Evaluating the impact of automation in long-haul trucking in the United States using USAGE-Hwy

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This report evaluates the macroeconomic effects of the introduction of automation in the long-haul trucking sectors in the United States using USAGE-Hwy v1.1. While much of the technology for full autonomous operation of trucks is still being developed, there are numerous examples where "level 4" autonomous technology[1] has already been deployed.[2]

A summary of the truck transport industries in USAGE-Hwy and the strategy for modeling the impact of automation in long-haul trucking is contained in Section 1. Section 2 details the shocks applied to USAGE-Hwy that reflect the impact of automation in the long-haul trucking sectors. The base year for these data and all simulations is 2016. Section 3 sets out the macroeconomic results from simulations that evaluate the impact of automation in long-haul trucking and justifies them via back-of-the-envelope (BOTE) theory and calculations. Concluding remarks and possible directions for future research are given in Section 4.

1. Modeling the impacts of automation in long-haul trucking

This section provides a summary of the different aspects of the Truck Transport industries in which we model automation in long-haul trucking as having an impact. These include labor-saving technological change, as automation allows trucks to be operated without drivers. Automation is also expected to impact the productivity of capital in the trucking industry, since driverless trucks can be operated for much longer periods without drivers who would otherwise need rest. Automation should also improve fuel efficiency and should also impact road safety with implications for fatalities and safety costs.

1.1 Automation and the truck transport industries in USAGE-Hwy

USAGE-Hwy has always included NAICS industry 484 "For-hire truck transportation" as a separate activity. Earlier analysis with USAGE-Hwy involved the introduction of four In-house or Private transport industries, one of which modeled industry 47OT.484 "In-house

[1] "The sustained and operational design domain-specific performance by an Automated Driving System (ADS) of the entire Dynamic Driving Task (DDT) and DDT fallback without any expectation that a user will respond to a request to intervene." (SAE International 2018:19).
[2] For example, UPS in partnership with tech startup TuSimple have been transporting mail using level 4 autonomous technology on the route between Phoenix and Tucson Arizona since May 2019 – see https://www.azmirror.com/2019/08/16/autonomous-semi-trucks-arizona-ups-tusimple/.

truck transportation". Another task involved updating the database behind USAGE-Hwy from 2012 to 2016. As a result, data for the two truck transport industries in USAGE-Hwy v1.1 reflect 2016 BEA and TSA data that were used in the update process. Activity in these industries in USAGE-Hwy was calibrated to be consistent with total demand for "For-hire truck transportation" in 2016 as reported in the BEA and for "In-house truck transportation" in 2016 as reported in the TSA. Also, the labor and capital inputs in these sectors were calibrated to match "Compensation of employees" and "Gross operating surplus" as reported in the 2016 TSA USE table for NAICS industries 484 and 47OT.484, respectively. Table 1.1 below summarizes the two truck transport industries in USAGE-Hwy v1.1.

Table 1.1: Truck Transport industries in USAGE-Hwy v1.1 ($m)

NAICS industry	Intermediate inputs	Compensation of employees	Gross operating surplus	Taxes	Value of industry output	Value of commodity sales
484 For-hire truck transportation	156,224	90,051	52,920	8,040	307,235	320,016
47OT.484 In-house truck transportation	175,978	86,338	50,738	0	313,054	313,054

The specific focus of this report is the impact of automation in long-haul trucking. We assume that the long-haul segment of this industry will be the first to be impacted (compared to other segments of heavy truck and tractor-trailer driving) in part because:

1. Current driving automation system development focuses on limited access highways because they are a less-complex environment than surface streets;
2. Unlike the short-haul segment, the long-haul segment involves long periods of uninterrupted highway driving; and
3. Long-haul drivers have fewer non-driving responsibilities than short-haul drivers.

Of course, there are different degrees of automation that could be implemented in long-haul trucking. For example, in a Level 4 application where a human driver remains onboard, the human driver may not need to remain in the driver's seat at all times, and theoretically could ride in the sleeper cab when the ADS is engaged and the vehicle is within its operational design domain (ODD). The driver could potentially receive their FMCSA-mandated rest or engage in other non-driving tasks while riding in the cab during the automated portion of the trip, increasing overall worker productivity. Alternatively, we could "… envision an environment when the longer, line-haul portion of truck freight movements are completed by autonomous trucks and local pick-up and delivery routes are completed by drivers" (Costello 2017:12). Either way, the most direct impact of the adoption of automation in long-haul trucking would be an improvement in labor productivity in the trucking industries.

Labor-saving technological change:

To model the impact that automation in long-haul trucking would have on labor-saving technological change, we need to isolate the component of total "Compensation of employees" in Table 1.1 above that would be impacted by the introduction of driverless trucks. We begin with data from the BLS Occupational Employment Statistics which reports "total employment" and "mean annual wage" for NAICS industry 484000 "Truck Transportation" as 1,476,970 and $46,340, respectively (see line 19161 in the file "nat3d_M2018_dl.xlsx", available from https://www.bls.gov/oes/special.requests/oesm18in4.zip). Of these employees, 880,710 are employed in the Standard Occupational Classification 53-3032 "Heavy and Tractor-Trailer Truck Drivers", earning a mean annual wage of $46,230 (see line 19503 in the above-named file). As a result, we assume that 59.5% [= (46230·880710) / (46340·1476970)] of the "Compensation of employees" listed in Table 1.1 above represents compensation to "Heavy and Tractor-Trailer Drivers" in USAGE-Hwy's trucking industries.

But not all "Heavy and Tractor-Trailer Drivers" would be affected by automation in long-haul trucking, since only some of these are long-haul truck drivers. We follow Gittleman and Monaco (2020:16-18) who employ data from the 2002 Vehicle Inventory and Use Survey. Their Table 4 reports the share of heavy trucks by sector and range of operations. Since we are interested in long-haul trucking, we consider only those heavy trucks whose range of operations was more than 200 miles. As a result, we assume that of all "Heavy and Tractor Trailer Drivers" employed in the for-hire trucking and private trucking sectors (ie: USAGE-Hwy industries TruckingServices and InHouse Trucking), 51.52% [= (6.1+12.5) / (33.1+3.0)] and 8.13% [= (3.5+1.7) / (41.3+22.7)] were long-haul truck drivers, respectively.

Finally we use the results from a 2015 study by the McKinsey Global Institute that "analyzed the detailed work activities for over 750 occupations in the US to estimate the percentage of time that could be automated by adapting currently demonstrated technology". For the occupation "Heavy and Tractor-Trailer Truck Drivers", this study found that the maximum technical potential for automation was 81.4%. This will be the maximum of the value of compensation of employees attributed to long-haul ltruck drivers that could be saved upon adoption of automation in long-haul trucking. This reflects the fact that even long-haul truck drivers execute non-driving tasks that may be difficult to replace through automation, including "checking vehicles, following safety procedures, inspecting loads, maintaining logs, and securing cargo" (Gittleman and Monaco 2020:12).

Before finishing this subsection, we estimate the number of truck drivers in both the For Hire or TruckingServ sector and the Private or InHouse Trucking sector, since we will be interested in how automation in long-haul trucking could lead to layoffs of labor in the trucking industry. BLS Occupational Employment Statistics reported that in 2017, of the 1,476,970 employed in NAICS industry 48400 "Truck Transportation", 880,710 were Heavy Truck and Tractor-Trailer Operators. Since the BLS does not report employment statistics in the "In-house Trucking" industry, we estimate employment there by subtracting the number of Heavy Truck and Tractor-Trailer Operators in NAICS industry 484000 "Truck Transportation" (880,710) from the total number employed in Occupation 53-3032 "Heavy and Tractor-Trailer Drivers" (1,800,310), presuming that all Heavy and Tractor-Trailer Drivers not in NAICS industry 484000 are employed as In-House truck drivers. So 919,600 [= 1,800,310 - 880,710) Heavy Truck and Tractor-Trailer Operators were employed in the "In-house Trucking" industry. Following Gittleman and Monaco (2020:16-18), we argued that 51.52% and 8.13% of these were Long Distance Tractor-trailer Drivers in the "Trucking Services" and "In-house Trucking" sectors, respectively. We conclude that in 2017, there were 453,742 [= 880,710 · 0.5152] and 74,718 [= 919,600 · 0.0813] Long Distance Tractor-trailer Drivers in the "Trucking Services" and "In-house Trucking" sectors, respectively. These the number of driving jobs at risk of elimination due to adoption of automation in long-haul trucking.

Fuel cost savings:

There is evidence that automation of long-haul trucking could lead to reductions in fuel costs. Driving automation could decrease fuel costs by optimizing throttle and brake controls to minimize fuel burn. Other types of automation have also been shown to lead to fuel savings. For example, the practice of "truck platooning" involves the implementation of systems that allow communication and close following between a number of trucks travelling close together. When Level 1 platooning was tested, Shladover *et al*. (2018:31) found that a three-truck platoon traveling at 65 mph could save between 5 and 6 percent of its fuel. Fuel savings can also be experienced due to maintaining lower speeds than human drivers typically choose: A truck traveling at 65 mph instead of 75 mph will experience a 27% improvement in fuel use.[3] The US is currently pursuing several policy options to improve fuel economy in large trucks (speed regulators, improved fuel economy standards) so it is difficult to estimate the incremental impact that automation will have. For the purposes of this analysis, we adopt a central case value for the reduction in fuel use by long-haul trucks due to automation of 5.22%. This value is derived from the estimated fuel savings using a 65mph limiting device on combination trucks (see USDoT (2016) Table 72 on p.130) and consistent with the fuel savings due to truck platooning cited above in Shladover *et al*. (2018), the 5 to 5.5% fuel savings expected from mandated speed controls[4] and the 15% realized fuel savings claimed by TuSimple.[5]

Capital-saving technological change:

Automation in long haul trucking should lead to a reduction in labor costs, and should also lead to fuel cost savings. But we should also expect automation to lead to capital-saving technological change, due to improved fleet utilization from the ability of trucks to potentially run nearly nonstop, without the need for human drivers to rest. Of course, while a truck could be run more hours per day, we must also account for the fact that the truck will wear out sooner. An estimate of capital cost savings due to the adoption of automation of long-haul trucking is in McKinsey (2018:19) who estimate that full driver autonomy could reduce the total cost of ownership (TCO) by 45 per cent.

Fatalities and safety costs:

In 2017, there were 4,237 fatal crashes involving large trucks: Of these 2,910 involved combination trucks, the type used in long-haul trucking (see US Department of Transport (May 2019) Trends Tables 4 and 16). Crashes involving just a single large truck killed 885 people (often the driver of the truck but sometimes pedestrians and bicyclists) and injured approximately 17,000 other people (US Department of Transport (May 2019) People Table

[3] 'https://www.nationalgeographic.com/news/energy/2011/09/110923-fuel-economy-for-trucks/
[4] https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/speed-limiter-pria-082016.pdf
[5] https://venturebeat.com/2019/09/17/tusimple-raises-120-million-to-expand-its-fleet-of-driverless-delivery-trucks/

14).[6] Of these single large truck fatalities, we estimate that 29.36% involved long-haul trucks.[7] Craft (2008) found that the critical factor was related to the driver (lack of sleep, inattentiveness, speeding or aggressive driving, etc.) for 87% of large truck crashes. Based on this information, and assuming that automation could eliminate all of the single vehicle crashes where the critical factor is related to driver performance, we estimate that approximately 155 fatalities [= $885 \cdot (2910/4237) \cdot 0.87 \cdot 0.2936$] of fatalities involving large trucks in 2017 would be avoided if the entire long-haul fleet was automated. To derive an estimate of safety costs that could be saved due to automation, we use the observation that the cost per injury crash involving a truck tractor with 1 trailer in 2005 dollars was $22,934 (USDoT 2007:10 Table 4). We update these 2005 costs to 2017 using the US health care inflation rate of 1.43.[8] As a result, we assume that automation would save $97.8 million [= $17000 \cdot (2910/4237) \cdot 0.87 \cdot 0.2936 \cdot 22934 \cdot 1.43$] in annual (2017) medical costs.

2. Constructing shocks to simulate automation in long-haul trucking

Simulations with USAGE models consist of a baseline run representing a business-as-usual evolution of the economy; and policy runs which show the evolution of the economy with the addition of policy shocks to the baseline. Comparison of a policy run to the baseline shows the effects of that policy. The baseline reflects macro and energy forecasts informed by the Annual Energy Outlook published by the Energy Information Administration. To analyze the effects of automation in long-haul trucking, we construct shocks to reflect the expected impacts of automation in long-haul trucking described in Section 1. These shocks are applied in the policy simulations.

Results from these policy simulations are compared to a common baseline which is consistent with annual increases in real GDP of 2.4 per cent, reflecting the following baseline behaviour in USAGE-Hwy macroeconomic aggregates:

- 2.7 per cent annual growth in aggregate real consumption
- 1.7 per cent annual growth in aggregate real investment
- 1.7 per cent annual growth in aggregate real government spending
- 5.2 per cent annual growth in aggregate real exports
- 4.8 per cent annual growth in aggregate real imports

The consumer price index is chosen as the numeraire, and the real exchange rate is set to devalue by -0.6 per cent per year. Aggregate labor market behaviour is characterized by:

- 1.085 per cent annual increase in hours worked
- 1.1 per cent annual increase in the aggregate real wage

We assume that the annual increase in the U.S. population is 0.936 per cent.

[6] We focus on crashes involving only a single large truck (as opposed to multi-vehicle crashes). These crashes must be the fault of the truck or truck driver. Since some multi-vehicle crashes will also be the fault of the truck driver, our estimates represent a lower-bound on the fatalities and safety costs impacted by the adoption of automation in long-haul trucking.

[7] A detailed derivation of this share is provided in subsection 2.2 below.

[8] This US health care inflation rate is compounded over 2005-2017 using data from https://ycharts.com/indicators/us_health_care_inflation_rate.

USAGE-Hwy v1.1 represents an initial 2016 equilibrium. We suppose that the first firms in the trucking industry begin adopting automation in long-haul trucking starting in 2021. This assumption allows us to explore the possible economic consequences of automation. In truth, Level 4 automation is not currently available: An environment where a driver can be completely removed from the vehicle is not a technical reality. The limited number of pilot tests for long-haul trucking still use a test driver at the wheel and operate only under favourable conditions. The rate at which these firms adopt automation will be affected by a number of factors including anticipated labor and fuel cost savings, as well as the costs associated with the driving automation systems themselves. To reflect the uncertainty around these factors, we consider three separate time paths that dictate the share of the trucking industry that begins to adopt automation in long-haul trucking over a period of 30 years.

3. Effects of automation in long-haul trucking

Simulations:

We describe a baseline simulation over a 30-year time horizon, consistent with average growth in real GDP and population in the US of 2.4% and 1%, respectively. Against this baseline, we suppose that automation in long-haul trucking is adopted over either a fast, medium or slow scenario, such that within 10 years of the technology becoming available, about 95%, 60% or 30% of firms have started adopting automation in long-haul trucking. The average lifespan of a long-haul truck in the US is 9 years, so we assume that any firm adopting automation in long-haul trucking will have converted all of its capital to accommodate automation in 9 years. After 30 years, all firms have reached an adoption rate of 100% under all three scenarios. We assume that to adopt the technology needed to convert their fleet, firms incur costs that are proportionate to the maximum labour-savings that could be achieved under full automation of their long-haul trucking fleet.

After incorporating the shocks to labour-saving technological change, fuel cost savings, capital-saving technological change and fatalities described above into policy simulations, preliminary results under the fast adoption scenario suggest that the adoption of automation in long-haul trucking could yield cumulative gains in real GDP of about 0.3% relative to baseline. Output of trucking services (in-house trucking) could increase by 3% (0.5%) relative to baseline while employment in trucking services (in-house trucking) could fall by 16% (3%). According to BLS occupational turnover projections, turnover for the occupations affected by AV averages 10.5 percent per year for trucks (Groshen et al., 2018), partially offsetting the reduction in employment of log-haul truck drivers.

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4. Concluding remarks and directions for the future

The Highway Economic Requirements System (HERS) is a highway model for the U.S. incorporating detailed technical information provided by transport engineers. It gives results for many variables which are normally outside the scope of economic models. These include: time use, fuel use and other operating costs in trucking and private road transport; highway infrastructure and maintenance costs; safety and medical expenditures associated with the use of highways; and highway fatalities.

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