CHAPTER ONE

Historical perspectives on managing automation and other disruptions in transportation

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Overview

Automation is coming to transportation. Exactly how and when is subject to intense debate, but experts agree that sooner or later, it is

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inevitable. Some believe vehicle automation is a scourge; others believe it is a panacea. Equally uncertain is the impact of this automation on jobs, both for personal mobility and freight.

While automation in transportation is new, automation in other sectors is not. Historical precedents can provide clues about how automation and other technological disruptions in transportation will likely affect the workforce and economy. In this chapter, we explore four instances—in manufacturing, farming, shipping, and food preparation—in which automated labor-saving devices brought deep structural changes to employment and work. These case studies can and should inform preparations and expectations for the automated-vehicle (AV) revolution.

We find many reasons to be optimistic about the net economic and labor effects of vehicle automation. With passenger travel, we know that automation will displace many drivers—for taxis, limousines, Uber, and Lyft—but we also know that AVs will enable workers to more productively use the massive amounts of time currently wasted driving and create jobs at all skill levels. Highly trained professionals such as programmers and data scientists will be needed to develop and optimize AV algorithms. Lower-skilled workers will be needed for customer care, cleaning of cars, and more. New services might be offered in the vehicles, such as personal care, business services, and entertainment. With goods movement, automation of long-haul trucking could increase total freight activity and hence increase demand for workers to load, unload, and stock goods—tasks that are less easily automated.

But the rapid pace at which automation in transportation is occurring warns against complacency. When automation is introduced over generations (as was the case with farming), there was ample time for workers to adjust. Natural attrition of older workers occurs through retirement, and younger workers can be educated and trained to maximize the advantages of automation. If change comes much faster, society as a whole may still benefit but only at the expense of disruptive localized job loss.

Regardless of the exact labor impact, informed public policy is critical for maximizing positive outcomes of AVs, while minimizing costs. Leaders and decision-makers will need to proactively help workers build skills needed in an automated world. Programs should be established soon to support the workers and businesses that automation will inevitably displace in transitioning to new opportunities. And provisions should be put in place to ensure that the benefits of automation in transportation are equitably distributed across geographic regions and socioeconomic classes.

The transportation workforce and economy are changing fast. Society must be prepared to adapt.

History of economic and technological transformation

Through the broad reach of history, technology that helps automate tasks—here broadly defined as reducing the labor input required for a given output—has profoundly transformed our societies and economies. But details matter. Time and scale matter the most. Labor impacts will be most disruptive if change is fast and widespread. But net impacts on jobs are likely to be positive.

Division of labor

For millennia, human beings had only two main jobs—hunting and gathering. They also had only two ways to get around—their left and right legs. It may seem inappropriate to review ancient history, but doing so reminds us of the incredible power we have to change and improve our lives. More or less everything we consider essential today—shelter, clothing, mobility, sanitation, health care, and more—is a product of human ingenuity... and automation.

As societies became more stationary and food supplies more stable, division of labor allowed individuals to develop specialized skills and pass those skills onto future generations. Specialization fostered innovation, allowing people to create and improve technologies, trade knowledge with other parts of the world, and collaborate on projects too advanced for any one person to carry out alone.

Specialization remains important today. Research shows that all else equal, countries with low specialization are able to do less with capital investment than countries with high specialization [1]. This makes intuitive sense, as a low-specialization workforce is less able to take active, value-generating roles in new technology that arrives alongside investment.

Technology substituting for labor

Classic macroeconomic models of the market depend on capital and labor, and allow technology to essentially substitute for labor. When technology substitutes for labor, by definition some jobs in that specific application will be displaced. It might be natural to think that this would have on net reduced labor's share of economic production. Over a century of study, however, this has not been the case [2], as overall growth and new employment in other sectors has more than made up for replaced labor.

Autor and Salomons point out that this has given "grounds for optimism that, despite seemingly limitless possibilities for labor-saving technological progress, automation need not make labor irrelevant as a factor of production" [3]. However, they also find in their recent review that "although automation—whether measured by Total Factor Productivity growth or instrumented by foreign patent flows or robot adoption—has not been employment displacing, it has reduced labor's share in value-added" [3]. So, while technology has only created economic surplus on the net so far, there are some reasons to question whether this trend will continue in perpetuity.

Many areas where technology substitutes for labor also require energy inputs. Smil has extensively reviewed the history of energy technology and shown that energy and technology together effectively have a multiplying effect on labor, allowing much more output per worker [4].

The net effects of technology introduction historically are so strongly and unambiguously positive that it is hard to imagine a counterfactual world. These changes have happened over decades or centuries, and so seem to have a diffuse effect that is hard to measure during the transition. Introductions of technology for labor can also cause local harm such as pollution and job displacement. In short, substituting technology for labor often results in indirect but widespread benefits for the many at the expense of direct adverse effects of the few. These situations in general can make it very challenging for policymakers to maximize public good [5,6].

Impact of automation in other sectors

Understanding how labor-saving technologies affected other sectors in the past provides insight into how automation is likely to affect transportation in the future. The introduction of technology in farming, mechanization in factories, and standardization of freight with containers each had transformative effects on the workforce and the economy.

These industrial examples are well-documented cases of economic substitution of technology for labor. Automation is also increasingly present in our daily lives. Ready availability of labor-saving devices may have contributed to a shift away from in-home services.

Lastly, dining out has changed some of an unpaid service (cooking in the home) to a paid one (eating in a restaurant or ordering take out). While this is not an effect of automation per se, it may be instructive as an example for some aspects of automation in transportation.

Farming

For centuries, farming was a heavily manual occupation: tilling, sowing, irrigation, and harvesting were all done by hand. Most farms were relatively small (since an individual farmer could only manage so much land), and farming employed a high percentage of the workforce (since many workers were needed to produce enough food to support the population). For hundreds of years, well over half of the population was employed in farming and food production [7]. Starting around 1800, with technology developed from the Industrial Revolution, the share of people involved in farming began to fall precipitously. Technological introductions such as the cotton gin (1793), the McCormick Reaper (1834), commercial fertilizer (1843), the gasoline tractor (1892), and hundreds more amplified the person-power of each worker.

This change accelerated dramatically beginning in the early 1900s. The 20th century saw the share of U.S. workers employed as farmers or farm laborers decline steadily from roughly a third in 1910 to less than 1% in 2000 (Fig. 1.1). Farms also consolidated, with the number of farms nationwide dropping as average farm size rose (Fig. 1.2).

Meanwhile, agricultural productivity improved dramatically. Agricultural output in the United States climbed even as inputs remained essentially constant (Fig. 1.3). Agricultural value added per worker in the United States increased to nearly $100,000, a figure that is 10−100 times higher than in less-developed economies [9].

Productivity increases have resulted in food becoming much cheaper and more accessible. The price of wheat, for example, has fallen by more than a factor of 5 (in inflation-adjusted terms) since 1800. Many other commodity food prices have dropped similarly (Fig. 1.4). The share of the average U.S. family's disposable income spent on food decreased from nearly 25% in 1929 to less than 10% in 2014 [10]. Greater agricultural productivity and lower food prices have done much to improve health and quality of life worldwide despite a rapidly growing population.

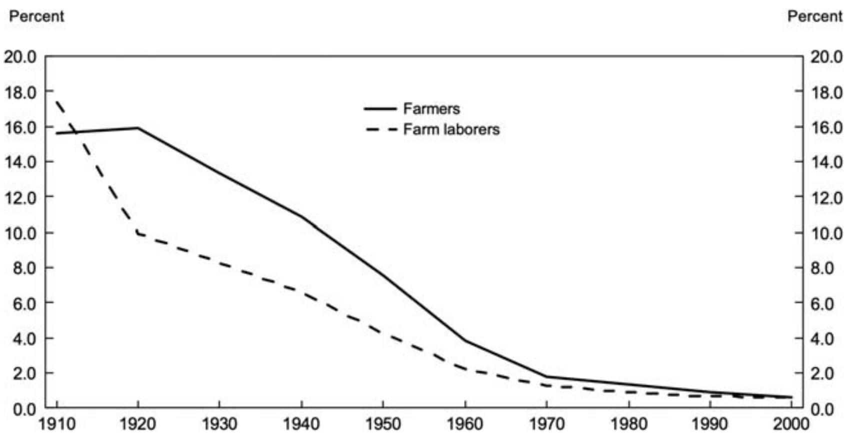

Figure 1.1 Percent of total U.S. employment accounted for by farmers and farm laborers. Combined employment fell from about 30% to about 1% over the course of the 20th century. *From I.D. Wyatt, D.E. Hecker, Occupational changes during the 20th century, Bureau of Labor Statistics, Monthly Labor Review. <https://www.bls.gov/opub/mlr/2006/03/art3full.pdf>, 2006 [8].*

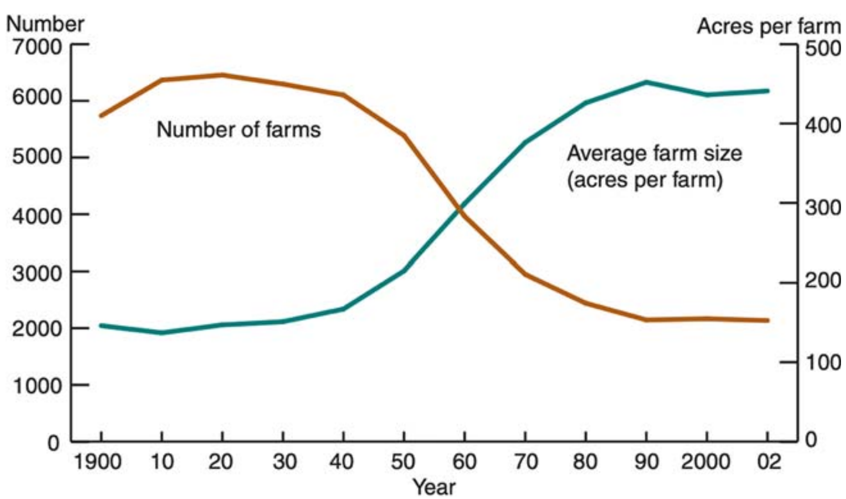

Figure 1.2 Introduction of new farming technology was one reason that farm size grew and farm number dropped beginning in the mid-1900s. *From C. Dimitri, A. Effland and N. Conklin, The 20th century transformation of U.S. Agriculture and Farm Policy, Economic Information Bulletin Number 3, Economic Research Service, U.S. Department of Agriculture. <https://ageconsearch.umn.edu/bitstream/59390/2/eib3.pdf>, 2005.*

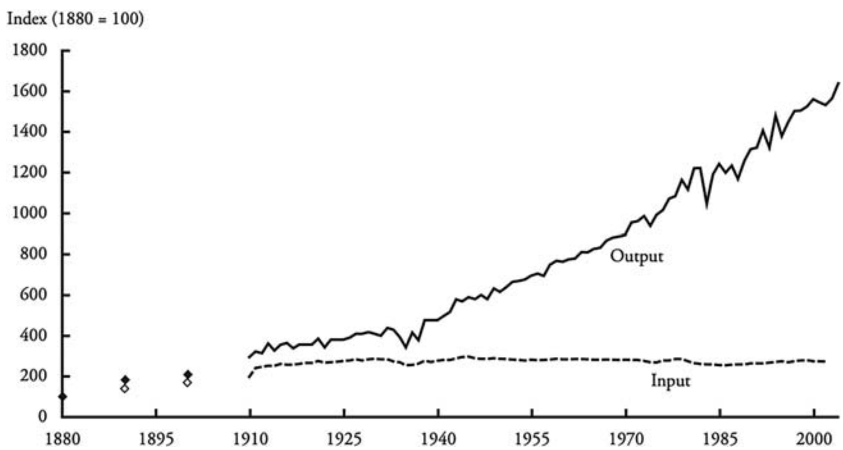

Figure 1.3 Farm productivity has increased dramatically since 1880. *From J.M. Alston, et al., A brief history of U.S. agriculture. In Persistence Pays: U.S. Agricultural Productivity Growth and the Benefits from Public R&D Spending, 2010, Springer Verlag, New York.*

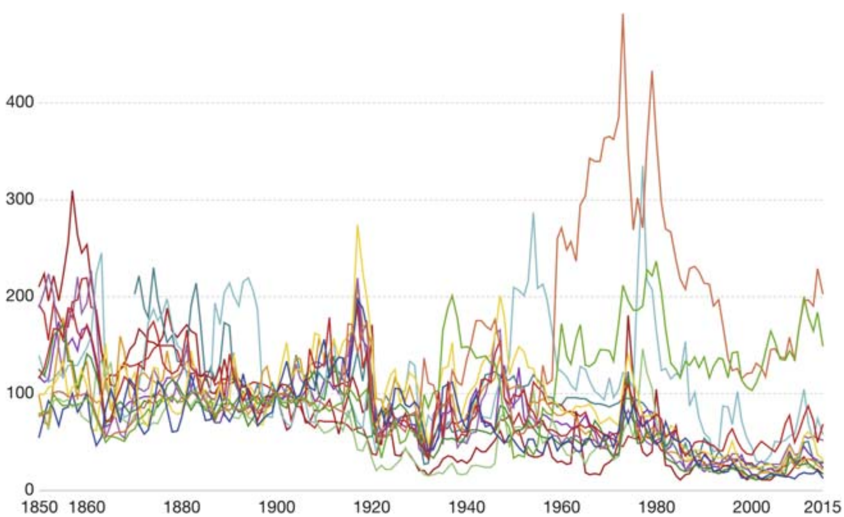

Figure 1.4 Global long-term price index in food commodities, 1850−2015. Commodity price index in food items dating from 1850 to 2015, measured relative to real prices in 1900 (i.e., 1900 = 100). Most food commodities have decreased significantly in real price. *From M. Roser and H. Ritchie, Our world in data, food prices. <https://ourworldindata.org/food-prices>, 2018.*

A major driver of these trends is advancement in farming technology. The adaption of the internal combustion engine to mobile tractors—coupled with the design of tractor attachments for planting, harvesting, threshing, and more—enabled farmers to substantially expand acreage, while new pesticides, herbicides, and fertilizers increased productivity per acre. Improved irrigation systems made it possible to farm well even in water-limited areas. The list goes on.

Not all of the effects of the 20th-century agricultural revolution have been positive. Industrialization of agriculture has increased greenhouse-gas emissions and nutrient runoff while depleting aquifers and soils and limiting the genetic diversity of crops. But the net positive effects for society do not seem to be in doubt. Few would ask to return to an era where most people farmed for a living in tough conditions, food was expensive, harvests were unreliable, and few crops were available. The country accepted and embraced the transition from family farming to large-scale farming because the benefits were large and because the change was gradual. The decline in agricultural employment came mostly through natural attrition rather than large-scale layoffs, and those who remained in the agricultural sector had time to learn new skills and adapt to new practices.

Manufacturing

Factory automation is probably the best-known example of technology replacing labor. The term Luddite, now in general use for someone who fears the advance of technology, has its roots in factory workers who tried to stop the adoption of automated looms in the early 19th century. This is far from the only example of job displacement in manufacturing. Indeed, the labor and economic effects of factory automation remain hot-button political issues today.

In the United States, manufacturing has declined significantly as a share of employment but remained relatively steady as a share of GDP [11] (Fig. 1.5). These trends reflect increasing levels of automation and a shift away from domestic manufacturing of goods that are highly labor-intensive to produce. As with farming, factory automation dramatically lowers end costs of goods. This in turn increases the real purchasing power of consumers. Greater use of technology in manufacturing has also enabled mass production of new types of goods—such as computers and other electronics—that would be impossible using human labor alone.

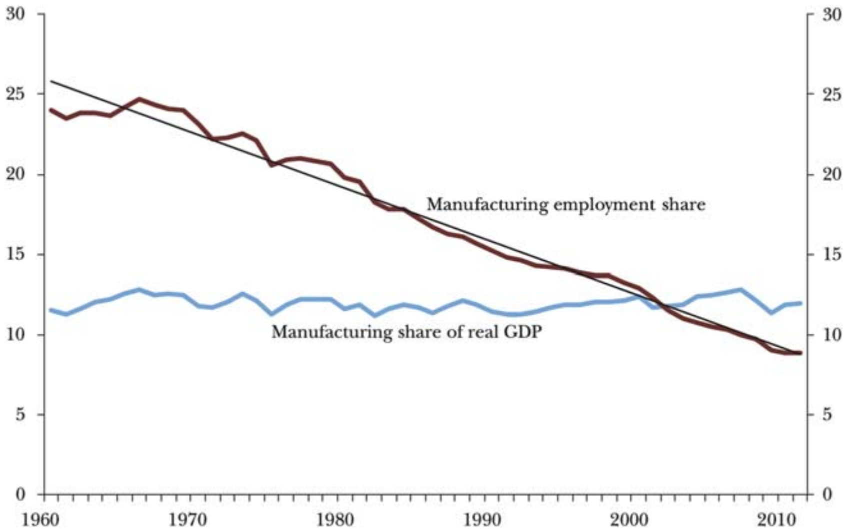

Figure 1.5 Manufacturing value added and employment as a share of the total U.S. economy, 1960–2011. Manufacturing has decreased as a share of employment but remained constant as a share of real GDP since 1960. *From M.N. Baily, B.P. Bosworth, US manufacturing: understanding its past and its potential future, J. Econom. Perspect. 28 (1) (2014) 3–26.*

Also as with farming, the shift from manual labor to automation in manufacturing has taken decades. But in many cases, automating factories is more disruptive than automating farms. Manufacturing jobs tend to be concentrated in "factory towns." Factory automation is therefore more likely than farming automation to cause widespread layoffs in a particular community. This can cause localized economic depression that can persist for generations. Such impacts may not be captured by aggregate metrics but must not be ignored. Possible solutions include offering retraining programs, improved unemployment benefits, and other resources to workers adversely affected by automation.

Shipping

Maritime shipping has been a cornerstone of global trade and economic growth for centuries. Yet as ship technology evolved from sail power to steam power to the power of fossil fuels, shipping technology remained largely the same. Goods were shipped loose, so loading and unloading a ship meant hiring a crew of dockworkers to manually move individual pieces of cargo into and out of the hold. This grueling process could take days. Loose shipping also meant that companies had to be strategic about minimizing cargo exposure to weather, maximizing available storage space, evenly distributing cargo weight, and a host of other factors [12].

Change came with the invention of shipping containers in the 1950s. Little more than a set of standard measurements and connectable corners, this easily overlooked technology revolutionized the shipping industry [13]. Combining lots of individual pieces of cargo in large, standard containers meant that freight could move from ship to train to truck with a tiny fraction of the labor and logistical headaches previously required.

Containerization wrought change more quickly than the introduction of new technology in farming or manufacturing, at both a local and international level. Locally, the dockside workforce experienced large-scale layoffs. Containerization did create some new dockside jobs for laborers such as crane operators, but not nearly enough to absorb the loading/unloading crews whose services were no longer needed.[1] Dockworkers in some cities were able to fight off containers,[2] but their victory was short-lived. Major ports that eschewed containers are now no longer major ports, having watched their business move to neighboring cities that were more open to change.

Internationally, containerization made long-range shipping across the ocean much more accessible. This opened new avenues for trade and specialization. Easy, low-cost goods movement means that goods will be produced where it is cheapest or where the local economy is otherwise most suitable, rather than where markets are closest. Indeed, Bernhofen et al. found that adoption of containerization was an important determinant of a country's development as a global trade leader [14]. Economic globalization is frequently the subject of political attacks and tariffs seeking to protect domestic industries. Improved access to markets in other countries can undoubtedly undermine some businesses. A business in Iowa producing carpets for $500 each will run into trouble if a new trade route opens U.S. markets to a business in Indonesia producing similar carpets for $50

[1] It is difficult to assess the precise magnitude of containerization's effects on the workforce in coastal cities. Gomtsyan [13] finds that even though dockworker employment did decline in some coastal cities following containerization, those declines are correlated with a faster drop in unemployment overall for those cities, implying that it may have created economic growth in other sectors to more than offset job loss by dockworkers.

[2] For a detailed history of the introduction of the shipping container and resulting disputes, see Levinson [12].

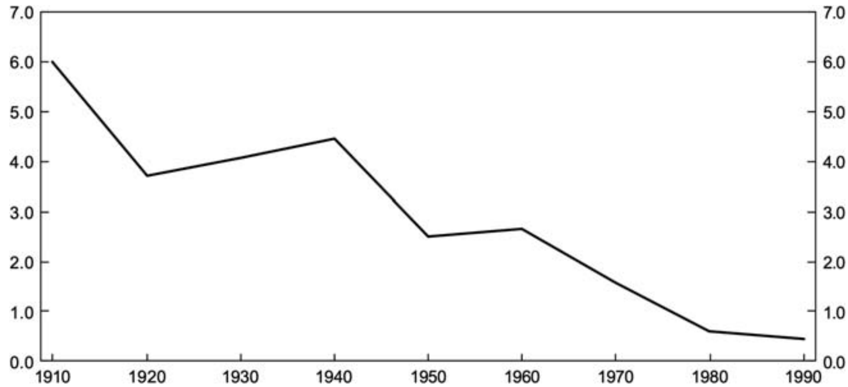

Figure 1.6 Percent of total U.S. employment accounted for by private household service workers. Employment fell from about 6% to less than 0.5% over the course of the 20th century. *From I.D. Wyatt, D.E. Hecker, Occupational changes during the 20th century, Bureau of Labor Statistics, Monthly Labor Review. <https://www.bls.gov/opub/mlr/2006/03/art3full.pdf>, 2006.*

each. But economists generally argue that, on average, trade improves all participant economies and creates jobs.[3]

Home care

In-home care by private household service workers (such as cleaners, personal attendants, in-home chefs, and other household staff) used to be a major employer in the United States, accounting for 6% of all employment in 1910. By 2000, this figure had fallen to less than 0.5% (Fig. 1.6). The economic research literature in this area is relatively sparse, so we can only observe the correlation and speculate that one contributing factor may be the development of technology for the home that reduces the need for human help. For example, the vacuum cleaner made cleaning easier and modern stoves and ovens, refrigeration, and microwaves decreased the time and training needed for food preparation.

Of course, economic and social factors have played a role here too. During some of this period (1910–50 especially), economic inequality decreased in the United States and prevailing wages increased, which may have decreased the number of families that could afford full-time household services [16]. Although economic inequality increased again in the

[3] For a review, see Irwin [15].

1980s, employment of household workers continued to decline. Because of these uncertainties, this example should be viewed as tentative at this time.

Food preparation

Each example so far has been in an industry that has seen job losses due to technology substituting for labor. In other cases, technology could create jobs by making it more affordable, and therefore common, to take an unpaid activity and turn it into a paid one. The increase in food-preparation employment is a concrete example of this effect.

Food preparation (i.e., working at restaurants) has grown significantly as a share of employment in the United States (Fig. 1.7). The major factor driving this trend is an increasing share of meals eaten outside the home. The share of meals eaten outside the home was very low before 1910, and grew from less than 20% in 1980 to more than 30% by 2012 (Fig. 1.8). There are many economic and social factors driving this trend, including "a larger share of women employed outside the home, more two-earner households, higher incomes, more affordable and convenient fast food outlets, increased advertising and promotion by large food service chains, and the smaller size of U.S. households." [17].

This is a useful example because it shows that employment in a sector can increase when there is a shift from unpaid labor (here, cooking in the

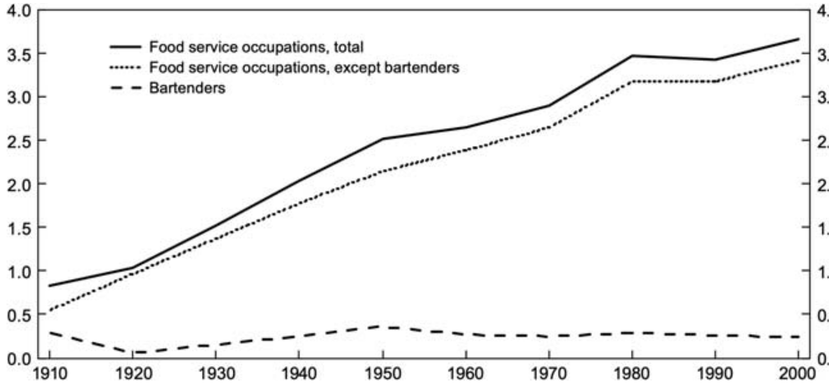

Figure 1.7 Percent of total U.S. employment accounted for by food service occupations. Employment increased from less than 1% to more than 3.5% over the course of the 20th century. *From I.D. Wyatt, D.E. Hecker, Occupational changes during the 20th century, Bureau of Labor Statistics, Monthly Labor Review. https://www.bls.gov/opub/mlr/2006/03/art3full.pdf, 2006.*

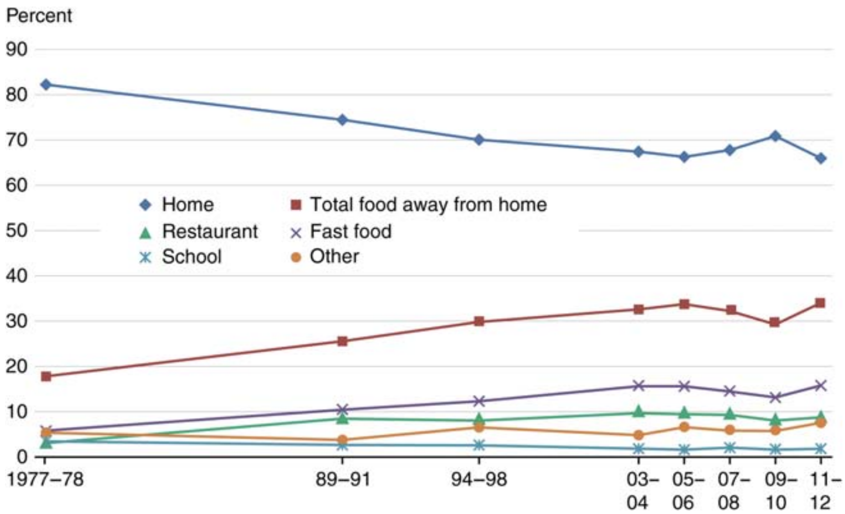

Figure 1.8 Average share of daily calories for U.S. population aged 2 years and older, by source. Since the 1970s, the share of meals eaten outside the home has increased from less than 20% to almost 35%. *From The 30-year upward trend in eating out briefly reversed in 2007–10, Economic Research Service, United States Department of Agriculture. <https://www.ers.usda.gov/data-products/chart-gallery/gallery/chart-detail/?chartId = 79054>, 2016.*

home) to a paid service (eating out) in that sector. Many factors, including increased income and changing social norms, have contributed to the increases in food eaten away from home. This is a useful indicator that if another sector (in the case of this chapter, driving) shifts from an unpaid to paid service, it could increase in-sector employment.

Summary

The introduction of automated and other types of labor-saving technology in farming, manufacturing, and shipping had substantial economic benefits. Cheaper food, goods, and goods movement increased real purchasing power for consumers. Greater productivity freed dollars and people to pursue new opportunities. Factory automation and freight containerization in particular dramatically expanded access to certain goods and markets, benefiting society as a whole.

These benefits were accompanied by some adverse workforce effects. Automation decreased overall employment in U.S. farming and manufacturing, and freight containerization resulted in mass layoffs of dockworkers in coastal cities. In farming, effects were relatively gradual and geographically dispersed. In manufacturing and shipping, however, effects were more concentrated in time and space, making it more difficult for workers to adjust. In the next section, we discuss how lessons from these historical precedents can be applied in the transportation sector to smooth the transition from human-driven cars to AVs.

Impacts of automation in transportation

Automation of the transportation sector is already well underway. Most new cars in Europe, the United States, Korea, and Japan are already partially automated with features such as adaptive cruise control, lane-keep assist, and more. Companies like Google have been testing fully driverless cars for years, and driverless mobility services are being tested at the pilot scale in multiple cities. Some of the effects of vehicle automation on the workforce and the economy are already evident. Others will depend on how automation continues to evolve. In this section, we explore the emerging and likely impacts of vehicle automation on personal mobility and freight. We also consider how these impacts depend on the pace at which automation occurs. Throughout, we assume that vehicle automation occurs alongside two other revolutions in transportation: vehicle electrification and vehicle sharing.[4] We focus on the United States, although we expect many of our conclusions to be applicable to other countries as well.

Effects on personal mobility

Workforce effects

Vehicles account for most passenger-miles traveled in the United States (Table 1.1). The vast majority of vehicle trips are taken in personally owned and driven vehicles. Only a few percent of personal trips use transit, and less than 1% are in a light-duty vehicle with a paid driver (Fig. 1.9). The latter figure is beginning to increase as transportation network companies (TNCs) such as Uber and Lyft continue to gain popularity and market share. But while TNCs have rapidly eclipsed taxis and approached transit in terms of number of trips taken (Fig. 1.9), they are

[4] A deeper analysis of the intersections among vehicle automation, sharing, and electrification can be found in Sperling [18].

Table 1.1 U.S. passenger-miles traveled by transportation mode, 2016.

Transportation mode	U.S. passenger-miles (millions)	Percent of total
Air	670,437	12.5
Vehicle	4,580,725	85.7
Transit	56,672	1.1
Rail	39,608	0.7

Source: calculations based on this data: <https://www.bts.gov/content/us-passenger-miles>.

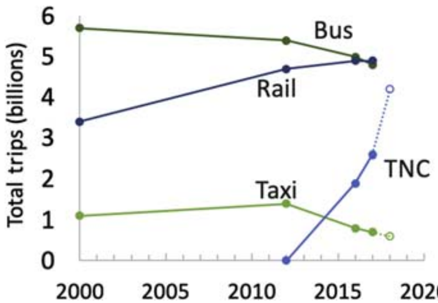

Figure 1.9 TNCs account for a rapidly growing share of travel and may soon pass bus and rail in popularity. The dotted line indicates projections. *From D. Sperling, A. Brown, M. D'Agostino, Could ride-hailing improve public transportation instead of undercutting it? UC Davis Policy Institute for Energy, Environment, and the Economy. <https://policyinstitute.ucdavis.edu/could-ride-hailing-improve-public-transportation-instead-of-undercutting-it/>, 2018.*

still dwarfed by the personal vehicle. There are also fewer TNC drivers than is commonly perceived. As of 2015, only 0.5% of people in the United States were or had been gig-economy workers, a category that includes many workers besides TNC drivers [18]. This figure may mask the fact that TNCs have pushed to have their drivers classified as independent contractors rather than employees. Nevertheless, the bottom line is unchanged. Drivers-for-hire represent only a very small share of the American workforce.

Far more people are employed to design, manufacture, sell, and service vehicles (approximately 3 million jobs [19]) and related infrastructure [20]. Transportation also directly represents approximately 5% of all GDP [21] (Fig. 1.10).

These jobs will still exist in a world dominated by AVs and may even grow in number, though they may change to be more technical. For instance, TNCs already have many employees developing pricing algorithms and techniques for matching supply and demand. More people will be needed in these roles if, as we expect, TNCs begin to adopt AVs for

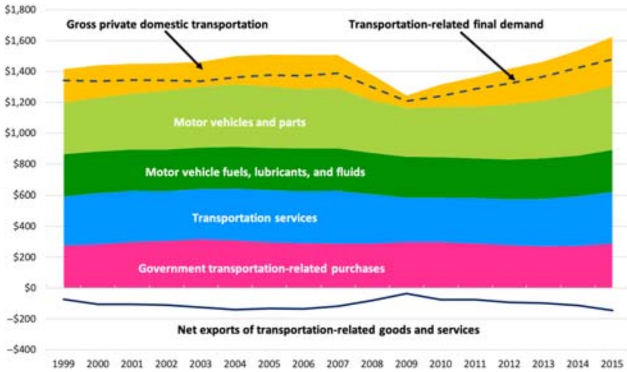

Figure 1.10 Transportation contributions to U.S. GDP. *Figure replicated from Transportation Economic Trends 2017, Bureau of Transportation Statistics, United States Department of Transportation. <https://www.bts.gov/sites/bts.dot.gov/files/docs/browse-statistical-products-and-data/bts-publications/215901/transportation-economic-trends-2017.pdf>, 2017.*

commercial use. TNCs will also need people to monitor automated fleets and respond to issues in much the same way that employees of bike- and scooter-share companies do now. Vehicle-cleaning and maintenance personnel will become more important as fleet ownership of vehicles displaces personal ownership, since passenger-miles and trips will be more concentrated in a smaller number of shared AVs. It is important to note that worker retraining may be necessary even in jobs that persist. Vehicle and infrastructure maintenance is one good example. Mechanics will need to learn how to inspect and repair advanced sensors and other components absent from conventional vehicles. If AVs are electric as well, mechanics will also need to learn how to install and maintain batteries and charging infrastructure.

Automation may expand and create jobs outside of TNCs. Skilled employees will be in high demand to design hardware and software for AVs. New firms (or new branches of existing firms) may open to provide insurance products appropriate for owners and operators of AVs. A plethora of opportunities may open for service providers. Vehicle passengers no longer occupied with driving will likely look for ways to make the most of their commute time. And as self-driving features make vehicle components like brake pedals, steering wheels, and seatbelts obsolete, it will be possible to redesign vehicle interiors to accommodate in-vehicle services. Some vehicles could double as beauty salons, employing stylists who can give haircuts or manicures while en route. Other vehicles could double as restaurants or bars, employing staff who can provide a mobile happy hour for friends or coworkers. These are just some of the possibilities.

Economic effects

Automation of personal mobility is likely to have substantial net positive economic effects for society as a whole. These positive effects will result from several factors. First, automation frees workers to use time in transit productively instead of wasting it driving. Montgomery [22] estimated that this "unlocked" time could be worth as much as $153 billion (at 100% penetration of AVs).

Second, AVs will drive more efficiently and safely, thereby reducing congestion, oil consumption, and accident rate and severity. Montgomery estimated the total value of these public benefits at up to $633 billion (again, at 100% penetration of AVs). More efficient operation will also enhance productivity in jobs that rely heavily on driving, such as home health care or delivery services. Less time spent driving from stop to stop means more stops completed in any given amount of time.

Third, combining automation with vehicle sharing will enable fuller use of vehicle capacity. The average car is driven only 4% of the time, spending the rest of the time sitting idle as a rapidly depreciating asset. Shared fleets of AVs will have much higher utilization, thereby spreading capital costs over many more users. This in turn increases consumer purchasing power by decreasing travel costs. Travel costs will further decrease if vehicle electrification keeps pace with automation and sharing, since electric vehicles are expected to have much lower operations and maintenance costs than gas-powered vehicles [18].

Shared fleets of AVs will also be able to better respond to real-time changes in demand. Travel demand is highly uneven, spiking both temporally (e.g., during commuting hours) and geographically (e.g., near transit hubs and events). One way for fleet operators to address this problem is by employing enough cars and drivers to meet peak demand without anyone waiting. The downside of this strategy is that it is expensive—and the costs get passed onto customers. Think the lines of taxis that often sit ready at hotels or airports. To have this supply of taxis on hand, fares need to be high enough to compensate drivers not just for active time, but also for time spent waiting.

An alternative that TNCs have adopted is to use "surge pricing" and other cues and incentives to encourage human drivers to work in areas where supply is low and demand is high. These strategies are not always successful. Employing human drivers on a supply-/demand-driven basis may be economically efficient but can make it difficult for TNC drivers to earn a reliable income. What TNCs advertise as flexibility has been deemed exploitation by some drivers and labor groups. Studies so far of driver wages have been mixed, finding incomes of over $19/hour [23] or below $10/hour [24] depending on methodology and specific markets. Human drivers may also avoid certain areas, such as rural communities (where it is more difficult to find customers) or lower-income neighborhoods (where drivers may perceive safety risks). This creates a market failure, may exacerbate socioeconomic stratification, and results in inequitable access to transportation. Shared fleets of AVs have the potential to address all of these issues simultaneously.

Effects on transit

Transit is a significant paid transportation mode, especially in cities, and provides many jobs that may be affected or displaced by automation and new mobility. The interactions of new mobility with transit are already complex and are likely to become more so going forward. Researchers have begun intensive study of key questions such as what modes are disrupted by use of new mobility. The literature so far is mixed [25], but indicates that in urban environments TNCs probably draw from transit ridership on net. In less urban environments, however, TNCs can support transit by serving as an effective feeder system. More affordable new mobility could also potentially compete with personal vehicle ownership, and therefore empower transit for other trips.

The transit industry in the United States is working to figure out how to best accommodate new mobility. Some operators are trying out pilot programs, while others are adopting a “wait-and-see” attitude. Depending on how these new services develop, new mobility could benefit transit (by feeding high-ridership routes from lower density areas), replace transit (by eroding the farebox revenue of transit systems), or become transit (if transit operators start using new-mobility technologies directly or through partnerships). In the most positive futures, transit operators will double down on what transit is good at: providing fixed-route service to move lots of people at once. Transit operators can rely on new mobility to serve the needs of those outside of core lines. This could reinvigorate stagnating transit systems and enrich employment opportunities in the sector at the same time.

Effects on freight

Workforce effects

Unlike personal mobility, where only a small fraction of trips involve a paid driver, all goods movement involves paid employees. In the United States, 1.9 million people work as drivers of heavy and tractor-trailer trucks. Another 1.4 million work as drivers of delivery trucks [26]. The Bureau of Labor Statistics projects [27] that these numbers will increase over the next decade as freight volume continues to grow. Truck driving is only one component of goods movement.[5] Employees are also needed to load and unload goods at origin and end destinations, manage routes and logistics, and monitor performance.

Automation is easiest for the long-haul portion of goods movement, that is, for hundreds of miles along highways. Such automation indisputably has the potential to put human long-haul truck drivers out of work. But the physical and psychological demands of extended driving hours and time away from home has made human long-haul truck drivers hard to find anyway [28]. In the short to medium term, at least, automation could help meet commercial needs for long-haul goods movement without significant adverse workforce effects. Automation in this model also preserves or grows, at least in the medium term, jobs at both the origin and delivery ends of the supply chain [29].

In the longer term, though, automation of shorter-range delivery could displace human drivers. Minimizing the impacts of this shift will require resources and retraining programs that help drivers transition to other jobs in the freight industry or in other sectors.

Economic effects

Automation is likely to dramatically reduce the cost of goods movement. Driver wages account for 36% of truck operating costs [30], so simply eliminating this expense would be a big financial savings. Automation also enables trucks to safely travel in "platoons," two or more vehicles moving closely together in synchronization. Platooning reduces aerodynamic drag, making all vehicles in the platoon more efficient and cutting down on fuel costs. Moreover, because aerodynamic drag forces are proportional to the second power of speed, these benefits are particularly large for highway travel, which accounts for the majority of long-haul truck travel [31].

[5] Note that in this section, we focus on land-based goods movement. Freight is also transported by rail, air, and sea, but these modes are less relevant to a discussion of vehicle automation.

If automation is accompanied by electrification, fuel and maintenance costs would drop even further. The investment firm Morgan Stanley estimates that automation in freight could yield savings of $168 billion from these and other factors [32]. Cheaper goods movement increases consumer purchasing power, supports specialization, and bolsters economic activity for society overall.

Indeed, automation in freight has the potential to lower the cost of delivery enough to fundamentally transform the way Americans live, shop, and do business. Companies like Amazon have given us a preview of what happens when shipping is free for most transactions: demand for delivery increases and personal travel decreases [33]. Ready availability of cheap or free shipping for a vast online inventory of products makes it difficult for many brick-and-mortar stores to compete. But one study found that on a macroeconomic level, growth in e-commerce from 2007 to 2017 more than compensated for declines in physical retail, while also providing better-paying jobs [34]. Physical stores may also evolve in the future from serving as the point of sale to serving as "showrooms" where customers can test out products in person before ordering online.

Timeframe

One of the most hotly debated questions in transportation research today is "When will AVs be here?" This question is highly relevant to assessments of the likely workforce and economic impacts of automation in transportation since, as historical precedents have shown, slower adoption of automation tends to make it easier to manage adverse impacts but also delays realization of the benefits automation can provide. Predicting the future is always difficult, but particularly so for AVs. One challenge is determining precisely what we mean by "here." Some companies have announced plans to have driverless vehicles available for public use as early as 2020. But it could still take quite some time for AVs to dominate the market. The growth rate of the AV market will depend on factors including how quickly consumers come to accept AVs, how quickly AV technology advances, and the regulatory environment.

A second challenge is that vehicle automation involves the intersection of two industries: one (information technology) that has developed rapidly, and one (transportation) that has been much slower to evolve. Additional research is needed to determine which pace is more likely to dictate the future of AVs. Published estimates of the share of vehicle trips that will be automated by 2030 range from less than 5% [35] all the way to 95% [36]. Given this level of uncertainty, it is important to start establishing retraining programs and resources now for workers likely to be affected by the shift to AVs, in case this shift happens faster than many expect. Decision-makers should also design flexible AV governance policies that can be easily adapted as the AV industry matures.

Summary and net impacts

Automation in transportation is likely to affect both personal mobility and freight, resulting in workforce and economic effects. As was the case for automation in farming, manufacturing, and shipping, we expect automation in transportation to have adverse workforce effects. Automation will inevitably displace some human drivers-for-hire and truck drivers. Yet automation will also expand demand for some existing jobs, as well as create jobs that are entirely new. Moreover, the aggregate economic benefits of automation—including increased productivity from "unlocked" travel time, safer and more efficient travel, and lower goods costs—are likely to far outweigh economic declines associated with job loss in a few sectors. Based on historical precedent and our own analysis, we expect the net impacts of automation in transportation to be positive.

The literature contains additional support for this prediction. Acemoglu and Restrope examined the effect of automation and artificial intelligence on demand for labor, wages, and employment and found that while these technologies do displace labor, displacement is counteracted by increases in productivity and capital accumulation [37]. Hawksworth (2018) argues that artificial intelligence in general could create as many jobs as it displaces [38], though the transportation sector is likely to experience the greatest amount of direct job loss [39]. Almeida examined the job impacts of information technology (IT) adoption in Brazil and found that IT reduced demand for nonskilled labor and shifted the economy towards skilled labor [40]. Montgomery found that automation in transportation is unlikely to cause net job loss, though job loss on a local scale is probable [41]. Montgomery estimated the economic benefits of automation in transportation at up to approximately $800 billion per year [41].

History shows that efforts to hold technological progress back are generally ill-advised, and that technology entering a new sector on net provides massive benefits. While net impacts of automation in transportation are likely to be positive, the magnitude of these benefits—as well as their geographic and socioeconomic distribution—depends on how and at what pace automation develops. Faster adoption of automation may yield benefits sooner but may also make it more difficult for people in certain locations and jobs to adjust. Fortunately, there are steps that policymakers can take to help manage the transition to an automated future, even though the precise nature of this future remains uncertain. These steps are discussed further in the following section.

Managing the transition

Policymakers, including legislators, regulators, city planners, and transit operators, may rightly wonder what position to take when it comes to AVs. Should they welcome this technology and assume only benefits, or should they introduce bans due to the possibility of unintended consequences? Neither extreme is the right course.

Our working hypothesis as a research and policy community should be that this new phase of transportation will yield economic benefits that, on net, outweigh local disruptions. But we should also be vigilant in case they do not. We should set up policy frameworks that allow changes as transportation systems evolve, since it is much more challenging to put such frameworks in place once a new service is widespread.

We are not alone in recommending a managed transition approach. Atkinson found that "[o]f all the concerns being offered for this next uptick in innovation the only real valid one is the need to do more to help workers who lose their job due to technological innovation to transition to new employment" [42]. The Center for Global Policy Solutions found that "certain population groups and areas of the country would be disproportionately affected" by vehicle automation and offered possible policy solutions [43], including automatic unemployment insurance, progressive basic income, education and retraining, automatic Medicaid eligibility, and expanding support for entrepreneurs.

In a recent study of shifting workforce needs from automation [44], the American Center for Mobility recommends these steps:

- Conduct additional research that captures the input of the vehicle operators in different workforce sectors on what training they would be interested in pursuing;

- Identify, in greater detail, the specific skill sets needed by the automotive and technology industries to facilitate the creation and adoption of AVs;
- Establish rapid coursework and training that meets those specific needs;
- Conduct additional research to quantify the overall positive financial impact of AV technology on the economy as a whole, and the potential for job creation.

A managed transition approach

Legislators, regulators, city planners, transit operators, CEOs, and other decision-makers need to strike a balance between embracing the advantages of automation in transportation and treading carefully for fear of unintended consequences. Below, we offer six recommendations to help thread this needle.

Recommendation 1. Work proactively to identify sector-specific impacts and needs associated with transportation in automation

Automation will have differential impacts across the transportation world. Leaders must think critically about how to prepare accordingly. Transit operators may need to shift resources from first-/last-mile bus service (which can be efficiently provided by automated fleets) to longer-distance rail travel. Transportation agencies may need to train workers on how to install “smart” traffic signals that can communicate wirelessly with AVs. Regulators may need to figure out how to set safety standards for design and performance of AV algorithms as well as standard vehicle components. Education professionals may need to expand opportunities for students to learn coding, project management, and other skills that will have increased economic relevance.

Recommendation 2. Provide displaced workers with access to resources and retraining programs

Transportation-sector workers will need resources to adjust to the adoption of automation, particularly if adoption is rapid. Such resources can be funded by the productivity gains associated with automation. This approach has precedent in freight containerization [11]. Some port employers used a portion of the profits associated with adoption of the new, more efficient technology to provide financial benefits and in-kind support to dockworkers. Similarly, policymakers could impose taxes on automated fleet services that are not high enough to kill the industry, but nevertheless yield sufficient revenue to offer displaced workers short-term unemployment benefits and access to retraining programs.

Recommendation 3. Establish protections for gig-economy workers

The emergence of the part-time "gig economy" in the United States has left many people without access to benefits like employer-provided health insurance and retirement savings plans that are often extended only to full-time employees. Gig-economy workers account for only a small fraction of the U.S. workforce today [45], but automation in transportation could expand the number of gig-economy jobs—for instance, for people working as in-vehicle service providers. Policymakers should explore strategies for protecting these workers. One option is to establish mechanisms for employers in the gig economy to offer partial benefits for part-time workers that could be pooled, making it feasible for workers in multiple part-time positions to assemble a compete benefits package.

Recommendation 4. Emphasize equitable distribution of benefits and impacts

Rapid adoption of automation in transportation will affect workers at all levels. The potential for adverse impacts is greatest for lower-income workers, who have the least financial capacity to successfully adjust. We must ensure that automation in transportation does not exacerbate the stark wealth inequality that already exists in the United States. Providing displaced workers with access to resources and retraining programs (Recommendation 2) can help. Establishing fora and processes for policymakers to work with labor representatives and community advocates will enable identification of other strategies for achieving a just transition to an automated future.

Recommendation 5. Ensure that policy frameworks are flexible and adaptable

Automation is indisputably coming to transportation, but it is unclear when and how. Although some policymakers have responded to this uncertainty by taking a "wait and see" approach to AV governance, we recommend against this strategy. It will be much easier to establish effective policy frameworks proactively than to try and impose them once automation is already widespread. However, it should be easy to adjust such frameworks in response to future research insights and developments in AV technology. It is also wise to pilot policy approaches on a limited scale before deploying them broadly.

Recommendation 6. Support further research and data collection

Research insights are key to informed AV governance. The American Center for Mobility notes that further research is particularly needed to:

- Capture the input of the vehicle operators in different workforce sectors on what training they would be interested in pursuing;
- Identify, in greater detail, the specific skillsets needed by the automotive and technology industries to facilitate the creation and adoption of AVs;
- Quantify the overall positive financial impact of AV technology on the economy as a whole, and the potential for job creation.

Another important research need is greater inclusion of economic considerations in modeling studies. Most AV-impact modeling to date focuses on safety, congestion, and environmental outcomes. Models should be expanded to also estimate impacts on factors such as employment and productivity. Pursuing these research objectives will require better data on job numbers and quality in different transportation and service sectors, as well as on other economic metrics. Partnerships among researchers, government agencies, and the private sectors can facilitate collection of such data.

A backup plan if this transition is different

While we argue that past examples demonstrate net benefits of automation under a managed transition, history is not a perfect model. Each example we cite comes from the last two centuries. While that timeframe may seem long, it represents a relatively brief snapshot in the course of human history. It is risky to extrapolate too broadly from these examples.

There has been speculation at least for decades that automation could be the "end of work." Sometimes this is discussed as a benefit, a vision for a short work week and easy labor. Other times it is presented as a future of low employment and nonexistent economic opportunities.

If the replacement jobs we expect do not materialize, policymakers need a course of action. It is never too early to begin developing contingency plans. Policymakers can also pilot approaches to managing the transition in early markets and use the results to inform broader efforts.

One idea to protect workers if automation reduces jobs overall, popularized by Bill Gates, is effectively asking the "robots" to pay—that is, to recapture some of the gained productivity and use it to pay those displaced [46]. This is similar to what port employers did in response to containerization, as discussed in Recommendation 2.

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