The Economics of Shared Mobility Series

Future

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Predictive Models, Labor Economics, Autonomous Vehicles, and a Real Solution to Traffic Congestion

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…a very great deal more truth can become known than can be proven.
Richard Feynman, 1965

The basic fact is that technology eliminates jobs, not work.
Blue-Ribbon National Commission on Technology, Automation, and Economic Progress, 1966

Technological Transitions and Shared Mobility

If you're at all involved with in the transportation industry, whether professionally or personally, you've likely noticed a shift in thinking in recent years. Where once personal transportation was considered the unquestionable ruler of transportation, recent micro- and macroeconomic events have changed what consumers deem as feasible transportation options.

In the past two reports to this series, we have explored this subject matter in great detail. From the history of ridesharing, to the socio-technical development of web-based transportation platforms, the first report in this series provided substantive context for the growth of the most dominant form of new mobility in America: ridesharing.

The next report to this series was split into two. The first took a more theoretical approach to shared mobility. It aimed to provide economic context to the development of shared mobility. In particular, the report addressed the fundamental economic question of ownership itself—why it is economically beneficial to own capital and why western socioeconomic institutions have traditionally discouraged widespread sharing of capital.

Those familiar with the insurance industry will be unsurprised to learn that risk and uncertainty are the main drivers of capital ownership. When one owns a car, one is actually hedging the against the risk of others abusing a commodity they value. What's more, by owning a car, one greatly increases the probability that they will still have a means of transportation in the future—barring acts of God or theft.

In no uncertain terms, the psychological comfort ownership affords by guaranteeing future transportation can be thought of as one of the most significant reasons for car ownership. The act of owning one's self, one's land, one's car, is a declaration of exclusivity to the world, turning what may have been use-uncertainty into use-risk. It is a fact of life that known risk is far more comforting than unknown uncertainty.

Ownership is not entirely beneficial, however.

As with all other economic interactions, the act of car ownership involves socioeconomic sacrifice. The direct costs of the vehicle ownership and maintenance including insurance costs are just some expenses people experience from ownership. Other expenses include social costs—if my friends know I have a car, they know who to call when moving; psychological costs—the myriad stressors of driving; and, health costs—studies indicate that skin cancer rates can rise in traffic-heavy areas due to prolonged sun exposure.[1]

[1] *Traffic*

Taken together, these costs can be thought of as "burdens of ownership"—the costs imposed on individuals for capital ownership. To most individuals the burdens of car ownership have been less-than-or-equal-to the overall benefits of ownership. Part 1 and part 2 of the previous reports have indicated a shift in this traditional calculation, however. Thanks in large part to the wide availability of increasingly cheaper smartphone technology, and coupled with the integration of real-time transportation demand, traditional assumptions about the benefits of ownership have become uncoupled from the idea of transportation risk. No longer does one need to own a car to guarantee convenient and (relatively) cheap transportation.

To those looking for a simple explanation the consumers shift in thinking, there it is.

To others who seek a more nuanced and accurate understanding of present shared mobility market, the answer goes beyond the availability of technology. Though many may not see it as such, evidence suggests that the cost of using ridesharing services today is being subsidized to a loss by major providers such as Lyft and Uber.

Another factor in the shift to new mobility may be the overall debt those who use rideshare services possess. Research suggests that millennials, defined for the sake of convenience as persons 18-to-39, are the most frequent users of ridesharing services; they are also the most indebted generation in American history when adjusting for inflation.

Is it not out of the realm of feasibility that those in debt would eschew further burdening themselves with long-term debt by replacing auto ownership with shared mobility services?

History suggests it is possible.

In the most recent shared mobility report, the history of the automobile revolution was described at great length. This was more than an intellectual exercise. Few people are aware that between the mid-1910s and the 1920s, the diffusion of the automobile into American society affected more than the mobility of Americans. New markets were opened up as well.

For the first time, credit lines were offered to Americans for the purchase automobiles. So successful were the credit lines in getting Americans to purchase cars that the success of the auto-industry began attract similar offerings to other markets in the country.

They weren't called the roaring '20s for nothing.

Eventually, however, the tide began to change. Stock prices that had begun to rise on a dual-tide of consumer sales and high manufacturing productivity (thanks in large part to technological innovations of Frederick Wilson Taylor) had further encouraged already exuberant investment in the American economy.

The price of stocks rose at a fever pitch; so much so that brokers, cognizant the increasing demand for credit on Wall Street, shifted available credit away from American consumers and towards stock-hungry traders.

With credit no longer as easily available to consumers, they could not make purchases at the rates reflected by stock prices. As prices rose further, some traders could not take the exuberance any longer—they began to sell their stocks. Others soon followed, until a trickle of sales became a wave, and the stock bubble popped.

Contrary to popular believe, the stock market crash of 1929 did not itself cause a depression. Most Americans did not have their money invested in stocks and did not lose wealth directly to the crash.

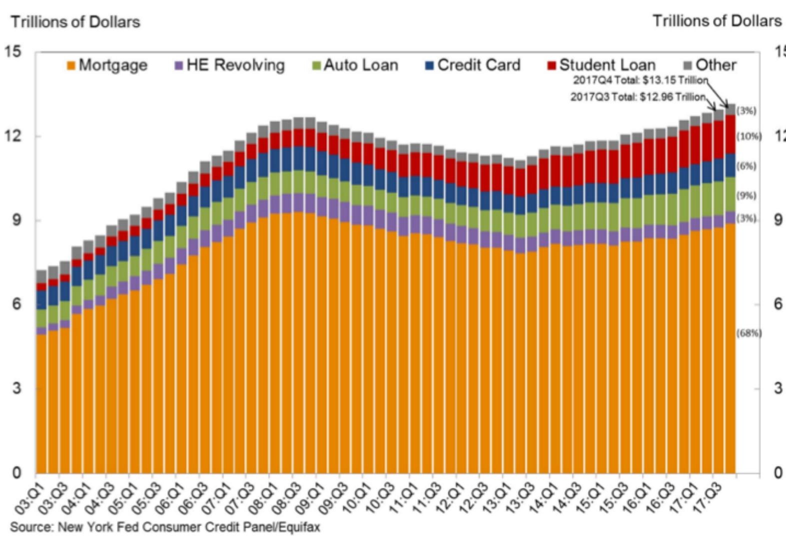
Instead the crash served as a *psychological* burden upon the mind of workers. Americans, largely burdened by debt amassed during the 1910s and 1920s, saw the stock market crash as a threat to their livelihoods—after the crash many were convinced it wouldn't be long before their wages were cut. *As a consequence Americans began to reduce their spending in order to pay off their debt in anticipation of these cuts.*

The significant reduction in spending—in demand—served as a downward pressure on the overall economy, encouraging economic uncertainty and helping it to spiral out of control.

Here's the point: For almost a century, economists have known that America's relationship with transportation serves as a helpful barometer of the health of the entire economy. When Americans begin to shift their relationship to transportation, as has been the trend in recent years, it is therefore significant; especially if this shift is in response to economic uncertainty or indebtedness.

Today Americans are encumbered by over $13 trillion in consumer debt, the most debt ever accumulated. According to recent data out of the Federal Reserve Bank of New York, as of Q4 2017, household debt was up for the 14th consecutive quarter, a 17.9% increase from the most recent debt tough of Q2 2013 (see below).[2] As the chart below demonstrates, over the past 15 years, student loan debt has steadily become an extensive source of debt for Americans, second only to mortgage debt.

Younger workers in particular are taking on the brunt of this student loan debt, having become the most indebted generation of youth ever.[3]



Total Debt Balance and Its Composition[4]

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[2] Federal Reserve Bank of New York, "Quarterly Report on Household Debt and Credit," *Research and Statistics Group*, (Released February 2018, on Q4 2017).

[3] Carl Tannenbaum, Ryan J. Boyle, Vaibhav Tandon, "Weekly Economic Commentary," *Northern Trust* (April 6, 2018).

[4] Federal Reserve Bank of New York , 2017.

In Part 2 of the Economics of Shared Mobility Report we investigated the source of this debt in greater detail. We found that, according to a recent Federal Reserve study, despite an 81% increase in the price of in-state college tuitions over the past decade, demand for college education has not decreased. When steep increases in price do not dissuade demand, economists call this price inelasticity—consumers are not sensitive to changes in price.

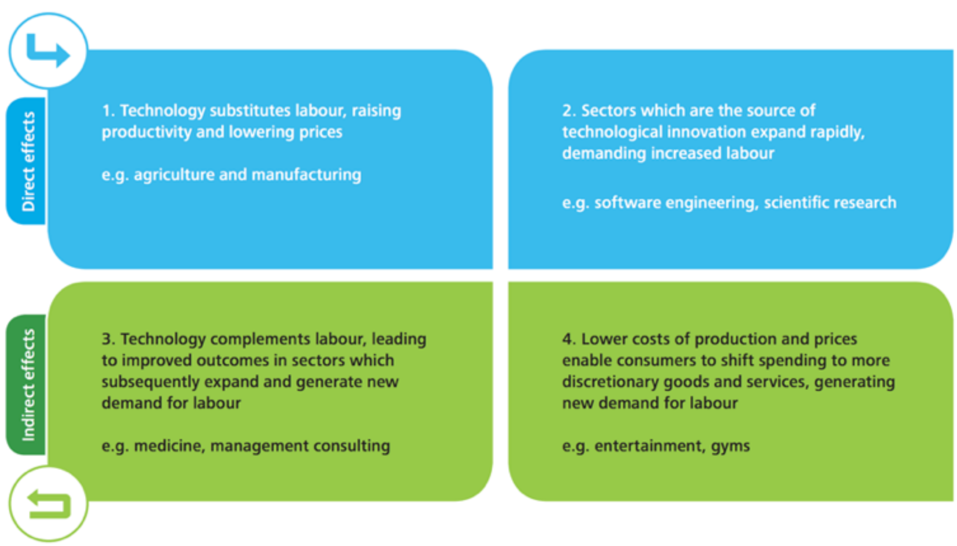
What could explain this shift?

One possibility is that advancements in technology are replacing jobs that have traditionally required less education or training. Or, at least, that (young) workers may be shifting their *expectations* about these advancements and about which jobs will be lucrative in the long-run.

When advancements in technology occur systemically—that is, when many or most citizens act on the belief that technology trends are moving markets in a significantly different direction—economists call this a ***technology shock***. The widespread dissemination of automobiles, and arguably consumer credit lines, were substantial technology shocks upon the economy.

As the name suggests, technology shocks need not always result in universally positive economic developments for everyone. Often these shocks encourage investor exuberance and consumer risk taking, such as the accumulation of debt, to adjust to the changing economic landscape. Almost necessarily, one consequence of these shocks is **technological unemployment**—the replacement of labor with machinery or technology.

I have found the following illustration[5] helpful in describing the direct and indirect effects technology shocks.



Four Technological Mechanisms Affecting Employment[6]

[5] Michael Osborne and Carl B. Frey, "Technology and People: The Great Job-Creating Machine," *Deloitte, LLP* (2014)

[6] Ibid, 5.

As can be seen technology shocks are often, in fact, net boons for economies. In three of the four squares about, laborers benefit, industries expand, and the costs of production are lowered. In only one square are individuals directly and irrevocably affected by technology. Unfortunately, by its very nature, this one square causes much uncertainty to those who stand to be affected by it.

The esteemed economist and macroeconomic theorist Joseph Schumpeter described this phenomenon well when he wrote, "Surely, nothing can be more plain or even more trite common sense than the proposition that innovation…is at the center of practically all the phenomena, difficulties, and problems of economic life in capitalist society."[7]

For many current and future American workers in the last few decades the information technology (IT) revolution has been the source of their difficulties and anxieties. Many have lost their jobs to automation and technological advancements, while others, younger citizens have seen their families affected by this unemployment, have seen the writing on the wall, and have adapted employment expectations accordingly.

Perhaps this is why the economist and esteemed theorist Joseph Schumpeter deemed capitalism a "…perennial gale of ***creative destruction***."[8]

As a consequence of this shift in expectations, it was argued, many people have taken out extensive loans to attend schools to attain degrees they feel would shield them from capitalism's perennial gale. The consequences of this larger debt may have encouraged those with more debt to abandon traditional methods of ownership to less financially prolonged methods of travel such as ridesharing.

Here it is worth noting that, while many workers have lost their jobs, in the past decades many more have *gained* employment. In fact, as will be shown, one largely held and consistent agreement among economists across the political spectrum has been that innovation is both good and necessary for society—and that generally more prosper from innovation than suffer.

Lawrence Summers, the economist and former director of the National Economic Council, spoke to this point in 2014 when he pointed out that technology is generally viewed positively among economists, that "[t]he premise of essentially all economics … is that leisure is good, and work is bad." If technology can encourage leisure, this has generally been viewed positively.

Summers also points out, however, that "[e]conomics is going to have to find a way to recognize the fundamental human satisfactions that come from making a contribution" [9]

Why insert this thought? Because as ever-more technological advancements are anticipated in the American economy, questions and anxieties remain as to what the future of employment will look like. As will be seen, the question of technological employment has long been considered one of the core questions of the capitalist system.

Indeed, in 1930, a year after the Great Crash, the economist John Maynard Keynes anticipated the paradoxical benefits that innovation might afford to humanity, writing in

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[7]Joseph A. Schumpeter, *Business Cycles: A Theoretical, Historical, and Statistical Analysis of the Capitalist Process* (New York: McGraw-Hill, 1939), 143; W. Michael Cox, "Economic Insights: Schumpeter in His Own Words," *Federal Reserve Bank of Dallas* 6, no. 3, (2001).

[8] Joseph A. Schumpeter, *Capitalism, Socialism, and Democracy*, 3rd ed. (New York: Harper and Brothers, orig. pub. 1942), 84; Cox, (2001).

[9] (Mokyr 2015, 32).

"Economic Possibilities for our Grandchildren," that "for the first time since his creation, man will be faced with his real, his permanent problem—how to use his freedom from pressing economic cares, how to occupy the leisure, which science and compound interest will have won for him, to live wisely and agreeably and well."[10]

Keynes' anticipation of the future may have been at least a century early, but it was still amazingly prescient. Today, thanks to the IT Revolution, portable pocket-sized computers are streamlining once protracted processes. Companies such like Tesla, GM, and Ford, are investing heavily into the future of transportation. And old economic regimes such as ridesharing are finding a groundswell of use from companies like Uber and Lyft. Together, technological and business innovations are shaking up perception of near-term human potentialities.

Meanwhile workers are anxious. With innovations in AI and vehicle autonomy fast underway, can workers expect to have jobs in the future? To address such questions full scale are surely beyond the scope of this report. Instead, the goal of this report is to narrow the scope of these questions to relevant sectors within the transportation industry.

This report will address important, open-ended questions about the future such as: how does innovation affect economies? What does the future look like for workings in the automotive and professional driving industry? Will we really develop autonomous cars and what will be their effects on society? Will we finally be able to relieve some of our most intransigent transportation problems including car accidents, transportation fatalities, and traffic itself? These, and many more questions will be answered within this report.

Before we can address these issues, however, the nature of this report should be made clear. Making predictions about the future is a dangerous game. That is why in this report we have chosen to focus on the near-term. The logic behind this decision is simple: The near term is far easier to understand and adapt to than the long term. Those who are better able to adapt to near market trends are far likelier to last in the long run

Still, even near-term predictions and anticipations can be off. That is why throughout the report great effort has been made to make explicit the relevant assumptions behind the data or claims that are made.

Of course, it would be impractical to overtly express every assumption made in this report. Instead, a legitimate effort has been made to clarify relevant analytical assumptions in this report. As will be expressed consistently, this is because perhaps more than at any other time, when thinking about the future, *our assumptions define our expectations*.

If one thing of value is taken from this report, let it be this: Those people who are best suited to adapt to future developments are those who understand the power of assumptions.

Transportation Disrupted

If there's one thing market insiders would have you know about the state of the current auto industry, it's that the future looks bleak. Almost every study and article relating to the car

[10] (Keynes 1930; Mokyr 2015, 41).

market is issued with foreboding words about the future of the industry. Just today, the third headline on LinkedIn boldly declares "Are Dealerships' Days Number?".[11]

If we are to trust reports of industry survey, auto executives are worried too.

A recent KPMG industry report found that survey of 800 automotive industry executives in 38 countries, 74% believed that more than half of current car owners will not want to own a vehicle in the near future. Another study by the firm RethinkX predicts an 80% reduction in US car ownership by 2030, from 247 million vehicles in 2020 to 44 million in 2030. In a country where over 90% of its citizens currently own cars, such a prediction is significant.[12]

But are these claims true? Is the auto industry as we know it over?

While it's true that the auto industry is changing, one need only consult the market activities of US OEMs to gauge how they are structure their business models for the future. Below I have charted a cursory overview of the investment and acquisition activity of the top three US OEMs by market share—General Motors (GM), Ford, and Toyota, respectively.

Just a brief overview of these firms' funding activities suggests that they are actively involved in adapting for a future market. Ford's acquisition and investment activity over the last three years is particularly descriptive. As you can see, in the last five years Ford Motor Company has invested just over $1.2 billion dollars in areas ranging from 3D printing and artificial intelligence (AI), to sensor technology and autonomous vehicles. And these are simply outside investments. Recent reports have it that Ford's is investing over $10 billion just in electric vehicles by 2020.[13]

So, clearly the transportation landscape is shifting—but by no means does this imply that the automotive industry will be a dead market. The market research firm McKinsey & Company predicts that by 2030 the OEMs will see a 30% increase in revenue pools, an increase of $1.5 trillion.[14] Taken together with the information so far provided, we can conclude the following: The prevailing sentiment within transportation is that old business models will change (and are changing) and that new models must be adopted.

Whether we trust projected revenue or growth estimates is beside the point.

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[11] "Are dealerships' days numbered?" *Linkedin. Accessed* Monday April 9th, 2018. <https://www.linkedin.com/search/results/content/?anchorTopic=692945&keywords=Are%20dealerships%27%20days%20numbered%3F%20&origin=NEWS_MODULE_FROM_DESKTOP_HOME>; Adrienne Roberts. "Car Dealerships Face Conundrum: Get Big or Get Out ." *WSJ*. 8 Apr. 2018. Web. 9 Apr. 2018. <https://www.wsj.com/articles/car-dealerships-face-conundrum-get-big-or-get-out-1523192401>

[12] "The Driverless, Car-Sharing Road Ahead," *The Economist*, 9 Jan. 2016, accessed 9 Apr. 2018. <https://www.economist.com/news/business/21685459-carmakers-increasingly-fret-their-industry-brink-huge-disruption>; Kevin Rawlinson. "Fewer car owners and more driverless vehicles in future, survey reveals." *the Guardian*. 9 Jan. 2017. Web. 9 Apr. 2018. http://www.theguardian.com/business/2017/jan/09/fewer-car-owners-more-driverless-vehicles-future-survey-reveals; Dave Gershgorn. "After decades of decline, no-car households are becoming more common in the US." *Quartz*. 28 Dec. 2016. Web. 9 Apr. 2018. https://qz.com/873704/no-car-households-are-becoming-more-common-in-the-us-after-decades-of-decline/; James Arbib and Tony Seba, "Rethinking Transportation 2020-2030," *RethinkX*, 2017.

[13] Nick Carey. "Ford plans $11 billion investment, 40 electrified vehicles by 2022." U.S.. n.d. Web. 9 Apr. 2018. <https://www.reuters.com/article/us-autoshow-detroit-ford-motor/ford-to-increase-electric-vehicle-investment-to-11-billion-executive-idUSKBN1F30YZ>

[14] Detlev Mohr, Hans-Werner Kaas, et al. "Automotive Revolution—Perspective Twoards 2030," *McKinsey & Company* (2016).

Those familiar with the Allocations vs. Expectations model in the second paper to this series would do well to recall why. As was explained, even when a disproportionate number of resources are invested within an established industry, if enough people shift their expectations towards new markets, resources are likely to move to that new market. Said another way, the

General Motors			
Acquisitions	**Date Acquired**	**Price Paid**	**Industry**
Cruise Automation	11-Mar-16	$1B	Autonomous Vehicles
Sidecar Technologies	19-Jan-16	--	B2B Delivery/Transportation
Investments	**Announced Date**	**Money Raised**	**Industry**
SolidEnergy Systems	18-Dec-17	$34M	Rechargeable Battery Cells
Mcity	6-Nov-17	$11M	Autonomous Vehicle Research
Lyft	28-Dec-15	$1B	Rideshare App

Ford			
Acquisitions	**Date Acquired**	**Price Paid**	**Industry**
Autonomic	25-Jan-18	--	Artificial Intelligence, Transportation,
Trans Loc	25-Jan-18	--	Public Transit, Real-Time Passenger Information
Chariot	9-Sep-16	--	Sustainable Mass Transit
SAIPS	16-Aug-16	--	Machine Learning Algorithms
Investments	**Announced Date**	**Money Raised**	**Industry**
Desktop Metal	19-Mar-18	$65M	3D Printing Metal
ZoomCar	16-Feb-18	$40M	ZipCar-Modelled Car Rental
Mcity	6-Nov-17	$11M	Autonomous Vehicle Research
AutoFi	24-Aug-17	$10M	Online Vehicle Financing
Argo AI	13-Feb-17	$1B	Artificial Intelligence, Transportation,
Voldyne LiDAR	16-Aug-16	$150M	Sensor Technology
Civil Maps	15-Jul-16	$6.6M	Sensor-less Vehicle Autonomy
Pivotal	5-May-16	$653M	Cloud Software

Toyota			
Acquisitions	**Date Acquired**	**Price Paid**	**Industry**
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Investments	**Announced Date**	**Money Raised**	**Industry**
JapanTaxi	9-Feb-18	$69M	Cab-Hailing Mobile App
Sansan	7-Aug-17	$38M	Business Card Mobile App
HDS Global	7-Aug-17	$13M	eCommerce
Preferred Networks, Inc.	4-Aug-17	$95M	Internet of Things, Machine Learning
Mazda Motor Corp.	4-Aug-17	--	Automobiles
Grab	24-Jul-17	$2B	Ride-hailing App
Getaround	20-Apr-17	$45M	Car Sharing Mobile App
Getaround	28-Oct-16	$10M	Car Sharing Mobile App
Xevo	13-Jan-16	$10.2M	Automobile AI, Machine Learning
Preferred Networks, Inc.	18-Dec-15	$8.2M	Internet of Things, Machine Learning
Tesla	20-May-10	$50M	Electric Mobility
BioAmber	17-Jan-10	$12M	Sustainable Chemicals

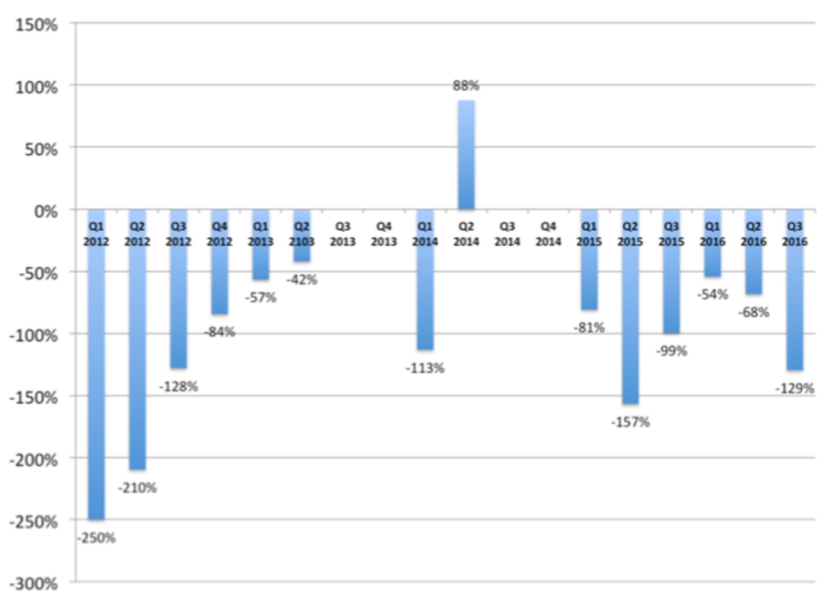
Acquisitions and Investments of Top Three US OEMs by Market Share[15]

established business models by which automakers operate are likely to change if more and more firms begin to act as if these models will change—even had it been the case that the previous models would have sufficed.

The key economic insight we can glean from present trends, therefore, is that companies are investing as if markets will change. And, in doing so, they make it more likely that these changes will occur. Reports like those from the industry research firm Strategy Analytics predict that autonomous vehicles will change the fabric of economic landscapes. While the Brookings Institution predicts the sharing economy to grow from a $14 billion industry in 2014 to a $335 billion industry in 2025—an increase of over 2000%.[16]

Again, in many ways it may be presumptuous to predict the future to be dominated by sharing economy provides such as Uber—which arguably started this trend of change in the first place. One estimate has it that only 1% of vehicle miles travelled in 2016 were by rideshare providers.[17] As the very first report in this series illustrated, the very emergence of ridesharing in 1914 was quite similar to its recent incarnation a century later.

Ridesharing, in the form of the "Jitney", bursting onto the American scene in the early attaining such extensive ridership that it soon became the fastest mode of transportation Americans had ever adopted. Yet, despite its prominence, problems inherent to the Jitney's use were not solved. As a consequence, jitney use plummeted into obscurity.



[15] Crunchbase. "Crunchbase: Discover innovative companies and the people behind them." *Crunchbase*. n.d. 10 Apr. 2018. https://www.crunchbase.com

[16] Roger Lanctot, "Accelerating the Future: The Economic Impact of the Emerging Passenger Ecnomy," *Strategic Analytics*, 2017; Niam Yaraghi and Shamika Ravi, "The Current and Future State of the Sharing Economy," *The Brookings Institution*, 2017.

[17] Russell Hensley, Asutosh Padhi, and Jeff Salaar, "Cracks in the Ridesharing Market—and How to Fill Them," McKinsey & Company, 2017.

Uber Losses as a Percent of Revenue[18]

Thankfully, some good ideas don't always die. Today what we call rideshare is essentially the Jitney Era Redux. Unfortunately, now as then, many similar problems that plagued the Jitney remain; problems involving safety, regulation, insurance, and, importantly, profitability.

Because Uber is not a publically run company (in part, one of its key profitability problems), recent earnings data for the company is scarce. Still, the above chart provides a helpful snapshot of the company. The chart, using data compiled in collaboration between a number of media outlets, graphs Uber's losses as a percent of its revenue by quarter from Q1 2012 to Q3 2016. The blank spaces on the chart represent unavailable data.

Still, from the chart we do have, the results are clear. Quite possibly did Uber only reach a profit one quarter of the years charted. It is at least certain that the company operated at a net loss in 13 of the 19 quarters available—likely 17 if its pattern of losses is any indication.

Yet still, despite the unprofitability of Uber, predictions reign that shared mobility will grow-ever prominent in our lives. If Uber tends to operate at a consistent net loss, why are companies like Ford and GM and Toyota investing billions of dollars into new modes of transportation? To answer this question, we'll need to familiarize ourselves with the nature of predictive models and data.

The Limitations of Predictive Models

The fields of economics and data science have a lot in common. Like data scientists, economists love data. Like data scientists, economists love to identify trends. And, like data scientists, economists are passionate about "models." Unfortunately, in this way the denizens of both fields suffer the same critical flaw. For all their love and reliance of models, experts in both fields often misrepresent what models can say and what they cannot.

This is regrettable because, at their best models can be used to forecast likely futures, allowing business executives and social leaders to plan efficiently and effectively to avoid misfortune. At their worst, however, models can be misrepresented, misinterpreted, and misbelieved by individuals without the skills to interact with them.

Any number of consequences can result from such misunderstandings. Our most recent recession should have proven all too well the consequences of making ill-informed decisions on the faith of obscure models.

In his acclaimed polemic on forecasting *The Signal and the Noise*, the statistician Nate Silver wrote to this effect, arguing that "the best way to view the financial crisis is as a failure of judgment—a catastrophic failure of prediction." According to Silver, there is a common theme among flawed predictive models, writing:

> The most calamitous failures of prediction usually have a lot in common. We focus on those signals that tell a story about the world as we would like it to be, not how

[18] Jim Edwards. "Uber's Leaked Finances Show The Company Might — Just Might — Be Able To Turn A Profit," *Business Insider*, 27 Feb. 2017. Accessed 10 Apr. 2018.

> it really is. We ignore the risks that are hardest to measure, even when they pose the greatest threats to our well-being. We make approximations and assumptions about the world that are much cruder than we realize. We abhor uncertainty, even when it is an irreducible part of the problem we are trying to solve.[19]

Although here it may seem as though he is simply referring to models, in raising the issue of our aversion to uncertainty, Silver is actually alluding to a deeper human tendency to which, as a statistician, he is well acquainted: our common desire for certitude.

Though uncertainty is not exclusive to it, those within the insurance industry will likely be familiar with the innate desire to calculate the incalculable. How convenient it would be to model every factor, to account for every possibility. The insurance industry, which, for all the slack it gets, does the best it can, acts as a bastion of light against life's dark uncertainties for the public, and works to ameliorate uncertainty by modelling risk.

As has been described in previous reports, we have not always had this ability. Though its characterization has always existed in some form, being an innate feature of life, only in 1921 did the concept of risk receive a strict economic definition. It was in that year that the economist Frank H. Knight defined risk as those events which "occur with any measurable probability."[20] Uncertainty, therefore, is any event which occurs with no measurable, or at least no as yet measured, probability.

The point is this: What are models if not tools to shape reality into discernable, reproducible parts? Tools which allow businesses to transform consumer uncertainties into quantifiable risks, assuaging their fears, reducing the frictions of their otherwise uncertain economic actions? Predictive risk models, in other words, reduce the vicissitudes and volatilities of life by convincing consumers that some entity out there *knows* what can happen.

This is essentially the job of every modeler, to make the unknown known and provide us fallible humans with some sense of security through insight. But models are no panacea. Problems arise when we grant too much power and faith into our capacity to make the unknown known. The mathematician Emanuel Derman explains the shortcomings of the models well when he writes:

> Theories describe with the world on its own terms and must stand on their own two feet. Models stand on someone else's feet. They are metaphors that compare the object of their attention to something else that it resembles. Resemblance is always partial, and so models necessarily simplify things and reduce the dimensions of the world. … In a nutshell, theories tell you what something is; models tell you merely what something is like.[21]

In other words, modelers are human, and therefore their creations are fallible. Uncertainty will *always* exist. By the very nature of the assumptions they make, models prohibit

[19] Nate Silver, *The Signal and The Noise Why So Many Predictions Fail - But Some Don't* (New York, NY: Penguin Books, 2015): 19- 20.

[20] Morgan Rose, "Risk versus Uncertainty, or Mr. Slate versus Great-Aunt Matilda," Library of Economics and Liberty, November 5, 2001, accessed December 26, 2017.

[21] Derman (2011), 6

our understanding everything. The polymath Kurt Gödel proved this point almost as an afterthought in 1930 while he attempted to solve his well-known Incompleteness Theorem—a theorem about the limitations of arithmetic.

Gödel's afterthought, a proof referred to as the Tarski Proof, effectively reveals the following: The language of a well-defined system cannot be used to prove itself. In other words, systems are limited by the very factors which create them. Because every model assumes *something* about the world, there are necessarily truths which it will be at odds to demonstrate.[22]

The Tarski Proof is powerful because it formally establishes what any sensible individual could already tell you: No one knows everything.

And yet, often times we make the mistake of acting as if models *can* tell us everything.

Much fault can be attributed to communication error. You may have found, for example that we academics, analysts, and business people will commonly wave our hands and casually cite "models" as proving some point of ours without having clearly described the world these models are assumed to represent.[23] This communication breakdown is not only socio-psychological, it is also a classic logical fallacy known as "Appeal to Experts."

The fallacy goes like this: Stephen Hawking is a great physicist. Stephen Hawking says nothing can escape a black hole. Therefore, nothing can escape a black hole. It's an easy claim to believe. How many people do you know outside of the physics community who would have seriously challenged Stephen Hawking on his views of black holes?

This is an especially potent example because Hawking would later work to disprove this argument which he originally presented![24] As experts, or at least as individuals with exposure to our particular fields, it is therefore all the more important that we work with great intention to educate our audiences about how to appropriately receive our data, and how to challenge us properly. In doing so, we do ourselves the favor of guarding against our own forecasting errors.

According to the cognitive scientist Steven Pinker, this may be harder than it sounds. Neuroscientists have conducted tests which suggest that our brains have trouble recalling what it was ever like to have not known the subjects to which we are intimately acquainted. Pinker aptly calls this phenomenon the "curse of knowledge," and describes it thusly, "The better you knowing something, the less you remember about how hard it was to learn. The curse of knowledge is the single best explanation I know of why good people write bad prose."[25]

Here Pinker is referring to a common plight of writers such as myself—the inability to explain clearly ideas that are otherwise intimately familiar. As Pinker contends, this difficulty often arises because we are innately designed not to remember the process of familiarization. We are physically limited in our ability to empathize with those who cannot see what we ourselves once did not see.

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[22] Roman Murawski, "Undefinability of Truth. The Problem of Priority: Tarski vs Gödel," *History & Philosophy Of Logic* 19, no. 3 (1998): 153-160.

[23] For instance, the Allocation vs. Expectations Models assumes that sectoral returns depend positively on the number of individuals already active within a sector. Though this is likely, it may not be true after *n* number of individuals.

[24] Thanks to Hawking's work, it is now commonly believed that "Hawking Radiation" is emitted from black holes. A great example of why humbleness can lead us to greater insight.

[25] Steven Pinker, *The Sense of Style*, (Penguin, 2016).

With Pinker's cognitive context in hand, it becomes easier to understand why many data scientists and economists such as myself regularly cite complicated models, such as the Allocations vs. Expectations Model I referenced above, without proper explanation.[26]

Familiar concepts are neurologically overlooked.

Those who regularly work with models understand that they are a way of reaching insights about the world. Oftentimes *what* these models suggest is far more exciting, or more useful in proving a point, than *how* they came to suggest their insights.

It is therefore unlikely that those who use models will overcome the tendency to gloss over details. When discussing predictive models then, it is necessary that the audiences to information possess a "grammar of graphs"—a *lingua franca* with which to adequately judge the models and data presented to them, such as those contained in this report.

Such a grammar of graphs could be as simple bearing in the following three questions every time data, models, or trends are encountered:

1. What assumptions does this model make? Or, what assumptions does the author make about this data?
2. What were the incentives of those who produced this data?
3. How much can I reasonably generalize from this data? (i.e. Where is the uncertainty?)

As has been explained, every model makes assumptions. When presented with this information, then, if modelers neglect to explain their assumptions outright, then it's important not to act on their information without knowing what world it was designed to live in.

In general, this second question is one economists constantly consider, and so should you. Everyone works through incentives, whether tacit or otherwise. Although incentives are not good or bad, considering what may have influenced an analyst's projections is always a worthwhile endeavor.

All data has its limitations. In asking yourself how far this data can be stretched relative to its conclusions, you are in reality distinguishing between calculable risk and incalculable uncertainty. It is one of the smartest interpretative moves audiences to information can make.

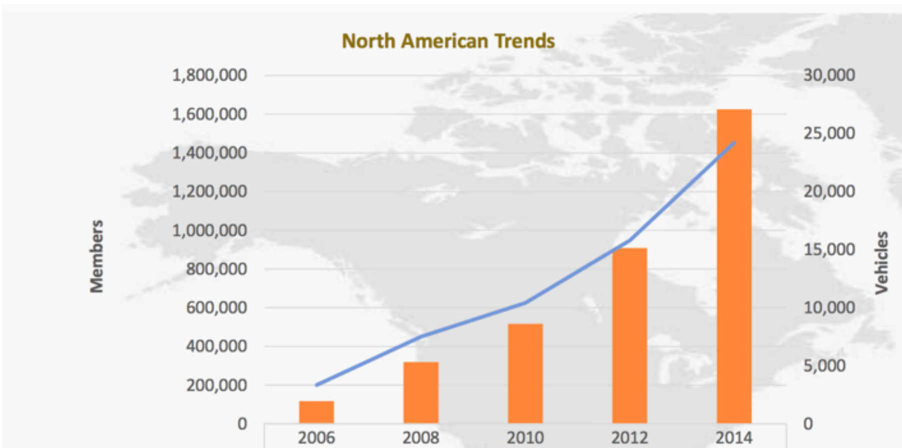
Banking on a Shared Future

Having established the limitations of predictive models, we are now ready to answer the question of why markets are forecasting shared mobility into the future, despite the consistent losses of firms like Uber. One of the first assumptions these firms likely make is in what they interpret growth to mean about consumer preferences. To help illustrate this point, I have included the graph below which charts every two years of data on car sharing membership and vehicle use between 2006 and 2014 in North America. The left vertical axis quantifies membership, the right vertical axis quantifies vehicle use, and the table below the chart

[26] Incidentally, I do explain this model in great detail in: Benjamin Labaschin, "The Economics of Shared Mobility: Part 1 of the Present," *Arity* (2017).

indicates growth-rates: the rise in car share membership and vehicle use relative to the year before.

As a business, here is what we interpret this chart as saying: Between 2006 and 2014, there was about a 1,281.7% increase in demand for car sharing.[27] ?? (Grady, why am I getting different numbers in growth rates than these people?) Behind demand is often another tacit assumption. Namely, if we define demand as being an economic activity where consumers desire some good or service—that is, they are willing and able to makes purchases—and demands *grows*, then unless there are barriers preventing firms to enter the field, there is potential profit to be made.



	2006	2008	2010	2012	2014
Members	117,656	318,898	516,100	908,584	1,625,652
Membership Growth Rate		65%	27%	33%	34%
Vehicles	3,337	7,505	10,420	15,795	24,210
Fleet Growth Rate		50%	18%	23%	24%
Member-Vehicle Ratio	35.3	42.5	49.5	57.5	67.1

Car Sharing Membership and Fleet Growth, 2006-2014[28]

So, we have a first potential insight into why businesses may be predicting growth: rising demand implies potential profit for firms who enter the market. One side of supply and demand equation, we called economic growth spurred by consumer preferences ***demand-led growth***. Still, we should not overlook the importance of the barriers to entry concept. Sticking with the car sharing example, let's return to the graph above.

One of the primary barriers to market entry is investment in capital. For a carsharing business, purchasing fleets of vehicles may be among the many investments it has to guarantee its viability. Car share providers that aggregate their cars into fleets are operated a business-to-peer (B2P) model. That that simply run connectivity platforms for users to lend out their cars engage in peer-to-peer (P2P) models.

As the data above indicates, the member-to-vehicle-ratio among fleet providers grew over these 14 years, from 35 members for every vehicle in 2006, to 67 members for every vehicle in 2014. This data may suggest to potential B2P providers that there is a minimum

[27] Businesses calculated growth by: $\frac{present-past}{past} = Growth$

[28] Car Sharing Cite

amount of capital they must be able to provide if they are to keep up with demand. If they cannot provide this capital, then they must charge higher prices for their services, allowing competition to undercut their prices.

Thus another indication from our is that entities with the ability to leverage large amounts of money have fewer barriers to market entry. And, indeed, we have already been presented with evidence to support this claim. In the last few years, both Ford and Toyota have invested almost $100 million just in car sharing companies.

Which leads us to our final insight and original insight as to why insiders are predicting shared mobility services will grow in the future: businesses are investing heavily into shared mobility. When markets experience large amounts of growth in supply, prices tend to lower, and consumers who otherwise would not have participated in markets may begin to do so. This is the supply-side of the supply and demand equation which we call ***supply-led growth***.

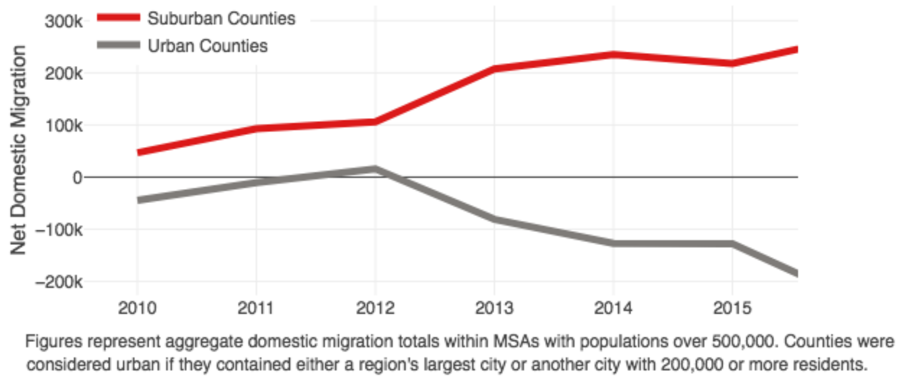
To be sure, by no means are the above reasons a comprehensive list of why market insiders are banking on the growth of shared mobility market. For more reasons, one need only to consult previous reports. Demand- and supply-led growth coupled with low barriers to entry are simply a handful of powerful reasons attracting the attention of businesses who fear market disruption, but also sense opportunity on the horizon.

Expectations and Reality

High growth and ease-of-entry may be *reasons* why OEMs like Ford and Toyota are entering the car sharing market, but this does not mean they're guaranteed to do so. In practice, demand-led and supply-led growth are models which economists use to better understand the economy. To paraphrase Emanual Derman, they are the metaphorical simplifications that reduce the world into digestible chunks. To state that because economies have grown in the past for supply-side or demand-side reasons, and therefore we should invest, is no guarantee of future success.

The expansion of assumptions within models matters because there is an inverse relationship between the breadth of assumptions used in a model, and the certainty of its predictions. Many predictive models today that project shared mobility will be dominant in the future are based on more than rigorously established statistical theories—they often also assume future events that are less than certain—that people won't be driving cars in the future (won't they?), or that most people will be living cities (will they?).

It may seem like a fruitless exercise to question our most cherished perceptions about the world, but a little doubt goes a long way. For example, unless you have read previous reports, it may come as a surprise to learn that for at least the last 7 years suburban areas have experienced more growth than cities (see chart below). According to one analysis, in 2016



Acceleration of Suburban Migration[29]

Americans migrated "to suburban counties at greater rates than they did to nearby urban counties in 72 of 82 metro areas with at least 100,000 suburban residents."[30] Of course, this data does not mean Americans do not want to live in cities anymore. It is instead to say that our expectations face volatility due to unforeseen, incalculable circumstances.

It is therefore important for businesses when considering investments about the future to ask the following question: are my assumptions independent of one another, or related? Models like demand-led and supply-led growth rely on historical precedent to predict the future, and they may be right to do so, but not all markets operate the same.

The stock market is often used as an example of a market that cannot be predicted based solely on historical data. Markets such are these are said to function stochastically. Also known as "random walk" models, these are systems where each step in the system is independent to the one which preceded it.[31]

Many economists argue that stock prices must be random because (they assume) most major institutions, whose behaviors most affect stock prices, essentially have equal access to information. If the prices of stocks represent their true value (they assume), and the emergence of new information is essentially random—that is it is equally likely to emerge anywhere—then stock prices are unpredictable using historical data.

Notice that the randomness of the stock market is based on many assumptions—still, in the long run, economists believe, this is essentially the case. Indeed, the use of the random walk model is not meant to dissuade the use of predictive models—robust predictive models have time and again demonstrated the capacity to out-predict humans.

Using simple linear regression models on historical weather data, for instance, models have been able to predict the yearly quality and price of Bordeaux wine far more accurately

[29] Chart plots US Census data of metropolitan statistical areas with population of at least 500k. Mike Maciag, "Population Growth Shifts to Suburban America." *Governing*, June 2017. Accessed April 10, 2018. http://www.governing.com/topics/urban/gov-suburban-population-growth.html

[30] Maciag (2017)

[31] Burton Malkiel's *A Random Walk Down Wall Street* provides a well-known perspective on this matter, though I also suggest reading William Bernstein's *The Four Pillars of Investing*.

than human experts.[32] To the collective horror of oenophiles, evidence indicates this is something that can be determined without ever tasting wine.[33]

Models certainly have their use. It is instead to say that the faith placed into a model should be proportional to the validity of its underlying assumptions. Said another way, the scrutiny of a model's underlying assumptions should be roughly equal to the usefulness of the model's predications.

So, which combination of fundamentals are analysts assuming about the future of SMS? At their most basic, many models seem to assume the following: that demand for shared mobility will increase and that technology and innovation will reduce production costs and/or increase supply. (cite). Firms are already emerging to help reduce costs in a process known as backward linkage. (Cite). When costs are too high for a firm to lower it themselves, other firms may develop to help lower those costs

Insurance companies are one instance of market linkages—they exist because other markets exist where the cost of risk is too high. New technology and methods are also being developed or adopted to help lower costs as well. (Cite)

Is it reasonable to assume firms and technological adoption will lower costs enough to encourage a substantial market share in shared mobility? Again, there is no guarantee. True, firms are emerging to help ameliorate issues of the past. (Cite) But how profitable, and therefore how sustainable these firms are, remains questionable. (cite)

Further, if the sustainability of central firms is in question, so too is the sustainability of market-linked firms. Blacksmiths may have created horseshoes and swords, but as sword use diminished and horses were replaced by bikes, trollies, and cars, smithing would be affected. Auto-Insurance is in the same predicament, if fewer people drive or purchase cars, such an industry is threatened. Consider auto-mechanics today—if transportation shifts fundamentally, the skillsets needed to repair cars may be altogether different in the future.

Firms which rely exclusively on the sustainability of shared mobility into the future at risk themselves. This is not a big claim to make—any firm that relies exclusively on one industry is, by its nature, no diversifying its cash flow portfolio. But this does mean that if linkages to shared mobility at all provide a significant cash flow, its growth should be fostered.

How can we foster a future of shared mobility services?

As stated, fostering a more sustainable future for shared services comes down to the assumptions of growth. Some of these factors are generally out of the hands of firms, such as increasing the income of all people. However, by lowering production costs for goods and services it is *as if* firms have increased consumer income.

One way to reduce production costs is the adoption of more efficient industry practices and through technology. By reducing cost through technology in particular, supply can also increase, therein increasing sale volume and revenue. By leveraging technological capabilities such as telematics and analytics are being insights can be provided high-risk shared mobility services, allowing them to cull risk factors, and lower costs. (Cite).

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[32] Orley Ashenfelter, "Predicting the Quality and Prices of Bordeaux Wine," *The Economic Journal* 118, no. 529 (2008): F174-184. http://www.jstor.org/stable/2010883

[33] Ian Ayres and Michael Kramer, *Super crunchers,* (Westminster 2007).

But will technology be adopted fast enough, and will it reduce costs enough, to make shared mobility services viable options to build demand?

If SMS are to gain a substantial market share in transportation, they will need to do so. It is imperative to understand the economics of technological transitions—what the common pain points are, how to overcome them.

Seeking Behavior and Easing Friction

In business, as in life, singular events are more notable than slow processes. Unveiling a new transportation service to the public, for example, is apt to garner more appreciation than one the public is already accustomed to receiving.

No doubt this trait relates in some way to our neurological predilection against the familiar. Indeed, all mammals, from humans to pigs to chickens, are predisposed towards novelty in a process called ***seeking behavior***, described by the neuroscientist Jaak Panksepp of Washington State University as "the basic impulse to search, investigate, and make sense of the environment."[34] In other words, seeking behavior is our drive for novelty and fresh information. It is, in point of fact, the internet incarnate.

Seeking behavior relates to our discussion about the future of shared mobility more than you might think. Recent advancements in neurology, the study of the nervous system and brain, may actually explain why some firms misjudge and overreact market developments.

Studies of the human mind over the last ten years have suggested that the neurotransmitter dopamine, a pleasure-inducing chemical substance released by neurons in the brain, is responsible for the seeking behavior. According to researchers, the more we encounter novel stimuli and unexpected rewards, the more likely our dopamine levels will rise.[35]

What could be more stimulating than coming up with and discussing new possibilities about the future? Think of all the dopamine.

Pleasure principle notwithstanding, if firms and researchers today are not careful, they may succumb to their biology, offering newer, novel predictions that never come to pass.

This is not hyperbole either.

In the 1990s, tech stocks seemed like they could only rise in value. The relatively new toy website eToys.com, for example, saw phenomenal growth. Compared to its brick-and-mortar competitor Toys R US, the growth eToys saw was remarkable—quintupling its customer base to 2 million in only a year, managing to outsell Toys R Us that holiday season. So successful did eToys seem that in its May 1999 IPO the firm ended up raising $166 million, quadrupling its price per share to $76.50.

Heartened by its investor support, the company spent aggressively to gain market share, spending $150 million on two distribution centers which spanned 2 million square feet in size. Eventually, however, investors desire returns on their assets. Expecting sales like the years

[34] Temple Grandin and Catherine Johnson, "*Animals Make Us Human: Creating the Best Life for Animals*," (Boston: Houghton Mifflin, 2011), 6-7; Jaak Panksepp, "Affective Consciousness: Core Emotional Feelings in Animals and Humans," *Consciousness and Cognition* 14 (2005): 30-80.

[35] Grandin and Johnson (2011), 308; Panksepp (2005).

before, eToys confidently informed investors to expect sales of $240 million in Q4 of 2000. If it met this goal, it could prove to investors that it was on a path to profitability.

But the sales never came—instead shoppers went to physical stores like Walmart and Toys R Us.

At the end of December 2001, the company had to inform their investors that they had reached only half their expected sales, and that they had operated at an $87 million loss. By February of next year, the eToys stock dropped to 9¢ per share.

The moral of the story is this: Growth does *not* necessarily need to be sustained, especially growth in technology. Just as correlation does not equal causation, so too does technology not always yield lasting productivity.

In the history of American business, it is possible to count on one hand the number of technologies that singularly and irrevocably improved both productivity *and* the livelihoods of all citizens (and most of these innovations occurred in the 1800s). As will be seen, there is a large difference between innovation of technology and its widespread adoption. The researchers Brownyn Hall and Beethika Khan, economists at the National Bureau of Economic Research (NBER), summarize this difference well, writing:

> Unlike the invention of a new technology, which often appears to occur as a single event or jump, the diffusion of that technology usually appears as a continuous and rather slow process. Yet it is diffusion rather than invention or innovation that ultimately determines the pace of economic growth and the rate of change of productivity.[36]

Said another way, even if an invention is socially beneficial, barriers act to prohibit widespread adoption, making societal transitions more volatile. The rougher these transitions are, the less likely productivity growth will be and the less likely firms sporting the innovation will prosper.

American society has been shaped heavily by the automobile—from the suburbs, to fast food and delivery services, to entire cities (i.e. Detroit and Los Angeles), car production and ownership has shaped the American identity over the last century.[37]

Indeed, previous reports have explained at length why ownership is itself is the go-to economic decision among western nations. The idea of ownership was and largely remains a fundamentally American idea. Let's not forget that it was only a decade ago that then President George W. Bush promoted the idea of the Ownership Society. Americans, and indeed most westerners, traditionally gravitate toward the ownership of property in some form, whether it be their houses or their cars. Shared mobility services, with their models of de-coupling economic use from economic possession, are therefore not be perceived as guaranteed economic realities, but potentialities.

If the shared economy is to grow, the transition into a shared economic paradigm must be sustained—and firms like Uber and Lyft cannot do it alone. Firms with business models

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[36] Brownyn H. Hall and Beethika Khan, "Adoption of New Technology," *National Bureau of Economic Research* (2003), 1.

[37] Mark S. Foster, *A Nation on Wheels: The Automobile Culture In America Since 1945* (Belmont, CA: Thomson, Wadsworth, 2003).

inharmonious to established market enterprises have historically relied upon the economic concept of ***backward linkages*** to survive. A concept that has been repeated throughout these reports, backward linkages are complementary industries which ease frictions inherent to the production or use of certain services and goods. Auto insurance providers, mechanics, gas stations are all examples of backward linkages—without them it is unlikely that automobiles would have seen the adoption they had, and without the automobile it is unlikely these firms likely would have ever developed.

And therein lies the contention to which these reports have been building, to our question about the future of shared mobility.

If shared mobility services, with their business models of shared capital, are to survive into the future, they must be able to reduce the cost of their services. From the very beginning, in 1914 when L. P. Draper began the ridesharing phenomenon, the economics of his decision were costly: he would bear the burden of capital depreciation, of labor, and of risk, for a simple "jitney" payment. Despite their scaled-up nature, shared mobility models today have hardly reduced these costs, but they must.

In order to encourage the growth of shared mobility services, firms must emerge to reduce the economic frictions inherent to the operation in the shared economy.

What is the production of produce autonomous vehicles if not the reduction of labor costs? What is the use of telematics to generate business insights, if not a means of mobility optimization? What is user-based insurance if not the reduction of expensive risk?

Just as the existence of roads, auto mechanics, and auto insurance encourages the use of automobiles, so too will businesses that ease *immediate* costs in the shared economy (not future costs) foster sustainability of the firms which they serve. Each service they provided to reduce the costs of shared mobility acts as a lubricant to the friction inherent to their business model. As a matter of inertia, it will be these firms who look to the near future and provide *transition solutions* that will also be well positioned to take advantage of the future markets that are, now, more likely to develop.

So far, there have been many points. To summarize: The sustainability of shared mobility firms is not guaranteed; in fact, their business models work are inharmonious to traditional American business models and economic fundamentals. The momentum of the American market has always leaned towards ownership. American firms, moreover, have a history of falling prey to their own desire for novelty—investors love the idea of investing in high growth, progress-oriented firms, but expect returns on their investments. Despite the successes of some large-scale business that took time to make profits (e.g. Amazon), if firms like Uber do not reduce their losses, investors may reduce their funding. If shared mobility services are to last, firms must form cost-easing backward linkages to ease operation costs inherent to shared economy business models—they must reduce economic friction. The firms that establish themselves as industry leaders will be those who provide economic relief to the friction inherent to periods of technological transition.

To better understand these frictions, in the next sections the economics of technological transitions are explained.

Technological Transitions into the Future

What exactly are technological transitions? Frank Geels, Professor of Systems Innovation at the University of Manchester, defines these periods as "major technological transformations in the way societal functions such as transportation, communication, housing, feeding are fulfilled." Though here it may be useful to consider the word "technology" in its loosest sense.

As Professor Geels readily admits, technological transitions do not need to develop by stereotypical means. Not every transition need be caused by cell phones, cars, and computers. Other, less-familiar "technologies" can just as easily cause major social upheavals, from changes in regulations (e.g. The Stamp Act of 1765) to major infrastructural and industrial expansions (e.g. The Interstate Highway System), can just as easily be the root of comprehensive socio-economic change.[38]

Whatever does manage to cause systemic change, the central theme of technological transitions is that certain significant innovations can, at times, encourage (or force) individuals, institutions, and societies to alter how they might otherwise operate.

Few are immune to these changes, too. The advent of the digital computer, for instance, didn't simply change communication. Between 1930 and 1960, office practices, layouts, and cultures all shifted in response to the substitution of familiar punched card technology.[39] Lest you doubt the long-term effects of these substitutions, note that we are still experiencing the consequences of these technological shifts today. After all, what are Silicon Valley startups today, with their open spaces and casual dress codes, if not manifestations of the Computer (and subsequent IT) Revolution?

Perhaps the most famous technological transitions occurred in America and the United Kingdom from 1760 – 1830 and 1870 – 1914. These periods are better known as the first and second Industrial Revolutions—though the title of "Industrial" may be a bit of a misnomer. Whereas the first Industrial Revolution was characterized by advancements in machine production in factors, the second Industrial Revolution could not be characterized in the same way. The changes that spread throughout the American economy during the latter period would be better described as a revolution in network-infrastructure rather than industry, with technologies such as the telegraph, sewage systems, railroads, and roadways all developing during this period.

The major point here is this: technological transitions can, and often do, encourage complementary transitions in the future, but must each be driven by central thematic changes. The Computer Revolution, driven by innovations in microchip production described in previous reports, certainly gave rise to the Information Technology Revolution—but these periods cannot and should not be mistaken as being the same. Each technological transition culminates from the result instances of singular technological innovation, followed by extended periods of technological adoption.

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38 Frank W. Geels, "Technlological Transitions as Evolutionary Reconfiguration Processes: A Multi-Level Perspective and a Case-Study," *Research Policy* 31, 2002: 1257.

39 Ibid; J. Van den Ende and R. Kempe, "Technological Transformations in History, how the Computer Regime Grew Out of Existing Computing Regimes," *Research Policy* 28, 833-851a.

The prolonged interval which define each industrial revolution—indeed, their very inexactness—demonstrates a key characteristic about periods of technological transition: They are by their nature gradual developments of socioeconomic thought precipitated by the continual “diffusion” of technology into societies and culture. Social changes, no matter how fast they may seem, diffuse into economies over time.

Understand here that the term diffusion takes on a very specific meaning to social economists. The NBER researchers Hall and Khan define the term well:

> Diffusion can be seen as the cumulative or aggregate result of a series of individual calculations that weigh the incremental benefits of adopting a new technology against the costs of change, often in an environment characterized by uncertainty (as to the future evolution of the technology and its benefits) and by limited information (about both the benefits and costs and even about the very existence of the technology).[40]

In so many words, diffusion is the ***opportunity cost*** to technological adoption—what risks and uncertainties, benefits and costs, decision-makers take when choosing to adopt a technology.

Every choice has a cost. When it comes to technology, consider this: Most new technologies are *not* adopted. One unconfirmed but commonly cited statistic has it that 95% of patents are never actually put to use.[41] To an economist this would not come as a surprise. It is a central tenet of the field that all decisions come with a cost. Indeed, while a defining feature of technological transitions is innovation itself—defined as an improvement of production processes, the efficient allocation of resource use, and a shifting what seems possible—we will see that periods of technological transitions should also be viewed as periods of cost to the most society’s most vulnerable. Modernization necessarily comes at a cost to those who cannot themselves acquire the skills or capital needed to modernize.

For now, suffice it to say that technological adoption is costly.

Most new physical technology, like cell phones and cars, are expensive, for one. Supply is low and the cost of producing are not likely to have yet scaled. But novel technologies also afford other costs to their users. As the NBER researchers noted above, adopters of new technology take on new risk and uncertainties—and risks can be costly. Some costs and risks are so common that economists have gone as far as to give them names.

For instance, when adopting technology there is always the chance that a new, better, or cheaper product emerges. Why buy the newest cell phone when an even newer model might be released in 6 months? Decisions made the avoidance of an uncertain future are called ***Risk Averse*** decisions.

There are other relevant types of risks and costs associated with technological transitions as well. For those who have ever learnt their first coding language, they’ll know how frustrating it can be to become fluent. It’s the nature of the computing world, however, that many languages become obsolete over time. But instead of switching languages, in many

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[40] Hall and Khan (2003), 1.

[41] Jay Walker, “Our System Is So Broken, Almost No Patented Discoveries Ever Get Used,” *WIRED*, January 5, 2015. Accessed April 13, 2018.

instances you'll find programmers will stick to their original language of choice—even if it's less powerful or efficient.[42]

Whether its choosing a new coding language or selecting a more dependable service provider, many of our choices entail integration and familiarization costs—monetary and non-monetary obstacles inherent in acclimating to a new product. In economics, we call these obstacles ***switching costs***.

Though there are certainly many additional types of cost and risk types, the ***sunk cost fallacy*** is surely one of the greatest barriers to technology transitions. Perhaps the most pervasive barrier to economic adoption, agents engage in the sunk cost fallacy whenever they make choices on irrelevant historical data. Very often economists cite the sunk cost fallacy when businesses or governments refuse to reallocate investments more lucratively, despite there being a more efficient choice being available. As we shall see, often times we become attached to our choices—believing that once we have made a choice, we must invest fully into this choice.

As you may have intuited, the very same fallacious logic is often applied to historical data trends—if the market has generally acted one way in the past, it therefore is just as likely to act the same way in the future.

Whatever names we give particular costs and risks, it is certainly natural to avoid them. It's when our choices become economically unsustainable, when they endanger entire industries or the social order, that problems emerge.

Remember, technological transitions are the exception to the rule. Much time can pass between periods of systemic change. Let enough of time go by, however, and industries are liable to become ***locked-in*** to certain ***technological regimes***. Quite simply, technological regimes are the dominant rules and practices industries and businesses adopt. Lock-in occurs when these regimes are so dominant that entities refuse to adopt viable alternatives—even in the face of evidence that switching would be more efficient, effective, or socially advantageous.[43] In many ways, this is where many insurance companies found themselves when faced with the prospect of Usage Based Insurance.

In truth, we are all subject to lock-in. Beyond sunk cost stubbornness, indeed even beyond aversion to risk, exists another confounding factor to technological diffusion: ***status quo bias***. A fundamental lack of imagination, for many people certain institutions and regimes have always been, and will always be, the proper and *only* way to be productive or to achieve certain ends. This characteristic is at the heart of the status quo bias: The inability to comprehend how the same activity could be achieved more efficiently.[44]

Status quo bias, switching costs, risk aversion, the sunk cost fallacy: Taken together these four forces can cause each of to be unwilling or unable to calculate benefits and costs of new technology. As a result, many of us will simply refuse to switch our perspectives, habits, or choices, even if it would be to our benefit. The 19th century economist, Arthur T. Hadley effectively described the universality of locking-in when he lamented:

[42] "Why do people hesitate to use Python 3?" *Stack Exchange*, 2010. Accessed April 13, 2018.
[43] Zeppini, et. al. (2013, 2), Nelson and Winter 1977, Arthur (1989).
[44] (Samuelson and Zeckhauser, 1988, 37), Perelman 38).

> People are bound by custom where they have ceased to submit but law. ... The standard of life of every family is fixed in large measure by social conventions. Few are intelligent enough to break away from those conventions even where they are manifestly foolish. … With most men, custom regulates their economic action more potently than any calculation of utility, which they are prone to make. The success of advertising shows how little intelligence is habitually exercised in these matters. … The authority of custom and tradition can only be overcome by the authority of drums and trumpets.[45]

Despite the objectively bleak tone Hadley adopts, his general point should be inoffensive: Great expenditures of energy oft need be taken to dislodge people, firms, and governments from inefficient habits or choices. And even then, change can occur at glacial speed.

This is essentially the role of disruptive firms and markets like the shared economy: To leverage market mechanisms to overcome lock-ins wholesale. When economies such as ours, become entrenched in certain regimes—say, the technological regime of personal transportation—novel markets may emerge to challenge them.

Do not be mistaken. Firms who have adopted dominant technological regimes do not take this encroachment sitting down. Alfred Marshall, the father of modern microeconomics reflected upon the technological regime of "customs" almost a century ago, commenting:

> For it has already been noticed, and it will become more clear as we go on, that the direct effects of custom in causing a thing to be sold for a price sometimes a little higher and sometimes a little lower than it would otherwise fetch, are not really of very great importance, because any such divergence does not, as a rule, tend to perpetuate and increase itself; but on the contrary, if it becomes considerable, it tends itself to call into action forces that counteract it. Sometimes these forces break down the custom altogether; but more often they evade it by gradual and imperceptible changes in the character of the thing sold, so that the purchaser really gets a new thing at the old price under the old name.[46]

Put in this way, it would take considerable effort not to view custom as another form of technological regime. And as we well know, customs can be hard to break. In other words, technological change is not inevitable—new regimes do not necessarily break down old ones. Simply changing the character of a good, adding a slight alternation to the familiar, companies can rebrand and repackage what is essentially the same good or service.

The ability for established firms to tweak their products and quash competitions stands as another barrier to market entry, making certain established business models more impenetrable to change than others.

The fragility of a business model is often inversely related to the nature of what new markets demands of their participants. Take car sharing, as an example. The nature of the car

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[45] (Hadley, 1986, 69-70; Perelman37).

[46] Alfred Marshall, *Principles of Economics* (London: Macmillan and Co., Ltd. 1920), 559-560; Perelman, 37

sharing model requires that consumers change their habits and shift their perceptions of ownership all while interacting in some capacity with other humans. When put in this manner, it becomes understandable why many people would prefer simply to own their own cars.

The car sharing business model is likely vulnerable to attack from the established business forces it threatens. Competing firms such as car dealerships who dislike the idea of change need only embellish to the public the risks car sharing, the foreignness of its model, in order to build barriers to consumer participation. Does this seem unlikely? Recall that a century earlier similar tactics were enacted by the railcar industry against what they viewed as the encroachment of the jitney.[47]

By comparison, the ridesharing business model may be easier for the consumers to digest—it does not require people to change their habits wholesale. Many people take taxis despite owning cars, and as we have demonstrated in the past, legalistically, ridesharing is almost indistinguishable from the taxi.[48]

Rideshare presents its own form of problems too. True, evidence does suggest that consumers enjoy the benefits of ridesharing and would prefer business models to advance unencumbered into the future. But recent advances in technology, from autonomous driving to telematics and analytics, indicate we may be closing in on, or have even entered, a new period of technological transition. If correct, if this transition really is to occur, then not all will benefit in the short run. As was alluded to earlier, periods of transition necessarily upend the livelihoods of those allow established industries to function, such as car manufactures and professional drivers.[49] Consequently, many workers within these industries develop ***technological anxiety***.

Technological anxiety might be thought of as the opposition or reticence to adopt technology for moral and ethical reasons. These anxieties can take many forms, but three in particular are notable. The first and most common form of anxiety is what we might call ***Techno-Cyclical Anxiety***. Like the business cycle and the change of the seasons, cyclical technological anxiety is a kind of public technophobia that develops like clockwork within each period of technological transition. According to the acclaimed economic historian Joel Mokyr, such fears are characterized by the widespread concern that automation will substitute labor, causing technological unemployment, "and a further increase in inequality in the short run, even if the long-run effects are beneficial."

Techno-Cyclical Anxiety was a primary concern for the earliest founders of the economic tradition. Surprisingly, it has been an area of almost ubiquitous agreement. Take the political economists John Stuart Mill and Karl Marx: Each egalitarian in their approach to economics, each divergent in their socioeconomic influences. Both men found common ground when it came to the integration of the innovation into the economy. Mill wrote, "I do not believe that…improvements in production are often, if ever, injurious, even temporarily, to laboring

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[47] Benjamin Labaschin, "The Economics of Shared Mobility: Past," *Arity, LLC* (2017).

[48] Benjamin Labaschin, "The Economics of Shared Mobility: Present Part 2," *Arity, LLC* (2017).

[49] Aaron Smith, "Shared, Collaborative and On Demand: The New Digital Economy," *Pew Research Center*, 2016. Lisa Eadicicco, "Uber Drivers Aren't Worried About Self-Driving Cars — Yet," *Time,* April 10, 2017. Accessed April 14, 2018.

classes in the aggregate." Meanwhile, as Mokyr points out, "…for Marx as well, technological improvement was part of a social and political process that would lead eventually to widespread prosperity. (Of course, the Marxist vision of progress also eventually required a wholesale overthrow of the existing capitalist economic system.)"[50] The point is that for some time, economists have understood innovation to be a natural, necessary, and net social good *in aggregate*.

So if technology is a good thing, why do economists still discuss its draw backs?

Because, for just as long economists have also understood that in the short-run innovation can cause disturbances in the social order. The influential classical economist David Ricardo, someone who was fundamentally for technological improvement, admitted as much when he wrote that the "substitution of machinery for human labour is often very injurious to the interests of the class of laboureres… [It] may render the population redundant and deteriorate the condition of the labourer."[51] Despite the fact that laborers tend to suffer in the short run, Ricardo, and indeed most economists, contend innovation is beneficial because they differentiate between short-term volatility and long-term gain.

This narrative may be to their detriment.

The economist John Maynard Keynes certainly thought so. In his *A Tract on Monetary Reform*, Keynes commented on this tendency of economists to rely on long-term trend lines, rather than the volatility of the present. This led Keynes to pen his famous line: "… this *long run* is a misleading guide to current affairs. *In the long-run* we are all dead. Economists set themselves too easy, too useless a task, if in tempestuous seasons they can only tell us, that when the storm is long past, the ocean is flat again."[52] Keynes' point reflects a major theme of this report. Namely, it is easy to contend that technology will eventually usher in a positive outcome in transportation, but if in the near-term millions lose their jobs without recourse, how smooth with that transition be?

The second form of technological anxiety I will call ***Techno-Logo Anxiety*** as it relates in many ways to psychotherapist Viktor Frankl's concept of *logotherapy*—a therapy in which clients work to establish meaning and self-actualization. In like fashion, those who demonstrate logo-technical anxiety express existential concern about *the implications* of technology on human welfare. Most of us today can empathize with the experience of logo-technical anxiety. With all the discussions about the development of artificial intelligence, many prominent figures openly worry about its implications for the human race.[53]

In fact, economists, who are typically immune to logo-technical anxiety, have themselves begun to question the implications of impending socio-technical regimes. Why the change of heart? To be clear, there is little evidence to suggest that technological transitions have been anything but net gains to society. Instead the worry among these economists is that even if technology improves the *lives* of individuals, it may not improve their *livelihoods*.

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[50] Joel Mokyr, et al., "The History of Technological Anxiety and the Future of Economic Growth: Is This Time Different?" *Journal of Economic Perspectives* 29, no. 3, (2015), 33-34.

[51] Ibid.

[52] John M. Keynes, *A Tract on Monetary Reform, The Collected Writings of John Maynard Keynes* (London: Macmillan, 1971).

[53] Peter Holley, "Bill Gates on dangers of artificial intelligence: 'I don't understand why some people are not concerned'," *Washington Post*, January 28, 2015. Accessed Apr 10, 2018.

The economist Lawrence Summers is an individual with more academic titles and government honors than need to be counted. His is a voice within the economic sphere that, whether enjoyed or not, commands attention. Summers has also raised the logo-technical red-flag himself, recently commenting, "The premise of essentially all economics … is that leisure is good and work is bad…[soon] economics is going to have to find a way to recognize the fundamental human satisfactions that come from making a contribution." From economists to government officials to business titans, an increasing number of individuals fear that technology will take the *meaning* away from human activities—and when people have too much time to think, there can only be a few results: philosophers, artists, or mobs. (phrsing Thoughts?)

It is worth mentioning that there is a third and altogether different form of technological anxiety altogether different from those listed above. This form of anxiety in fact doubt the very inevitability of progress of us assume to occur. We'll call this anxiety ***Techno-Nihilistic Anxiety***. Techno-nihilistic scholars believe that all of our best innovation is behind us. This is not a fringe perspective either. Popularized by the economist Alvin Hansen in 1939, the concept drew breath from his Hansen's so-called "secular stagnation hypothesis"—the belief that major growth was over for industrialized economies and that only government investment could stimulate growth.[54] Today, the contention of techno-nihilists is essentially the same: Yes, many interesting new inventions have been made in recent history, and indeed many novel innovations may develop in the near future, but few of these innovations, they believe, will provide significant, lasting, increases in productivity.[55]

For the purposes of this report, we will make two explicit assumptions: That significant macroeconomic growth is not necessarily over—that is, that growth can be stimulated by technology and shifts in production practices—and that recent and burgeoning innovations in transportation technologies and telematics insights will improve movement efficiencies, eventually. These assumptions seem reasonable to make, not because we'd *like* them to be true, but because, as we will see, research suggests we have already begun to see dividends from the investments made into these areas.

In addition to these two assumptions, we will focus on the first of these three technological anxieties—***Techno-Cyclical Anxiety***—to deduce whether those within the transportation sector are likely to lose their jobs.

Labor, Skills, and Job Loss in the Economy

Economists have maintained a similar mindset about the effects of innovation on job growth. For more than a century, the data has been pretty clear about the nature of technological unemployment: In the long-run new technology has *increased the aggregate*

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[54] Alvin H. Hansen, "Economic Progress and Declining Population Growth," *The American Economic Review* 29, no. 1 (1939): 1-15. http://www.jstor.org/stable/1806983.

[55] Mokyr For a primer, see "Gordon (2012) Is U.S. Economic Growth Over? Faltering Innovation Confronts the Six Headwind. Robert J. Gordon NBER Working Paper No. 18315 Issued in August 2012" or Gordon (2016) The Rise and Fall of American Growth, Princeton.

number of jobs.[56] Yes, in the short term, technological change has been shown to "hollow out" the skill distribution of many manual-skill and lower-technical workers.[57] But economists and businesses have been able to rationalized these losses as well, arguing that to "technological change [has] increased the demand for other types of labor that were complementary to the capital goods embodied in the new technologies."[58] In other words, technology that is capable of replacing labor has to be conceived, it has to be developed, implemented, tracked, maintained, and improved—all these tasks are potential jobs to be filled by specialized workers.

Of course, this does not stop Techno-Cyclical job anxieties. Like clockwork societies are presented with predictions of the end of workers as we know it.[59] And such sentiments are not exclusive to journalists either. Some contemporary researchers believe that demand for specialized, cognitive workers peaked around the year 2000.[60]

Take theorist Jeremy Rifkin's, author of the 1995 polemic *The End of Work*. In his book, Rifkin predicted that the diffusion of technology would function "[l]ike a deadly epidemic inexorably working its way through the marketplace, the strange seemingly inexplicable new economic disease spreads, destroying lives and destabilizing whole communities in its wake."[61] Rifkin went on to cite a union leader's prediction "that within thirty years, as little as 2 percent of the world's current labor force 'will be needed to produce all the goods necessary for total demand.'"[62] 22 years later, Rifkin's predictions have not seemed to pan out. Indeed, historical evidence suggests that technology itself has not caused net losses in worker employment.[63]

The point here is not that technology is always a positive. Sour predictions do have their place and technology does change lives. Despite their inaccuracies, predictions like Rifkin's may actually serve a positive social purpose—they are a real reminder that innovation can change lives, disrupting real people's livelihoods at the local level. Indeed, where Rifkin's economics may have been off, his social intuition may have been right on.

Historically, the economics behind technological innovation have yielded net benefits in terms of life expectancy, poverty alleviation, and education.[64] But the transition into technology itself is full of stories of adverse reactions, of pushback and general social unrest.

Social Unrest from Technology

From the Luddites, to Occupy Wall Street, social unrest often reflects economic uncertainty.[65] Often businesses ignore the disruptive effects of innovation on their or other

[56] Autor, "Where Are There Still So Many Jobs? The History and Future of Workplace Automation During the Industrial Revolution

[57] Margo 2013, Mokyr 2015, 35).

[58] Cite

[59] cite

[60] (Beaudry, Green, Sand 2013).

[61] p3

[62] (Rifkin, 8; Mokyr 2015, 43).

[63] Let us also here remember that just because evidence has not proved something has happened socioeconomically, doesn't mean it cannot. (Mokyr 2002, 256, Mokyr 2015, 35)

[64] Cite factfulness

[65] (Mokyr 2015).

workers, but the evidence of its effects is overwhelming.[66] One need only recall that the mass production of the automobile most assuredly reduced demand for blacksmiths and carriage drivers.

Businesses aren't the only parties guilty of having overlooked the disenfranchised worker. As has been demonstrated, most economists have failed to integrate the idea of worker's dignity in any systematic way into their thinking.[67] The result has often been a callous take on the real-world impact of disruption on workers.[68] But in preparation for the future, businesses may not be afforded such a luxury if they hope to operate in an efficient marketplace integrated with the latest technologies; technologies that may disrupt the livelihoods of millions of people.

As the social historian Williamson has stated, "Analyzing the economizing of transaction costs [in this case through innovation] without regard to dignity encourages the view that individuals can be considered strictly as instruments … [S]ensitivity to human needs for self- and social-esteem becomes important when the organization of work (labour markets) comes under scrutiny."[69]

Economist David Autor explains that their complicity may come from the cold fact that "there is no fundamental economic law that guarantees every adult will be able to earn a living solely on the basis of sound mind and good character." It has simply been the function of our resilient institutions and the internal engine of human progress and betterment that technology has advanced, and the demand for labor has risen.[70]

The result of technological disruption is often some form of ***employment-*** or ***wage-polarization***—inequalities in the availability of high quality or highly paying jobs.[71] The chart below illustrates this point well. As can be seen, it depicts changes in employment of ten major non-agricultural occupational groups over time, between 1979 and 2012. Employment numbers are colored roughly corresponding to decade, with the period 1979-1989, 1989-1999, 1999-2007, and 2007 measured.

Employment data on the y-axis is measured at a 100-times log scale. By scaling changes in employment this way, variations across different occupations can be visualized and compared more easily.[72] Vertical employment levels should therefore be read as percentage changes in employment over time. Occupations are organized conveniently, from left-to-right, into three occupational-trait groups: service occupations,[73] middle-skill occupations, and abstract-cognitive occupations.

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[66] (Autor, Katz, and Kearney 2006, 2008; Goos and Manning 2007; Autor and Dorn 2013; Michaels, Natraj, and Van Reenen 2014; Goos, Manning, and Salomons 2014; Graetz and Michaels 2015; Autor, Dorn, and Hanson 2015; Autor 2015, 13).

[67] Williamson 1986, 173

[68] Mokyr 37

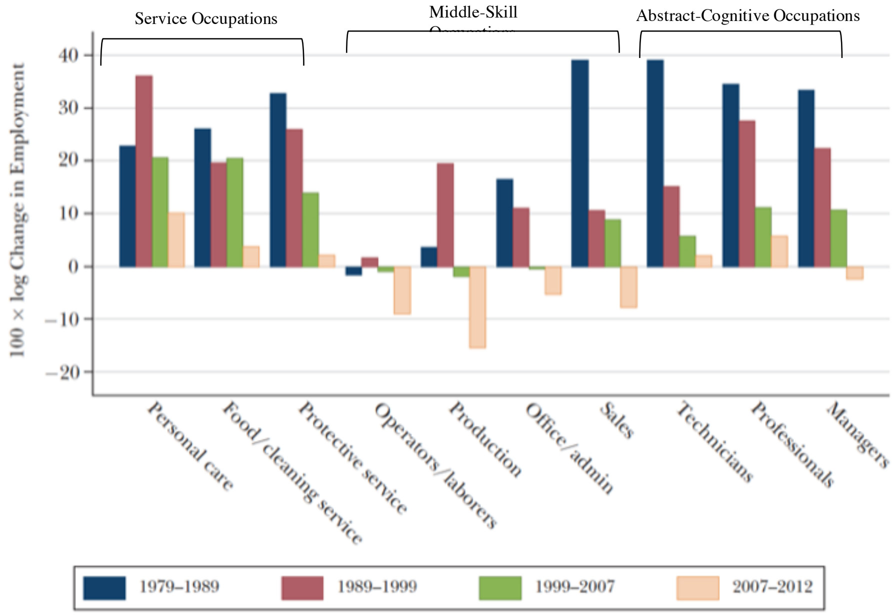
[69] Williamson 1986 177; Perelman 85

[70] Making the Future of Mobility Work 184

[71] (Making the Future of Mobility Work 184)—

[72] Agricultural occupations comprised 2.2% of employment over this time interval. Therefore. their omission is negligible on the chart. Autor 2015, 14

[73] "Defined by the census bureau as jobs that involve helping, caring for, or assisting others. The majority of workers in service occupations are in most cases below the other seven occupational categories." (Autor 2015, 14).



Sources: Author using data from the 1980, 1990, and 2000 Census IPUMS files, American Community Survey combined file 2006–2008, and American Community Survey 2012. The sample includes the working-age (16–64) civilian noninstitutionalized population. Employment is measured as full-time equivalent workers.

Change in Employment by Major Occupational Category, 1979-2012

As a general rule, we can therefore interpret these occupational groups as having on average ascending levels of educational background, with commensurate increases in pay. Beginning with the leftmost occupations (Personal Care, Food/Cleaning Services, Protective Service), we can see that service employment has grown parabolically—rising quickly to a peak increase of 35% in the 90s, and falling to a reduced pace of growth ever since.

By itself, the slackening of employment growth in the service industry does not mean much. Scan rightward across the chart and it becomes clear that employment growth slowed among all major occupations between 1999 and 2012. But in moving rightward we do see other relevant patterns in employment levels. By juxtaposing trends in service occupations with those of middle-skill and abstract-cognitive occupations, we see that middle-skill employments contrasts sharply.

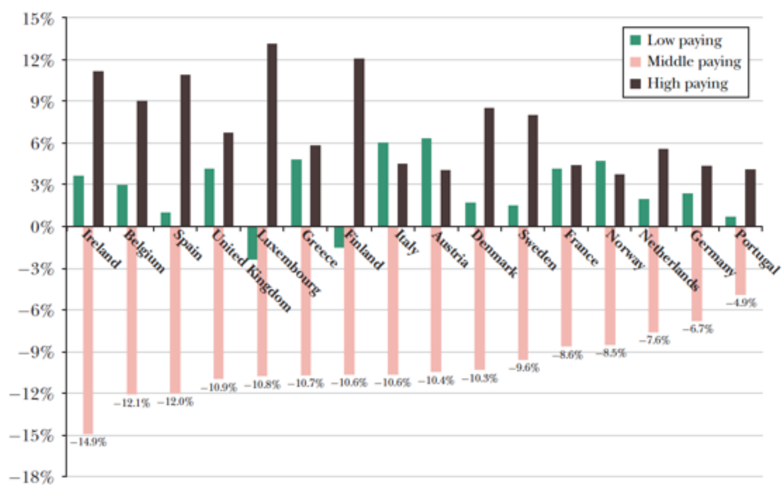
Compared to the growth trends on right and left sides of the chart, growth in physically-oriented and sales-based jobs are decidedly muted. This “barbell” pattern—that is, the spikes in growth at the extremes of the graph—are the tell-tale sign of employment polarization. Said simply, extreme growth at polar-ends of the top ten occupational categories of employment absorbed much of the potential growth by middle-skill jobs over the last 33 years.[74] In 1979, middle-skill occupations accounted for 60 percent of all employment. By 2007, this number had fallen 49 percent. Five years later, it had fallen 3 more points to 46 percent.[75]

If the hollowing out of middle-skill, middle-pay jobs were isolated to America, then we could simply look internally, to our own policies and habits to explain this shift. As the graph

[74] (Autor, 2015, 14).
[75] (Autor, 2015, 14).

below indicates, however, the hollowing out of middle-skill jobs is a trend America shares with at least 16 other European countries. Like the previous chart, the figures below represent changes to employment within 16 European countries.

Unlike the previous graph, occupation chares were tracked explicitly by their payment status (low, middle, and high paying occupations). On the y-axis, shifts in employment are measured as percentage changes from 1993 to 2010. On the x-axis are European Union countries from Ireland to Portugal. As can be seen, in every European Union country, middle paying occupational shared dipped, while most low paying and high paying job shares rose. Though EU and US data are not exactly one-to-one, the polarization the US experienced over this time would likely fall somewhere in the middle of the chart. More importantly, the commonality of employment polarization suggests that some common factor or factors can be attributed to these shifts.[76]



Source: Goos, Manning, and Salomons (2014, table 2).
Notes: High-paying occupations are corporate managers; physical, mathematical, and engineering professionals; life science and health professionals; other professionals; managers of small enterprises; physical, mathematical, and engineering associate professionals; other associate professionals; life science and health associate professionals. Middle-paying occupations are stationary plant and related operators; metal, machinery, and related trade work; drivers and mobile plant operators; office clerks; precision, handicraft, craft printing, and related trade workers; extraction and building trades workers; customer service clerks; machine operators and assemblers; and other craft and related trade workers. Low-paying occupations are laborers in mining, construction, manufacturing, and transport; personal and protective service workers; models, salespersons, and demonstrators; and sales and service elementary occupations.

Change in Occupational Employment Shared in Low, Middle, and High-Wage Occupations in 16 EU Countries, 1993-2010[77]

Though not solely the cause of polarization, IT has played a significant role in causing employment inequalities, alongside globalization and business cycles. Here it may be worthwhile to pause and summarize what we have learnt so far. A lot of information has been presented, much of which is difficult to puzzle together.

To review, we have learnt that many business leaders and consultants believe that in the future shared mobility services will dominate the transportation sector. We found that the

[76] Autor 2015, 14.
[77] Autor 2015, 15

models these experts use to forecast the market share of SM TNCs in the future are based on many human assumptions, and are therefore subject to fallibility. These assumptions are of the same kind that have led to great feats of prediction, such as the success of Sabernomics, as well as to great catastrophes such as the over-reliance on mis-calibrated market models that lead to the recent housing crisis.

We also made it clear that many of these assumptions deserve rigorous questioning not simply because of their potential negative consequences, but also because the effectiveness of predictive models depends on the nature of an industry. Some models, such as those built to predict stock values on Wall Street, are highly volatile in the short term due to the random and symmetrical nature of information availability. Indeed, returning to the models used in Sabernomics, we see that, although teams like the Oakland A's benefited initially by using predictive models in player choice, once teams like the Yankees and the Red Sox adopted these methodologies, the profit quickly evaporated. Similar informational symmetries occur in the prediction of stock values, but often in the span of seconds. A firm may briefly get price information that others do not see, but this information is quickly adopted into models, making any gains transient-affairs. In so many words, historical precedent may not be sufficiently informative about future developments in rideshare.

Of course, the rideshare market is not Wall Street or Baseball, and historical information, at the very least provides us with a helpful framework with which to interpret the rideshare market. Still, when coupled with data that suggests shared mobility services only occupy a small percentage of the contemporary transportation market, it becomes clear that the probing of our future assumptions is imperative.

Turning to assessment of the future of shared mobility, we sought to understand the foundational assumptions about the future of the market. The core assumption most shared mobility forecasters adopt is that significant technological advancements will allow transportation providers to provide mobility services in ways far more efficiently and profitably than today.

Underlying this assumption is the belief that technological advancements will help to overcome the problems current SM providers face, such as high insurance costs and high transaction costs (paying drivers). The technology capabilities to achieve these goals would be significant and would necessarily permeate much of the economy. Profound, technology induced changes like this have occurred before, such as with the mass production adoption of the automobile.

Periods such as the automobile revolution are characterized bringing about "disruption" in the economy—periods where external effects (technology, war, etc.) cause markets to cease functioning normally. If disruption is extensive enough, and if it is caused by new technology, a period may qualify as a period of technological transition. We established that in the long run, more firms and workers have benefitted from technological improvements than have suffered. In the short run, however, many firms and workers have suffered from the short-term volatility of technological disruption.

Often firms refuse to adopt to pervasive socioeconomic change, and in doing so risk their very survival. Other firms choose to adopt new technology with open arms. Unfortunately, these firms often also assume that adoption means substituting labor with tech. This philosophy, that technological substitution is the way of the world, is often viewed as an unavoidable reality of the market.

In an increasingly integrated economy, however, such assumptions may be shortsighted. Increased growth necessarily assumes that technological transitions will occur more rapidly than before, becoming a part of the norm. This may leave firms in a socioeconomic Catch-22. On one hand, if they do not adapt they may lose market share or worse. On the other hand, the firms that do adapt may end up generating socioeconomic inequalities that threaten the longevity of the economy within which they operate.

Far from being a distant reality, by exploring contemporary data we have seen a "hollowing out" of over the last three decades. Much of this hollowing out has followed a similar path to the charts shown above of the adoption of Information Technology. Of course, the adoption of the cell phone did not cause this hollowing out, *per se*. Rather, the same technology that allowed for cellphone use—microprocessors and computers—was also increasingly integrated into business's production methodologies, as shown by the Private Investment graph above.

In large part, IT investment has generated employment polarization—inequalities where large numbers of workers are employed at the extreme ends of the occupational spectrum. Which leads us to today. For those of us concerned with the near future of shared mobility, these insights allow us to generate several relevant questions that I have listed below. First, and most immediately, should we expect this hollowing out to continue into the near future? Second, and as a follow-up, how has or will this hollowing out affect or be affected by shared mobility services? And perhaps most critically, third. We have based future of SM transportation dominance on the assumption of significant technological advancement, what type of advancement do we expect to occur?

Addressing these questions in order, we will begin with the first. If employment has become hollowed out, will this process continue, and if so, how will it affect the shared mobility system? Continuing advancements in IT and automation stand to affect the livelihoods of many workers. For the purposes of this report, two groups in particular—autoworkers and professional drivers—will be examined.

While many other occupational stand to be affected by technological disruption, theory and evidence both suggest that professional drivers and auto workers will be disproportionately impacted. As has been discussed in previous reports the nature of a task, rather than a job (which is composed of many tasks) determines its computability and therefore the risk of its replacement.[78] In recent years, automotive manufacturing jobs have declined significantly, while professional driving jobs have seen skyrocketed. Yet, both are under threat of disruption?

Just what would the impact of this future disruption entail? What can we expect from disruption?

It depends which numbers you consult. Among leading consulting firms and think tanks, commonly cited figures for the number of autoworkers and professional drivers employed in the United States are around 7 million and 4 million respectively.[79] Upon closer inspection of the graph below, however, we see that these numbers are bit more nuanced.

[78] Labaschin (2018a).
[79] (Deloitte, Auto Alliance https://autoalliance.org/in-your-state/)

Economic Impact	Automakers	All Motor Vehicle-related Manufacturing (incl Automakers)	Auto Dealerships	TOTAL
Employment				
Direct employment	322,000	843,000	710,000	1,553,000
Intermediate	805,000	2,069,300	246,700	2,316,000
Total (Direct + Intermediate)	1,127,000	2,912,300	956,700	3,869,000
Spin-off	1,316,000	2,687,700	693,300	3,381,000
Total (Direct + Intermediate + Spin-off)	**2,443,000**	**5,600,000**	**1,650,000**	**7,250,000**
Multiplier	7.6	6.6	2.3	4.7
Compensation ($billions nominal)	167.7	375.3	116	491.3
Less: transfer payments & social insurance contributions	-21.6	-41.5	-15.9	-57.4
Less: personal income taxes	-23	-44.7	-19.4	-64.1
Equals private disposable personal income ($billions nominal)	123.2	289.1	80.7	369.8
Contribution as % of total private economy				
Employment	1.6	2.9	0.9	3.8
Compensation	1.7	2.7	0.6	3.3

Automotive Worker Estimates and Employment Multipliers[80]

According to data collected by the non-profit think tank Center for Automotive Research, as of 2014, about 1,553,000 US workers were employed directly by automotive industry—where direct employment includes jobs within automotive headquarters, offices, research spaces, and jobs involved in automotive design and development, manufacturing, assembly and logistics.[81] Meanwhile, those intermediate workers of the auto industry—people employed by suppliers to the motor vehicle industry—numbered 2,316,000. Finally, there is "spin-off" employment—employment as a consequence of the habits of direct and intermediate employees of the auto-industry—estimated at 3,381,000 workers. Like any representation of data, the chart below provides us with both a more robust understanding of these numbers, it also demands further explanation.

Directly and indirectly, the chart suggests that automakers employed approximately 1.13 million workers as of 2014—an amount that has likely risen based on trends recorded by the Bureau of Labor Statistics.[82] The chart also introduces an important concept of employment forecasting—key to any economic conversations of future employment: the so-called "employment multiplier," and more generally the "multiplier effect." To better understand this concept, it might be helpful to take a brief conceptual-detour.

The noted physicist and Nobel laureate Richard Feynman is lauded today, not only for his many scientific contributions, but also for his unique ability to explain complicated scientific ideas simply. By his own admission, it was this ability to breath clarity into dense and abstract ideas that helped Feynman to win a Nobel prize in physics. In his 1965 prize acceptance speech

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[80] CAR

[81] (CAR 2014, CAR 2015).

[82] . https://www.bls.gov/iag/tgs/iagauto.htm#emp_national

for his work in quantum electrodynamics, Feynman described his first-hand experience with knowing something versus being able to prove it.

As it turns out, Feynman's experiences also help to describe economic multipliers. During his talk, Feynman, who had chosen to recount the process that led him to his discoveries, admitted that he had figured out how to determine his scientific results before he had been able to prove them in a mathematically rigorous fashion. Kind of like how most people know that the sum of two even numbers will always be even—but if asked to prove it, they wouldn't know where to begin. Despite not knowing his to prove his results, Feynman nonetheless found his results thrilling. In his own words, "…they convinced me, at last, [that] I did have some kind of method and technique and understood how to do something that other people did not know how to do." After showing his work to others, Feynman was pressured to publish "…because everybody said it looks like an easy way to make calculations, and wanted to know how to do it."

Unsurprisingly, once he did publish the work, he began to receive criticism for neglecting to include a rigorous mathematical proof of his methodology. The very reason he hesitated to publish in the first place. This experience led Feynman to conclude, "In the face of the lack of direct mathematical demonstration, one must be careful and thorough to make sure of the point, and one should make a perpetual attempt to demonstrate as much of the formula as possible. Nevertheless, a very great deal more truth can become known than can be proven."[83]

Feynman's experience in Physics shares many similarities with research in economic multipliers. Like Feynman's discoveries, or the sum of two even numbers, the concept of the economic multiplier is foundationally intuitive, but theoretically difficult to prove. Multipliers such as those used to justify linked-employment in the auto sector above, are defined as the number of additional jobs created for every job in an industry.

In the case of the auto-industry chart above, for every one job directly related to manufacturing cars, there may be an additional 7.6 jobs created elsewhere in the economy. For those readers of previous reports, multipliers are the quantitative manifestation of the "backward linkages" concept introduced in earlier studies. As a refresher, during the course of economic activity certain goods and methods are created that actually encourage the production other goods or services to support their use. These are called "backward linkages." For example, in the early decades of the 1900s the United States saw a proliferation of road construction and quality, which in turn helped increase the use of shipping goods by truck when railroad use became expensive. The use of trucks was a backward linkage of road construction.

And road construction itself was a backward linkage of innovation in automobile manufacturing. In both instances, manufacturing improvement and road construction, linked industries emerged, acting as downward links on an economic chain that connected all the way to automobile production. To economists concerned with the aggregate effect of, say, a new industry, there is a great desire to calculate these links of production. By following the links down the line, aggregating each additional job as they move down the chain, economists can theoretically calculate how many new jobs are created for every one job in found at the start of

[83] All references to Feynman can be found here: (Richard P. Feynman - Nobel Lecture, December 11, 1965)

the chain. The result is a so-called "employment multiplier." The higher the multiplier, the more jobs created by an industry, the more beneficial it is to the well-being of a society.

In the case of the auto industry, if we divide total employment by direct employment from the data in the chart above, we will find that for every one job within the whole automotive industry, there are approximately 4.7 jobs created "down the chain" in indirect and spin-off employment.

Evidently the auto industry has a net positive impact on the US economy, generating 64.1 billion dollars in income taxes and 369.8 billion dollars in disposable (after-tax) income to the US economy as of 2014. The charted data also suggests that, at present, somewhere between 322,000 to 843,000 directly employed car and car-part manufactures could lose their jobs to automation.

With all this talk about multipliers, you may be wonder why we don't use multipliers to predict future employment in automation. Unfortunately, multipliers suffer from several limitations.[84] Just as Feynman could find the results he was looking for, economists, adopting a few assumptions, can also estimate how many additional jobs industries create. But often these estimates after-the-fact. Without data indicating levels of future demand, the employment level of new or altered industrial sectors, such as those affected by the development of autonomous vehicles, are difficult to estimate. In other words, assumptions about the future state of the world and industries have to be made to generate future multipliers.

Due to the unpredictable nature of the market, assumptions used to calculate multipliers may neglect the effects of pertinent market changes in the future, such as the effects of steel tariffs auto sales. These assumptions matter. If cities make investments in September based on a job prospects in November, only for the market to change drastically in October, those investments may have been wasted.

Take the future economic effects of autonomous vehicle adoption. Estimating the potential economic of these new vehicles impact is inherently difficult because these new products act as "substitute goods"—goods or services that can be used alternatively to achieve similar desires. Hailing an autonomous taxi instead of human-driven taxi would be an instance of substitution. Choosing user-based insurance (UBI) modelled using telematics data instead of a traditional policy using historical data is another instance of economic substitution. Either way, the same or similar objectives are achieved, even if different products are used.

Indeed, it is important to understand this latter. Even if the quality of one good or service is substantially different than another, as long as it is perceived to fulfills a similar desire, it is a substitute good. For those in the tech industry this can be both galling and also a source of frustration. Say the data and algorithms of service A are substantially more accurate and useful than those provided by service B. If consumers view product A and B similarly, if they perceive them as offering similar services, *the products are substitutes even if they do not achieve the same results in practice.*

The perceived and real substitutability of products A and B, their "economic nature," are therefore crucial pain-points to businesses because every price-sensitive consumer who is indifferent or ignorant of product quality serves as a potential loss of revenue. Consider the real-world example of peanut butter. When I walk into the store, I tend not to care which brand

[84] (Consumer's Guide to Regional Economic Multipliers) (Cletus C. Coughling)

of peanut butter I get. As long as it's peanut butter I am getting, and I do not get sick when I eat it, I am certain to choose the cheapest option I am provided. As a consumer, I am *completely ignorant* to the processes that went into the creation of peanut butter. One producer may know that the peanut butter they create is of superior quality to that of others. But unless I as the consumer know, believe, and appreciate this difference, the truth of the matter is relatively inconsequential.

Technology and auto manufacturing firms both face similar obstacles to those that produce peanut butter. As innovative technology like as autonomous vehicles and risk analytics become increasingly available, affordable, and desirable to consumers, the economic nature of these products will determine their profitability. Put simply, the nature of a good, how it interacts with other commodities and how it can be used, can affect spending habits and therefore shift inter-regional buying patterns, altering the coefficients of multiplier estimates.

Speaking of coefficients—which are quantitative inputs often assumed as fixed in models—the fixed nature of these quantities also limit a multiplier's effectiveness. If models assume there an excess of supply already in existence such that a change in the model would not affect purchasing decisions based on price. "For example, suppose a region's auto assembly plant plans to increase its production and sales to other regions by 50 percent. If the plant's suppliers within the region were operating at, or near, full capacity, the assembly plant would have to buy a larger proportion of its inputs from firms outside the region, at least until local suppliers could expand their production."[85] Multipliers measure short-run effects. Employment multipliers don't distinguish between full-time and part-time workers.

Still, these models are quite valuable. So, read at face value, prospects might look auspicious for auto employment. Whereas direct jobs may continue to diminish over time the supply chain, and therefore the number of indirect jobs within the industry could grow.[86] But multipliers are based on historical data—and, as we have now learned, historical data cannot always be relied on to accurately measure long run effects.

So what can we reasonably say about the future of jobs automotive jobs in the coming 3 to 5 years? Based on what we do know about the nature of the industry, fewer jobs still will remain in the auto industry. If cars are integrated with the IOT, then indirect jobs would emerge—representing a substantial multiplier effect.[87] Based on the information so far provided, this is the extent of what we can predict.

In many ways, disruption has already begun for these two groups. Below is a Bureau of Labor Statistics graph depicting the number of autoworkers employed in the US from 1990-2018.[88] The y-axis measures the number of employees in thousands, while the x-axis records month-by-month employment numbers over the 28-year period.

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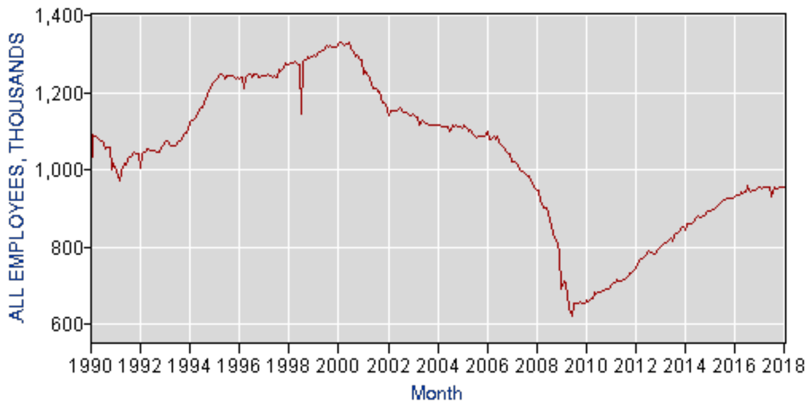
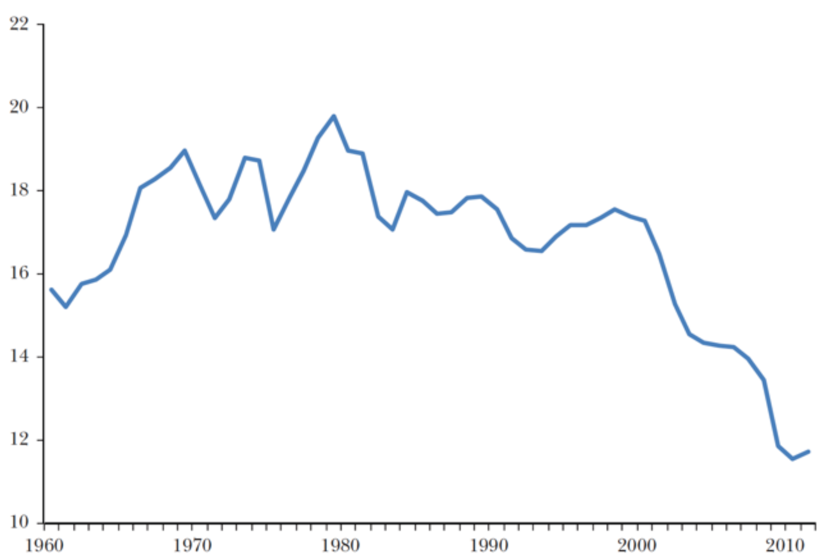
[85] (25)
[86] cite
[87] (US manufacturing Baily Bosworth 20)
[88] (Bureau of Labor Statistics).



Automotive Workers in US Over Time[89]

As can be seen, since approximately the year 2000, employment among auto-workers fell precipitously, from about 1350 thousand (1.35 million) autoworkers, to just over 600 thousand autoworkers at its lowest point in 2009. At face value, the dip in employment of autoworkers appears precipitous—and it is. But autoworkers were not the only group to suffer a significant loss in employment. Like adjusting a camera's magnification outward, the graph below zooms-out our focus from autoworkers in particular, to all people employed in manufacturing in the US over a similar period.

Persons Engaged in Production in US Manufacturing, 1960–2011
(millions)



Source: Industry Accounts of the Bureau of Economic Analysis.
Note: Persons engaged in production are measured as full-time equivalent employees plus the self-employed.

As you may be able to see, this complete manufacturing picture, which covers the years 1960 to 2011 on the x-axis and manufacturing workers in millions on the y-axis, portrays a

[89] Automotive Workers

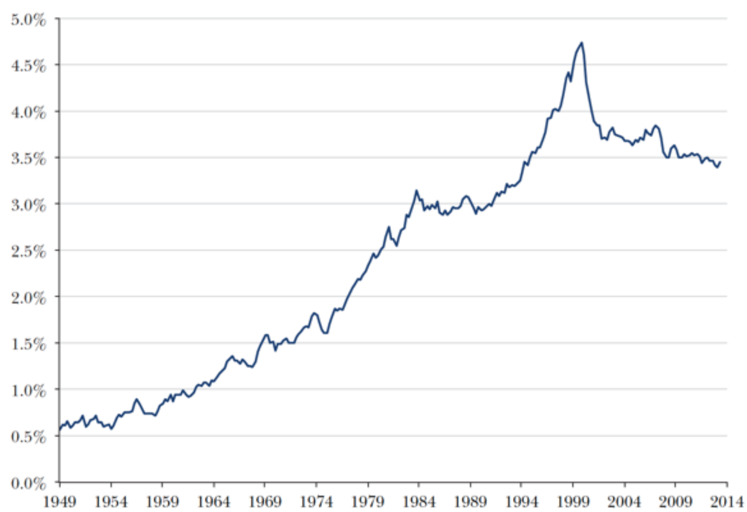
familiar story to the graph which proceeded it.[90] Like the BLS graph above, here we also see that around the year 2000 there is a significant dip in employment, representing a loss of almost 5 million manufacturing jobs in just ten years' time. Since autoworkers are a subset of all US manufacturers, we are therefore led to believe that the dips we saw in the auto manufacturing chart were actually part of a larger, economy-wide in the United States.

After all, if you look at the tail-end of the graph, you will see a similar uptick in jobs around 2010, just like that which occurred in the auto manufacturing graph. Our intuition is therefore supported by the trends presented in these graphs present. But have these shifts in manufacturing employment been the result of automation?

David Autor isn't convinced. Though it's not unreasonable to suspect automation as a culprit, Autor points out that our expectations do not fit with the data. See for yourself.

Below is a graph of private investment in Information Technology (IT) equipment and software by non-governmental entities (i.e. businesses and private citizens) in the United Stated over time as a percentage of Gross Domestic Product.

Private Fixed Investment in Information Processing Equipment and Software as a Percentage of Gross Domestic Product, 1949–2014



Source: FRED, Federal Bank of St. Louis. http://research.stlouisfed.org/fred2/graph/?g=GXc (accessed 8/3/2014).

In other words, for any given date on the x-axis, some percentage of all economic activity in the US is dedicated to purchasing IT in a given year on the y-axis. Two distinct periods appear over the 65-years of private investment covered by the chart: IT investment before 2000 and IT investment after 2000. From 1949 to 2000, IT investment as a percentage of GDP increased substantially, from near 0.5% to about 4.75%. After 2000, the proportion of IT investment in the economy drops rather drastically down to 3.5%. Just around the same time that manufacturing employment plummeted. But, unlike the graphs above, IT investment does not seem to have rebounded around 2010.

Professor Autor considers the behavior of this data telling. "If information technology is increasingly replacing workers [with specialized skills]," he argues, "one would expect a surge of

[90] (Baily Bosworth Journal of Economics Perspectives 2014, 12).

corporate investment in computer hardware and software. Instead, [the chart] shows that in early 2014, information processing equipment and software investment was only 3.5 percent of GDP, a level last seen in 1995 at the outset of the 'dot-com' era." In other words, despite the pervasiveness of automation anxiety, evidence indicates it's unlikely that technology *alone* is responsible for replacing workers.[91]

A confluence of factors may be attributed to the relative decline in manufacturing jobs since 2000. Those familiar with previous mobility reports might think to consider productivity as a factor in employment. And they would be smart to do so. But, according to the authors of "US Manufacturing: Understanding Its Past and Its Potential Future," output over the last 20 years has increased. From 1987 to 2011, output from total nonfarm businesses rose 2.8% on average annually. Manufacturing in particular rose an average of 1.7% annually, though when removing computer manufacturing from this, it really only rose 0.8%. By comparison, yearly computer output rose an average of 8%.

So, output was up in the overall economy over a 24-year period, but efficiencies varied widely. Parsing the numbers further, Baily and Bosworth find that labor productivity growth—a subset of productivity growth—also rose consistently and in a similar pattern to the numbers above, with computer productivity far-greater than other sectors.[92] Evidently, employees in all industries were improving their productivity, but, unsurprisingly, the IT revolution represented the brunt of that efficiency.

In fact, we can measure the effects the IT Revolution has had on the manufacturing industry directly by using the output and labor productivity data listed above to calculate "multifactor productivity." A good definition of multifactor productivity (known to others as total factor productivity) is provided by the Organization for Economic Cooperation and Development.

> Multifactor productivity (MFP) reflects the overall efficiency with which labour and capital inputs are used together in the production process. Changes in MFP reflect the effects of changes in management practices, brand names, organizational change, general knowledge, network effects, spillovers from production factors, adjustment costs, economies of scale, the effects of imperfect competition and measurement errors. Growth in MFP is measured as a residual, i.e. that part of GDP growth that cannot be explained by changes in labour and capital inputs. In simple terms therefore, if labour and capital inputs remained unchanged between two periods, any changes in output would reflect changes in MFP.[93]

This is all to say that by using the output and labor productivity data above we can tell whether changes such as the use of technology have been made to increase output efficiency. We assure ourselves of this inference by means of the economic Law of Diminishing Returns.

[91] Cite Autor
[92] (Baily Bosworth 11)
[93] Cite

It stipulates that even if inputs to production (labor or machines) are increased, increases in output are not linear (i.e. always rising)—eventually they must fall. Therefore, if increases in output continue to rise over time, this must be attributed to some *other* residual reason such as a change in tactics or technology.

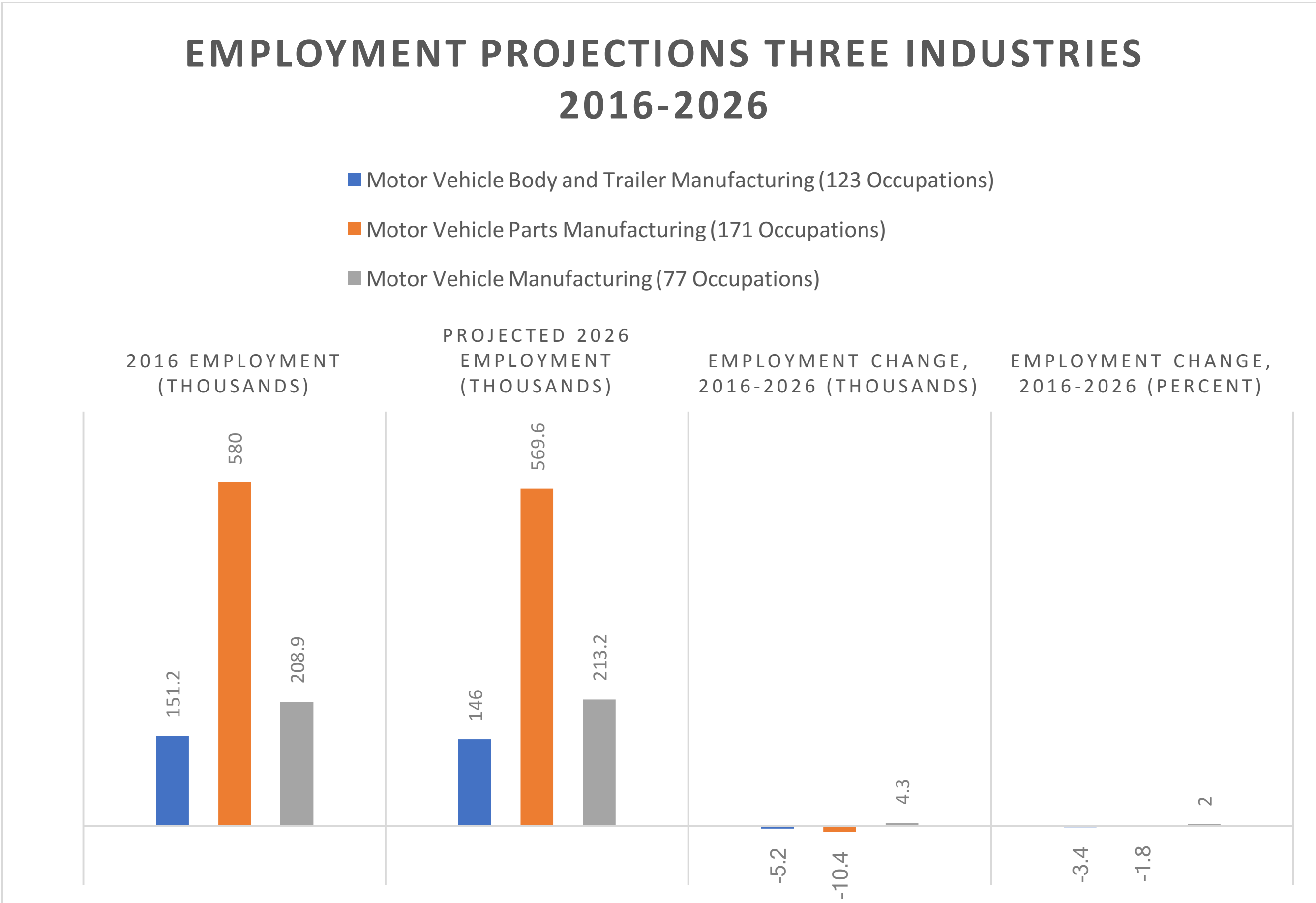
According to Baily and Bosworth's calculations, average annual multifactor productivity in the US economy was as follows between 1987 and 2011: 0.9% for nonfarm businesses, 1.3% for manufacturing, 9.7% for computers, 0.3% for manufacturing excluding computers. Recall that the higher the MFP residual, the more efficient output was, the more likely new methods such as the use of technology were used to improve output.[94]

Whereas it's clear that the efficiency of computers and technology production has improved greatly over time (think Moore's Law), non-computer production efficiencies have *not* improved over time. Indeed, between 1987 and 2000, average annual MFP in manufacturing was actually -0.1%! Between 2001 and 2011, efficiencies improved slightly to 0.7%, lower efficiencies than the economy as a whole.

So what are we to make of low MFP in US manufacturing (excluding computers)? Evidently, technological automation has not in any significant way been replacing autoworkers. Indeed, the graphs above already show that autoworkers began to regain jobs around 2010, a counterfactual to the notion of automation. So too have the absolute number of manufacturing jobs begun to increase in the US, rising to just under a million autoworkers by 2018.

Evidently automation has *not*, in any significant way, destroyed manufacturing jobs. But does that mean that they won't in the future? Yes and no.

[94] Cite Baily



Above is a graph I created using Bureau of Labor Statistics data that charts employment projections of autoworkers into 2026. Starting to left of the chart, the first two bars measure 2016 and projected 2026 employment numbers of the entire automotive industry in the thousands. The two bars to the right track the projected change in thousands, and as a percent of total automotive employment, the first two bars illustrate.

Though formatted simply, the data these bars represent is deceptive. While the automotive industry is often referred to as a singular entity, the Bureau of Labor Statistics (BLS) actually classifies the automotive industry into three distinct sectors: Motor Vehicle Body and Trailer Manufacturing (MVBT), Motor Vehicle Parts Manufacturing (MVP), and Motor Vehicle Manufacturing (MV), with each category being composed of 123, 176, and 77 occupations, respectively.

The car manufacturing industry may have a singular product—automobiles—but three industries are involved in the process of their creation, each of which are comprised of many specialized works such as mechanical engineers, electricians, and sheet metal workers. So, what does the chart say? It provides us with a few notable insights.

First, the BLS predicts that by 2026, two of three automotive industries will reach a net loss of employment. By the numbers, MVBT manufacturers are predicted to reduce employment by 5.2 thousand workers in the next eight years. Employment in MVP manufacturing is predicted to fare worse. The BLS forecast suggests a doubling of MVBT's losses for MVP employees at -10.4 thousand workers by 2026.

For its part, MV manufacturing employment is expected to rise by 2026, with an additional 4.3 thousand workers by 2026. In summary, the BLS forecasts MVBT employment down by 3.4%, MVP employment down by 1.8%, but MV employment up by 2% by the year 2026. But what kind of jobs will be disrupted?

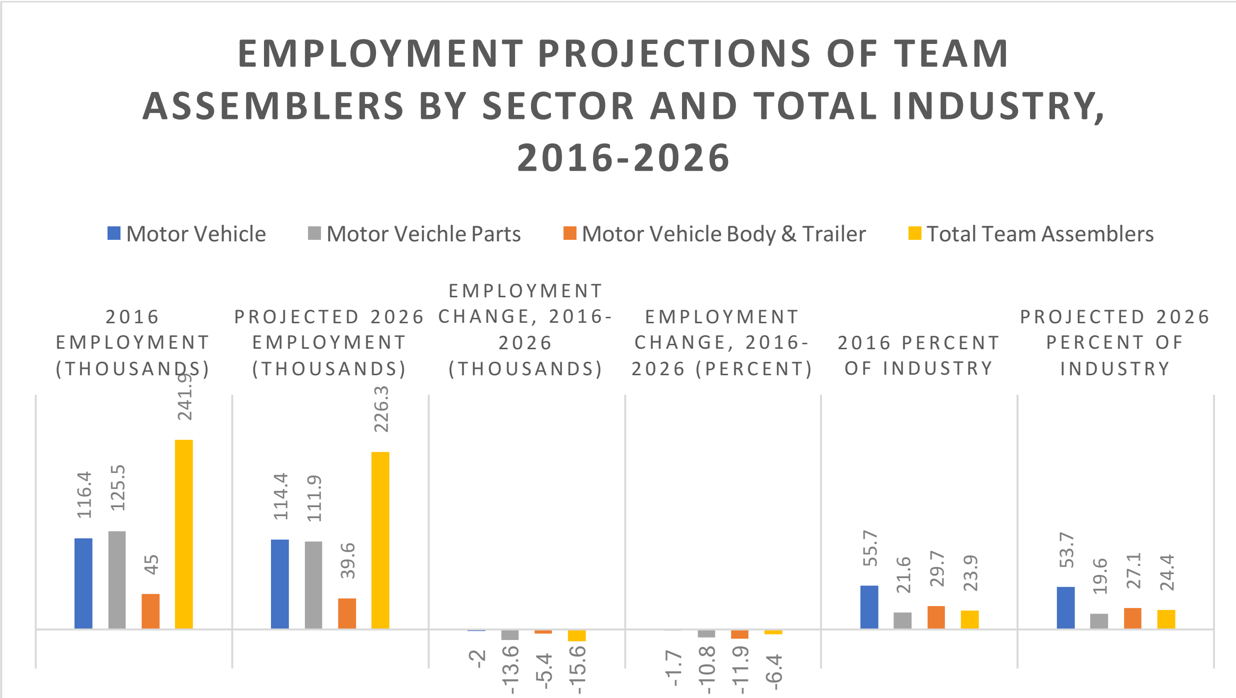
Still, these numbers are a bit coarse. After all, of the 301 auto-industry jobs the BLS measures, which kinds of jobs can we expect to be effected? By tracking these changes, we may have an idea of what is to come. Let's start with the job with highest share of workers.

By far, the job with the highest share of employment across all three auto-sectors are the team assemblers. Team assemblers do just what their name suggests—they assemble cars and parts, typically cycling through a number of different roles over the course of time, rather than specializing in a particular skill.[95] With an employment share of 21.6%, 29.7%, and 55.7% of MVP, MVBT, and MV manufacturing, team assemblers are most employed type of workers in the automotive industry at 28.3% of all industry jobs.

The fate of team assembly jobs therefore represents the greatest potential lost to a single job across all three sectors of the automotive industry. In the graph below, I chart BLS 2016 employment data and 2026 employment projections for Team Assembly jobs by automotive sector and as a total of the entire industry. Beginning with the leftmost batch of columns, we can see from the first group that MV and MVP employ most team assembly workers, at over 100,000 workers each. Moving rightward, we see that BLS predicts a drop in overall employment for team assembly workers by 15.6 thousand workers, or a drop of 6.4% workers overall.

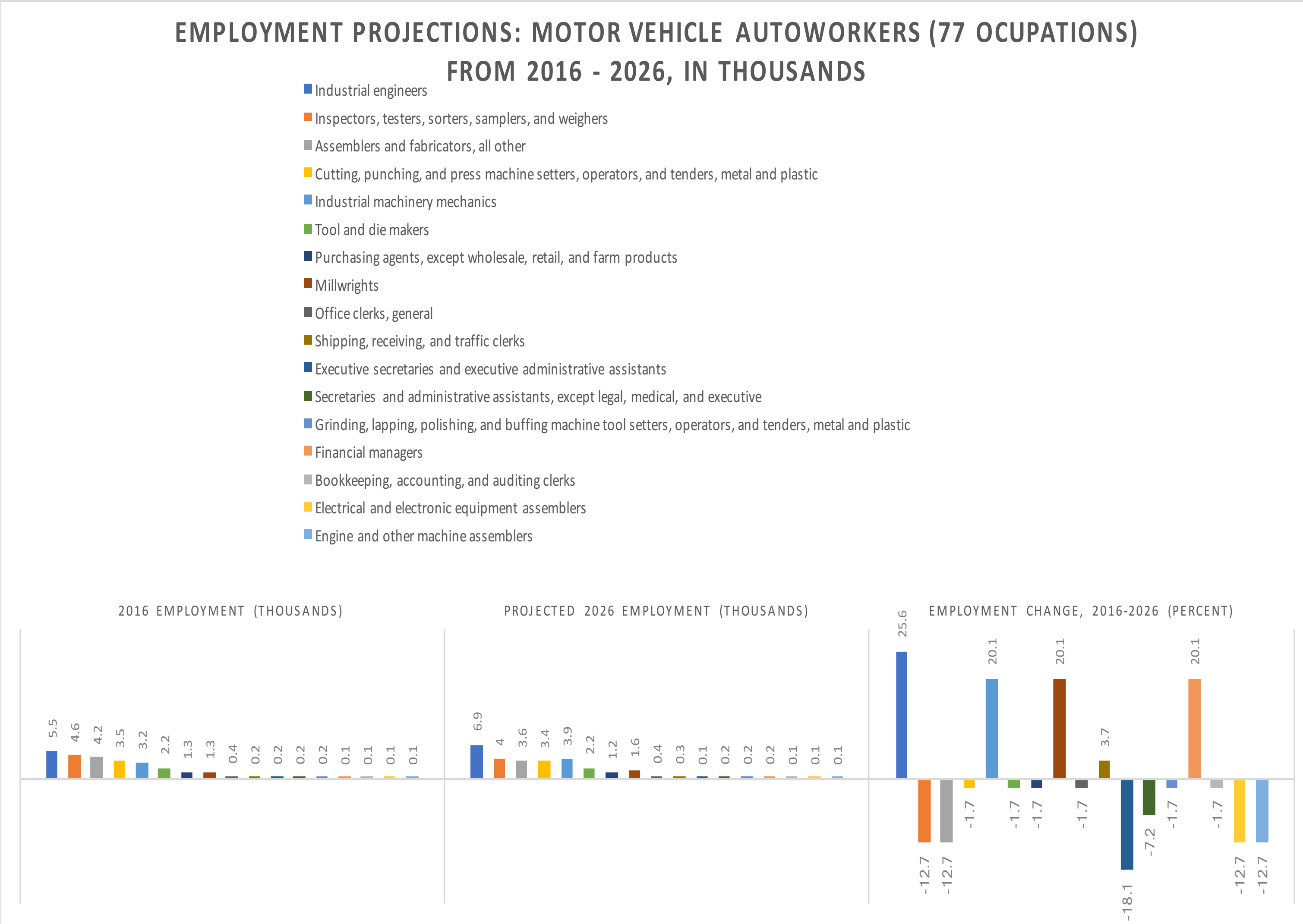
Moving further right still, we note that, while team assembly were 23.9% of autoworkers as of 2016, by 2026 the portion of assembly workers actually *increases* to 24.4%, despite a *reduction* in the number of team assembly workers! As it turns out, this seemingly odd result is correct—the percent of team assembly workers is projected to increase, despite a reduction in the number of workers—because the total number of automotive workers are projected to fall by 11.3 thousand in 2026, -1.2% of the industry.

[95] (BLS.gov/oes/current/oes512092.htm



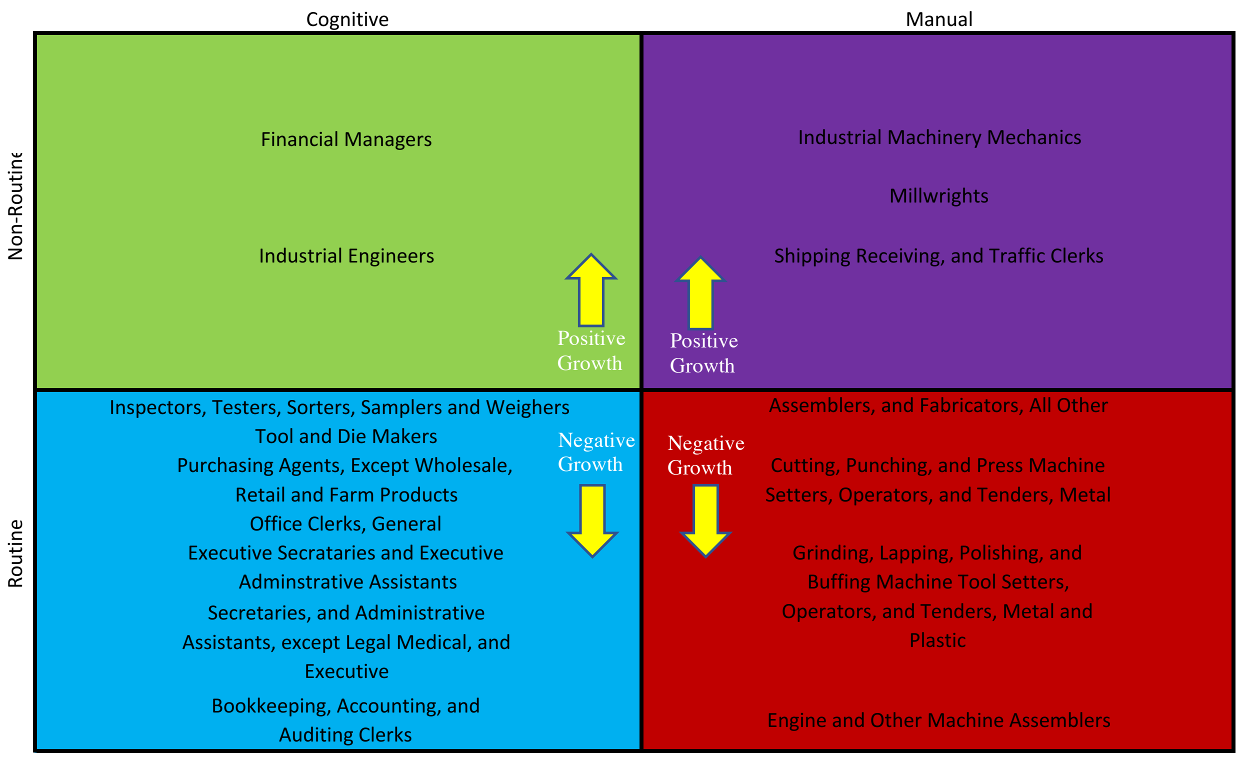
So, according to BLS projections, Team Assembly workers, and indeed the total number of jobs in the auto industry are expected to drop in the next 8 years. As economists, we are still left with an unanswered question however. If unspecialized team assembly employment is expected to drop, what *types* of jobs are expected to increase in the future?

The following graph charts the employment projections of 17 select occupations within the Motor Vehicle sector. These occupations were chosen due to typographic variety and the variance of their projections. Ranging from Industrial Engineers to Millwrights to Engine Assemblers, these are the typical jobs of the auto industry. Scanning the three charts below from left to right, we see the raw employment numbers charted in 2016 (left), employment projections for 2026 (middle), and the percentage these changes represent (right). Though the raw numbers may not seem significant (shifts are often not more than a few thousand), percentage-wise we can see that certain types of jobs are predicted to grow, while others are to shrink substantially.



To illustrate these changes a bit more clearly, I have plotted below these seventeen jobs into four "occupational types" previously described: Non-Routine Cognitive (green), Routine Cognitive (blue), Routine Manual jobs (red), and Non-Routine Manual (purple). By plotting jobs by their traits, a few notable characteristics emerge. Clearly, there are significantly more jobs in negative growth, routine boxes below than there are represented by the positive growth non-routine boxes above. Rather than confirming our worst fears, however—that more types of jobs are being lost than created—these results are an artifact of data selection. In fact, of the 378 within the three auto sectors, 285 jobs are predicted to experience some sort of growth, compared to just 93 that are expected to shrink—a 300% difference.

Our eyes do not deceive us, however, when we observe that the types of jobs that are expected to grow either require of education (non-routine cognitive) or an intimate understanding of machines themselves (non-routine manual). In other words, employment growth stems from designing systems (financial or industrial), or being able to fix them.



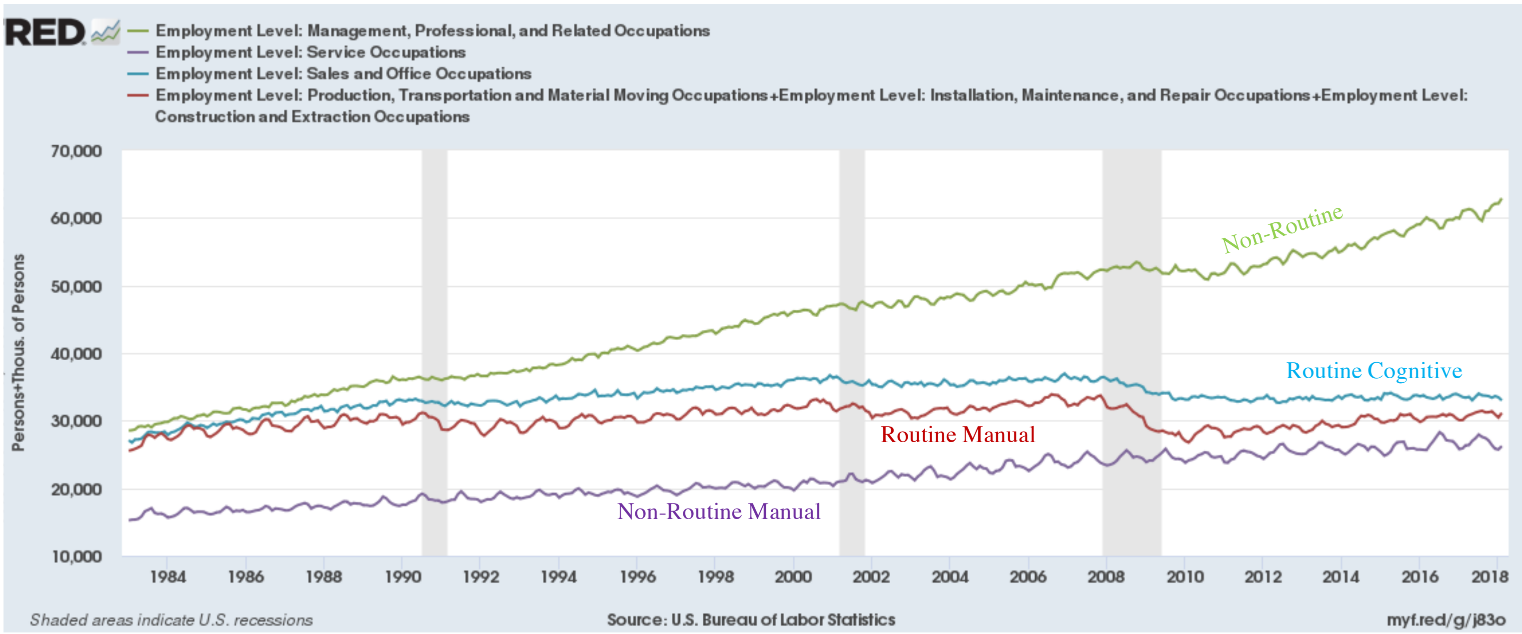
Definitions	
Cognitive	Job tasks that require abstract skills (e.g. problem solving, intuition, persuasion, and creativity), and generally require deep professional or academic training.
Manual	Activities that require adaptivity, resilient, visual and language recognition, and in-person interaction. Such tasks generally require innate abilities such as strength and dexterity and perhaps minimal training.
Non-Routine	Non-repetitive tasks that would be too difficult or resource intensive to codify. These tasks generally require analytic and/or interpersonal skills.
Routine	Well-defined job activities that can be accompished by a comparatively less-educated worker with minimal discretion or a computer program

Correspondence of Various Automotive Skill Types to Labor Forcasts

This chart indicates that employment growth may occur in the auto industry, but this grow is expected to be categorical in nature. The BLS estimations are not simply based on data; they are fundamentally reliant on the nature of jobs themselves. Categorical patterns have functioned for some time.

The chart below conveniently zooms out the automotive data once more into macroeconomic patterns. Below are trends in what are essentially, but not precisely, similarly colored trend lines matching the categorical pundit squares colored above: Non-Routine Cognitive (green), Routine Cognitive (blue), Routine Manual jobs (red), and Non-Routine Manual (purple).

As can be seen, employment-type trends in the automotive sector are fascinatingly reflective of overall macroeconomic trends, just as we saw previously when tracking strict employment numbers. In the vehicle manufacturing sector non-routine cognitive jobs such as financial managers and professionals are projected to grow similar to overall trends in non-routine cognitive jobs. Similarly, Routine jobs (such as Tool and Die Makers and Assemblers and Fabricators) are projected to experience stagnant to diminishing growth by 2026.



Our findings about the auto industry are not unique. Put it context, they are actually reflective conclusions made over 50 years ago by the "Blue-Ribbon National Commission on Technology, Automation, and Economic Progress." The commission, enlisted by President Lyndon Johnson in 1964, was formed in response to similarly-prevalent "automation anxiety" of the time—replace AI with room-sized computers and the threat our grandparents felt was essentially the same.

Then, as now, employment concerns rose in response to the perceived threat of commercialized computing technology, with publications like *Time* stoking public concern by writing, "What worries many job experts … is that automation may prevent the economy from creating enough new jobs. … Today's new industries have comparatively few jobs for the unskilled or semiskilled, just the class of workers whose jobs are being eliminated by automation."

For its part, the commission came to more nuanced, if less foreboding, determinations, concluding its report with the following summary:

> Thus technological change (along with other forms of economic change) is an important determinant of the precise places, industries, and people affected by unemployment. But the general level of demand for goods and services is by far the most important factor determining how many are affected, how long they stay unemployed, and how hard it is for new entrants to the labor market to find jobs. *The basic fact is that technology eliminates jobs, not work.*[96]

[96] (Autor 5)

In other words, our wants and needs—our ability to pay for a product or service and our willingness to do so—determines far more the longevity and resiliency of employment. Far more likely jobs are lost to changes in preferences, say for taking a Lyft than a cab, or a car rather than a horse drawn carriage, than technology eliminating employment altogether. Still, the commission and *Time* bring up good points—technology *does* eliminate *some* jobs *some* of the time, therefore it is both economically detrimental and ethically questionable to ignore this truth. For instance, according to these forecasts, at least in the next 8 years, automotive jobs are not going to be lost altogether—but many thousands will!

Pertinent economic questions therefore arise: Where will those workers go? How will they survive? How will their unemployment affect the resiliency of microeconomic institutions? And is there an opportunity to anticipate this job loss, creating revenue-generating business models that also assist these workers finding new jobs? Cannot a more modern and fluid economic model be generated by businesses that adapts to the modern world—where short-run technological unemployment becomes increasingly becomes the norm for under-skilled workers?

Some forecast that the shared economy is just such a business model. Before moving on however, you may have noticed that the Federal Reserve graph above does indicate a similarly interesting phenomenon. The lowest trend-line in purple, representing in-effect non-routine manual labor, suggests that, perhaps counterculturally, some manual labor jobs are labor-resilient—even during recessionary periods (shaded grey in the chart) employment patterns are similar to employment non-recessionary periods.

In fact, compared to the other three labor types, non-routine manual positions (nurses, bank tellers, etc.) seem *most* resilient to recessionary periods. In other words, evidence indicates that this type of work—especially service-based employment—is relatively "price-inelastic." In other words, prices may rise and fall, the world may change, but there are certain tasks that always need to be done and manual labor is there to do it.[97]

This may seem obvious—you don't need an economist to tell you that parents generally desire babysitters and students will tend to seek out tutors. Far more interesting is the evidence that demand for non-routine manual labor is also *income elastic.* suggests that as income rises, demand for labor activities also rises. Conversely, the lower your income, the less prone you will be to hire someone else to wash your dishes or nanny your child.

As you may see, this evidence suggests that as societal productivity and innovation increases—as technology helps raise per capita income—this indirectly increases demand for non-routine manual work![98] Evidently, technology can, if weakly, increase employment among the less-technically educated.

Contrary to intuition, moreover, research indicates that wages can rise in the non-routine manual even absent of macroeconomic productivity growth (often attributed to rising wages) to reimburse workers of the opportunity cost of *not* entering another field.[99] But the symptoms of rising non-routine labor may at times, also portend a deeper economic disease.

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[97] (Baumol 1967; Autor and Dorn 2013; Auror 2015, 17).

[98] (Clark 1951; Mazzorali and Raguli 2013; Autor 2015 17)

[99] Still, due to the relative ease of entry into non-routine manual labor, rising wages are often stifled in some respect. (Baumol 1967, Autor 2015, 17).

True, as we look into the near future we should expect some sort of manual labor to exist. But the consequences of an undertrained workforce mean that more workers will fall from middle-skill jobs families into routine and non-routine manual labor jobs. As labor supply increases, this may cause a labor supply glut, decreasing earnings for workers.

Theoretically, a supply glut may reduce the cost of ridesharing for the consumer, which is nice, but this assumes that firms pass those savings onto the consumer. Uber and Lyft, for instance, have yet to make any consistent profit. Depending on the competitive landscape in the future, they may absorb the difference in an attempt to be profitable. If current economic polarization continues as it has, we should not be surprised if a supply glut emerges in the shared economy.

After all, evidence indicates a huge rise in shared economy employment. At least, that's what the market researchers believe. According to a 2017 Juniper Research report on the shared economy, approximately 1.16 million drivers were working as contractors for mobility platforms in 2017.[100] A cursory reading into the data retrieval process informs us that this market conjecture is modelled from a 2015 Uber Driver report. Unfortunately, this report is one of few data stores available to market researchers. In other words, most data we see about the economics of the shared mobility market are derived from the same report.

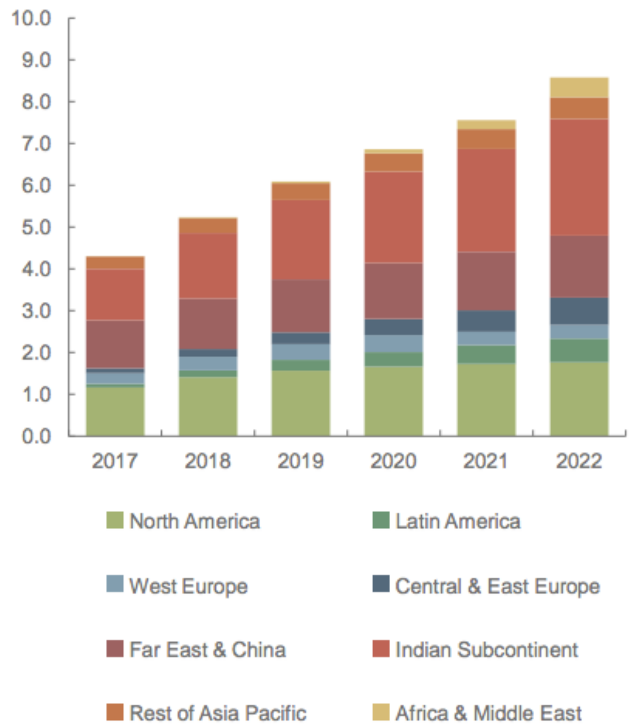
Typically, and as is with this case with these "current" numbers, a cumulative growth model is used on historical data to project current and future trends. As nice as this may seem, this leaves many in the industry reading numbers that may be inaccurate (many reports, for instance, do not provide a confidence intervals or standard errors). Still this data does give us some indication of the *current thinking* about the market. Although these numbers may be off hundreds of thousands, we would know if Uber or Lyft had *no* drivers. At the very least, the data these leading reports project indicate, essentially, the best guesses (plus or minus some standard error) of the market research industry. Viewed in this light, according to these thinkers, from 2017 to 2022 there will be a 53% increase in the of shared economy drivers in the US; from 1.16 million in 2017 to 1.77 million in 2022.

Should we believe these numbers?

It is probable that we should. There are few barriers to entry in the shared economy—almost anyone with a car and the willingness to work can drive for a shared mobility company. Moreover, we have already seen that there has been a steady trend in the growth of non-routine manual jobs over the last 30 years. As long as we can classify driving cars as a non-routine occupation—that is, as a non-mechanizable occupation, then there is reason to believe that these jobs will grow.

But will this pace of growth be sustainable? Whereas there has been great growth in rideshare contracting services over the last 5 years, most of industry growth is expected to occur outside the US in the proceeding 5 (see graph below). Meanwhile, market researchers currently predict that by 2022 *demand* for rideshare will almost double, from 787.1 million in 2017 to 1.41 billion in 2022. Yet, these analysts also predict that the average number of rides drivers make per month will only increase by three, from 64.1 per month in 2017 to 67.4 per month in 2022.

[100] (Juniper Sharing Economy Report, 2017, p. 18)



Estimate of Demand[101]

The only way the math can add up in this way—the only way that rides could double while predictions of driver growth remains low—is for researchers to expect a supplemental approach to develop in the next few years. In fact, it may be that recent developments in technology have inadvertently created a shift classification for professional drivers—instead of classifying driving as a fundamentally intuitive, non-repetitive task, developments in machine learning, sensor technology, and engineering has begun to change our understanding about what routine-work really is.

Jobs that were once untouchable by innovation are now threatened by capitalism's force of creative destruction. A 2016 report out of the Council of Economic Advisors (CEA) came to similar conclusions. The report, titled "Artificial Intelligence, Automation, and the Economy," comes to the significant conclusion: machine learning (what they call Artificial Intelligence) "…has already begun to transform the American workplace, changing the types of jobs available and the skills that workers need to thrive."[102] Using autonomous vehicle technology as a case study, the CEA notes that 2.1 to 3.1 million jobs that require driving automobiles may be threatened (see chart below).

[101] Cite
[102] Cite

Occupation	# Total Jobs (BLS, May 2015)	Range of Replacement Weights	Range of # Jobs Threatened
Bus Drivers, Transit and Intercity	168,620	0.60 – 1.0	101,170 – 168,620
Light Truck or Delivery Services Drivers	826,510	0.20 – 0.60	165,300 – 495,910
Heavy and Tractor-Trailer Truck Drivers	1,678,280	0.80 – 1.0	1,342,620 – 1,678,280
Bus Drivers, School or Special Client	505,560	0.30– 0.40	151,670 – 202,220
Taxi Drivers and Chauffeurs	180,960	0.60 – 1.0	108,580 – 180,960
Self-employed drivers	364,000	0.90 – 1.0	328,000 – 364,000
TOTAL JOBS	3,723,930		2,196,940 – 3,089,990

White House Estimate of Potential Losses in Professional Driving[103]

Of course, this data likely *under*estimates the number of jobs in the above industry. In a recent Bureau of Labor Statistics article on the data collection and the gig economy, the authors note that "…government data sources have difficulty counting how many gig workers there are"; due to the transient nature of shared economy jobs, normal classifications can be insufficient. As a consequence, "...workers could be in contingent or alternative employment arrangements, or both."[104] One area of future development, therefore, will have to be the ability to classify and track jobs within the shared economy.

More pressingly, however, the findings by the CEA indicate that millions of jobs could be lost to autonomous vehicles, despite the reality that new technology often *exacerbates entry into non-routine manual labor*. Put differently, the development of AV technology may also push more people into working the shared economy, despite there being less jobs in the sectors keystone industry: driving for rideshare.

If society really does being to integrate AV technology, we then can expect that the drivers *not* yet pushed out of the market will get paid ever-less. A glut in labor supply tends to push down wages. For those who choose or cannot work as drivers will then turn to other types of labor—contracting for other piecework shared economy jobs (e.g. on-call mechanics, cooks, nail workers).

Assuming this procession events were to occur, then we can also expect an increase in wage uncertainty—the income of piecework worker varies over time by nature. At this point, unless the public or private sphere interfere—that is, unless policies are enacted or labor demand rises for some other unforeseen reason—then discretionary spending might fall among these wage uncertain workers. Since previous reports have already established this to be the case,[105] it should suffice to say that the negative consequences lower discretionary spending can range from temporary inconvenience to full-blown recession or depression.

[103] Cite
[104] (Elka Torpey and Andrew Hogan Career Outlook, U.S. Bureau of Labor Statistics, May 2016).
[105] Labaschin 2017a

The amount with which spending is reduced often depends on the amount of debt consumers, firms, and municipalities have already accrued. As consumer debt is at its highest in modern history, it is not much of a leap to say that, were this string of events to occur, at least those dependent on piecework wages would suffer economic pressure.

Of course, this is a great amount of conjecture for a worst-case scenario. Still, it does merit consideration. The economists behind the CEA report think as much, writing of the same state of affairs that "although this scenario is speculative, it is included in this report to foster discussion and shed light on the role and value of work in the economy and society." Indeed, we have already established the precedent that technology tends to create complementary employment more so than it causes joblessness. As the authors of the CEA concede, "Ultimately, AI may develop in the same way as the technologies before it, creating new products and new jobs such that the bulk of individuals will be employed as they are today."[106]

Nevertheless, just because contemporary economic history has so far worked in favor of net job gains does not mean we should not at least prepare for a world in which the majority of routine workers have their jobs threatened. At the very least, we should expect in the future a great push in training workers to code and to work in the technical fields. Two things are certain. First, it is unlikely that the shared economy can bear brunt of the regular economy—only supplement it.

Second, the integration of autonomous vehicles into the economy will affect not only the shared economy, but the economy as a whole. As such, it is to this subject which we turn next. There is a *lot* of speculation about the future of autonomous technology. For those within the industry, talk about autonomous vehicles (AVs) and AV technology are a matter of when, not if. That said, reports are not without their nuance—many firms are taking a step-by-step approach to the evolution of AV tech.

You may already be familiar with the following conceptual chart by the Society of Automotive Engineers (SAE) which illustrates the standardized "Levels of Autonomy" cars are hoped (expected) to reach in the near future. For those who are overburdened with this talk, feel free to skip this section. For all others, the following chart helpfully depicts gradual ascendency from human-controlled mobility, to AV-controlled mobility.

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[106] CEA

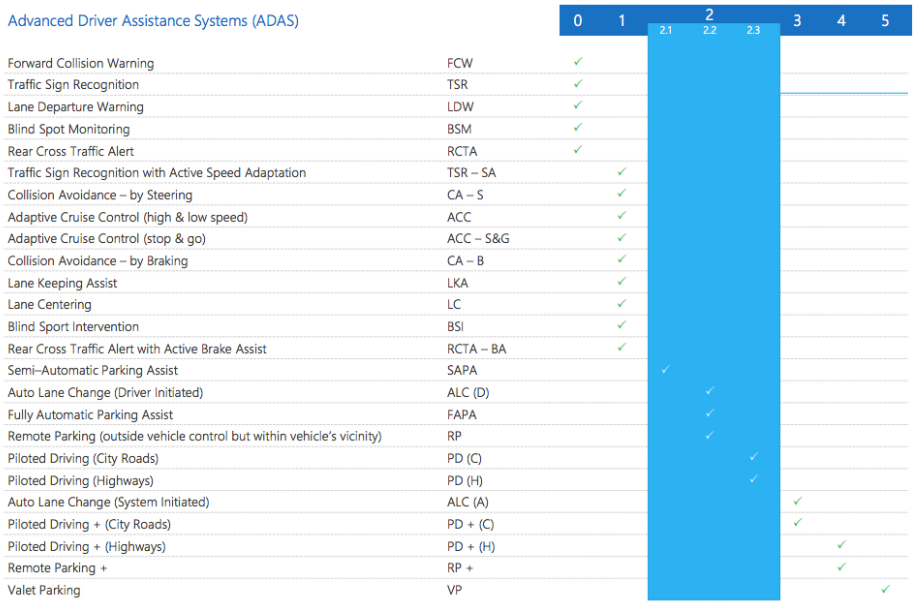
SAE Levels of automation	Level 0 No Automation	Level 1 Driver Assistance	Level 2 Partial Automation	Level 3 Conditional Automation	Level 4 High Automation	Level 5 Full Automation
Driver input	Complete control	Only one input – Steering or acceleration or braking	Permanent supervision	Intermittent supervision	Intermittent supervision	No input
Vehicle input	Warning only	Longitudinal or lateral control	Longitudinal and lateral control	Longitudinal and lateral control	Longitudinal and lateral control	Longitudinal and lateral control
Who is in control	Driver	Driver	Driver	Driver / Vehicle	Vehicle	Vehicle
Road / weather conditions	Some	Some	Some	Some	Most	All
System examples	Lane Departure Warning	Adaptive Cruise Control	Autonomous Parking	Traffic Jam Chauffeur	Traffic Jam Pilot	Universal Robot Taxi

Increasing Levels of Autonomy SBD Autonomous Car Guide — Q3 2017[107]

From Level 0 (No Automation) to Level 5 (Full Automation), there are several evolutionary steps to fully autonomous cars, each level bring comprised of four categories of characteristics that determine a vehicle's overall ranking. As can be seen, those categories include: Driver Input, Vehicle Input, Control Dominance, and Environmental Recognitions and Adaptivity. For example, according to the SAE a vehicle would be classified as Level 2 autonomous if it requires constant human oversight (someone at the wheel at all times and if the destination and vehicle choices are determined by humans.

So, where are we today? The chart below ticks off in greater detail the capabilities vehicles must possess in order to traverse autonomous level. The middle of the chart, as you'll see, is expanded however into three sublevels (Level 2.1, Level 2.2, and Level 2.3) this is because, as you might have guessed, today car manufacturers have produced commercial vehicles within this level—with varying degrees of advancement. In order to distinguish them, then, levels are broken down into these subcategories.

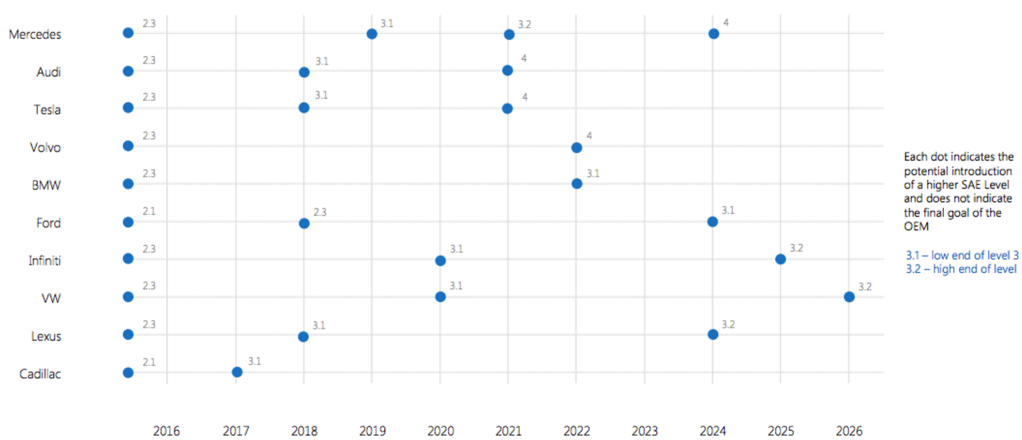
[107] Cite



Advanced Driver Assistance Systems (ADAS)		0	1	2 (2.1)	2 (2.2)	2 (2.3)	3	4	5
Forward Collision Warning	FCW	✓							
Traffic Sign Recognition	TSR	✓							
Lane Departure Warning	LDW	✓							
Blind Spot Monitoring	BSM	✓							
Rear Cross Traffic Alert	RCTA	✓							
Traffic Sign Recognition with Active Speed Adaptation	TSR – SA		✓						
Collision Avoidance – by Steering	CA – S		✓						
Adaptive Cruise Control (high & low speed)	ACC		✓						
Adaptive Cruise Control (stop & go)	ACC – S&G		✓						
Collision Avoidance – by Braking	CA – B		✓						
Lane Keeping Assist	LKA		✓						
Lane Centering	LC		✓						
Blind Sport Intervention	BSI		✓						
Rear Cross Traffic Alert with Active Brake Assist	RCTA – BA		✓						
Semi-Automatic Parking Assist	SAPA			✓					
Auto Lane Change (Driver Initiated)	ALC (D)				✓				
Fully Automatic Parking Assist	FAPA				✓				
Remote Parking (outside vehicle control but within vehicle's vicinity)	RP				✓				
Piloted Driving (City Roads)	PD (C)					✓			
Piloted Driving (Highways)	PD (H)					✓			
Auto Lane Change (System Initiated)	ALC (A)						✓		
Piloted Driving + (City Roads)	PD + (C)						✓		
Piloted Driving + (Highways)	PD + (H)							✓	
Remote Parking +	RP +							✓	
Valet Parking	VP								✓

Advanced Driver Assistance Systems (ADAS)
Defined by SAE Levels, SBD Car Guide Q3 2017[108]

In the chart below, 10 well-known automakers are listed. Though they are not the only Original Equipment Manufacturers (OEMs) in existence, they all currently offer commercial vehicles on AV tech spectrum. As of 2016, each OEM offered personal vehicles with Level 2 Partial Automation capabilities. The most advanced OEMs, all but Cadillac and Ford, offer Level 2.3 vehicles with "Piloted Driving" technology enhancements. These vehicles have the capacity to monitor their location within vehicle a lane by tracking lines on city streets. Despite this incredible feat of technology, drivers are still required to hold onto the steering wheel. For those who are curious, a quick internet will show you that, despite the predictions in the graph below, Cadillac does not yet provide for commercial use, any Level 3 automated vehicles.



Current State of Autonomy (5-Point System)[109]

[108] Cite
[109] Cite

For those who are curious, a quick internet search will show you that, despite the predictions in the graph below, Cadillac does not yet provide for commercial use, any Level 3 automated vehicles. This point provides a helpful transition to an important point. As I have pointed out, industry insiders often speak excitedly and expectantly about the future of autonomous vehicles. Many, perhaps most, rely on industry forecasts from consultant firms about just when technology will hit the market, and just how society stands to be affected.

As was easily demonstrated by the example above, however, accurate forecasts are difficult to find. What's far worse perhaps is that the data and assumptions underlying these predictions are not readily available to readers. This is just as much the fault of the consumers, who do not demand these aspects be made explicit, as it is the suppliers who can take a lax approach to forecasting.

As will be soon discussed, there is value is tracking historical accuracy of forecasters—by aggregating models together and tracking precision over time, businesses can get a leg up on the competition. For now, it is enough to say explicitly that all forecasts analyzed in the following sections are made by consultants who often make implicit assumptions about the future that may not be discernable and are therefore questionable.

These forecasts should therefore be interpreted as *suggestive of current and near-term thinking and expectations*; ***they should not be viewed as statistically robust nor universal.*** Why is new technology adopted in the first place? Do we need this new technology? What is its purpose? With context in hand, we might move forward to address some pertinent questions about AV tech. First and foremost, do we even need AV? Such a substantive technology is sure to disrupt society, if not trigger a technological transition into a new economic *status quo* as discussed in the previous section.

As discussed in previous reports, traffic is a significant problem in America. The chart below tracks the 10 most congested cities in America. In 2016, Los Angeles topped the chart, with the average commuting estimated as spending over 100 hours per year in traffic. The researchers who compiled this list estimated that the total cost of waiting in this traffic for the average driver ranged from $1590 per driver in Seattle to $2408 per driver in LA.[110]

In other words, traffic can be costly.

Taken together, of the 240 US cities researchers surveyed, they estimated that congestion cost consumers almost $300 billion, about $1400 for every driver.[111] This isn't a recent trend either. Were you to travel 2000 years back in time to ancient Rome, you find the ancient state suffering traffic congestion as well. Except where we have automobile-based traffic, they suffered cart-based traffic. So poor were traffic conditions in Rome that Julius Caesar himself famously banned carts from travelling using streets during the day. The consequence of this new law was an exercise in incentives: almost predictably merchants began to operate at night, filling evening hours with a cacophony once reserved for daytime commerce.

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[110] Cite

[111] Inrix, Inc. "Los Angeles Tops INRIX Global Congestion Ranking," February 20, 2017. Accessed December 15, 2017. inrix.com/press-releases/los-angeles-tops-inrix-global-congestion-ranking/

Rank	City / Large Urban Area	2016 Peak Hours Spent in Congestion	Percentage of Total Drive Time in Congestion (peak and non-peak hours)	Total Cost Per Driver in 2016	Total Cost to the City in 2016 (based on city population size)
1	Los Angeles, CA	104	12.7%	$ 2,408	$9.7bn
2	New York, NY	89	12.8%	$ 2,533	$16.9bn
3	San Francisco, CA	83	12.8%	$ 1,996	$2.5bn
4	Atlanta, GA	71	10.0%	$ 1,861	$3.1bn
5	Miami, FL	65	8.7%	$ 1,762	$3.6bn
6	Washington, DC	61	11.3%	$ 1,694	$3.0bn
7	Dallas, TX	59	6.6%	$ 1,609	$2.9bn
8	Boston, MA	58	13.4%	$ 1,759	$2.9bn
9	Chicago, IL	57	10.2%	$ 1,643	$5.2bn
10	Seattle, WA	55	12.6%	$ 1,590	$2.0bn

Ten Most Congested Cities in US[112]

If the satirist Juvenal is to believed, Caesar's only made life worse, writing, 'What sleep is possible in a lodging? The crossing of the wagons in the narrow, winding streets, the swearing of drovers brought to a standstill would snatch sleep from a sea-calf or the Emperor Claudius himself."[113]

What are we to make of this story? To me it shows that since the advent of urban movement, humans have been struggling to cope with traffic.

And it's only getting worse.

In 1983, there was only one urbanized area in the United States where the average driver spent more than 40 hours stuck in rush hour traffic. By 2003, there were 25 such areas.[114] As ancient as traffic's origins may be, it seems that modern conditions are only exacerbating congestion. Still, modernity has brought with it more than deteriorating traffic conditions. Advances in sensor technology, machine learning, and telematics have produced conditions favoring the advent of AV technology.

According to their proponents AVs are so revolutionary because they will solve one of the original problems of urban civilization: traffic. But will AVs traffic truly solve traffic the problem?

On the one hand, it's probably shortsighted to take it on faith that they will. On the other, the cost of this skepticism requires a deeper investigation into the problem of traffic in the first place. Fortunately, there have been many economists and traffic engineers out there who have attempted to understand the problem of traffic.

In the next two sections the structure of traffic, called Traffic Flow Theory, will be explored. Coupling this theory with the economics of Algorithmic Game Theory will be able to

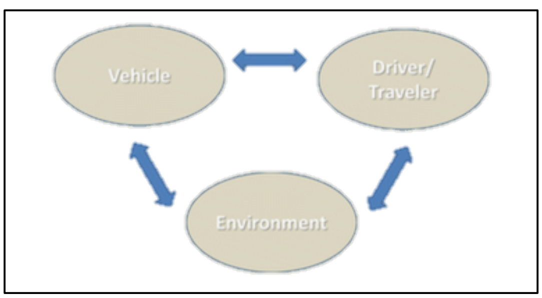
112 Inrix, Inc. (2017).
113 (PD Smith, City: A Guidebook for the Urban Age, 171-172).
114 Sowell, Economic Facts and Fallacies, 19).

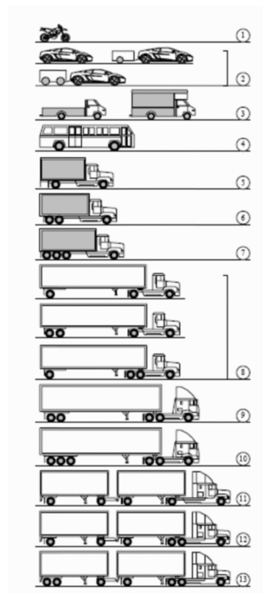
better answer for ourselves whether it is likely AVs will improve traffic in the way its proponents assert.[115]

Traffic Flow Theory: Understanding How AVs Could Improve Traffic

Traffic Flow Theory is a methodological approach transportation engineers use to understand the interaction between the three variables identified as influencing traffic behavior. Those variables are: the vehicles in movement, the drivers/travelers doing the movement, and the environment that influences movement (see figure a. below).

a.





b.

Key Elements Affecting Traffic Flow (a.) and Car Type Chart (b.)[116]

As we run the gamut of these variables, it will have helpful to keep this central question in mind: if traffic engineers believe these three variables influence traffic flow, how might the different levels of autonomy affect traffic positively or negatively?

With this question in mind, let us consider the first sphere of the figure above: the vehicle. You don't need to be a traffic engineer to understand that vehicle form and function affects its mobility. It should therefore come as no surprise that vehicles affect traffic flow. Because there are a variety of vehicle types and classes (see figure b. above), the physical nature of each determines their drivability and the drivability of others.

According Lily Elefteriadou, Director of the Transportation Research Center at the University of Florida, there are five common characteristics of vehicles that most directly affect traffic flow: Braking and Deceleration Capabilities, Weight-to-Horsepower Ratios (WT/HP),

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115 . goo.gl/a1cnt2

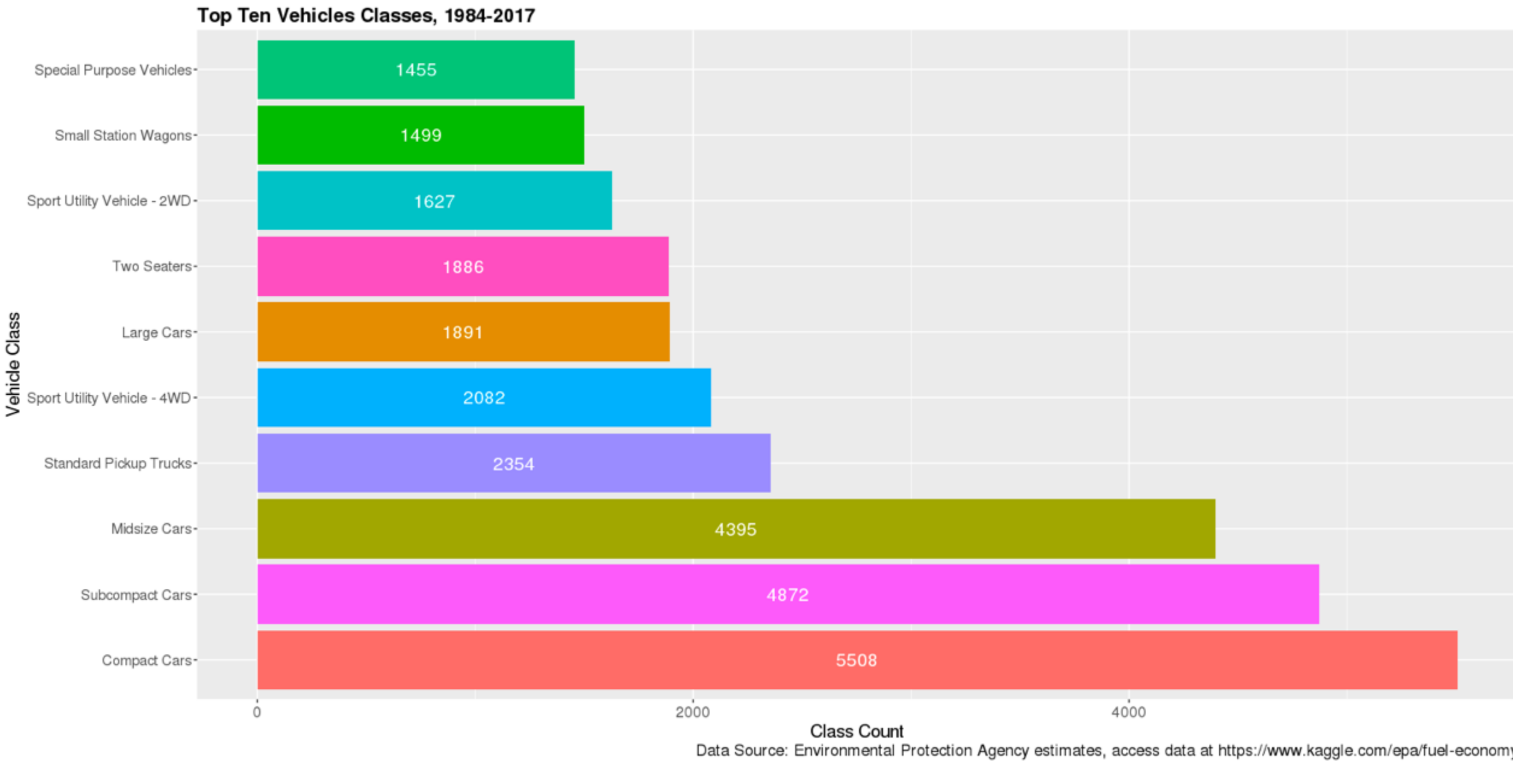
116 Cite FHWA vehicle types (From Jazar, R.N., Vehicle Dynamics Theory and Applications, Figure 1.21, page 27; Reproduced with permission of Springer-Verlag GmbH); Lily Elefteriadou. "An Introduction to Traffic Flow Theory."

Frontal Area Cross-Sections, Vehicle Height, and Width, Length and Trailer Coupling—an explanation of each can be found in the chart below:

Top 5 Physical Characteristics Affecting Traffic Flow	**Simple Terms**	**Example**
Braking and Deceleration Capabilities	A non-linear action, deceleration abilities decrease as vehicle size and weight increases.	Braking is determined by torque, vehicle momentum, antilock availability, resistance forces like traction and wheel quality.
Weight-to-Horsepower Ratios (WT/HP)	The proportion of the vehicle load to the engine power of the vehicle. Affects vehicle speed on steep upgrades (crawl speed) and acceleration capabilities, influencing the movement of surrounding vehicles.	Trucks: With their heavier loads and less engine power, trucks have a higher WT/HP. Passenger Cars: WT/HP is typically negligible for passenger cars
Frontal Area Cross-Sections	Affects drag on vehicle, reducing acceleration.	Humvees have wide cross-sections, thus decreasing their aerodynamics.
Vehicle Height	Can affect the forward-looking vision for cars located behind tall vehicles.	Following vehicles with low sight-distance may increase distance between vehicles, reducing road capacity.
Width, Length and Trailer Coupling	Dimensions affect driver behavior in narrow lanes and the front-wheel vs. rear-wheel drive capabilities	Width: Trucks and SUVs can induce adjacent drivers to raise or lower driving speeds, encourage shoulder driving, and more. Length and Trailer Coupling: Long trucks and buses must take wider turns, riskier behavior in particularly congested areas.
Source: Lily Elefteriadou, *An Introduction to Traffic Flow Theory*, (New York: Springer-Verlag, 2014)		

Returning to the question we posed above, if engineers like Elefteriadou find vehicle form and function to significantly impact traffic flow efficiency, how might autonomous vehicles improve efficiency? First, let’s take a look at how engine weight affects the fuel efficiency of passenger vehicles.

I have plotted a bar chart below of the ten most popular vehicle classes in American from 1984-2017 using US Environmental Protection Agency data. In the next graph, I then plot these ten classes by two variables: vehicle highway miles per gallon (y-axis) and engine weight (x-axis), colored by class. For convenience, I also inserted a trend line to chart the general path of the relationship.

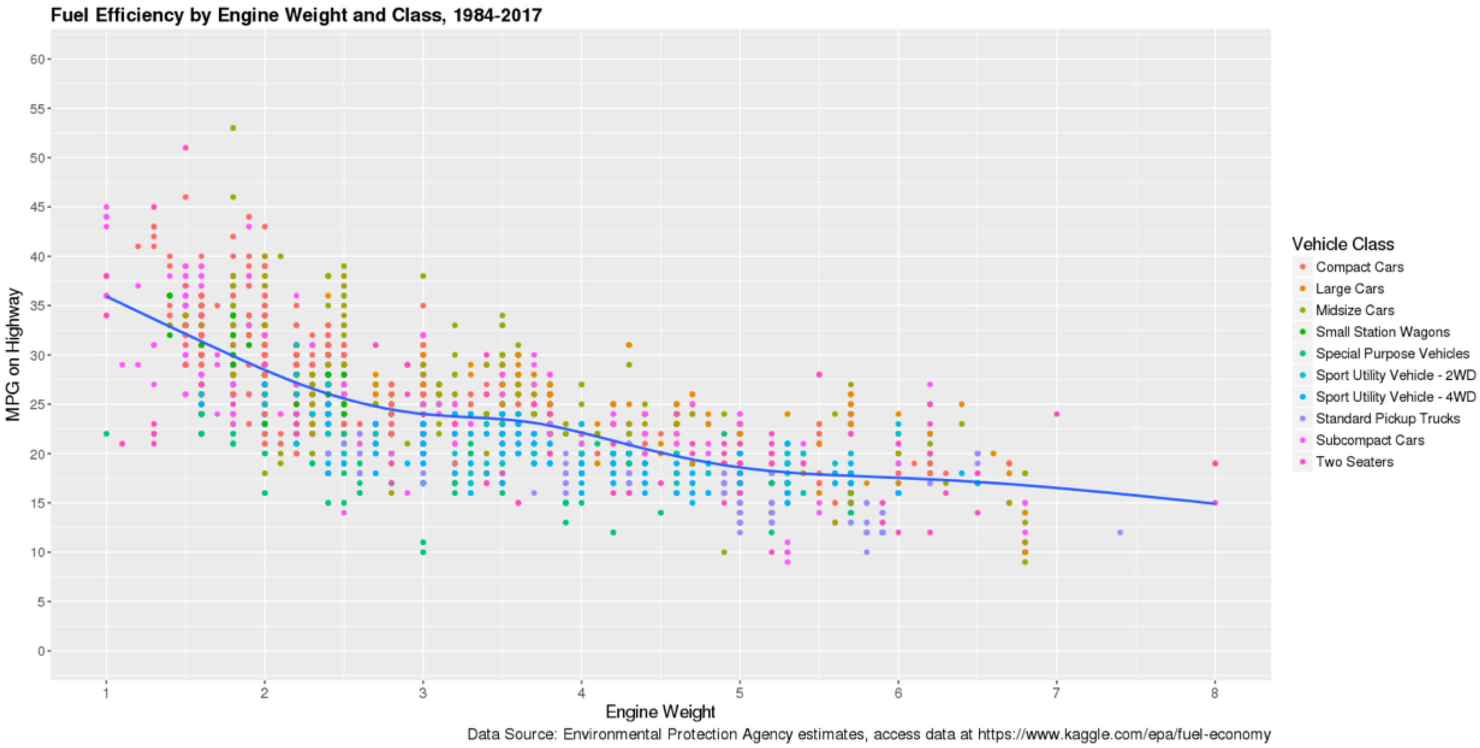


The data provides clear insight. First, as engine weight increases, generally vehicle fuel efficiency decreases. There are some exceptions, however, two-seaters tend to have better fuel efficiency despite their heavier engines. This can be explained by other factors. Manufacturers of two seater vehicles tend to compensate their heavy engines by reducing vehicle body size and frame.

By the same logic, as engine weight decrease, fuel efficiency tends to increase. Again, this depends on vehicle class. Compact cars tend to be the most fuel-efficient cars, followed by large, midsize, and subcompact vehicle classes. Meanwhile, pickup trucks tend to follow below the trend line, indicating less-than-admirable fuel efficiency.

If we assume that consumer demand influences the vehicle types provided to them, then this data indicates to us that Americans tend to prefer more fuel-efficient vehicles. The question is, will autonomous vehicles provide that convenience to Americans?

Let’s start with the evidence we do have available, then move towards theory.



You may have recently heard that Tesla is producing autonomous semi-trucks which will be used initially as a means of shipping cargo from one company site to another.[117] The question is, does such an advance improve the WT/HP ratio of vehicles—the most significant of the 5 Physical Characteristics—in a meaningfully different way?

Suppose AV technology advances to Level 5 in the next 8 years, even then it is doubtful these improvements will significantly reduce the WT/HP ratio of trucks will be reduced.[118]

In fact, AVs may exacerbate WT/HP ratios. Sticking with the Tesla example, these autonomous vehicles planned for the 2019 commercial market, weigh in at 80,000 lbs., the heaviest semi-trailer trucks allowed on US highways.[119]

But what about passenger vehicles?

It's uncertain. Some believe that AVs will allow for a reduction in safety standards in vehicles, allowing them to reduce the amount of material they use.[120] But this assumes that human-driven vehicles cannot or will not crash into autonomous vehicles. At least in the near, future, that is unlikely. Recent events in vehicle autonomy show that they are not immune to fatal accidents.[121]

As such, it is unlikely that in the near future AVs will reduce vehicle form and format substantially beyond braking features. If you refer back to our autonomous vehicle characteristics chart, however, you'll see that the only two braking systems believed to be

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[117] https://futurism.com/teslas-autonomous-semi-truck-spotted-california-highway/

[118] (Lily Elefteriadou, *An Introduction to Traffic Flow Theory*, (New York: Springer-Verlag, 2014)).

[119] https://www.forbes.com/sites/stevebanker/2017/11/17/the-tesla-truck-doubts-abound/#702b7d24eed1

[120] RAND).

[121] Cite.

integrated into vehicles have already been developed, are already within modern level 2.3 vehicles: Rear Cross Traffic Alerts with Active Brake Assist (RCTA – BA) and Collision Avoidance — by Braking (CA – B).

In that vein, I have provided the following link[122] (see footnote below) to demonstrate the potential of AV braking on traffic. In the brief video, University of Illinois Urbana-Champaign researchers demonstrate a classic experiment in an altogether new way. The experiment, called a "phantom traffic jam," traditionally positions cars equidistantly from each other in one large circle. Cars are then compelled to move simultaneous, driving around and around in a circle, one after the other. Finally, one car in the procession breaks suddenly. The effect of this sudden braking ripples across the procession of cars like a wave, each car compelled to brake similarly. But because of the cyclical position of the cars, the braking pattern never actually stops. Like some traffic purgatory, cars are now stuck in an endless loop of traffic—consigned to spend their days in inefficiency.

At least, that's what typically happens. Whereas traditionally the experiment has been used to illustrate how one braking can percolate downstream, creating traffic jams far from their point of origin, in this version of the experiment one car is supplemented with by AV tech. The consequences of this mixed-mobility experiment seem astounding. In the beginning, the video shows the 21 cars driving in concentric circles, as expected. 20 of these cars, colored white, are driven by humans, while one, colored silver, is autonomous.

Soon, one car stops, and for the first 25 seconds it seems as if the cars are again destined to traffic purgatory—every car must slow down and adjust its speed to avoid colliding with the car in front of them. The truly impressive feat comes around 0:25 when suddenly you begin to notice that the cars are starting to slow down less, and less, until, unexpectedly they begin moving almost fluidly in circles, again and again.

What happened? The silver car has actually begun to *control* the traffic flow of the circle, braking efficiently and often enough that it actually reduces congestion altogether. According to researchers, the presence of the single AV car reduced the standard deviation in the speed of all the cars by about 54%, while reducing the number of sharp braking events as low 2.5-to-0 per kilometer. Add in the benefits of reduced braking (down 74.4%), and the average fuel savings of adding one AV was about 27.9%.[123]

So, how are we to interpret these results?

Certainly these results are significant. They indicate that AV tech can significantly dampen traffic waves caused on by lane changes and other slow-down events. At the same time, these events are in experimental conditions and simulate single-lane traffic. Although the authors contend these results can be expanded to multi-lane freeways, they also note that AV dampening can create wide-spaces between vehicles, incentivizing more lane changes, and potentially adding to traffic.[124]

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[122] goo.gl/8rwzmk

[123] https://arxiv.org/pdf/1705.01693.pdf).

[124] https://arxiv.org/pdf/1705.01693.pdf) p .14

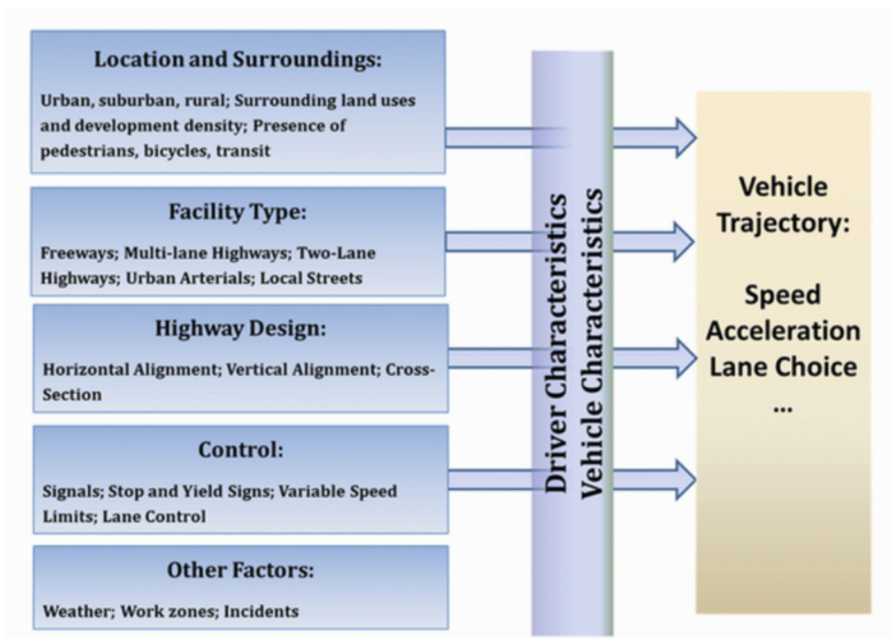
Top 4 Behavioral Characteristics Affecting Traffic Flow*	Simple Terms	Example
Attention and Information Processing	Emergent research on reaction time indicates that humans can process no greater than 60 bits of information per second.**	Traffic engineers are conscious of our reaction times, and design highways according to our processing abilities, providing road exit information sequentially, for instance.
Vision	Researchers believe 90% of the information drivers rely on is visual.	***Visual Skills Required for Driving*** **Visual Acuity** *distance vision* **Sensitivity to Contrast** *distinguishability between objects and their backgrounds* **Peripheral Vision** *detecting objects outside of area of most accurate vision* **Movement Depth** *the ability to infer speeds of moving objects* **Visual Search** *ability to search changing environment for relevant information*
Perception-Reaction Time (PRT)	The time it takes to sense an object, process the information, decide whether to respond and how, and initiate the response. Researchers believe that the upper limit of response times tend to be around 2 seconds.	***Factors Influencing PRT*** *Driving Environment* *The Object Detected* *Driver Characteristics*
Speed Choice	Can affect the forward-looking vision for cars located behind tall vehicles.	Following vehicles with low sight-distance may increase distance between vehicles, reducing road capacity.

Sources:
* Lily Elefteriadou, An Introduction to Traffic Flow Theory, (New York: Springer-Verlag, 2014)
** "New Measure of Human Brain Processing Speed," MIT Technology Review, August 25, 2009.

Due to their highly structured setting, these results should be taken with a grain of salt. At the very least, they indicate existing technology could reduce some traffic events, some of the time. Whether they fundamentally end traffic by changing the physical capabilities of vehicles is still up to debate. After all, the authors themselves indicate that lane-changes, a behavioral trait of driving, are highly potent methods of inducing traffic. Very likely then, the potential improvements AVs provide in reducing congestion will be behavioral rather than physical.

According to traffic engineers, four driving behaviors affect traffic flow: Attention and Information Processing, Vision, Perception-Reaction Time (PRT), and Speed Choice, each of which is explained in the chart below.

It is within these characteristics that proponents of AV technology propose to reduce traffic. AVs improve sensor range AVs never tire. AVs can react faster. But AV speed will be controlled externally. Finally, there are environmental factors, charted on the infographic below. Environmental factors consist of vehicle location and surroundings, facility (infrastructure) type, highway (road) design, control (regulation), and other factors (weather, parked cars, obstacles). Together, environmental factors, driver characteristics, and vehicle characteristics determine vehicle trajectory—movement behavior of singe and grouped vehicles.



Factors Affecting Traffic Chart [125]

Unfortunately for traffic engineers, modeling (and therein improving) the vehicle trajectory of many vehicles is far more difficult than modeling the trajectory of only one. In light of this reality, when thinking about vehicle trajectory and Traffic Flow Theory, it helps to keep in mind the difference between linearly related models and complexly related models—that is, models with variables that interact in an exponential fashion

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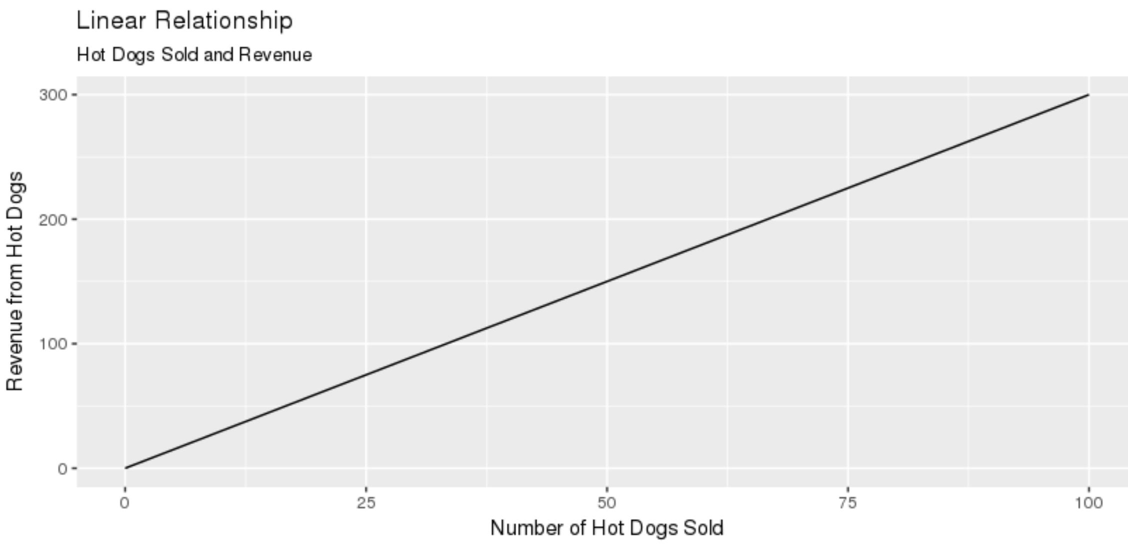
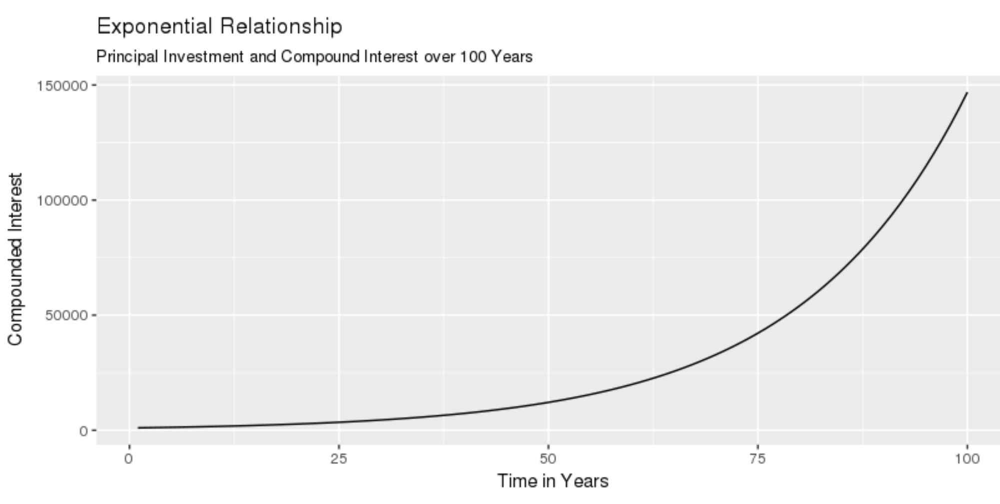
[125] Cite

Linear models illustrate a tit-for-tat reality that is ever-constant. Take the business model behind a hot dog stand for example. If a hot dog vendor sells her hot dogs for $3 each, she can expect to receive that amount for every item she sells. The interaction between the hot dogs she sells and the revenue she earns is one-to-one (see below).

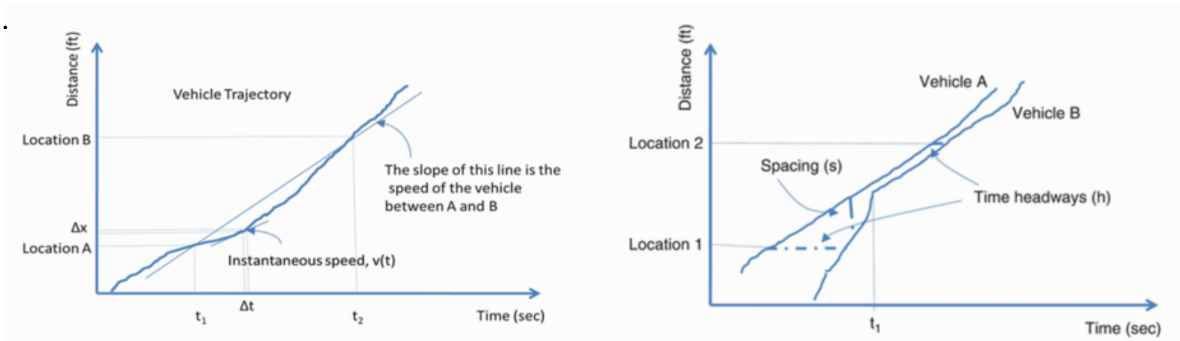


Complex models are a bit different—they are, by definition, more than the sum of their parts. A common example of a complex relationship is that of compound interest on an investment. If I invest $1000 into Really Big Bank, and they tell me I will earn interest on my principal—say 5%—then if I wait 100 years and check my bank account, I should expect to see a lot more money (about $146,879.50) than I started out with (see graph below).



That's the benefit of "compounding" dividends superlinearly—if the 5% interest I earned effected only to my initial investment, I would have less of an incentive to give the bank my money. Traffic flow models work similarly to the hot dog stand and the compound interest examples. At low volumes, cars can be easily modeled; their trajectory tends to be to be approximately linear over time. At higher volume, where the number of cars is substantial, travel efficiency begins to break down. The difference between these two states are illustrated on the graphs below.

L. R.



Single (L.) and Dual (R.) Dynamics of Traffic Map[126]

Graph L. realistically depicts the trajectory of a single vehicle between two points over the period of $t_2 - t_1$ seconds.[127] The uneven line represents a vehicle's position at any given time (t), where the instantaneous speed of the vehicle ($v(t)$) is $\frac{\Delta x}{\Delta t}$. The slope of the smooth line is the average speed between locations A and B. Overall, this graph illustrates that single vehicles tend to drive relatively efficiently—the smooth line essentially acts as a line of best fit.

Turning to graph R, we see that as more cars come on the road, driving behavior necessarily shifts. The graph models two cars on a single lane highway, Vehicle B following behind Vehicle A. Whereas the factors influencing Vehicle A's trajectory are essentially those that dictated its movement in graph L, those affecting Vehicle B's trajectory are slightly different. For one, it must take the additional step of tracking Vehicle A's movement so as to avoid a collision. Consulting graph R, we can see precisely its behavior.

Initially Vehicle B is driving faster than Vehicle A. However, as their proximity closes in—that is, as the spacing s between Vehicles is reduced—the Vehicle B's is completely unavoidably determined by Vehicle A by location t_1. We can confirm this observation by noting the change in each vehicle's "time headway" h—the time it takes for vehicles to pass a certain location. For example, at Location 1 Vehicle B's slope (its rate of movement) is steeper than Vehicle A's at the same location. Evidently, B is travelling faster than A and if it does not adjust its speed it will collide with the car in front of it. Thankfully, by Location 2 we can see it takes Vehicle B just around the same time as Vehicle A to pass Location 2—they are travelling at similar speeds.

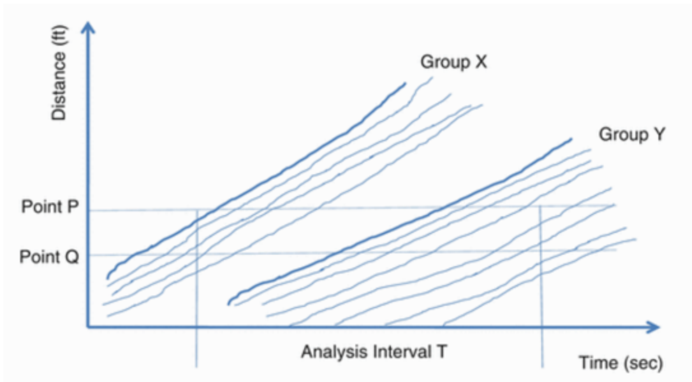
Graph M takes the Vehicle A-Vehicle B relationship one-step further by mapping the behavior of two groups of vehicles, Group X and Group Y. As before, the lead car of each group is depicted by the thick blue line, with the behavior of other vehicles responding accordingly. As can be seen, there is a significant amount of time and space between the groups—evidently the

[126] cite

[127] The imperfect nature of the graph serves as a helpful reminder that, once again, modelling reality is far "noisier" than theory often allows for.

leading car of group Y does not desire to reach the trailing car of Group X. Due to the difference in group speed, the vehicle flow of each group is also different. In other words, the rate at which cars pass point P would be greater than the rate of those passing point Q.

M.



Group Dynamics in Traffic Map[128]

For explaining just two groups of cars, the dynamics of traffic is already complicated. Imagine, now, not simply two groups of cars, but hundreds of groups of drivers. Instead of single lane highways, these groups of drivers are on vast, multi-lane highways—each driver containing their own preferences, their own biases, abilities, reaction times, and distractions. Now factor in weather, passengers, pre-existing conditions (such as lack of sleep and hunger), and *predicting* traffic proves to be a decidedly non-linear affair—one adverse action, like slamming on the brakes or tossing a bag out the window, has compound consequences.

For all this complexity, however, traffic flow density can be (unrealistically) simplified. The density of traffic is determined by tracking the number of mobile units (e.g. cars, trucks, bikes, pedestrians) per unit of distance (e.g. miles, kilometers, feet). Automobile traffic can be measured, for instance, by tracking vehicles per mile (VPM) or even vehicles per mile per lane (VPMPL).[129]

All infrastructure, sidewalks, train cars, highways and highway lanes, have a "maximum density" (D_{max}) that is estimated, like all models, by assuming facts about the world. In this case, engineers develop a "minimum spacing" figure (s_{min}) which is found by assuming an average vehicle's length and adding to it a minimum gap acceptable between vehicles (usually assumed to be the space between two stopped vehicles). For instance, the most common car in the United States is either the Honda Accord or the Toyota Camry (it changes year-to-year).

According to their respective brand websites, the average Camry length is approximately 191.1 inches, while the Accord is about 192.2 inches. So, let's average these together and call the average length of the most common vehicle in the US about 191.65 inches or just under sixteen feet. Then let's add to this the distance between two stopped cars. Since

[128] cite

[129] Actually, empirically measuring traffic density has been difficult historically. Telematics insights may be a solution to traffic modelling problems.

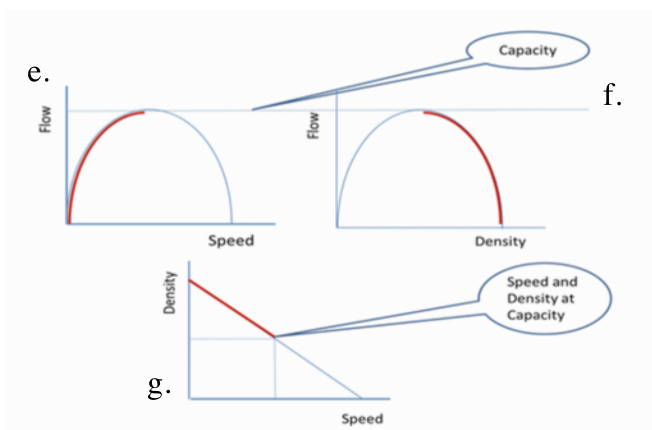
there is no hard-and-fast rule to determine this gap, we'll use half the average car-length—about 8 feet. So $s_{min} = \frac{191.65_{in}}{12_{ft}} + 8_{ft} \approx 15.95_{ft} + 8_{ft} \approx 23.95_{ft}$, or about 24 feet.

If we choose to measure density in vehicle per mile per lane units, and a mile is 5,280 feet, then we can establish the following formula for max vehicle density:

$$D_{max} = \frac{mile}{s_{min}} = \frac{5{,}280}{s_{min}} \approx \frac{5{,}280}{24} \approx 220_{VPMPL}$$

Of course, now that you have a glimpse into the arcane science of lane density, you understand what assumptions must go into vehicle length alone will fluctuate. For this reason, when researchers first began to model traffic, their reasoning was highly simplified (and linear!). Graphs e, f, and g are all iterations of "The Greenshields Model" (TGM)[130], the first traffic stream models. TGM is helpful to demonstrate the essential theoretical features of traffic flow that autonomous vehicles will have to overcome.

Starting with graph e we see in that as flow is low—that is, as the time it takes to move past a certain location is high—speed will also be low, and congestion will accumulate (red line). As speed increases, flow increases, and congestion eases (blue line). Graph f illustrates this point further: as flow increases, more cars can enter a limited space (the capacity line). As capacity is reached, density starts to accumulate (red line) and movement becomes restricted. Graph g. depicts the result of this relationship: at high density, speed is low, but as speed increases, density decreases.



Traffic Flow, Speed, and Density Charts at Capacity[131]

Theoretically, TGM illustrations of traffic flow are convenient, but this is because they are linear. In truth, modern traffic engineers understand that, at any given moment, modelling traffic is a non-linear affair affected by chance and behavior. The following model is one of the most recent iterations of flow modeling—note the difference in approach from TGM. The

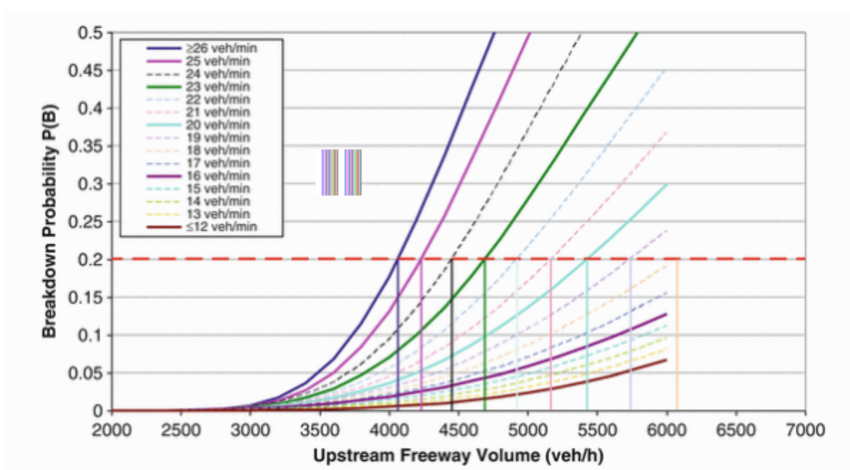
[130] Greenshields B (1935) A study of Traffic Capacity, Highway Research Board. In: Proceedings of the annual meeting of the Highway Research Board, vol 14, pp 448–477

[131] cite

model, called a Breakdown Probability Model, attempts to forecast a key question within Traffic Flow Theory: where will breakdown (the onset of congestion) occur. Of course, breakdowns some locations are more prone to congestion than others. So why don't engineers just focus on those locations? Well, has it ever happened that you were driving home from work and there was far less traffic than usual? It was about the same time, it wasn't a holiday, yet everything was eerily smooth.

Engineers are aware of this phenomena as well. That is why they approach the breakdowns not simply on a spatial-temporal scale, but probabilistically. The graph below represents a probabilistic model of a ramp-merge bottleneck—an area that is prone to breakdown. The roadway consists of two lanes per direction, and the ramp is metered—that is, vehicle road entry is controlled. The x-axis measures a range of demand for road access, the y-axis represents the probability of breakdown. Each curve on the graph depicts the likelihood of breakdown given a certain rate of metering—from less than 12 vehicles merging per minute, to more than 26 vehicles merging per minute. As can be seen, the relationship between vehicle entry rates and the probability of breakdown are exponential—as rates increase, the probability of breakdown is more than additive.

If we set our breakdown threshold at 20%–if engineers decide that a 20% likelihood of breakdown is acceptable—then meter rates must be adjusted accordingly. At a rate of 25 vehicles merging per minute (1,500 vehicles per hour), and a "upstream" capacity of 4,200, the total capacity of the roadway would be 5,700. Put another way, if we increased ramp throughput more, the number of vehicles on the roadway down the line would be higher, but the risk of congestion would also increase.



chart[132]

To review, modelling and forecasting traffic is a complicated endeavor. At a micro-level, individual cars, indeed even small groups of car, can be modelled relatively cleanly. But due to a confluence of factors, including the unpredictable nature of human behavior and the

[132] cite

cumulative effects of a vehicle movement, flow, and density, forecasting traffic flow on raw data alone can be difficult.

Enter: The proponents of AV technology.

According to these movers and shakers, the solution to this centuries old problem is to remove the consumer from the mobility equation entirely—that is, this solution is to adopt intermediary systems that separate destination decisions from movement decisions. In their proposed world of AVs, you can go where you want to go, but how you get there is not your choice—it's the system's.

What to make of this claim? When there is no empirical data to back a claim about future advancements, this is when theory has the potential to assist us. Economists who attempt to understand the choices and decisions individuals are involved in the theory of games. Developed by the polymath John von Neumann and the economist Oskar Morgenstern, Game Theory was developed as an attempt to predict the cooperativeness of foes and allies during high stakes situations. Game Theory, for instance, found great use during the Cold War as allies attempted to determine just how dangerous the nuclear threat was.

More recently, game theory has been joined with new computing capabilities to develop Algorithmic Game Theory, a subfield of game theory that uses computer algorithms to simulate the decisions of many agents with a stake in some outcome. In recent decades, Algorithmic Game Theory has achieved a sort of renaissance—developing into one the hottest new fields of the modern. One concept the field has produced is the so-called Price of Anarchy, a necessary concept to address in considering the potential effects of vehicle autonomy on traffic.

The Price of Anarchy and Selfish Routing

Admittedly, the Price of Anarchy (POA) doesn't sound like an appealing concept. But contrary to its name, the subject matter itself is pretty benign. Like gross domestic product (GDP) or the unemployment rate, the Price of Anarchy is really just a unit of measurement. In particular, POA measures the efficiency of a networks use in a particular way.

First, some definitions. A network can be thought of as an infrastructure of composed of at least two connections such as the connection between internet routers or a highway system. As for efficiency, this be taken to mean the average time to traverse a network, such as the average travel time between point A and point B on a highway system. What makes the POA so meaningful is that it is a measurement of two *types* of efficiencies: a centralized efficiency and a decentralized efficiency.

In a centralized model, agents travelling between two points do not get to choose which routes they take; they take their orders from a central hub. The benefits of this method is that that although some people will inevitably be routed to longer paths, the average time of all travel will be optimized. In the decentralized model, agents get to choose themselves which routes they take, leading to an inefficient allocation of routing. As a consequence, the average travel time among travelers is less than optimal.

You and I should be familiar with this latter model, after all, this is essentially how travel happens today. Game Theorists call this method of movement Selfish Routing. Now here's the fascinating part, according to theory the POA of Selfish Routing over its optimal counterpart

4/3. In other words, the average travel efficiency using Selfish Routing, the way we drive now, is *only a third less efficient than if travelers were to be assigned paths by a central hub—the most efficient allocation of transportation resources.*

If true, and many purport that it is,[133] then this is no small discovery. Such a theory would mean that the transportation revolution many expect to come from autonomous vehicles would never arrive; that AVs could only improve traffic flow by 33%. The theory implies, for instance, that if drivers in LA were to be allocated by a central system, traffic would be reduced by a maximum of 34 hours, from 104 hours annually in traffic, to 69.4. Certainly this is no small improvement, but it's a far cry from the ideal system of travel proponents of AV tech claim will occur.

So is the theory true? It's possible. In an email correspondence with the Tim Roughgarden, the heavily cited theorist behind the POA/selfish routing problem, said the following:

> The 33% bound (which seems to really stick in people's imagination) is specifically for the case of affine or concave cost functions. (Where the cost function describes the time per-unit of traffic as a function of the amount of traffic.) My work quantifies the analogous loss for all other cost functions as well, and the number goes to infinity (though not too quickly) as the cost functions get increasingly nonlinear. Heuristically, one might hope that in [transportation] networks that are not too overloaded, the cost functions are reasonably well approximated by affine (or at least low-degree polynomial) cost functions. This is the perspective I take in my 2016 book and this CACM article. Finally, there have been a few empirically studies trying to estimate the POA in various cities over the world (Boston, Singapore, and others) and the results are always oddly close to 4/3. [Though I am] [n]ot clear if this is a coincidence or not.[134]

Put in plain English: it depends. If one's rate of travel is a function of the traffic they are in and traffic times are linearly related, then theoretically yes a central hub controlling autonomous vehicles would be only able to improve traffic marginally. But if traffic is the result of complex interactions, then theoretically AVs could improve traffic exponentially. As far as we have demonstrated, according to Traffic Flow Theory both linear and complex traffic interactions tend to occur.

Theory Versus Data: A Debate as Old as Time

For many people, the previous section was probably a far more in-depth analysis of traffic and network systems than they ever expected to read—and this was without including a

[133] *Algorithms to Live By: The Computer Science of Human Decisions*, Brian Christian & Tom Griffiths (Henry Holt and Company, 2016: 237); "Driverless Cars Could Only Make Traffic 33% Better," Chris Weller, *Business Insider* (July 18, 2016); http://www.businessinsider.com/driverless-cars-wont-eliminate-traffic-2016-7; "Driverless Cars Represent the Challenges of Hyper-Innovation," James Mazarakis, *The Daily Collegian* (April 3, 2017) https://dailycollegian.com/2017/04/driverless-cars-represent-the-challenges-of-hyper-innovation/

[134] Personal correspondence with the author

majority of the math behind these claims! But, if we were to analyze for ourselves the claims of the proponents of AVs, a review traffic dynamics was unavoidable. As I have argued, when data is limited, theory is at least useful to help us think about nebulous matters—to fill-in conceptual gaps.

After exploring network theory, we discovered that many have latched onto Roughgarden's POA and Selfish Routing a limiting feel to them. After further exploration, and direct contact with Roughgarden himself, we discovered that these interpretations were a bit shallow. Depending on the nature of traffic, it's possible for AVs to improve traffic. We have therefore benefited from the knowledge that no one is quite sure; that reports of AVs improving traffic or being unable to improve traffic are not yet set in stone. More research must be done into this critical issue. If the cost functions of traffic turn out to be largely linear, billions of dollars could be wasted transitioning into an infrastructure that, at best, is only slightly more efficient than that of today.[135] If they are not, then AVs may sincerely improve traffic.

To summarize what we know so far, we have learned the dynamics of traffic flow theory. That single cars are easy to model, that groups of cars in single lane traffic demonstrate specific behavior, and that as the volume of traffic increases, so too does complexity. As result, the ability to for traffic engineers to forecast traffic becomes more difficult.

Next we reviewed the 9 factors traffic engineers believe affect traffic flow efficiency—4 physical characteristic s of vehicles and 5 behavioral characteristics of drivers. We determined that of the first category, AVs are predicted to innovate in only one area: braking. To that end, we reviewed some compelling empirical evidence that autonomous braking capabilities, by communicating with other vehicles, could substantially improve traffic flow efficiencies.

However, this data was collected highly stylized fashion and may not expand to the larger world. Even these efficiencies could expanded, moreover, researchers admit that they may create feedback loops that induce more traffic. Because most substantial advances in AV tech have yet to arrive, empirical evidence on the effectiveness of AVs on traffic reduction is scarce. Thus, we turned to the forefront of game theory to investigate how researchers believe AVs will affect traffic flow.

In turning to game theory we discover that the Price of Anarchy, a ratio of suboptimal efficiency over optimal efficiency, is 4/3. To many, this means that current traffic flows are only slightly less efficient than they could possibly be But, as we have said, these are highly stylized models that may not reflect the real world. These models certainly are helpful tools to guide our thinking about traffic efficiency, but more research must be done to determine their accuracy during the current period of technological transition.

In fact, we don't even have great data as to what a *mixed* transportation economy looks like. How can we be so sure that AV tech will be effective in reducing congestion during the *technological transition*. After all, 100% adoption may be nice, but when some are driving and others are not, won't that cause chaos. Just how long will it take for AVs to integrate into society in way similar to that of cars any?

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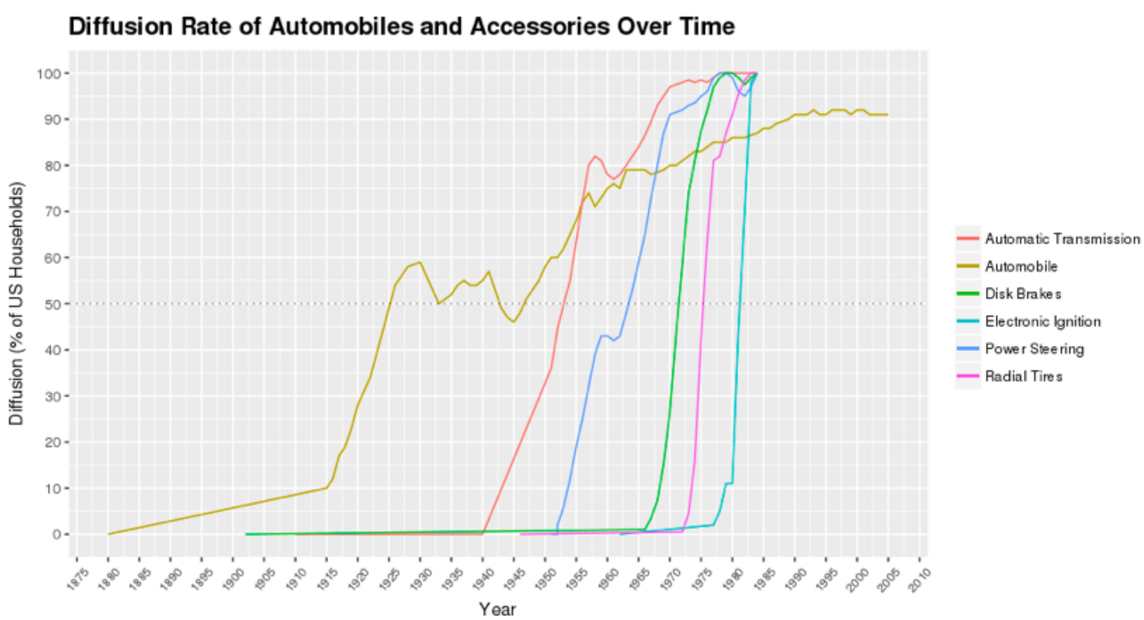
[135] Efforts have been made to connect Tim Roughgarden to receive his input on the matter. The report will be updated if and when a response is received.

Let's look at historical precedent. Below are the estimated diffusion rates to US households over time of the automobile and five supplemental technologies. The x-axis measures time since 1880. The y-axis measures the percent of households owning a particular technology. Finally, it is important to note that some variables lack pertinent data, especially early adoption rates for older technology. The result can be oddly straight lines such as that in the Automobile variable. We do know that the first automobiles arrived in America during the 1880s, but sufficient data was not collected until around 1908-1915. Much of the same can be said for the other variables. Therefore, this data should be taken as approximations to help our thinking, rather than absolute truth.

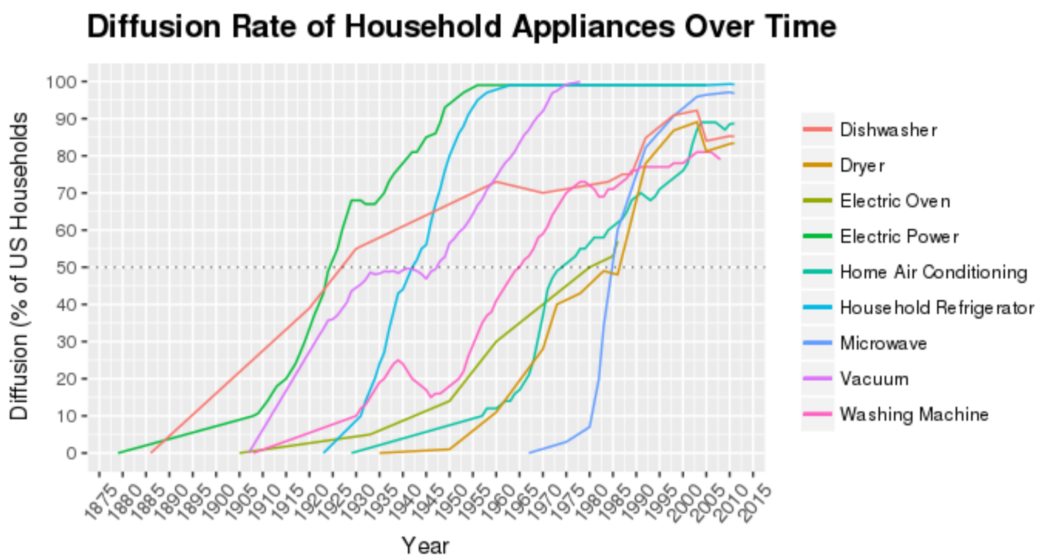
One way this data can guide our thinking is that it demonstrates the difference between the invention of technology and its widespread adoption. Disk brakes, electronic ignition systems, power steering, and radial tires, all were important features that improved the safety, efficiency, and drivability of automobiles. Even still, it took almost 80 years for innovations like disk brakes to become standard devices.

At the same time, the time span between invention and integration also seems to be decreasing, at least according to this data. Compared to disk brakes, electronic ignition systems were integrated relatively quickly, taking just over twenty years to integrate into all newly produced vehicles.

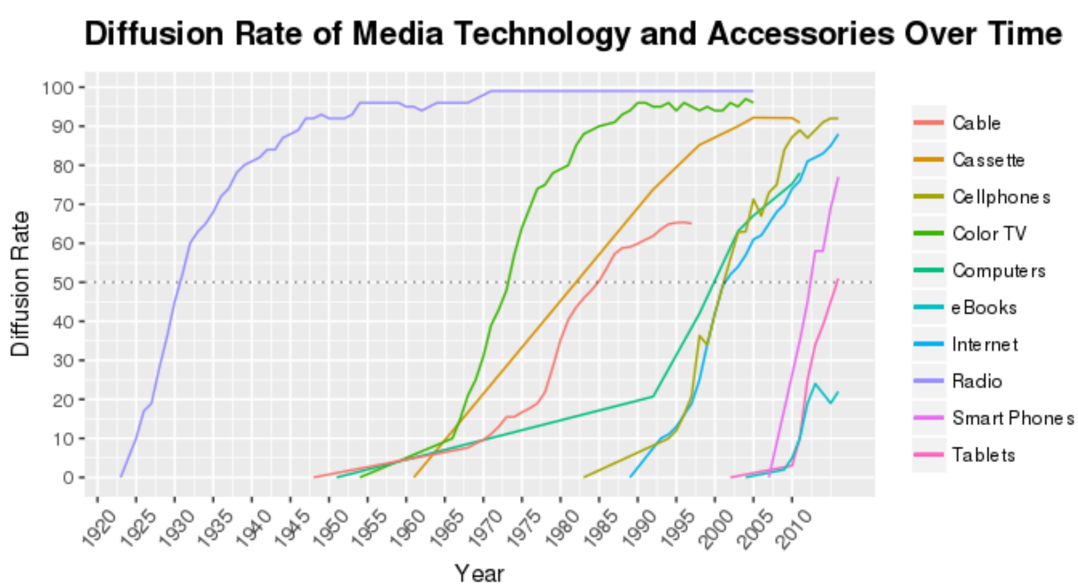


The diffusion rate of automobiles and automobile accessories over time illustrates two important points. First, there is a history of lag time between invention and adoption of automobile technology. If history is any guide to the pace of integration autonomous technology into vehicles, we might be safe in presuming there will be adoption delays. Economically this makes sense. Firms may rush to patent new technology to get an edge over the competition, but they must also then test this new technology, attempt to integrate it into their existing vehicles, and ensure they are allowed to sell them to the public.

Second, the time it takes to invent and adopt technology becoming demonstrably shorterat a macroeconomic scale.[136] Unfortunately, it would be a major digression to discuss why this is the case. Instead I provide the following sample of this well-established macroeconomic trend. In the first graph, I model the diffusion rate of appliances to American households over time. Note that newer technologies tend to have slightly steeper slopes.



But this is nothing compared to media technology. Below I have graphed the diffusion rates of media technologies to American households over time. Notice how steeper the slopes of newer technologies and media get?



136 scale

The difference between diffusion rates of household appliances and of media technology underlines an important point about forecasting product use: the nature of a product type influences the breadth of its adoptability.

Some products like dishwashers and dryers *generate* network effects—their singular nature encourages shared-use by many agents. Other products such as cell phones and the internet *rely* on network effects—the more agents use the product, the more pervasive and effective the product becomes. Traditionally, goods and products that encourage shared-use have also undercut their own necessity—an entire dormitory floor can use a single washing machine. For this same reason, not everyone needs an automobile—an entire family can share a car, even if access to the car might be contentious at times.

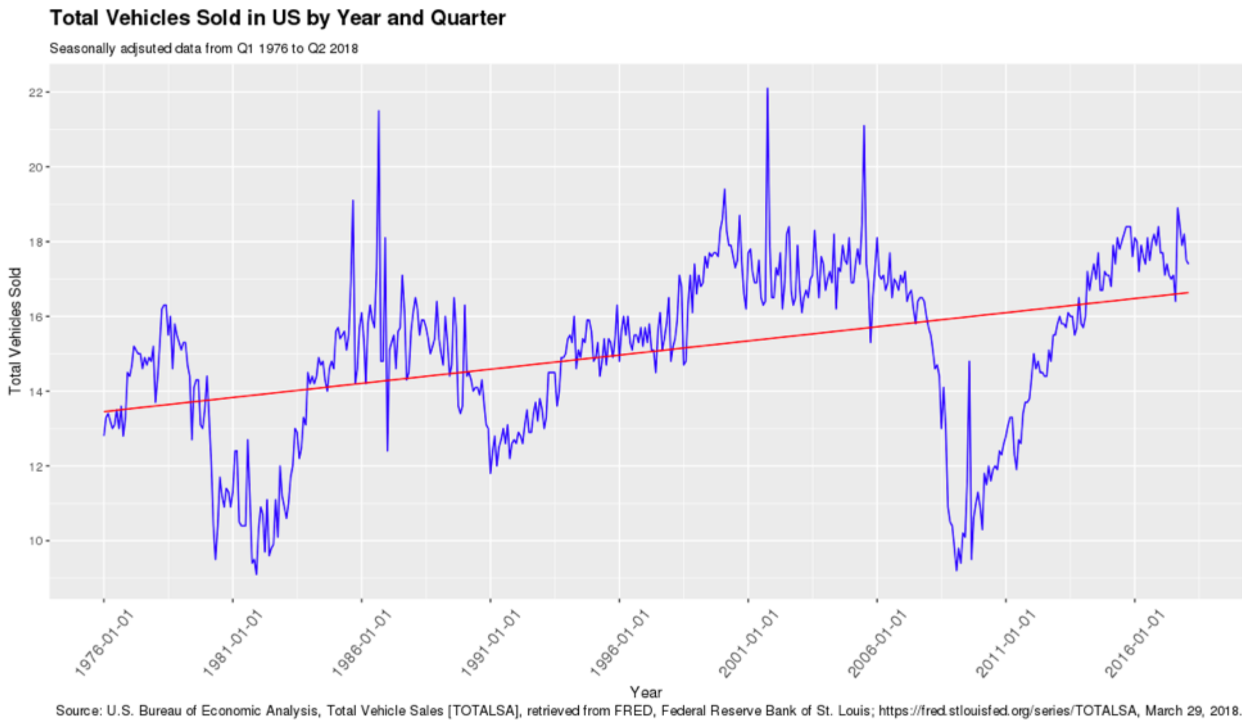
The historical data reflects this point. Some goods, such as automobiles, washing machines, and dryers tend to garner between 80% and 90% ownership among households. Others, such as electricity, refrigerators, and radios, achieve closer to 100% diffusion—I could share my refrigerator with others, but how can I guarantee my food will be there later?

In sum, these graphs demonstrate at a selective level the macroeconomic trend of increased technology adoption. The data also indicate that there are a variety of adoption rates to be found at the micro-level, however, and that forecasting will depend product-to-product. One way we can guide our intuition and thinking about the future of adoption rates is to ask whether a product *generates* network effects (automobiles) or *relies* on network effects (smart phones). Determining the nature of a product in this manner is a useful heuristic tactic when available data is lacking.

When it comes to autonomous vehicles, for instance, unless the cost of owning cars diminishes significantly or the usefulness of cars is otherwise replaced, we should expect similar trends in the sale of cars. As for supplemental automobile technology, such as disk brakes, the historical data presented above indicates that we should expect lag time between invention of autonomous features and the integration of this tech into commercial products.

But how much lag time exactly? After all, autonomous vehicles are markedly different than automobiles currently—they may achieve the same goal (transporting people from A to B) but the manner in which this is achieved is different. Let us also not forget that while firms attempt to be safe and follow the law before introducing a product, they are also in a race to enter a highly competitive industry. Below I have graphed federal reserve data on total vehicle sales in the US from 1976 to 2018. The data is seasonally adjusted by quarter—which simply means that weights are given to the data to even out annual fluctuations in vehicle buying habits.

So what does the data say? As can be seen, there is great fluctuation in auto sales quarter-to-quarter and year-by-year, but that overall sales tend to be relatively similar. This conclusion can be seen in the path the red line traces over total vehicle sales. Notice also the extreme points. In 1982 and 2009 total vehicle sales reached a nadir of about 9 million—both during recessionary periods. At their apex, total vehicle sales reached around 22 million vehicles in 2002.



As can be seen, in the short-run total vehicle sales can experience large fluctuations, even adjusted for seasonal variance. Overall, total car sales are up year-to-year, but not by much. From Q1 1976 to Q2 2018, total vehicle sales trends only increased by around 2,00,000 vehicles. Add to this the knowledge that the average age of passenger cars in the US is the highest its ever been (11.6 years according to one statistic),[137] and it becomes clear that growth in car sales is only getting harder to achieve.

Why is this relevant? Because, while a given year might see some gains in total vehicle sales, the overall slow growth in the market cuts into earnings potential, fosters wage uncertainty, and makes causes existing firms to compete more fiercely. Therefore, if new features can be added to cars, we can also be sure they will be as soon as is feasible. In a nutshell, if historical trends are maintained, the data indicates that lag time between invention and integration will get shorter as time moves forward.

Platooning Problems

At the very least, AVs won't replace personal vehicles overnight. But even when they begin to replace some, we can imagine there will be infrastructural changes. Recall if you will, that behavioral decisions most likely to induce traffic—from stimulating smart phones to distracting passengers, the number of opportunities presented to us to drive distracted are boundless. So what will roads look like when AVs and personal vehicles are joined together? Researchers can more than imagine the problems that may ensue.

[137] cite

Many believe autonomous vehicle will improve transportation networks and are hard at work modeling how AVs could potentially improve congestion.[138] Take "platooning" for example. To platoon AVs together is to engage in the not-so-simple task of grouping "smart" vehicles together close enough as to increase overall road capacity. According to one report, platooning vehicles together could increase road capacity threefold.[139]

The theory goes that by allowing for inter- and intra- car communication, and by using sensor technologies, platoons of vehicles could optimize road space more effectively compared to typical human drivers. Another area of optimization for platoons would be at traffic lights—whereas currently human drivers accelerate in *response* to the cars accelerating ahead of them (if they're smart), platoons of AVs could *simultaneously* accelerate, therein decreasing travel time and increasing road capacity.[140]

So the theory goes, anyway. In reality, the benefits of AVs may not pan out—at least, not in a mixed autonomy setting anyway. Simulation models in at least six studies indicate that, for traffic flows to see improvements on freeways, much or most cars must be autonomous.[141] To summarize the results of one study on the effect of vehicle autonomy on traffic flow:

a. Road capacity increases exponentially as the share of autonomous vehicles on the road increases.
b. As seen in the Phantom Braking example, the efficiency capacity occurs "as early as the first autonomous vehicle."
c. As opposed to increased capacity, increases in speed during periods of high capacity "…will only be possible for purely autonomous traffic."

Put even more bluntly, the report concludes by saying, during a transition period, "The introduction of autonomous vehicles will succeed, in the opinion of the author, only in their

[138] cite

[139] (J. Lioris, R. Pedarsani, F. Y. Tascikaraoglu, and P. Varaiya, "Platoons of connected vehicles can double throughput in urban roads," *arXiv:1511.00775*, 2015; Daliel A. Lazar, Samuel Coogan, and Ramtin Pedarsani).

[140] (J. Lioris, R. Pedarsani, F. Y. Tascikaraoglu, and P. Varaiya; A. Askari, D. A. Farias, A. A. Kurzhanskiy, and P. Varaiya, "Measuring impact of adaptive and cooperative adaptive cruise control on throughput of signalized intersections," arXiv preprint arXiv:1611.08973, 2016.)

[141] J. Vander Werf, S. Shladover, M. Miller, and N. Kourjanskaia, "Effects of adaptive cruise control systems on highway traffic flow capacity," Transportation Research Record: Journal of the Transportation Research Board, no. 1800, pp. 78–84, 2002; B. Van Arem, C. J. Van Driel, and R. Visser, "The impact of cooperative adaptive cruise control on traffic-flow characteristics," IEEE Transactions on Intelligent Transportation Systems, vol. 7, no. 4, pp. 429–436, 2006; R. Jiang, M.-B. Hu, B. Jia, R. Wang, and Q.-S. Wu, "Phase transition in a mixture of adaptive cruise control vehicles and manual vehicles," The European Physical Journal B, vol. 58, no. 2, pp. 197–206, 2007; Y.-M. Yuan, R. Jiang, M.-B. Hu, Q.-S. Wu, and R. Wang, "Traffic flow characteristics in a mixed traffic system consisting of ACC vehicles and manual vehicles: A hybrid modelling approach," Physica A: Statistical Mechanics and its Applications, vol. 388, no. 12, pp. 2483– 2491, 2009. [13] A. Kesting, M. Treiber, and D. Helbing, "Enhanced intelligent driver model to access the impact of driving strategies on traffic capacity," Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences, vol. 368, no. 1928, pp. 4585–4605, 2010; G. M. Arnaout and S. Bowling, "A progressive deployment strategy for cooperative adaptive cruise control to improve traffic dynamics," International Journal of Automation and Computing, vol. 11, no. 1, pp. 10–18, 2014; Lazar, Coogan, Pedarsani (2017).

ability to move safely in mixed traffic."[142] In other words, in a world without autonomous vehicles, our best and most consistent simulations indicate that they would not improve travel times; though they will probably improve how many cars can operate on the road.

Pigouvian Taxation and "Use-Based Pricing": Improving Traffic, With or Without Autonomy

It would be a shame to end this report having spoken in such detail about improving traffic without at least offering a viable alternative to the problem of traffic.

As has been said, traffic is a distinct problem of urbanity. Since at least the time of Caesar, urban spaces have suffered the double-edged sword of population density—higher returns, higher infrastructural costs.[143] So it should come as no surprise that the field of economics—which itself was a response to the enlightenment thinking growing out of urban spaces—has for just as long presented a proposed solution to the equitable use of public spaces.

In *An Inquiry into the Nature and Causes of the Wealth of Nations*, Adam Smith, the father of political economy, advocated that "publick works" such as "high roads" used by merchants of commerce and travelers alike "be so managed, as to afford a particular revenue for defraying their own expence, without bringing any burden upon the general revenue of the society."[144]

Though not a direct solution to congestion, the Smith example is useful contextualization; evidently, for some time society been hard-pressed to determine the optimal and equitable distribution of payment for public infrastructure.

For readers of these reports, it should come as no surprise to learn that a direct economic solution to automobile congestion was first offered during the automobile revolution of the 1920s. For economics aficionados, moreover, it should come as no surprise that the individual who provided this solution was the second of the two fathers of welfare economics, Arthur Pigou.[145] In his book seminal book *The Economics of Welfare*, Pigou writes the following:

> Suppose there are two roads ABD and ACD both leading from A to D. If left to itself, traffic would be so distributed that the trouble involved in driving a 'representative' cart along each of the two roads would be equal. But, in some circumstances, it would be possible, by shifting a few carts from route B to route C, greatly to lessen the trouble of driving those [sic] still left on B, while only slightly increasing the trouble of driving along C. In these circumstances a rightly chosen measure of differential taxation against road B would create an 'artificial' situation superior to the 'natural' one.[146]

[142] Bernhard Friedrich, "The Effect of Autonomous Vehicles on Traffic,"in M. Mauerer et al. (eds.) *Autonomous Driving* 2016, 332.

[143] Labaschin (2017b).

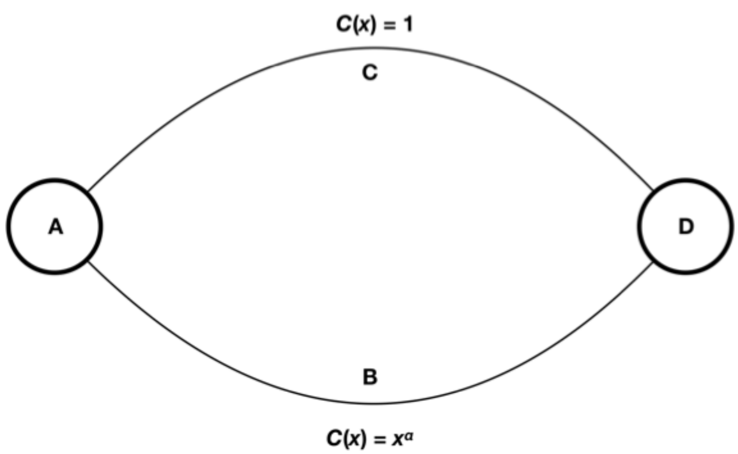
[144] (Smith; Robin Lindsey, "Do Economists Reach a Conclusion on Road Pricing? The Intellectual History of an Idea," *Econ Journal Watch*, 3(2), 2006, 297.)

[145] The other being Alfred Marshall, of earlier mention.

[146] (Pigou 1920, 194)

For those graphically-minded individuals, I have illustrated Pigou's thought experiment below. In a nut shell, by taxing path B, those carters who value the faster option will opt to continue taking the path—while all others will move to path C.

Pigou's Two Roads Problem



Incidentally, Pigou's Two Roads Problem was the inspiration behind the work in algorithmic game theory cited above. Unfortunately, Pigou's solution, although intuitive, was also a hard pill for most people to swallow. It is a general axiom that once a commodity is provided at less than its cost, the public will not want to pay any greater.

While the logic behind Pigouvian taxation and use-based pricing is economically sound, for some time there has little public sentiment behind the practice.[147] Though that thinking did begin to change with time. In 1948, economist William Vickrey made conceptual in-roads on the traffic problem by arguing that the price of congestion should be priced at the short-run marginal cost of use rather than average or long-run cost.[148] About ten years later, Vickrey returned to the subject of congestion, advocating for the integration of modern technology to alleviate the problem, writing:

> I will begin with the proposition that in not other major area are pricing practices so irrational, so out of date, and so conducive to waste as in urban transportation. Two aspects are particularly deficient: the absence of adequate peal-off [sic] differentials and the gross underpricing of some modes relative to others. In nearly all other operations characterized by peak-load problems, at least some attempt is made to differentiate between the rates charges for peak and for off-peak service. Where competition exists, this pattern is enforced by competition: resort hotels have off-season rates; theaters charge more on weekends and less

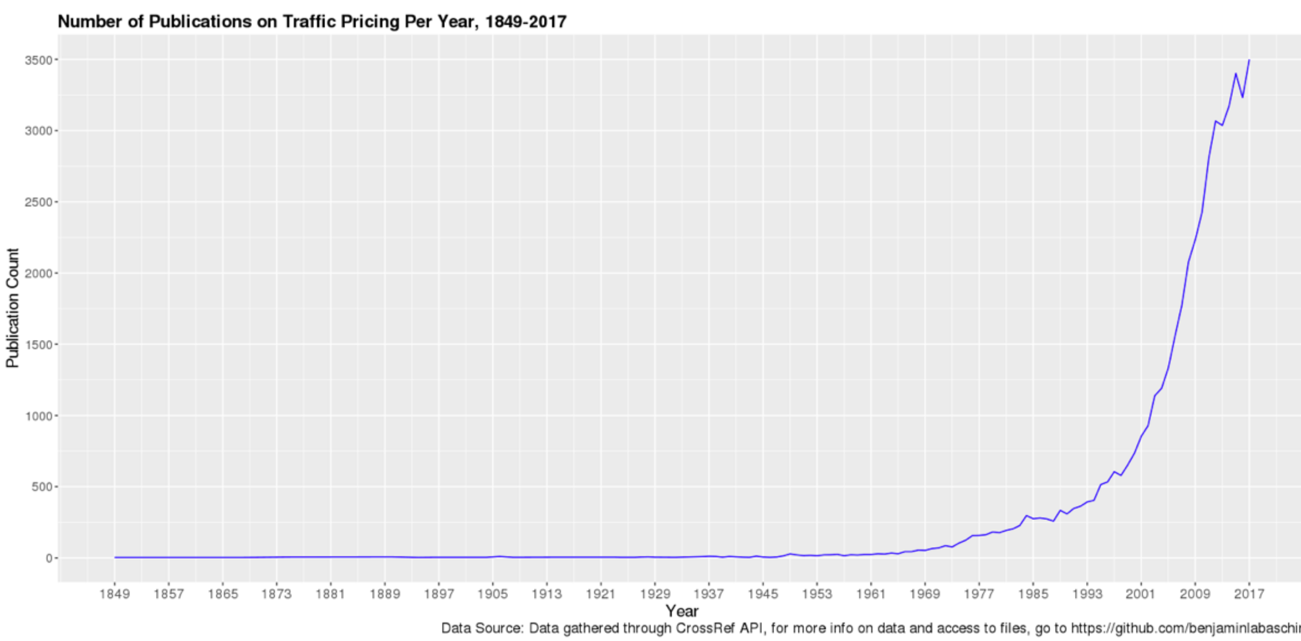
[147] Robin Lindsey).
[148] (Vickrey 1984, Lindsey, 303).

for matinees. … But in transportation, such differentiation as exists is usually perverse.[149]

Despite his sound logic, still transportation had not begun to be priced. Though thinking did begin to change on the matters. Beginning around the publishing of Vickrey's diatribe in the 1960s, economists began to realize they could contribute more robustly to the traffic problem they once considered wholly the realm of engineers.[150] Unfortunately for economists back then, technology was not half as good as in the '60s as it became beginning in the 1990s.

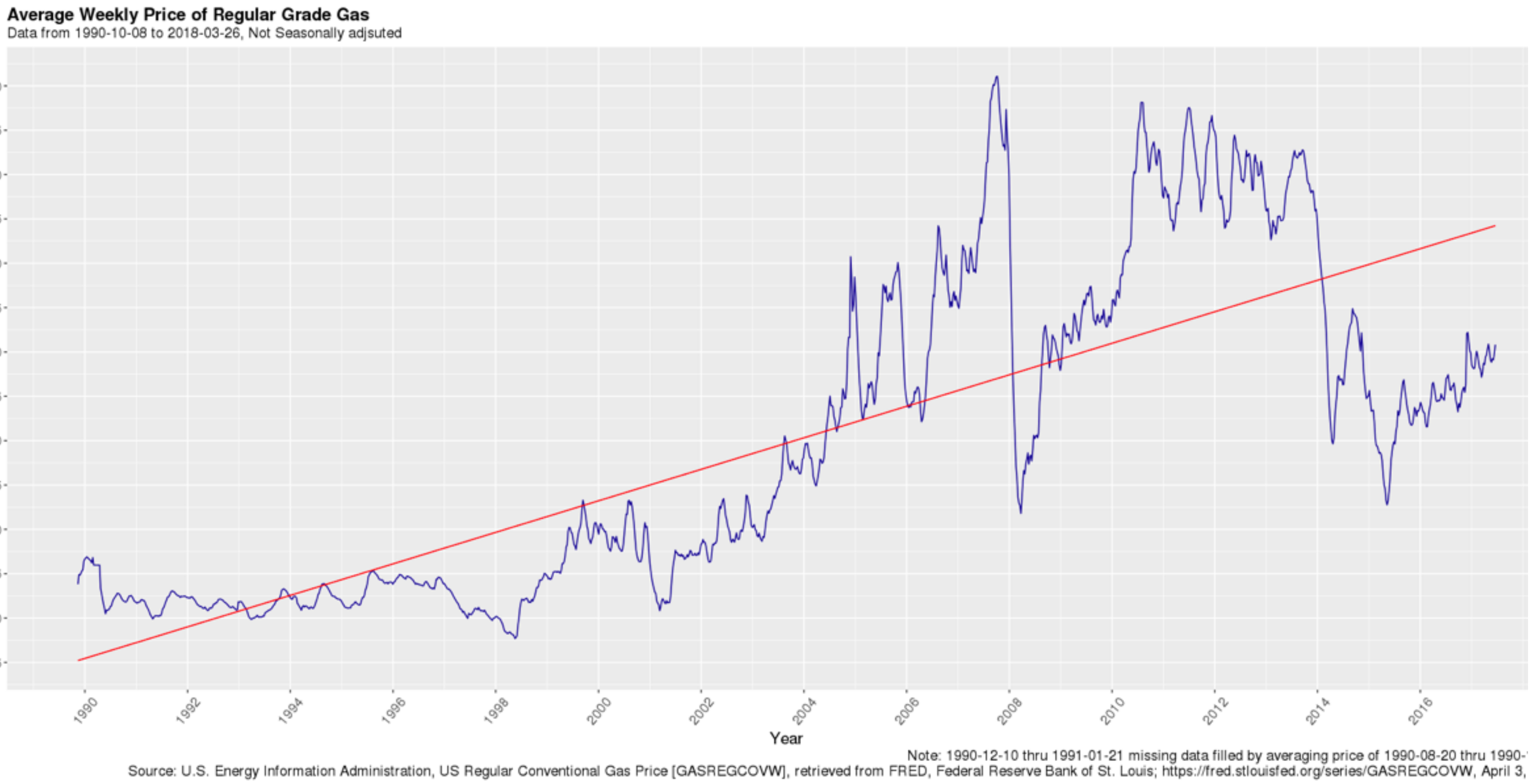
Indeed, it was the '90s in particular that saw a rise in the interest in congestion pricing, as demonstrated by the increase in the number of research papers publish about the subject—data which I have graphed on the chart below. As can be seen, there is a significant uptick of inquiries about congestion pricing starting around 1994 and lasting until 2004, the last full year of the inquiry. These results are consistent with similar technological achievements in transportation networking of the time such as the projects MINERVA and ATHENA, precursors to modern ridesharing platforms.[151]

Evidently, growth in technological potential and social interest in the mid-1990s set the stage for the shared mobility revolution that would begin about a decade later. Technological achievement was not solely responsible for the sudden interest in congestion pricing. Socio-economic conditions of the time seriously brought transportation back into focus.



To demonstrate this, let's focus on the price of gasoline. Below I have charted the weekly price of gasoline in the US. As can be seen, starting around the year 2000 until about 2008, the price of gasoline rose precipitously, reaching just above $4 a gallon.

149 (Vickrey 1963, 452).
150 (Thomson 1998, 94; Lindsey 303).
151 Labaschin 2017, Past



The high cost of gas may not have been an enjoyable experience at the pump, but to most economists of the time, such a rise in price was about due. In a 2007 blog-post titled "Hurray For High Gas Prices!", economics popularizer and *Freakonomics* author Steven Levitt reflected a sentiment shared by most serious economists of the time. Despite the rising price of gas that had no end in sight, Levitt wrote this unabashed admission: "For a long time I have felt the price of gasoline in the United States was way too low," and, "My view is that, rather than bemoaning the high price of gas, we should be celebrating it."[152]

In an article for the Eastern Economics Journal, the Harvard macroeconomist Gregory Mankiw expands upon Levitt's point in his open letter to the public: "Smart Taxes: An Open Letter to Join the Pigou Club." Lamenting the rift in thinking between the public and economists, Mankiw notes that "a 2006 survey of PHD members of the American Economic Association, 65.0 percent agreed that 'the U.S. should increase energy taxes.'" Why did/do so many economists believe in raising the cost of gas, despite its already high price, and what does this have to traffic abatement? Mankiw answers these questions in a manner that reflective of the tone of this report, writing:

> The job of economic theorists is to prove theorems. The job of policy economists is to figure out which theorems to apply. All theorems are based on axioms, so when applying any theorem to the world, one has to evaluate whether the axioms assumed by the theorem are valid. In the case of the fundamental

[152] "Hurray For High Gas Prices!", *Freakonomics.com*, Steven D. Levitt (June 18, 2007).

> welfare theorem, one key axiom is the absence of externalities. If an economic transaction imposes costs or benefits on individuals who are not part of the transaction, this theorem will not apply, and Adam Smith's invisible hand will fail to lead to an efficient outcome. This is a key lesson taught in introductory economics courses.
>
> There is, however, a simple way to remedy the market failure and restore the optimality properties from the fundamental welfare theorem: Individuals can be charged for the external costs they impose on others (and subsidized for the external benefits they give to others). The solution goes back to Arthur Pigou, the British economist from the early 20th century… In his honor, these corrective measures are called Pigovian taxes.[153]

The negative externalities of associated with the use of fuel, such as pollution and detrimental health effects, are costs that are not equitably paid by individuals; they are not included in price. As a result, the low price of gas compels individuals who would otherwise not drive, to drive more often. Indeed, were you to contact the 35% of economists who did not advocate for raising the price of gas, and ask them why, it is very likely they would simply advocate for alternative ways of reflecting the cost of driving.

These market alterations, to internalize negative (or positive) externalities, are called Pigouvian taxes, and they are exactly the solution many economists advocate for the social costs of energy in addition to the costs of congestion

Pigouvian Taxes, Congestion, and Telematics

As almost any economist worth their weight would argue, congestion is fundamentally an issue of price misevaluation. Just as the consumption of gas is seen as underpriced, so too do many transportation (and non-transportation) economists believe drivers do not pay the true of road use.

Take the monetary cost of pollution for instance. In 2013, a coalition of US agencies worked together to estimate the social costs of carbon dioxide emissions from vehicles. Social costs are those costs that negatively impact society. Though many of these costs to cannot be calculated outright (e.g. psychological costs and emotional costs), some can, including estimates about the cost of pollution and the cost of rising greenhouse gasses. According to the estimates of these US agencies, the central social cost of one metric ton of carbon dioxide will remain around $48 until 2020, though these estimates vary from $12 to $145 per unit.[154]

Using the estimate of $48 per metric ton, and emissions data released by the environmental protection agency, I have plotted below the transportation-related carbon dioxide emissions and costs over time. The graph illustrates five major modes of transportation: buses, light trucks, medium-to-heavy trucks, motorcycles, and passenger vehicles. The graph also tracks the total emissions and costs of these modes. The left-hand vertical axis tracks

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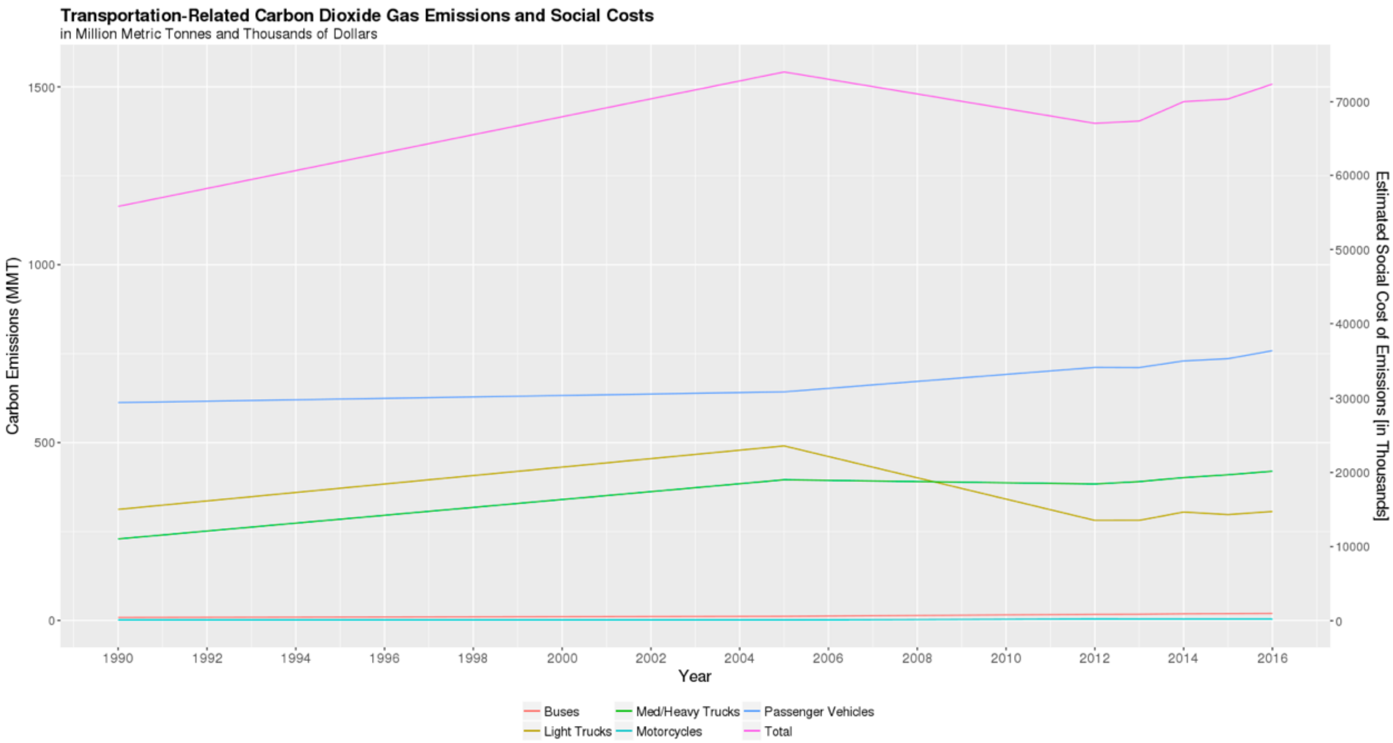
[153] Mankiw, Smart Taxes: An Open Letter to Join the Pigou Club."

[154] (US Interagency Working Group on Social Cost of Carbon 2013; RAND 11).

carbon emissions in million metric tons (MMT) while the right-hand vertical axis tracks the estimated social cost of these emissions in thousands of dollars.



Source: Environmental Protection Agency, 'Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2016' Table 2-13, 2018; US Interagency Working Group on Social Cost of Carbon, 2013

As can be seen, in 2016 automobiles released about 1500 MMT (about 1.5 billion tons) of carbon dioxide into the atmosphere. As a negative cost to society, that would amount to around $72 thousand, thousand ($72 million) in adverse effects; though the range could be as low as $18 million and as high as $217.5 million.

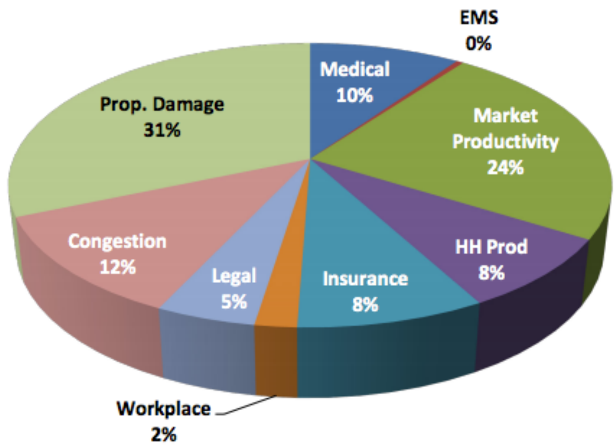
Remember, these are only the social costs of one form of pollution and greenhouse gas emissions. It says nothing of other costly social externalities. According to the most recent estimates from the National Highway Traffic Safety Administration (NHTSA), for example, in 2010 the total cost to society from motor vehicle crashes was $836 billion dollars.

Parsing the details a bit more:

a. Total direct social costs from motor vehicle crashes were $242 billion, or $784 per person in the US and 1.6 percent of GDP
b. The lifetime economic cost to society for *each fatality* is $1.4 million. More than 90% of this cost comes from the loss of workplace and household productivity and legal costs.
c. In 2010, total workplace productivity costs from crashes amounted to $57.6 billion
d. Congestion costs, including travel delay increased fuel use, and adverse environmental impact totaled $28 billion.[155]

[155] Rand

These are only some of the costs. Below is a graphic illustration of the share of the $784 billion the NHTSA accounted.



Components of Total Economic Costs Imposed on Society from Driving [156]

And these are only 2010 numbers.

The National Safety Council recently cited 2016 as the deadliest year in driving since 2007, estimating over 40,000 motor-vehicle fatalities. To make sense of those large numbers, think of it like this: these 40,000-motor-vehicle-related deaths amounted to a 6% increase from the preceding year and a 14% increase from 2014.[157]

This is not to mention motor vehicle injuries, which were up in 2016, too, reaching about 4.2 million incidents—an increase of 7% from the preceding year. As can be seen, driving imposes real costs onto society, environmentally, medically, emotionally, and then some. While some of these costs are paid, many are not.

As Gregory Mankiw articulated, when costs are not paid, the nominal price of activities such as driving are lower than their real price. These lower prices encourage more engagement in these activities than there otherwise would be at their proper price. Ostensibly, by raising the price of driving these costs will be internalized, and those who otherwise would not drive or value driving less than other may find alternate means of transportation.

But what are the empirical results of transportation pricing?

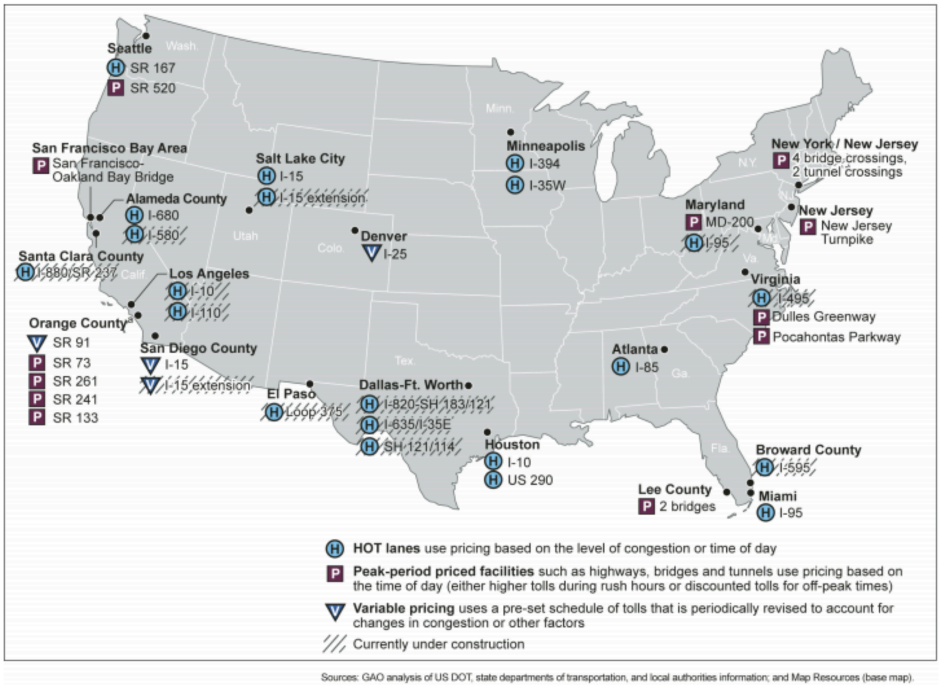
The first US congestion pricing project began in Orange County, California in 1995. Between then and 2012 over 30 additional pricing initiatives were initiated across the country. In total, the projects oversaw over 400-miles of roadway and included 12 High Occupancy Toll (HOT) lanes and 18 peak-period pricing facilities. HOT lanes are essentially what they sound like, exclusive lanes on roadways in which operators seek to use dynamic pricing to influence the speed and capacity of roadway travel.

Peak-period pricing areas are similar to HOT lanes, but instead of dynamic pricing, pre-existing toll roads are assigned fixed toll prices based on time of day and traffic precedent. Finally, several additional "variable" pricing projects were put into place in the western half of

[156] cite

[157] (NSC Motor Vehicle Fatality Estimates, 2017)

the country. These congestion pricing projects have all the characteristics of peak-period pricing, with the added feature of periodic cost revision.[158] The map below illustrates the location of these projects across the United States.



Map of US Congestion Pricing Projects as of 2012[159]

And the results of these projects?

Like so many other measurements, the success of these projects depends on what we care to optimize. If our goal is to reduce traffic, then there is reason to be optimistic. According to the evaluations of fourteen of the congestion pricing projects by the Government Accountability Office (GAO), pricing projects do seem to reduce traffic congestion. In particular, HOT lane projects increased the per unit rate of vehicle transportation ("throughput"), decreasing congestion, increasing speeds, and reducing total time driving in both priced and unpriced lanes. As for peak-period pricing, there is also evidence that drivers were compelled to drive during off-peak periods, as intended.[160] Indeed, if strict numbers are any measure of success, then the 600,000 individuals signed up for Orange County congestion pricing program as of 2016 may be a sign the public agrees.[161]

In sum, there is evidence to suggest that Pigouvian taxes are an efficient means of correcting the price inefficiencies that are detrimental to society. What is more, since the time

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[158] United States Government Accountability Office, "Traffic Congestion: Road Pricing Can Help Reduce Congestion, but Equity Concerns May Grow," *GAO* (2012), 3.

[159] Cite GAO

[160] GAO, "Traffic Congestion: Road Pricing Can Help Reduce Congestion, but Equity Concerns May Grow," *GAO* (2012), 15.

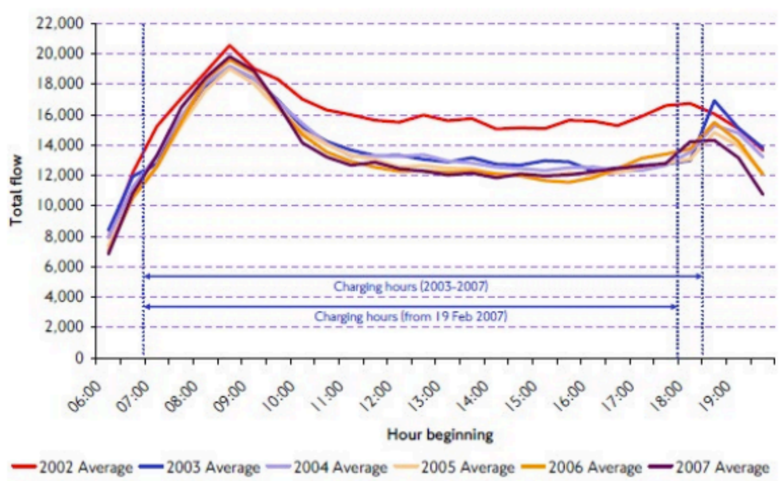
[161] Brain D. Taylor, "Traffic Congestion is Counter-Intuitive – and Fixable" *Access Almanac*, 2017.

of this study, advancements in sensor technology and telematics analysis have allowed operators to pricing congestion more precisely and dynamically. Global Navigation Satellite Systems (GNSS) allows for increased effectiveness.[162] “GNSS-based road pricing might be a fair charging instrument since these systems levy charges dependent on the distance travelled and therefore reflect a usage-based approach so that congestion cost is exactly incurred by those actors who are responsible.”

GNSS systems can charge by certain areas.[163] Why use telematics as opposed to current tech? After all, we have already demonstrated that other means of congestion abatement work. Take the experience in London, for example. On February 17th, 2003, a cordon-based congestion pricing system called was implemented within a 12-mile span of road of London. Called the London Congestion Charge, using license plates as IDs, drivers would be assigned a one-time, daily charge to enter the popular urban center.

For all intents and purposes, the congestion project has been deemed a success. One popular estimate suggests that between 2002 (pre-charge) and 2007 (4 years post charge), inner-city traffic was reduced by 16%.[164] The data charted below, however, provides a more nuanced story. On the y-axis the total traffic flow into the cordoned area is tracked. On the x-axis, daylight hours are tracked, with the hours of 7am-9pm being designated congestion pricing hours.

As can be seen, overall, traffic does decline over the 5-year period tracked. But the most congested period of time, between 7am and 10 am, shows no significant reduction in traffic flow.



Effects of London Congestion Charge on Traffic Flow Over Time [165]

How should we interpret these results? Most likely, the problem is the static nature of the cordoned area charge. Instead of charging drivers based on use and the amount of demand for roadways, drivers are being charged once at the door. One question we should ask ourselves is

[162] (Cui and Ge, 2003; Klumpp and Marner 2013,2)
[163] (Klumpp et al., 2011; Zabic, 2011; Klumpp and Marner 2013,2)
[164] (Leape, 2006; Klumpp, Marner 2013).
[165] Cite

whether is it wise to assume that all the vehicles within the area of concern are contributing to traffic equally.

The London Congestion Charge illustrates why telematics based congestion pricing is likely a superior, more efficient, and more effective means of charging consumers. In the future, it is likely that congestion pricing, not AVs, will provide the much sought after solution to our transportation inefficiencies.

Conclusion

This report represents the culmination of a four-part series on the economics of the shared mobility market. By the breadth and depth of the subjects covered within these reports, by now it should be clear how intricate the subject of transportation really is. Within these reports we have traced the centuries, from the development of ownership rights in the 1600s, to the advent of the ridesharing schemes in 1914. Within these reports have explored how and why urban spaces evolve and how our ability to move affects the economic capacity of these areas.

So wide has the scope of these reports been that four were needed simply to provide a comprehensive and satisfactory understanding of the shared mobility market and the economics of transportation. And, despite its length, four more reports about the future alone could written without repeating the concepts explained above. This is because the future holds such a wide-array of possibilities.

It was for this reason that five general areas of particular focus were chosen for this report. These areas—predictive models, labor and skills, autonomous vehicles, traffic, and congestion pricing—were chosen for the very reason expressed earlier in this report: Firms can predict all they'd like, but those firms which form the strongest backward linkages, that reduce the economic frictions inherent to the shared mobility and transportation markets—will be those best positioned to leverage future opportunities. The five-general subject reviewed in this report represented tangible, data-backed, and conceptually understood futures that firms can reasonably understand and take advantage of.

When it comes to predictive models, we have reported, not only data scientists but all whose come in contact interact with these models must hold a base knowledge of interpretation—what we called a "grammar of graphs." This grammar holds importance not simply for communication purposes, but also so that investments are not made on the false assumptions imprecise and unrealistic models.

We have written about labor and skills because many fear the replacement of workers. While we cannot guarantee that AI will replace all workers, we were able to show the threatens auto workers and professional drivers may face.

In that regard we were also able to show why the transition into autonomous infrastructure may cause at least as many problems as it solves. Traffic, for one, may not be solved in the short-run.

Finally, we were able to show that true solutions do exit to solve traffic congestion. What is more, these solutions are not fanciful; real data exists to support their effectiveness. Using telematics data and with government support, traffic could be a thing of the past.