost 13% of retail sales, excluding automobiles, gasoline, and sales in bars and restaurants categories that were not, until the pandemic[11], candidates for internet sales.

Figure 3. Total Retail Sales and Non-E-Commerce Retail Sales



Source: https://www.census.gov/data/tables/2017/econ/e-stats/2017-e-stats.html — Historical Table 4 data unadjusted for inflation

Two factors help to explain this growth: *convenience* and *cost*.

Convenience

In 1984, a CompuServe subscriber would have ordered from the Electronic Mall by first tying up their family phone line to connect their home computer to CompuServe (rather than using an always-on broadband connection). They would have chosen a product from the Electronic Mall's limited suppliers (rather than using a browser and search engine to examine an infinite number of suppliers). They would have exchanged emails and perhaps regular mail to select the item and complete the purchase (rather than pointing, clicking, and entering a credit card number and address that are instantly validated by a secure payment system). Ordering over the internet had changed from being hard to being easy in a process that affected jobs in logistics, brick-and-mortar retail, and call centers. As a call center manager ruefully said, "Think about how many phone calls it takes to complete an Amazon order."[12]

Speed of delivery increased in equally dramatic fashion—what is often called the "Amazon Effect" because of the 2005 Amazon Prime offer of two-day delivery for a fixed annual fee. The technology of two-day delivery began with a warehouse management system (WMS) that could quickly locate a product within the Amazon warehouse network.[13] The WMS was followed by robotics and scheduling software that allowed a product with priority delivery to move rapidly through the Amazon network and ultimately to the customer's home. We discuss each of these elements below.

Cost

At the same time, buying an item over the internet was, in many cases, cheaper than buying from a local retailer. For some firms, the cost advantage involved economies of scale in purchasing that had been exploited starting in the 1980s by Walmart, Costco, and other big box stores.[14] But e-commerce firms also gained cost advantages from the courts and government policy. In 1992, the Supreme Court in *Quill Corp. v. North Dakota* ruled that a state could not compel an out-of-state firm to collect sales taxes on items bought by North Dakota residents.[15] Twenty-six years later, the court reversed this decision; but in the interim, many consumers turned to e-commerce as a way to avoid paying state sales taxes.[16]

Similarly, when Amazon began Amazon Prime with two-day delivery, regular gasoline in the United States was selling for an average $2.30 per gallon. In France, a country with higher energy taxes, gasoline at that time was selling for the equivalent of $5.53 per gallon. If U.S. gasoline had been priced at $5.53, the economics of two-day delivery might not have looked as profitable.

THE RAPID GROWTH OF E-COMMERCE HAS CREATED TWO LOGISTICS CHALLENGES.

The first is the increased demand for frequent deliveries from distribution and fulfillment centers (warehouses) to individual residences, a trend accelerated by the COVID-19 pandemic. For example, in the second quarter of 2020, UPS alone delivered 21.1 million packages.[17]

The second challenge is the radically increased variety of individual items, or "eaches," that distribution and fulfillment centers now handle. Traditional distribution networks ended at retail stores and shipped items in bulk: a cardboard carton containing multiple bags of Fritos, a wardrobe carton holding six women's dresses for a store to unpack and display, and so on. Now distribution networks require picking, packing, and shipping individual items, including Barbie dolls and pizza stones, to an individual's home. As one distribution manager told us:

> "We began selling over the web three years ago. Since then, my volume has increased by 20% but my shipments have gone through the roof. Where I used to ship six pieces of clothing to one

store, I now ship six pieces of clothing to six separate addresses." (personal communication, June 28, 2019)

In this brief, we will apply three propositions on technology and work that are relevant not only in logistics, but also across the economy. We have just encountered one of these propositions:

Significant technology is not always the newest technology.[18]

Startups and the media both emphasize the new and provocative. As a result, discussions of technology and logistics often focus on autonomous trucks that require no drivers or automated, "dark" warehouses that require no people. We discuss both innovations below, but we should not forget that sales over the internet—the main force reshaping logistics—is a heavily refined version of an idea that was first implemented in 1984.

The following sections of this brief discuss how warehousing and trucking are adapting to this force.

Section 4: Technology and Warehousing

The e-commerce impact on logistics begins with warehouses. What had been drab storage buildings on the other side of town are now fulfillment and distribution centers—"strategic hubs" that sometimes include white-collar jobs and analysis units. Data from [Moody's Analytics] shows that warehouse square footage has grown by a total of 12% since 2010 [19] and now covers an area of 245 square miles. Data from real estate consulting firm CBRE shows that new warehouses are growing substantially in size:

> Demand for efficient logistics space that facilitates quick movement of goods to consumers has caused warehouses to increase in size and height. The average new warehouse completed in the U.S. between 2012 and 2017 increased by 108,665 sq. ft. (143%) and 3.7 feet in height since the last development peak between 2002 and 2007.[20]

Pressure for rapid movement of goods through these hubs has stimulated substantial automation development—a Google search for "warehouse automation" produces 67 million links—but automation adoption has been gradual. As one industry veteran noted:

> There are a few organizations out there that do surveys about this topic and levels of automation. Based on a few of these studies, it looks like the range of [distribution centers] that have some level of automation in the United States is about 40%–50%. That could be as simple as a few conveyor lines all the way up to more sophisticated sortation. About 5% of those surveyed felt that they had highly automated systems: robotics, [Automated Storage and Retrieval Systems], unit sortation, etc. (personal communication, 6/30/2020; brackets added).

The labor productivity data for warehousing and storage also tell a mixed story (Figure 2). Output per hour of work in warehousing rose fairly steadily through 2012—the result we should expect from automation. But starting in 2014, output per hour declined for the rest of the decade and was no higher in 2019 than in 2000.

As shown in Table 2, reconciling these facts begins by understanding the tasks that warehousing entails.

Table 2. Warehousing Operation Tasks

WAREHOUSING OPERATIONS TASKS
Unload incoming items
Store incoming items
Keep track of the locations of all incoming items
Receive and correctly interpret customer orders
Accurately pick items requested in customer orders
Move requested items into an order assembly area
Assemble and pack the order
Load packed items on the truck that will handle delivery
Keep accurate records of all activities

Up to this point, automation's broadest impact has come in moving information by tracking and recording the movements of goods through the warehouse. Many companies—including Manhattan Associates, Oracle, BlueYonder, HighJump, and Epicor market a warehouse management system (WMS) for this purpose. A modern WMS works together with scanners and items marked by barcodes or RFID tags to compile data on product arrival, storage location, and shipments to customers. The resulting information provides a basis for demand predictions and, more generally, improved operations planning. Roughly 80% of warehouses now operate some type of WMS.[21]

The automated movement of goods has evolved more slowly than the automated movement of information. Part of the explanation involves a second proposition on technology and work that applies across the economy:

Some tasks that are easy for humans remain difficult for computers.

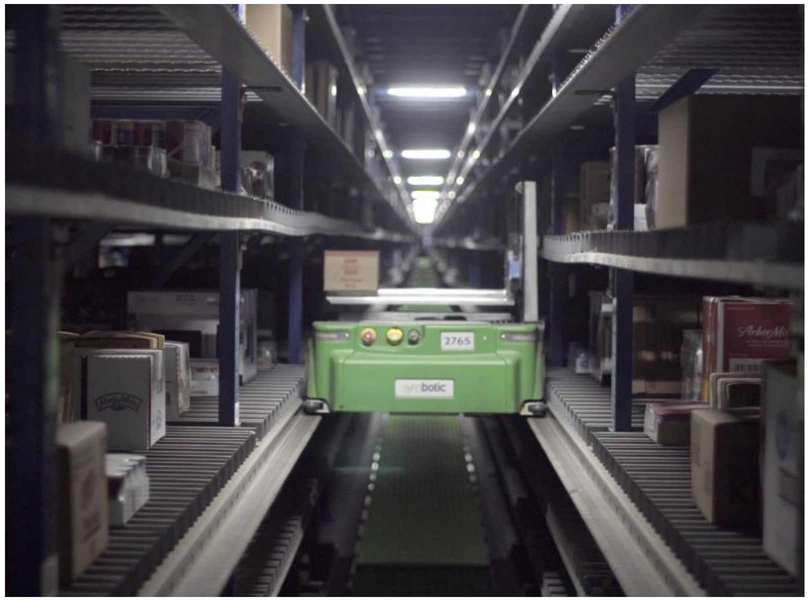
In particular, a four-year-old child who knows about ducks can pick a toy duck out of a basket of small, stuffed animals even if she has never before seen this particular duck. A robotic gripper has a very hard time with this problem, particularly if its software has not been trained on this particular duck. In robotics, this is known as the gripping problem.

With the increase in e-commerce, many distribution and fulfillment centers face the problem of unloading, unwrapping, storing, accurately selecting, and packing individual toys, individual bottles of hand disinfectant, small plastic bags of 1½-inch standard wire nails, and so on. Because of the gripping/toy duck problem, many of these tasks—in particular, picking and packing individual items—are almost always performed by people.

A counter-example proves the point. Modern grocery warehousing has made big gains in automation by exploiting the uniform shapes of wholesale grocery containers: 36 cans of creamed corn shipped in a rectangular carboard box, four six-packs of soft drinks in a cut-off cardboard box wrapped in plastic, and so on. In most cases—plastic-wrapped fresh produce remains a problem—the gripping/toy duck problem disappears, and the system confronts a limited number of standard containers that are identified by barcodes and easy to manipulate mechanically.

Firms such as Massachusetts' Symbotic and the British grocery retailer Ocado offer an automated storage and retrieval system (ASRS) whereby robots on rails, computerized elevators, and cranes can autonomously store cartons of groceries in tall racks of shelves; these same robots, elevators, and cranes will later retrieve individual cases of groceries to assemble a customer's order (see Figure 4). Beyond increasing output per worker, these automated structures can be designed with many vertical layers and a small "footprint" to fit into urban lots that are located near customers.

Figure 4. A Symbotic Automated Storage and Retrieval System (ASRS) for Groceries



While people perform the picking and packing in many warehouses, other physical tasks can still be automated. This automation often involves people collaborating with robotic systems, or "cobots," which can take many forms. What follows are several examples.

Pick-to-light systems (see Figure 5) are designed to increase the speed and accuracy in selecting requested items. The process starts with a human picker taking a plastic tote that has a set of item barcodes temporarily attached. The picker scans the barcodes, and the system lights guide the picker to the location of the nearest item on the barcode list. At that location, the system interface shows which items and how many of each item should be picked. Once the items are picked, the picker presses a button to confirm they are finished. System lights illuminate the path to the closest among the remaining items to be picked.

Figure 5. A LUCA Pick-to-Light System

The picker's movements involve two walking segments that are targets for automation: when the picker walks from one bin to the next selecting the requested items, and when the picker carries the completed order to a packing station.

The act of carrying a completed order to the packing station can often be automated without restructuring the warehouse by using an autonomous guided vehicle (AGV). A director of a Southeastern distribution center recounted a typical example (paraphrased here):

> In late 2018, we had taken on a contract we couldn't fulfill because the volume was too large—we were going to fail the contract. As a Hail Mary, we contacted Locus Robotics in Boston. Locus sent down a robot with a camera that mapped out the warehouse to set up the software. (Locus never visited the warehouse in person.) We had to put bumpers on specific corners, but we made no other warehouse modifications. We rented 40 robots from Locus at $1,800 per robot. The robots carried items from pickers to packers, and we made the contract.[22]

AGVs (including autonomous forklift trucks[23] and pallet movers) increase output per hour of work by moving items through the warehouse faster than a human can walk, allowing warehouse workers to spend more time picking items. (In many warehouses, a conveyor belt serves a similar purpose.)

By contrast, automating the walk from one bin to the next-—bringing items to the picker rather than the reverse—typically requires a warehouse restructuring. One solution uses a "less automated" version of the automated storage and retrieval system (ASRS) used in the grocery warehouses (see Figure 4). Instead of storing cases of groceries, these ASRS structures hold plastic totes of individual items (e.g., a variety of individual toys). Because the items are often small and have various shapes, they must be picked by hand. (They also are unpacked and stored in the totes by hand.) A person, acting as both picker and packer, stands at a station and requests an item by punching in or scanning a barcode. The ASRS, using robots on rails, moves the correct tote to the station and returns the tote to its place in the tower once that person has removed the item and added it to the order. Then the person sends the completed order by conveyor belt to the shipping area. The ASRS increases picking accuracy and, as with the pick-to-light system, is sometimes used to monitor the picker's work speed.

Amazon's Kiva robot system is, in essence, a more flexible version of an ASRS. Rather than storing item totes in a large, rigid tower, the totes are stored on short, moveable shelf units (see Figure 6). The warehouse management system treats the warehouse floor as a grid and keeps track of the location of every item in the warehouse at every point in time. A picker stands at a packing station and scans in the barcodes of items needed for an order. The software system assigns robots to go to each shelf unit that holds a requested item. Each robot picks up a shelf unit and brings it to the picker, who selects the item and places it in a shipping box. The robot then takes the shelf unit to an empty spot on the grid. When the picker has selected and boxed all units in an order, the box is put on a conveyor belt that carries it to the shipping area.

Figure 6. The Amazon Kiva Robot System

This kind of technology, while highly innovative, has limited industry penetration. After Amazon acquired the maker of the robots, Kiva Systems, in 2012, Kiva stopped accepting new customers and let existing customer contracts expire. Other companies, such as Locus Robotics, Tompkins Robotics, Honeywell Intelligrated, and Daifuku, make warehouse robotics, but so far demand has not been strong. A 2019 survey conducted by the Modern Materials Handling Institute confirms the quote at the beginning of this section: While 80% of survey respondents use warehouse management systems and 86% use barcode scanners, only 26% use RFID tags. With respect to automated goods movement, 63% use conveyor and sortation systems but only 22% use ASRS systems and 15% use AGVs.[24]

As one shipping manager explained,[25] investing in a highly automated system means restructuring a warehouse—an expensive and disruptive activity—while the rapid growth of e-commerce has created an uncertain investing environment. Since today's new system may not be optimal for tomorrow, it is hard to justify buying state-of-the-art technology that takes five years to pay for itself. One consequence is that smaller firms often pursue automation investment incrementally, including the robot rentals used by the Southeastern distribution center described above. A second consequence is that the largest warehouse firms gain a potentially big cost advantage because they have the resources to afford the risk and expense, including research and development expense, required to implement advanced automation. In this way, technology acts as a force toward greater concentration in the industry, a pattern that will reoccur in this brief.

Returning to the Productivity Puzzle

We return to the question raised at the beginning of this section: Why did output per hour of work in warehousing rise through 2012 and then fall after 2014?

The most likely answer involves the post-2014 surge in warehouse hiring. Based on U.S. Bureau of Labor Statistics data, employment in warehousing and storage grew from 511,000 in 2000 to 729,000 in 2014 (2.6% per year). After 2014, the expanding demands of e-commerce caused warehouse hiring to surge, reaching 1.19 million in 2019 (+10.6% per year between 2014 and 2019)[26]. As we have seen, the warehouse industry has been slow to adopt automation in part because the biggest efficiency gains require a heavily restructured (or new) warehouse, and in part because robotic gripping is still in development. It is likely that through 2012, when hiring was growing slowly, the rate of automation (including warehouse management systems) was fast enough to improve output per hour. Starting in 2014, when hiring surged, it is likely that the rate of automation could not keep up. Many new employees went into older, unautomated warehouses and new fulfillment centers that shipped individual items rather than items in bulk.[27] Both factors would have pulled down the average output per worker.

Despite the surge in labor demand, a significant part of warehouse work remains low-wage work. The U.S. Bureau of Labor Statistics reported that weekly 2019 earnings in warehousing and storage averaged $792 per week or about $20 per hour (Table 1). That figure, however, is an average across all persons in the industry. In 2019, about 30% of warehouse workers were classified as "Laborers and Freight, Stock and Material Movers, Hand" (i.e., manual laborers, many of whom are essential workers).[28] In 2018, this occupational group earned an average $11.76 per hour (including those who worked at Amazon warehouses where the minimum warehouse wage was $15.00 per hour). About one-fifth of these workers were not covered by health insurance.[29], [30]

The Future of Warehouse Work

Dramatic forecasts aside,[31] technology's impact on warehouse employment is likely to be gradual. Amazon, for example, predicts that a fully automated "dark warehouse" with no employees is a decade away.[32] In the meantime, progress on less dramatic technologies will continue to change how many people work in warehouses and what these people do.

Over the past two decades, employment in warehousing and storage has increased by 700,000 (+157%, Table 1). This growth is due to three factors:

- The rapid expansion of e-commerce and the resulting change from bulk order fulfillment to single-item order fulfillment.
- The limits of current robotic technology—in particular, the inability of robots to identify, pick, and pack streams of irregularly shaped items (the gripping problem).
- The slow adoption of existing technology due, in part, to the uncertain environment created by rapid expansion of e-commerce and, now, by the COVID-19 pandemic.

These factors have led to modest internal changes in the average warehouse and to a large demand for warehouse workers, many of whom are hired for their physical skill.

In the near term, this pattern is likely to continue as the pandemic has increased both e-commerce demand and the uncertainty of the economic environment. In the long run, e-commerce will continue to expand while automation will increase.

History tells us that technology prices fall over time. The falling price of sensors and the Internet of Things will enable warehouse managers to collect more data and new types of data from warehouse operations. Better data will allow the use of predictive analytics to anticipate product demands, compute inventory needs, and open possibilities for more efficient warehouse operations.[33] In the same way, prices of AGVs, ASRS, and other warehouse robotics will, like other technology products, fall over time, stimulating more adoption.

It is also likely that the gripping/toy duck problem will be solved. Sealed Air and other companies have automated wrapping an item in plastic (though unwrapping remains a problem). RightHand Robotics, Swisslog, and Soft Robotics are developing robotic grippers that can identify and pick selections of small individual items. Amazon and Honeywell are working on automated truck unloading, with the Amazon system utilizing a bank of suction cups in place of mechanical grippers.[34]

Over the next five-to-seven years then, falling technology prices and new technology will stimulate greater automation in the warehouse. The trend will be most obvious in newly built warehouses where new technology is installed from the start, but older warehouses will be retrofitted with AGVs and similar, flexible technology.

Greater automation will affect both the number of workers and the types of workers that warehouses require. More automated movement of goods will reduce the number of pick and pack workers and increase, by a smaller amount, the number of technicians who can keep the robots running. In an already evident trend, expanded possibilities for warehouse data have led to shortages for data scientists and analysts who understand how to collect data and use it to improve warehouse operations.[35] As an example, an operations manager at a distribution center said: "What I would really like is software that keeps track of every person and every robot on the floor and tells each of them what it should do next."[36] In fact, such software exists in a few large plants,[37] but adapting it more widely will require greater numbers of persons with technical skills.

Taken together, these trends point to a future warehouse workforce that is both smaller and more highly skilled than the workforce of today.

In the nearer term, technology in the warehouse will focus on increasing the output of current warehouse workers. ProGlove's wearable barcode scanners and Smartpick's augmented reality glasses are examples of such technologies designed to increase picking accuracy. These applications also affect job quality by more closely monitoring worker effort, a problem that arises with digital applications in many other industries, including call centers.

Section 5: Technology and Freight Transportation Arrangements

Between 2000 and 2019, output per hour in freight trucking grew by 14.8% (see Figure 2). Growing efficiency in trucking can come from either of two sources: more efficient trucks or the more efficient *use* of trucks—for example, scheduling fewer distant deliveries where the truck returns empty. In Section 6, we will see that the average quality of trucks on the road improves very slowly, leaving the more efficient use of trucks as the main source of increased productivity.

The industry category "freight transportation arrangements" accounts for one-seventh of trucking industry employment (see Table 1, NAICS Code 488510), but it operates a significant fraction of the trucking industry's digital technology. Within this category, truck brokerages primarily work with truckload carriers while third-party logistics providers (3PLs) work with both truckload (TL) and less than truckload (LTL) carriers.

While some 3PLs own trucks and warehouses, the main product of truck brokers and 3PLs are information-based services. Brokers and, in particular, 3PLs gather information from multiple sources and process it into services—information products—that shippers purchase. As technology has lowered the cost of collecting and processing information, the industry's offerings have expanded, as seen in Table 3.

Table 3. Information Services Provided by Truck Brokers and 3PLs*

3PL SERVICES (I.E. INFORMATION PRODUCTS)
Matching producers with trucks
Keeping records on driver performance
Scheduling shipments including routes
Tracking shipment pick-ups and deliver
Providing data on the shipment progress
Alerting the shipper to unanticipated problems (weather, road construction)
Resolving unanticipated problems
Executing financial settlements

***Truck brokers typically provide fewer of these services than 3PLs.**

The job of matching shippers to truckers addresses the high fragmentation of trucking markets. For example, the U.S. Bureau of Labor Statistics currently reports 45,445 TL carriers (excluding owner operators),[38] many of which own fewer than ten trucks. The TL market's demand side is equally fragmented with many small firms having only intermittent need for long-distance, full trailer shipments.

In the past, brokers connected shippers and truckers using relationships, a Rolodex, a telephone, and a fax machine. A firm with a need for shipping would call a broker or a 3PL. The broker would write down the job and begin calling truckers until one was found who was interested in the job. The broker would negotiate the price between the shipper and the trucker and would collect a fee once the job was completed. Because of the broker's relationships, the shipper knew the recommended trucker would likely deliver on schedule, and the trucker knew the shipper would likely pay on time. The system was limited by the size of the broker's Rolodex. A relatively small set of contacts made it likely that a broker could only offer a one-way job from which the truck would return empty.

The growth of the internet enabled the development of digital load boards—such as Truckstop.com and DATMembersEdge—where large numbers of shippers could post jobs. Now the task of making a match began, not with a phone call from shipper to broker, but with a shipper posting a job on a load board. Brokers would scan the load board looking for jobs they thought they could fill. In this system, there were looser connections among brokers, shippers, and truckers, but a broker's ability to see a large number of jobs increased the likelihood of making a good match.

In the past 20 years, travel agents, stock traders, and other market makers have faced strong competition from digital startups who rely on automated information flows and user self-service. Truckload truck brokers are now targeted by digital startups, including Convoy, Transfix, and Uber Freight. The startups' business model extends the digital job board by enrolling truckers to adopt the firm's smartphone app. The app allows a trucker to view the startup's job board and bid on jobs directly. Some startups also use artificial intelligence to assess the kinds of jobs an enrolled trucker prefers, and the system sends the trucker an alert when such jobs are posted. Human brokers are still needed to deal with special circumstances and unanticipated problems that may occur in a job.

In theory, these startups allow shipper-trucker connections to be made more quickly and reduce the human input per transaction, while the large number of participants increases the likelihood of profitable runs for the trucker. In practice, a startup's performance remains dependent on the size of its digital Rolodex and its ability to attract lucrative jobs. Their performance also depends on the possibility of the automated rating of trucker reliability.[39] These are high hurdles and, despite substantial investment, the digital broker's market penetration has been limited up to this point. As Jennifer Smith writes in the *Wall Street Journal*:

> In 2019, digital freight brokers accounted for about 2% of the $83 billion domestic transportation market, which includes brokerage and other logistics services, according to research firm Armstrong & Associates.[40]

3PLs such as C.H. Robinson, XPO, DHL, Coyote, and Transplace offer information services beyond connecting shippers and truckers, and serve both the TL and LTL markets. Technology and scale allow 3PL firms to provide these services at lower cost than a shipper could provide them internally.

For example, a shipper who uses the LTL market knows that its shipment will be one of several shipments on a truck that will deliver to multiple destinations. Calculating an efficient combination of deliveries can be a challenging problem. As early as the 1980s, 3PLs were using VisiCalc and Lotus 1-2-3 to speed up the trial-and-error process of constructing efficient shipment combinations. Today, the spreadsheet has been replaced with a transportation management system (TMS) developed by firms including Oracle, JTS, and BluJay. A modern TMS can rapidly propose alternative transportation plans and keep track of required documentation, among other functions.

Beyond configuring efficient driving routes and soliciting bids from drivers, technology allows 3PLs to provide additional services described in Table 3: keeping updated records on a trucker's insurance record and Hazmat certification, collecting and recording all the shipment's paperwork, and monitoring the shipment's progress for the shipper to view in real time. In some cases, these services fail without a driver's buy-in. As one 3PL manager said:

> Tracking shipments in "real time" is only as good as the driver's ability to trigger the electronic tracking, even if the cab is set up to track and the transport provider has a TMS. If we don't manage compliance and expectations, all these great technologies can come unraveled.[41]

THE FUTURE OF WORK IN SHIPPING ARRANGEMENTS

Between 2000 and 2019, employment in freight transportation arrangements increased by about one-third (see Table 1). The increase reflected shippers' demands for information to increase efficiency—better scheduling, better handling of paper flows, and tracking the real-time movement of shipments. Brokers and 3PLs responded to this demand by developing digital tools to create this information at costs that shippers were willing to pay.

In the next five-to-seven years, it is likely that the set of information services will continue to increase in number and quality. Simultaneously, some of these services involve routine clerical functions that are being subsumed by robotic process automation.

For example, drivers often cannot be paid until the shipper receives a PDF with a recipient's signature on a bill of lading to certify that the shipment was received. If the recipient does not belong to a payment network, they may post the bill of lading on their own website and the 3PL must retrieve it. In the past, retrieval of these documents would be performed by high school graduates who were paid by the hour. It is now increasingly performed by automated routines that scrape the Web.

In this example, as in warehouse automation, increased technology is decreasing demand for unskilled workers and increasing demand for software engineers, analysts with college degrees, and other workers with advanced logistics experience.

At the same time, the technology used by brokers and 3PLs, like warehouse technology, is reducing labor input per transaction. A cost advantage goes to firms with the resources to develop and implement technologically advanced software. Here, too, technology appears as a force for industry concentration.

Section 6: Technology and Trucks

In 2013, Bill Wade, a trucking industry writer, predicted the major technologies that would reshape trucking by 2020. Wade's list included a shift from diesel engines to electric/battery engines and dual-fuel engines (diesel, liquid natural gas); rapid communication links carrying route scheduling, driver performance, and other information; lane departure warnings; and improved collision protection.[42]

In the seven years since Wade penned this list, truck manufacturers have progressed in all these and other technologies, including autonomous low-speed driving in traffic jams.[43] Yet, as we have noted, the average truck on the road has improved slowly (see Section 3). These two facts are reconciled by the long life of the average truck. The newest trucks are typically purchased by national fleets that keep them for four years of long-haul work and then sell them to regional truckers. Regional truckers keep the trucks for an average of five to six years before selling them. In the end, the typical Class 8 truck (trucks over 33,000 pounds) has been on the road an average of 14 years before it is junked[44]. The combined average age of light trucks and cars on the road is 11.8 years.[45] Trucks' long service life means today's improvements will take a long time to affect the performance of the average truck. The main exceptions to slow improvement are add-on electronics: GPS devices, electronic logging devices,[46] and satellite phones in the 1990s now replaced by app-filled smartphones. To the extent these communication devices improve truck productivity, it is because they carry improved scheduling and other information developed by brokers and 3PLs (see Section 5).

On October 20, 2016, in what seemed to be a second exception to slow truck improvement, a fully autonomous semi-trailer truck developed by Otto, a San Francisco startup, drove 50,000 cans of Budweiser beer from Ft. Collins, Colorado to Colorado Springs without human intervention[47]. The Otto demonstration and other tests soon inspired journalists' articles suggesting a "tsunami" of job displacement[48].

In 2019, there were roughly 800,000 long-distance truck drivers in the United States (see Table 1). Had the journalists' predictions been accurate in the near term, the result would have been dramatic increases in unemployment and in output per hour of work in trucking (see Figure 1), since autonomous trucks would be delivering shipments with little labor input. But, like much popular technology writing, the articles exaggerated what was just around the corner.

An in-depth discussion of progress in autonomous vehicles is contained in a companion research brief, *Autonomous Vehicles, Mobility, and Employment Policy* by John Leonard et al.[49] We can summarize the state of play with a third proposition on technology and work that applies throughout the economy:

If a problem is too hard for a computer, try to simplify the problem.

Machine learning algorithms—"the brains" of autonomous vehicles—are best at solving problems they have seen before. Simplifying the autonomous vehicle problem begins with limiting operation to a digitally mapped ("geofenced") area in which the vehicle can "know where it is." In a further simplification, the area should have minimal unanticipated obstacles like complicated intersections and blind driveways. Simplification also means an area where the vehicle can operate at moderate or lower speeds to minimize panic stops when the software can't interpret its environment. Finally, simplification means operating without rain or snow that could degrade the autonomous vehicle's sensors.

Current tests of autonomous vehicles incorporate many of these limits. Waymo has launched a small number of fully autonomous taxis (without safety drivers) in a digitally mapped, 100 square mile area of Chandler, Arizona. The mining company Rio Tinto has run autonomous ore haulers at their Australian mines for some years [50]. U.S. autonomous truck demonstrations, such as Aurora Innovation and TuSimple, currently operate with on-board safety drivers who can intervene in case problems arise. All these firms indicate that they will remove safety drivers at some point, but no firm has yet reached that point.

The long-run goal of these developers is to achieve Level 4 of the five-level autonomy scale developed by the Society of Automotive Engineers:

> *The vehicle is capable of performing all driving functions under certain conditions. The driver may have the option to control the vehicle.* [51]

With respect to trucking, "certain conditions" usually means driving autonomously on limited-access highways in regions with an absence of rain or snow. (Few people expect autonomous trucks of any size to run in the complexity of city streets in the near future.) A potential intermediate step toward autonomous highway driving involves a modification of truck platooning.

Platooning is a long-standing technique used by long-distance truck drivers in which one semi-trailer truck closely follows a second semi-trailer truck at highway speeds. The close following results in reduced drag and better gasoline mileage for both trucks. Startup firms including Peloton have refined this process using software, Wi-Fi, and actuators that allow the driver on the lead truck to control acceleration and braking on the follower truck. In the Peloton model, the driver of the first truck is responsible for acceleration and braking. The driver of the following truck sees the road through a screen on the truck's dashboard and remains responsible for steering and emergencies.

As a next step, Peloton and others are considering a fully autonomous second truck with no driver. Automating this problem is not easy – for example, reacting to a car that cuts between the two trucks – but it is easier than developing full autonomy on an interstate highway in traffic. Automated platooning would provide a testbed for learning about aspects of fully autonomous trucks.

While autonomous trucks on local streets are well into the future, startups Starship Technologies, Kiwibot, Amazon's Scout, TeleRetail, and FedEx are testing autonomous sidewalk delivery robots to address the "last-mile problem"—the problem of staffing today's large number of home deliveries of individual items, a trend that the COVID-19 pandemic has accelerated.

These robots move slowly and must navigate an extremely complex environment. While urban street traffic is complex, cars (and pedestrians crossing streets) still follow the general rules of the road. On sidewalks, pedestrians follow far less predictable patterns, suddenly turning to look into a shop window or stopping to talk to an acquaintance. There is also a problem of knowing where to drop off the delivery. The standard Google or Apple map used for directions locates the point on the street that is closest to the desired address, but that's not a place to leave a package.

Current demonstrations of these delivery robots are monitored by human operators with back-up radio control. The promise is that these operators, like the safety drivers in autonomous cars and trucks, will be removed at some point in the future. But the complexity of the environment, including navigating curbs and pets, suggests that it will be hard to achieve autonomous operation outside of the constrained space of a college campus or a gated community.

A different solution to the last-mile problem—unmanned aerial vehicles (UAVs, or drones)—appears to be having somewhat greater success. Flying mainly in low-density areas, the UAVs are either remotely controlled or autonomous and are used for transporting food, medicines, mail, and small packages over short distances. Amazon's Prime Air, DHL, and UPS are a few of the firms testing drone-delivery mechanisms. Though progress has been made in the development of drones, the Federal Aviation Administration (FAA) must have airspace regulations for UAVs in place before large-scale commercial operations can commence[52].

THE FUTURE OF WORK IN TRUCKING

While advancements in technology will eventually eliminate truck-driving jobs, the timeline is likely to be slower than the automation timeline in warehousing.

Steve Viscelli, a sociologist and one-time LT driver at the University of Pennsylvania, has conducted the most careful analysis of this timeline. He expects autonomous truck demonstrations on stretches of interstate highways within two years. But Viscelli sees roughly a decade to bring the technology to market, in order to pass federal and state safety regulations and to reduce costs enough to make the technology a good investment.[53]

When autonomous trucks do come to market, they will be purchased by large, well-capitalized fleets. A much-discussed example is United Parcel Service (UPS), a firm with a unionized, high-wage labor force. It is easy to imagine UPS shifting to autonomous trucks for their line-haul work—the highway runs that move cargo between distribution hubs. The speculation is reinforced by the fact that UPS is an investor in TuSimple, the truck startup mentioned above.[54]

Estimating future job losses involves multiple details. As Viscelli noted:

> Reports suggest there are 3 or 4 million driving jobs at risk, but they use broad categories to represent "driving occupations." As other experts have clarified, in nearly all the jobs that fall under such broad headings, driving is one task among many others, and driving may not even represent a majority of the work in many of these jobs.[55]

The advent of automated trucks will create new jobs to develop and maintain equipment, to plan routes, to monitor vehicles while they are in transit, and so on. Each of these jobs assumes one person servicing multiple trucks, so the new jobs created will ultimately be less than the driver jobs that are lost.

In sum, it is likely to be at least a decade before fully autonomous Class 8 trucks displace significant numbers of long-distance truck drivers. In less than a decade, smaller numbers of truck driver jobs are likely to be replaced by automated platooning. When these trucks are ready for market, the technology is likely to raise the same concentration issues that arise in warehousing and, to a lesser extent, in freight transportation arrangements. We have seen that the long-distance trucking market is highly fragmented with large numbers of firms having fewer than ten trucks (see Section 5). When autonomous trucks come to market, they will be purchased by large, well-capitalized truck-for-hire fleets like J.B. Hunt, and corporate fleets like UPS and Walmart. Small trucking firms will be priced out of much of the long-distance interstate market.

Last-mile delivery will likely rely on human labor for the foreseeable future. In the near term, drones may begin to operate regularly in rural areas and some urban areas, among buildings with landing pads. Similarly, robotic delivery vehicles may start operating regularly in low-traffic areas like college campuses and gated communities. It is unlikely that either delivery mode will operate in a broad enough area to affect many urban delivery driver jobs. Rather, the next significant change in last-mile deliveries will be a switch to small electric trucks with human drivers.[56]

Section 7: Looking to the Future

Up to this point, internet technology, working through e-commerce, has created far more logistics jobs than automation has destroyed. The three industries discussed in this brief—warehousing and storage, freight trucking, and freight transportation arrangements—employed 3.1 million persons in 2019, up from 2.2 million persons in 2000.[57]

In the future, new habits learned during the COVID-19 pandemic will almost certainly increase demands for e-commerce. Nonetheless, the dramatic growth in logistics employment is unlikely to continue in the face of increased automation. In warehousing and storage, automation will expand through both newly constructed warehouses and the retrofitting of existing structures with technologies like AGVs. This trend will accelerate as the gripping/toy duck problem is solved. In the meantime, however, many warehouse jobs, including essential jobs, will continue to be low wage jobs. In freight transportation, automation will move more slowly, but automated platooning will likely begin replacing truck-driving jobs before the decade is over.

In both industries, automation will create a modest number of new jobs for technicians, software developers, data scientists, and similarly skilled positions, but it will eliminate a larger number of picker and packer jobs in warehousing and driver jobs in trucking. The occupational structure of freight transportation arrangements already favors skilled positions, and continued automation of routine clerical tasks will further tilt the balance.

Since the early 1980s, American labor market policy has failed to cope with the collapse that occurs when manufacturing jobs suddenly disappear from local communities.[58] Policy to address the job losses projected in this brief face a potentially easier challenge. Where manufacturing plant shutdowns are often sudden, automation in these three industries is proceeding relatively slowly. Where manufacturing plant shutdowns are highly concentrated in particular communities, both warehousing and trucking employment are dispersed throughout the country (Figure 1).

In this situation, a first set of policies should address these goals:

- Help employees to move into higher skilled jobs that are less vulnerable to automation.
- Since warehouse automation is likely to proceed slowly, improve the pay of low-wage warehouse jobs that continue to exist.
- Strengthen the safety net for persons displaced by automation.

What follows are first steps toward these goals:

- Expand Access to Career Training for Current Employees. Amazon's Career Choice for Amazon warehouse associates and Walmart University for Walmart employees are examples of firms offering skills courses to prepare entry-level employees for better jobs. The two programs have similar goals but differ in details. Walmart University trains employees for better jobs in the Walmart organization. Amazon warehouses have a flat occupational structure, and Career Choice trains employees for better-paying jobs in local labor markets (e.g., medical assistant, IT technical support). Both programs are designed to be accessible for students with full-time jobs (and, often, family responsibilities). Walmart University courses are taught online, while Amazon Career Choice courses are taught in classroom space in fulfillment centers.

Large firms, including Walmart and Amazon, use these programs to attract ambitious employees and to gain good publicity. Smaller firms see less benefit from such programs, so expanding career training will require public-private consortia involving multiple smaller employers. Community colleges have a significant role to play in this expansion. Many community colleges have experience teaching on-site courses for firms (including courses in Amazon's Career Choice program). A growing number of community colleges have experience dealing with employer consortia as part of the growing number of youth apprenticeship programs.

- Leverage Local Economic Development Incentives to Improve Warehouse Jobs. We noted that rural jurisdictions pursue fulfillment and distribution centers to add property to the tax rolls and to increase jobs for less educated workers (see Section 1). As the COVID-19 pandemic has accelerated the use of e-commerce, new warehouse sites have become a seller's market[59]. Even in slower markets, a warehouse looking to locate on a desirable site—one with fast interstate access—would receive economic incentives that come with conditions on a minimum number of new jobs and the average wage of those jobs. As the site market tightens, local economic development officials should explore expanding those conditions to include the lowest wage the warehouse will pay and to require participation in the career training consortia described above. Raising the minimum wage paid may have ripple effects[60]. Recent research suggests that employers located near an Amazon warehouse are raising their own lowest wages to compete with Amazon's $15.00 minimum wage.

- Apply a Federal Vehicle Miles Traveled (VMT) Tax to Autonomous Trucks. The International Brotherhood of Teamsters is currently developing the details of a proposal to create a workers fund—a safety net for displaced drivers. At the same time, the VMT would offset those aspects of the current tax code that stimulate investment in robots[61] and increase the operating cost of autonomous vehicles to slow their adoption. Unlike a general tax on robots, a VMT would not be bogged down in definitions even when a truck can drive both autonomously and with a human driver.

- An Unanswered Question. A question that runs throughout this brief is: What is the role of technology in the growing concentration of economic activity in a small number of firms? This question is relevant to a current debate in antitrust policy. From the late 1970s through the present, antitrust enforcement was focused on what was best for the consumer regardless of other considerations.[62] More recently, many legal scholars are proposing that the application of antitrust enforcement return to an earlier standard that also considered size per se, the political power of large firms, and the effects of large, "superstar" firms on workers' incomes.[63] A better understanding of technology's contribution to "bigness" would be a valuable contribution to this debate.

Endnotes

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15 *Quill Corp. v. North Dakota*, 504 US 298 (1992) More precisely, the court's ruling applied to out-of-state firms that maintain no physical presence (e.g., a warehouse) in North Dakota.

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