Teaching Theory of Perfect Competition using an Example of Autonomous Vehicle Technology in Trucking Service Industry (Not for Circulation)

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Disclaimer

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- Kazumori is responsible for the paper.

Use of This Material

- This material can be used for
  - Acemoglu, Laibson, and List (2016). Chapter 7: Perfect Competition and the Invisible Hand.
  - Greenlaw et al. (2016). Chapter 8: Perfect Competition.
  - Mankiw (2016). Chapter 14: Firms in Competitive Markets.
  - Parkin (2016). Chapter 12: Perfect Competition.

1. Introduction

Goal of Economics Education

The goal of this course

=develop economic thinking and knowledge using real world examples to the end that greater happiness and prosperity may come to all through better economic understanding.

- Based on http://www.kazanjian.org/our-focus

What We Will Learn in this Lecture

- Students learn the theory of perfect competition analyzing a real-world case of the new autonomous vehicle technology in the trucking service industry.

- Students will learn how to analyze the real world question using the theory of perfect competition.

Example: Trucking Service Industry

- The industry provides transportation services for companies to haul heavy things.

- 10.5 billion tons of freight per year (over 70% of freight tonnage moved in the US.)
  - http://www.trucking.org/News_and_Information_Reports_Industry_Data.aspx

- Truck driving is the most popular occupation in 29 of the 50 states.
  - https://www.marketwatch.com/story/keep-on-truckin-in-a-majority-of-states-its-the-most-popular-job-2015-02-09

New Autonomous Vehicle (AV) Technology

- "Self-driving" vehicles can sense their surroundings and guide themselves without human intervention.

- The technology was developed with the DARPA Grand Challenge.

Video Clip: The Races That Jump-Started the Self-Driving Car (Click the Screen to Play the Video)

(https://www.youtube.com/watch?v=9PIJKE5KMtU&t=2s)

"Autonomous trucks are now rapidly becoming reality"

- In October 2016, the Uber-owned Otto made its first delivery from Fort Collin. Co to Colorado Springs.

- "There is little doubt that the autonomous truck, once portrayed as nothing more than a myth, is now rapidly becoming a reality."
  - https://www.freightwaves.com/news/2017/10/4/examining-the-benefits-risks-of-the-autonomous-truck

Video Clip: Self-Driving Truck Makes Beer Delivery (Click the Screen to Play the Video)

(https://www.youtube.com/watch?v=GEUSeGXFAZU)

2016 Executive Office of the President Report and the 2017 Administration Guidelines

- "AV technology will likely cause disruptions in the labor market as the economy adapts to new paradigms. " (p.17)
  - https://obamawhitehouse.archives.gov/sites/whitehouse.gov/files/documents/Artificial-Intelligence-Automation-Economy.PDF

- "CEA estimates that 2.2 to 3.1 million existing part- and full-time U.S. jobs may be threatened or substantially altered by AV technology." (p.17)

Video Clip: Trump administration unveils guidelines on self-driving cars (Click the Screen to Play the Video)

(https://www.youtube.com/watch?v=pcrmCKsWhB8)

Economics Questions

- How does the AV technology affect consumers, workers, and firms, and the economy?

Video Clip: Self-Driving Trucks Are Hitting the Highways (Click the Screen to Play the Video)

(https://www.youtube.com/watch?v=e71s0Uvd3zM)

Economics Questions

- What is the impact of the AV technology on consumers, workers, and firms, and the economy?
  - How will it affect the market for trucking service?
  - How will it affect the consumers?
  - How will it affect the companies?
  - How will it affect the drivers and workers?
  - What will be the net effect for the society?

- What policy should the government take?

- How will it affect a student's career?

Analysis Methodology

- We apply the theory of perfect competition to study this question.
- Section 2: We formulate trucking firm's production technology and cost functions.
- Section 3: We then derive the short-term industry equilibrium to see whether it explains the current industry situation.
- Section 4: We then describe how the AV technology affects the production functions and cost functions.
- Section 5: We examine how firms who adopt the AV technology will affect a market equilibrium.
- Section 6: We examine the effect of possible options of robot tax, universal basic income, efficiency-improving education, and MaaS demand enhancement.

Economic Mechanisms

- AV is a capital intensive technology that
  - substitutes unskilled drivers
  - increases productivity of skilled drivers

- The firm who adopts the AV technology will have
  - higher fixed cost from AV investments
  - lower marginal costs for more efficient AV technology

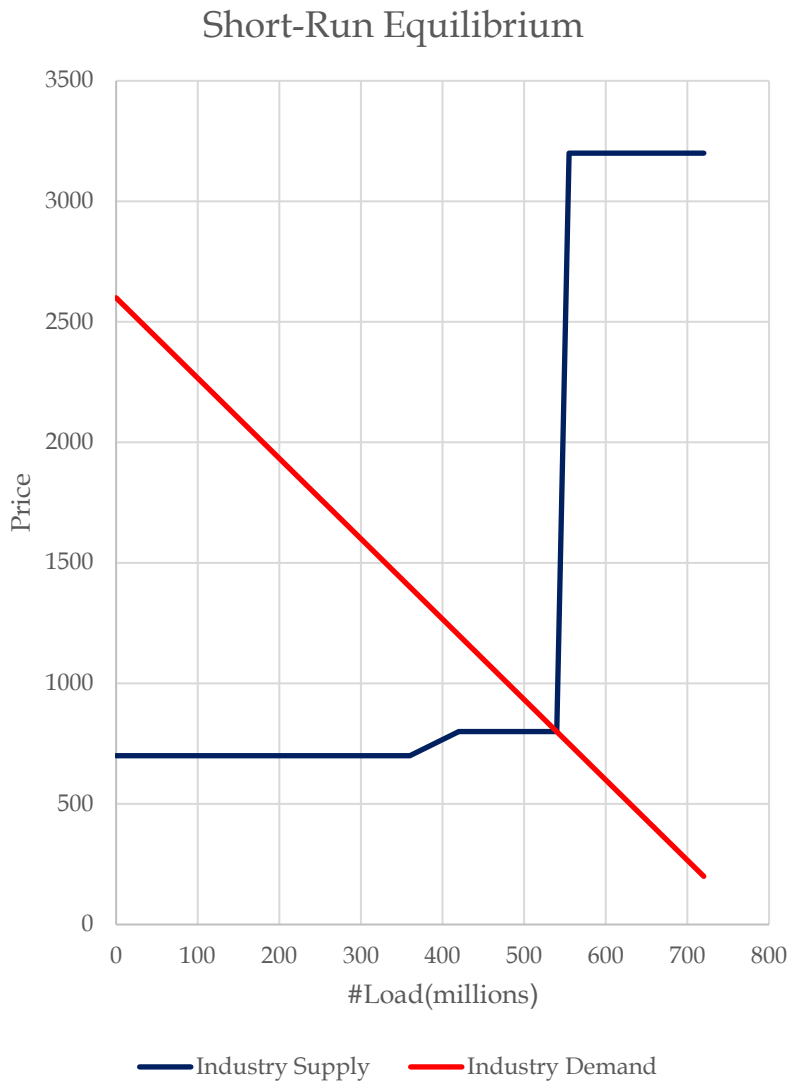
- AV technology will affect the market as follows:
  - lower the market rates of trucking loads
  - increase the equilibrium trucking loads
  - increase the consumer surplus and social surplus
  - decrease the employment of unskilled drivers
  - Increase the employment of skilled drivers

- AV is a technological progress and not a market failure.
  - An effective labor policy is to support creation of new service using AV technology to increase labor demand.

Main Results: Current Industry Equilibrium

- In a current equilibrium,
  - loads rates $800
  - 540M loads per year
  - consumer surplus $486B
  - producer surplus is $45B
  - 1.2M trucking firms
  - 7.2M employees in the industry

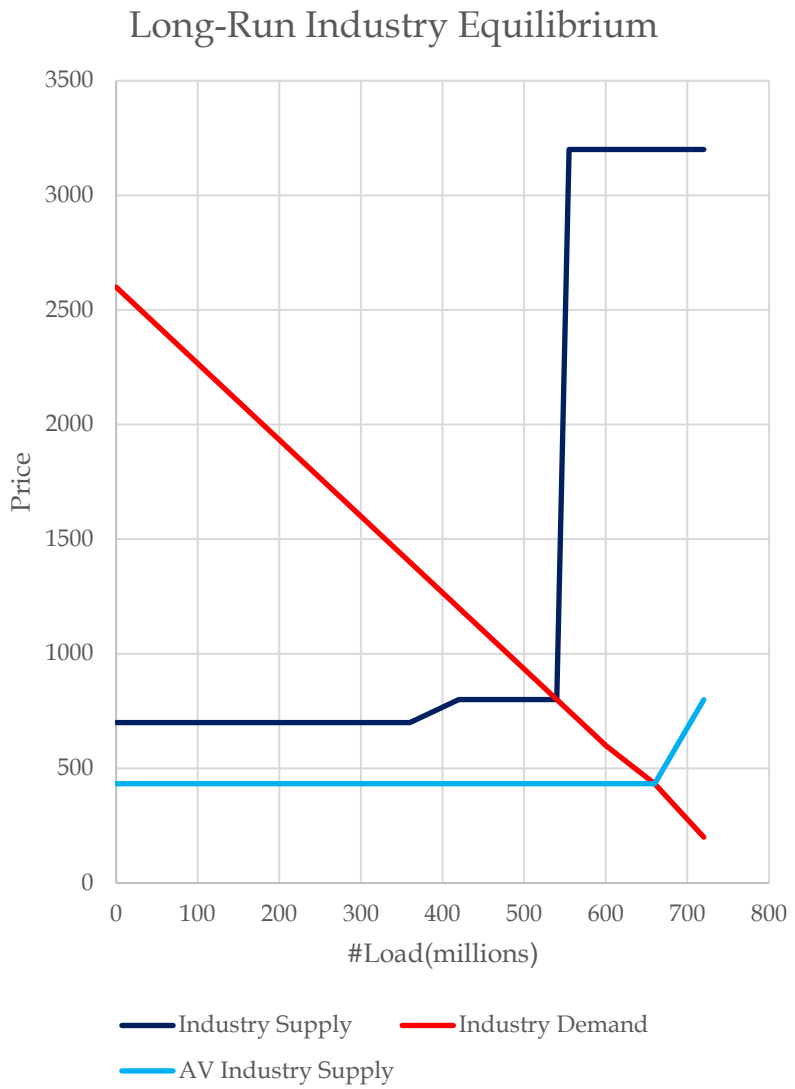
- Consistent with the statistics that industry revenues are $676.2B and the expense ratio is <8%.



Counterfactual: Long-Run Equilibrium with AV

- With AV,
  - loads rates $433
  - 660M loads per year
  - consumer surplus $714B
  - 733,000 trucking firms
  - 4.4M employees in the industry

- Consistent with the CEA estimates that 2.2M to 3.1M existing jobs may be threatened.



2. Trucking Service Market Overview

Section 2 Outline

- We now study the current situation of the trucking service markets.
  - Step 1: The Market for Trucking Service
  - Step 2: Supplier: Operators business model
  - Step 3: Capital (trucks)
  - Step 4: Labor (workers)
  - Step 5: Driving Hours of Service Regulation
  - Step 6: Loads
  - Step 7: Loads rate
  - Step 8: Operating ratio

Step 1: The Market for Trucking Service

- Trucking service transports large quantities of goods over land
  - Moving goods from manufacturing plants to retail distribution centers
  - Moving large amounts of rocks, dirt, concrete, and other building materials used in construction.

- Trucking industry revenues are $676.2 Billion.
  - http://www.trucking.org/article/ATA-American-Trucking-Trends-2017

- The trucking industry as a whole traveled 279.1B miles in 2014.
  - http://www.trucking.org/News_and_Information_Reports_Industry_Data.aspx

Step 2: Supplier: Trucking Service Operator

- A trucking service operator inputs trucks (capital) and drivers (labor) to produce and sell freight services.

- There are about 1.2M trucking service companies in the U.S.
  - http://www.trucking.org/News_and_Information_Reports_Industry_Data.aspx

Video Clip: Becoming an Owner operator in the trucking business
(https://www.youtube.com/watch?v=tbeZrrafwdE)

Step 3: Capital (Trucks)

- There are 3.4 million heavy-duty Class 8 trucks in the industry.
  - http://www.trucking.org/News_and_Information_Reports_Industry_Data.aspx
- 90.8% operate 6 or fewer trucks.
- 97.3% operate fewer than 20 trucks.
  - http://www.trucking.org/News_and_Information_Reports_Industry_Data.aspx

Step 4: Labor (Workers)

- 7.3 million people employed throughout the economy in jobs that relate to trucking activity.
  - http://www.trucking.org/News_and_Information_Reports_Industry_Data.aspx
- The average wage is $36,500.
  - http://www.esa.doc.gov/sites/default/files/Employment%20Impact%20Autonomous%20Vehicles_0.pdf

	Motor Vehicle Operators	Other On-the-Job Drivers	All Occupations
Occupational Employment Statistics, 2015			
Employment (thousands of workers)	3,796	11,666	137,006
Employment Share (%)	2.8	8.5	100.0
Mean Annual Wages	$36,500	$46,700	$48,300
American Community Survey, 2015 Public Use Microdata Sample			
Share of Employed Persons (%)	3.0	14.3	100.0
Median Age (years)	46	43	41
Educational Attainment			
Less than HS (%)	14.8	9.2	9.5
HS or GED (%)	45.6	27.1	24.7
Some College (%)	32.0	36.1	32.4
Bachelors Plus (%)	7.6	27.7	33.4
Unemployment Rate (%)	4.7	4.6	6.3
Male (%)	88	68.8	52.7
Race			
White (%)	70.3	76.8	74.9
Black (%)	17.6	11.4	11.5
Other (%)	12.1	11.8	13.6

Step 5: Driver Hours of Service Regulation

- Current rules say drivers can work no more than 60 hours in seven days or 70 hours in eight days.
  - https://www.fmcsa.dot.gov/sites/fmcsa.dot.gov/files/docs/Drivers%20Guide%20to%20HOS%202015_508.pdf

- A driver average daily run is nearly 500 mile.
  - http://www.trucking.org/article/Professional-Truck-Drivers-and-the-Trucking-Industry

- An average yearly run is 100,000 miles.
  - http://www.trucking.org/article/Professional-Truck-Drivers-and-the-Trucking-Industry

Video Clip: CMV Driver Basics Hours of Service (Click the Screen to Play the Video)
(Click the Screen to Play the Video)

(https://www.youtube.com/watch?v=viF3MBAzJTM&index=4&list=PLWc-yg2ciyipYc_iBMx2qPP8pNrbBEwm5)

Step 6: Loads

- The average haul length is about 500 miles.
  - http://atri-online.org/wp-content/uploads/2016/10/ATRI-Operational-Costs-of-Trucking-2016-09-2016.pdf

Table 3: Survey Respondent Trip Types

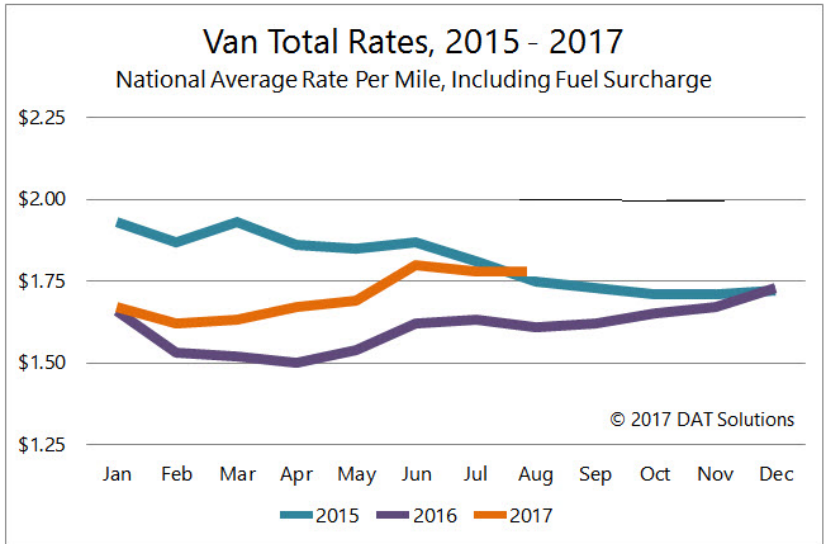
Trip Type	Survey Respondent Share of Trips
Local pick-ups and deliveries (less than 100 miles)	21%
Regional pick-ups and deliveries (100-500 miles)	40%
Inter-regional pick-ups and deliveries (500-1,000 miles)	23%
National (over 1,000 miles)	16%

- Thus we estimate 540M loads per year.
  - Trucking industry has 279.1B miles in 2014.

Step 7: Load Rates

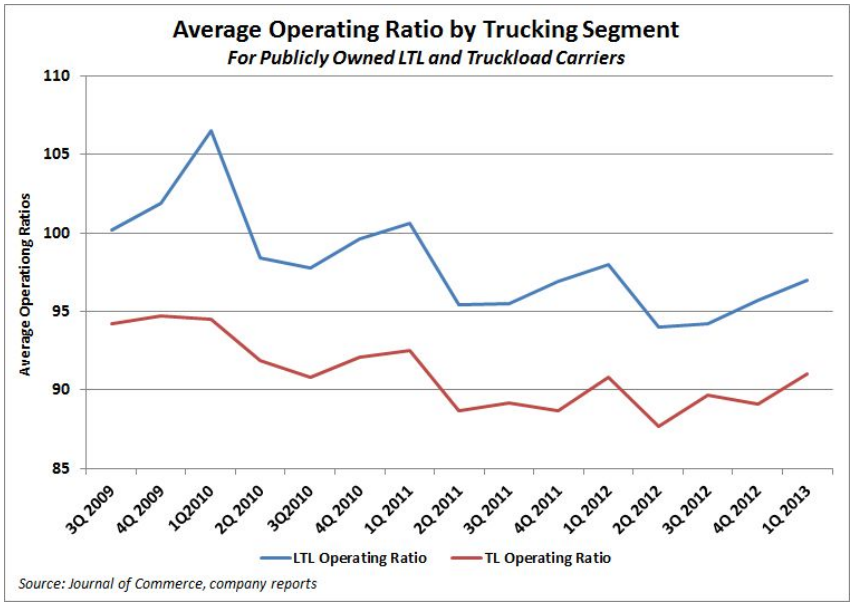
- We take the average rate to be $1.6 per mile.
  - https://www.dat.com/blog/post/rates-hit-multi-year-highs-whats-next1

- Thus we estimate the average load rate to be about $800.



Step 8: Operating Ratio

- Operating ratios measure expenses as a percentage of revenue.
- Truckload operating ratio is 91 and LTL ("Less Than Truckload") operating ratio is 97.
  - https://www.joc.com/trucking-logistics/ltl-shipping/average-ltl-truckload-operating-ratios-rise_20130522.html
- The industry is very competitive.



3. Modelling Trucking Service Operators Short-Term Cost Functions

Section 3 Outline

- Given the information in the previous section, we first model a firm technology and cost functions
  - Step 1: Write down production technology assumptions
  - Step 2: Write down production plans
  - Step 3: Calculate production function
  - Step 4: Calculate marginal product
  - Step 5: Calculate average product
  - Step 6: Calculate fixed cost
  - Step 7: Calculate variable cost
  - Step 8: Calculate total cost
  - Step 9: Calculate marginal cost
  - Step 10: Calculate average fixed cost
  - Step 11: Calculate average variable cost
  - Step 12: Calculate average total cost

Step 1: Write down production technology assumptions

- **Fixed inputs: Trucks.**
- Consider a trucking company with 3 trucks.
- # of trucks is fixed in short-term.
- Each truck costs 30K.

- **Variable inputs: drivers.**
- Each driver can have 100 loads per year.
  - Sanity Check: average haul length is about 500 miles (one-way)
  - A driver's yearly run is 100,000 miles.
  - It is about 2 loads per week.
- A driver is assigned to one truck.
- Each driver costs 40K.

Step 2: Write Down Production Plans

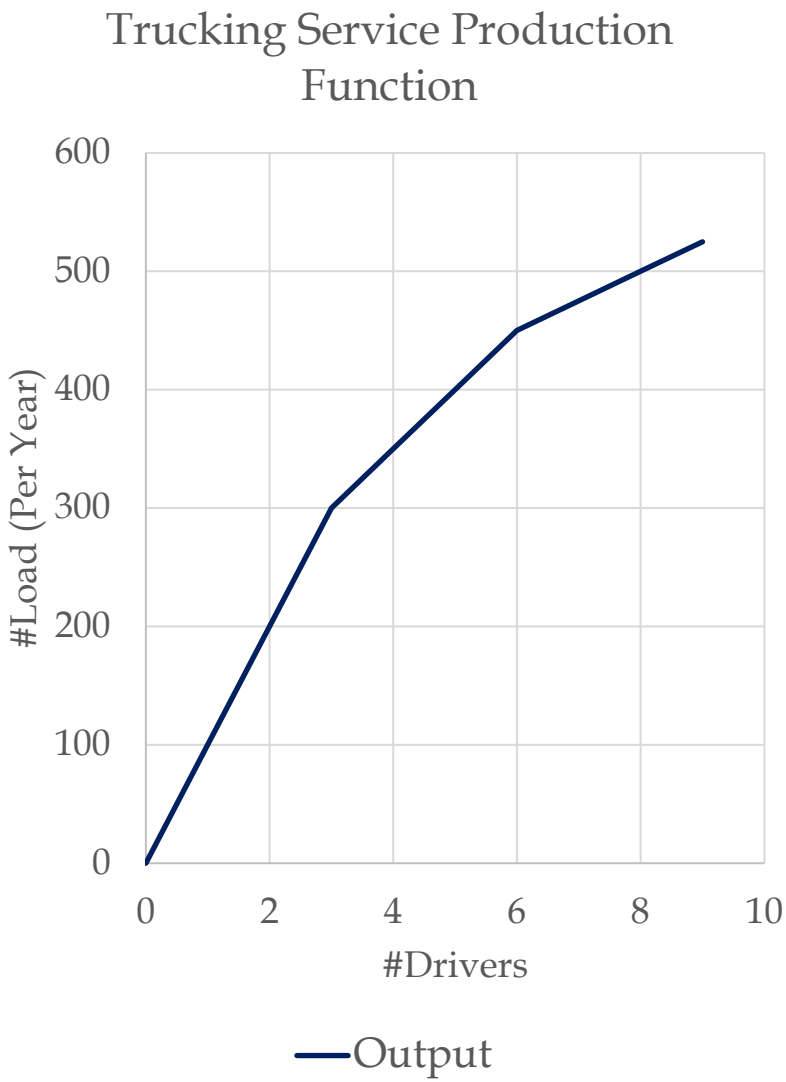
- Write down a production plan as output (loads) feasible for each number of drivers the firm can hire.

	#Drivers	Output (#loads)
	0	0
First driver for each car	1	100
	2	200
	3	300
Second driver for each car	4	350
	5	400
	6	450
Third driver for each car	7	475
	8	500
	9	525

Step 3: Calculate Production Function

- Derive the short-term production function as the relationship between
  - labor inputs (drivers)
  - outputs (loads)

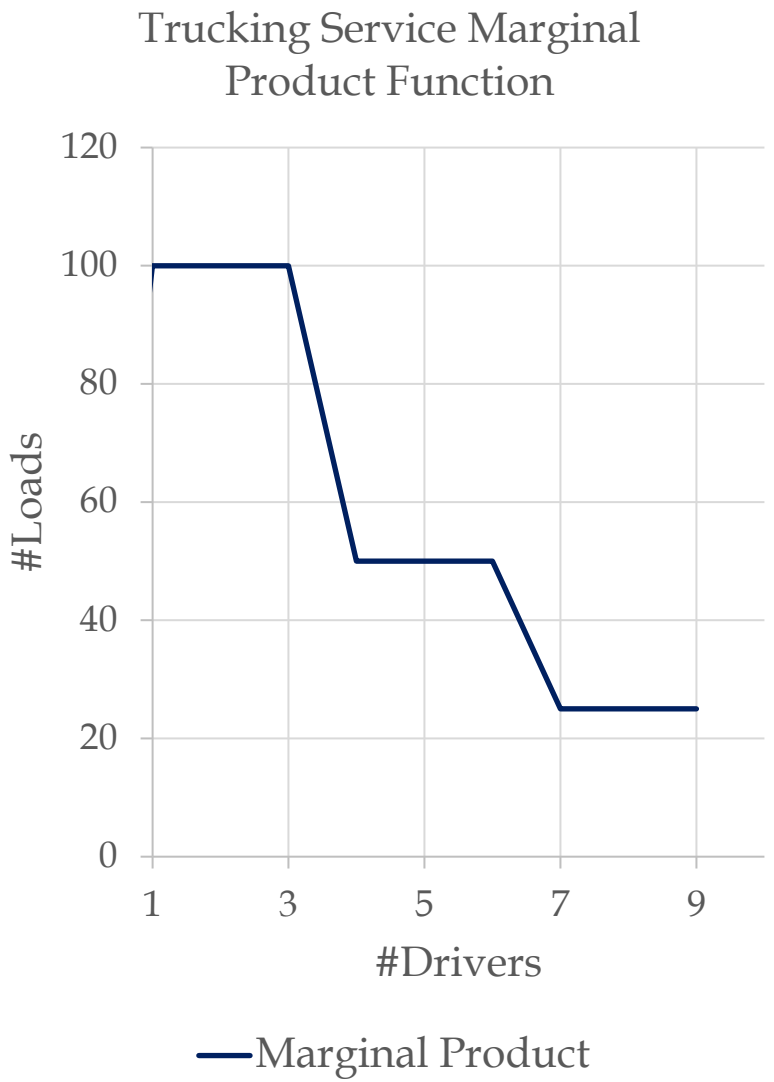
- Observe that
  - as the firm hires more drivers, the output increases.
  - but the output is eventually restricted by the availability of trucks



Step 4: Calculate Marginal Product

- Calculate the marginal product as the change in output (loads) from one more unit of labor (driver).

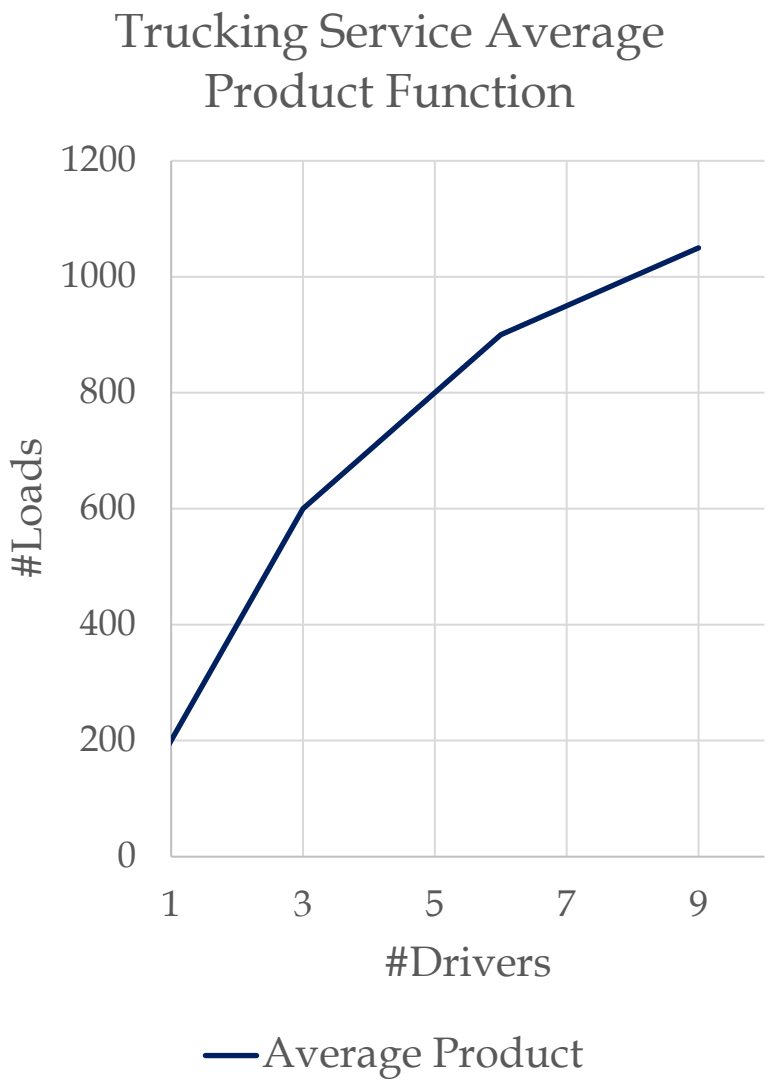
- Observe that the marginal product function satisfies diminishing marginal return
  - Decrease in a driver productivity as the # of drivers is incrementally increased since # of trucks is fixed



Step 5: Calculate Average Product

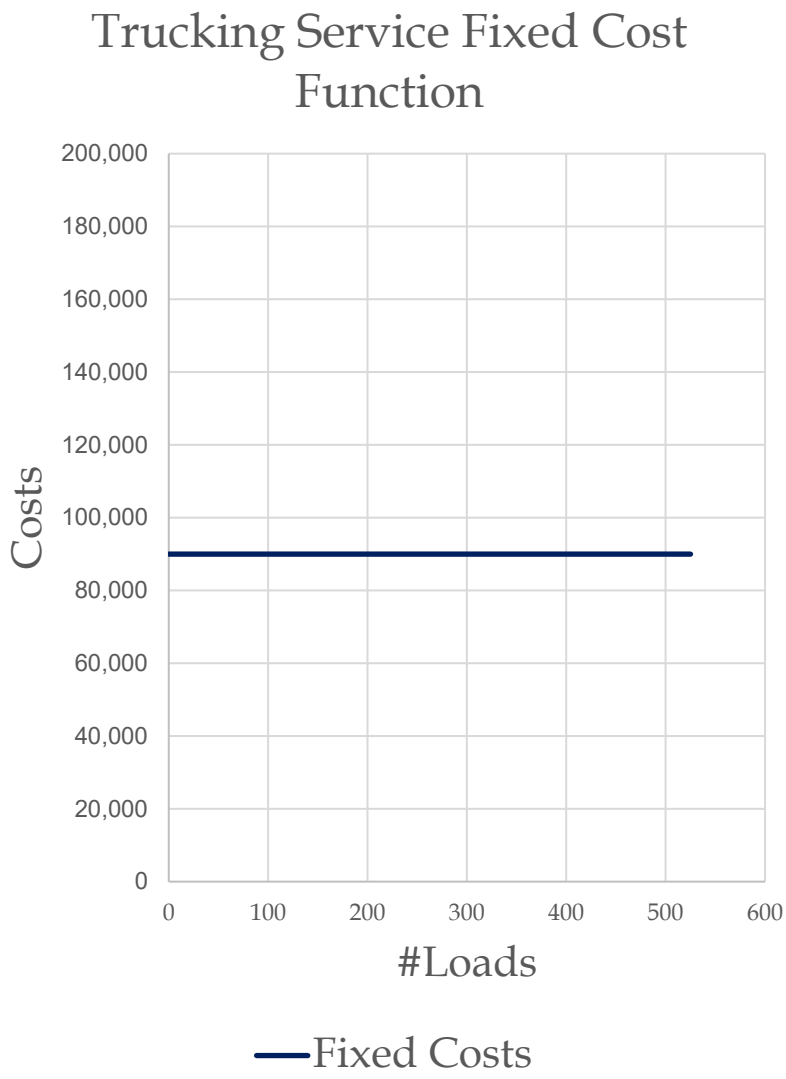
- Calculate the average product as the average output (loads) for one input (driver).

- Observe that
  - the average product function is increasing
  - the rate of increase slows down due to the law of diminishing marginal product



Step 6: Calculate Fixed Cost

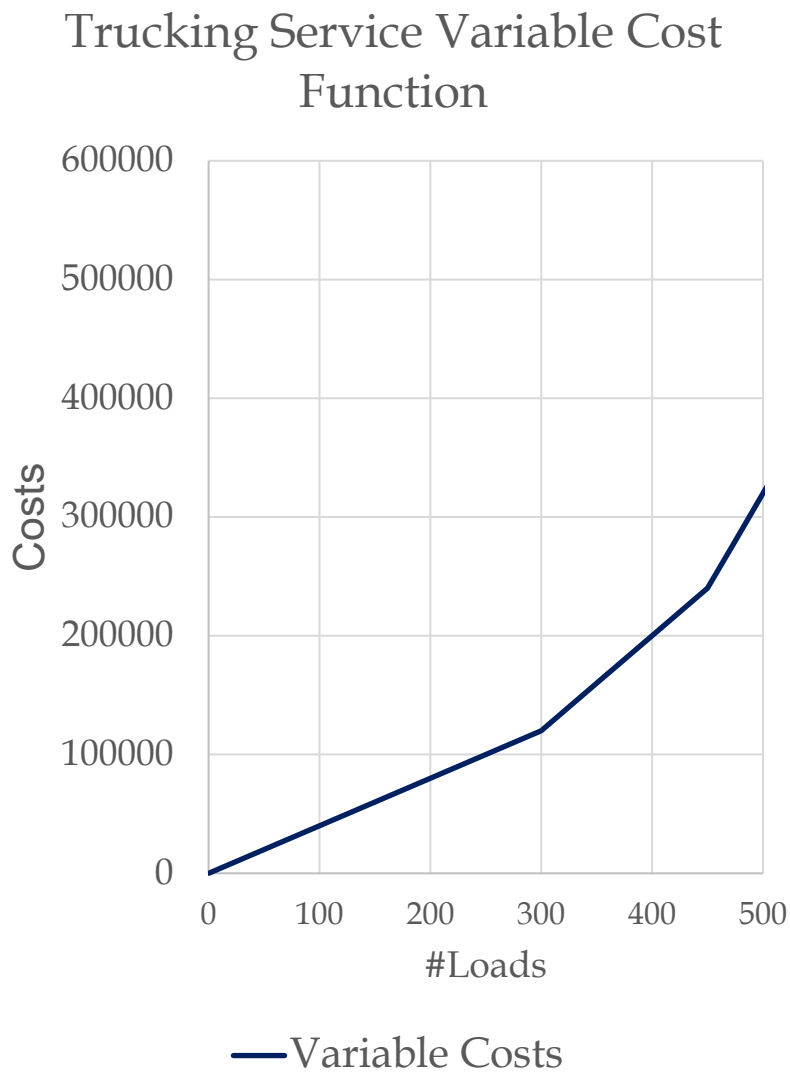
- We begin the study of the cost structure.
- Calculate the fixed cost function as the relation between
  - output
  - cost of capital
- Observe that, since #trucks (3) is fixed in the short term, the fixed cost is a constant.



Step 7: Calculate Variable Cost

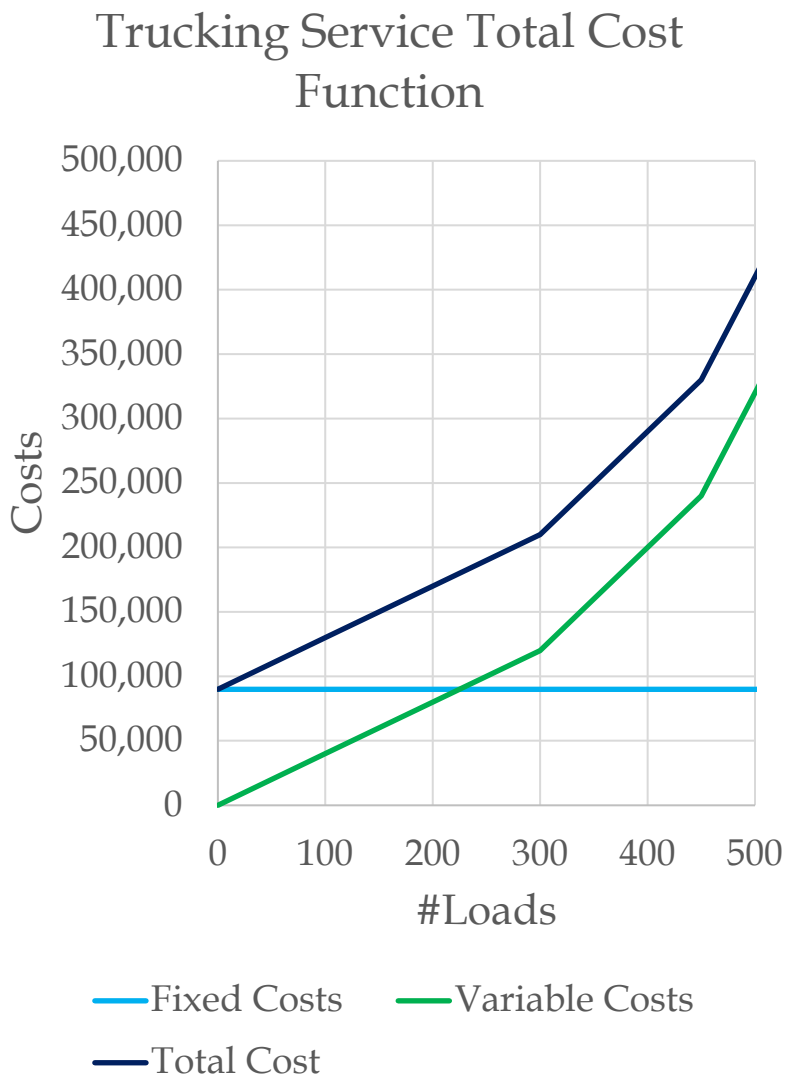
- Calculate the variable cost function as the relationship between
  - output
  - variable inputs costs (wages).

- Observe,
  - since more loads requires more workers, the variable cost function is an increasing function.
  - The rate of increase accelerates as the firm hits the trucks capacity constraints.



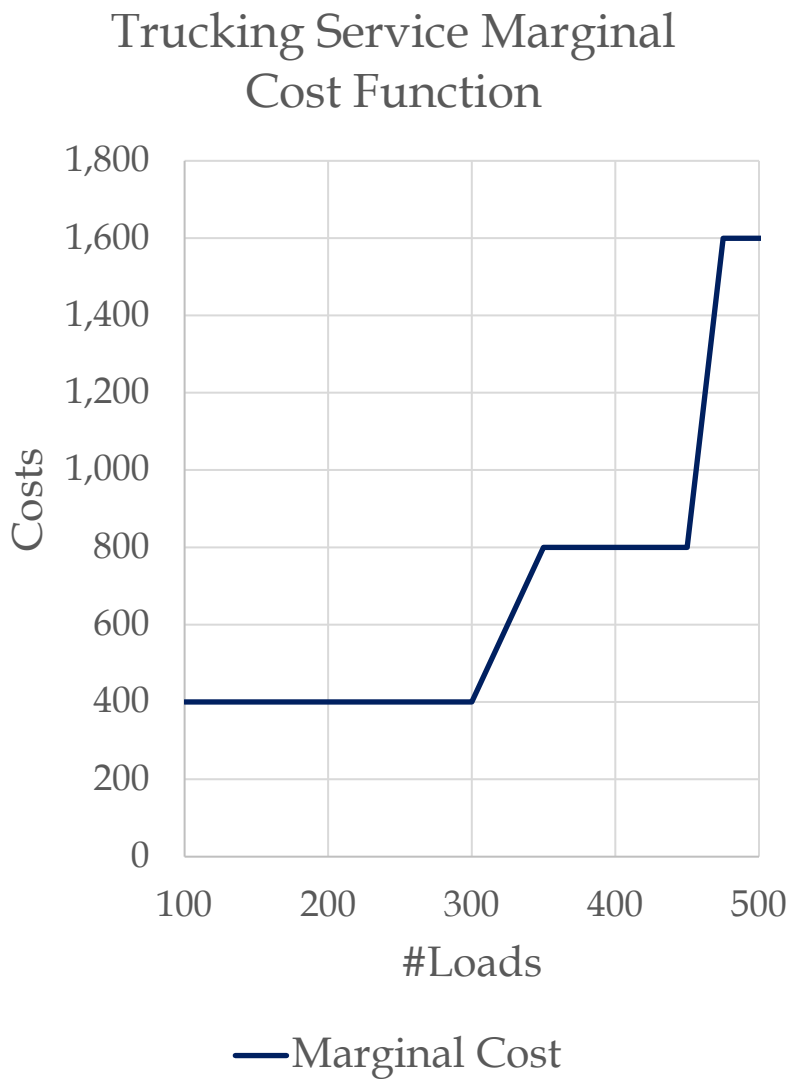
Step 8: Calculate Total Cost

- Derive a total cost that is the sum of the fixed cost and the variable cost.
- Observe that, as the output increases, the variable cost increases, thus the total cost increases.



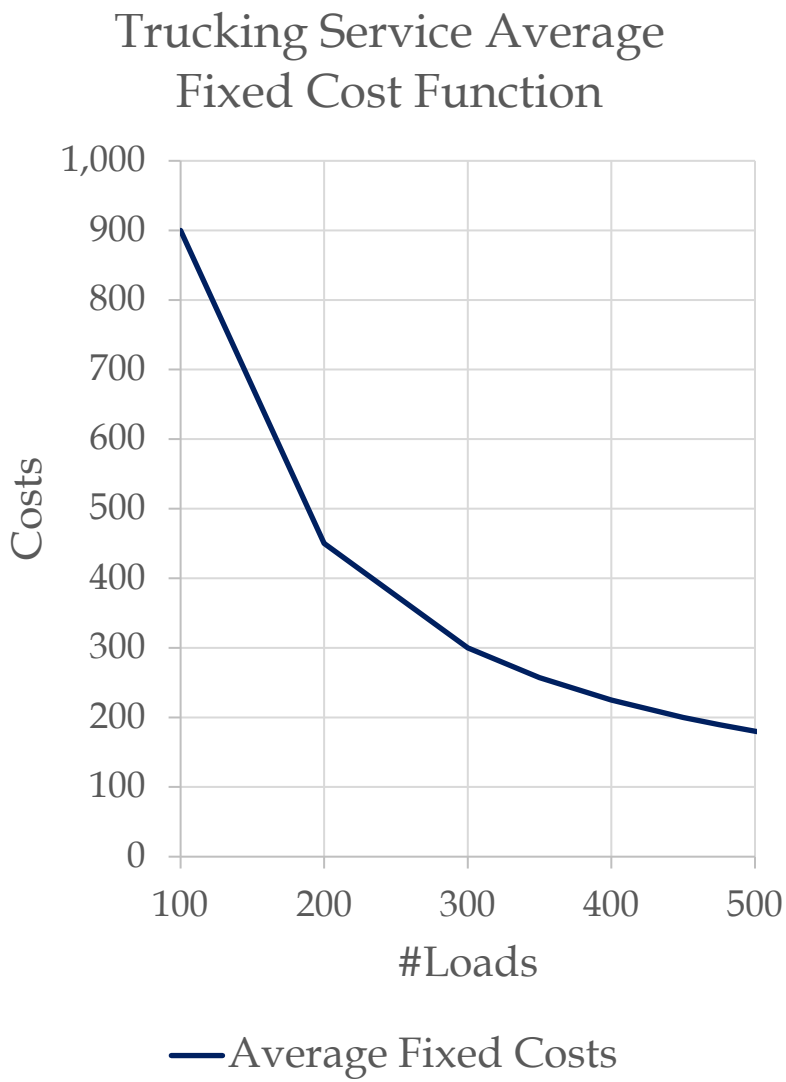
Step 9: Calculate Marginal Cost

- Calculate marginal cost as the increase in the total cost from a one-unit increase in output.
- Observe that, since large loads deal with trucks capacity constraints, the marginal cost function is increasing.



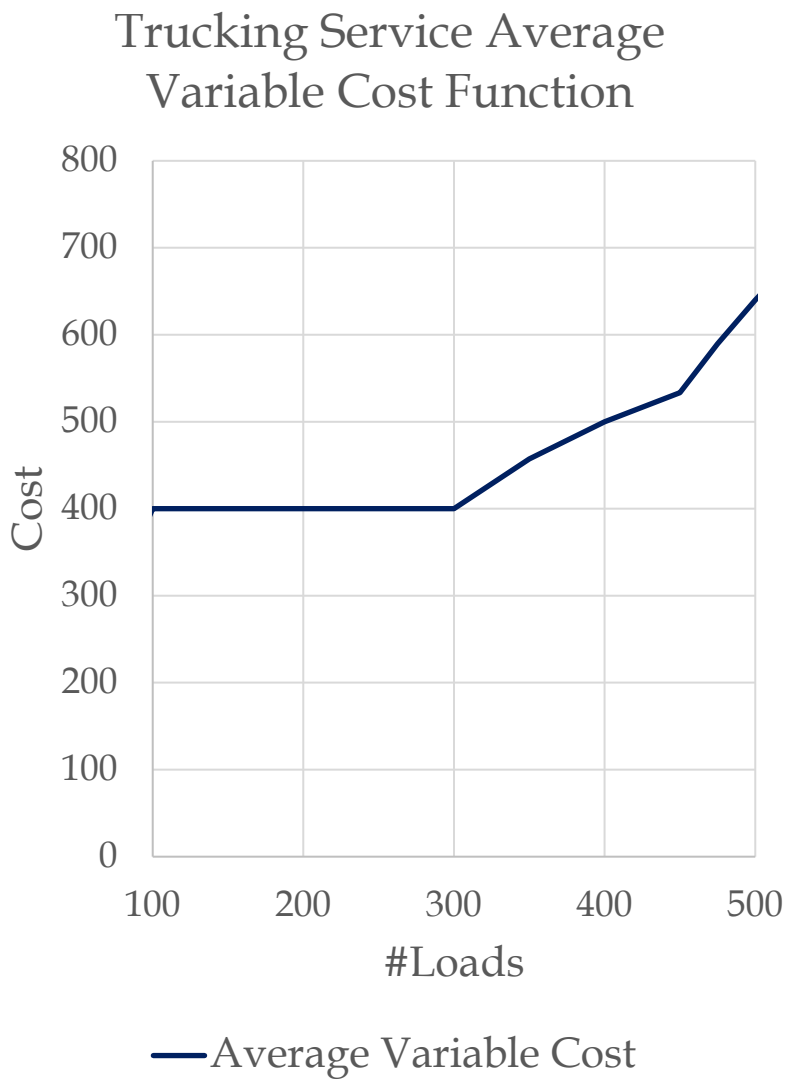
Step 10: Calculate Average Fixed Cost

- Calculate the average fixed cost as fixed costs per unit of output.
- Observe that, since the number of trucks is fixed, the average fixed cost function is a decreasing function.



Step 11: Calculate Average Variable Cost

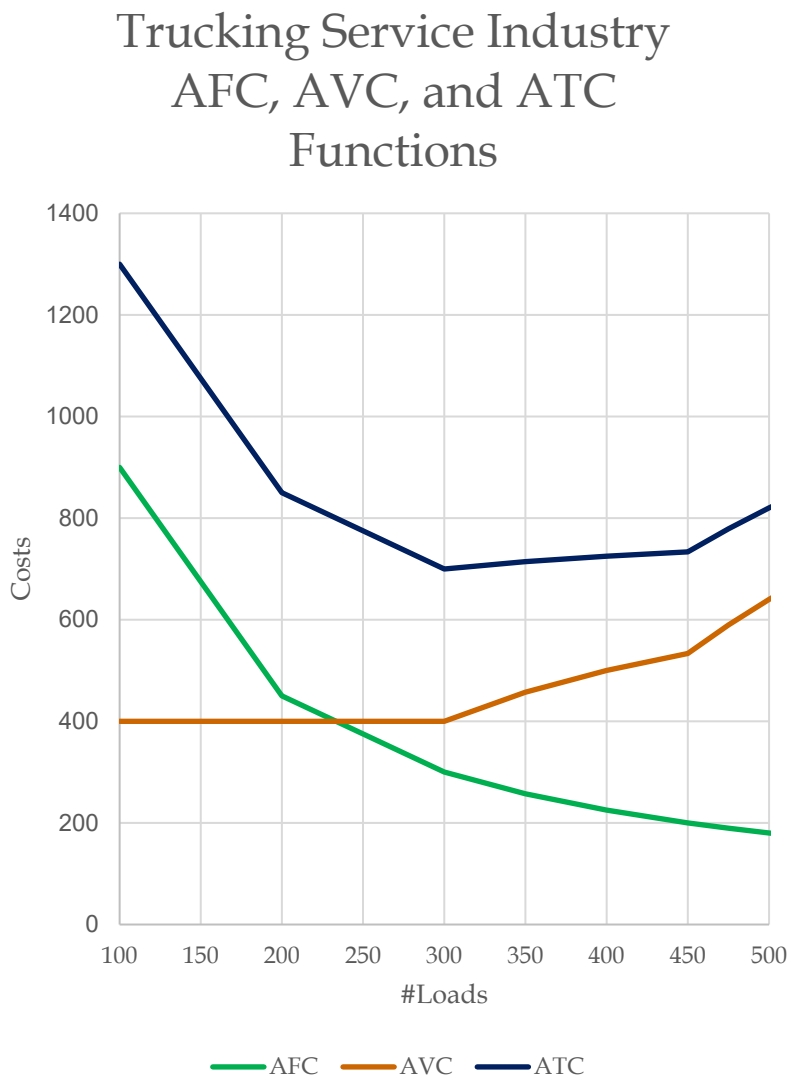
- Calculate that the average variable cost as the variable cost per unit.
- Observe that, since increasing the output requires more drivers to deal with the truck capacity constraint, the function is an increasing function.



Step 12: Calculate Average Total Cost

- Calculate the average total cost as the total cost per unit.

- Observe that the *ATC* curve is U-shaped because
  - Spreading total fixed cost over a larger output—*AFC* curve slopes downward as output increases.
  - Eventually diminishing returns—the *AVC* curve slopes upward and *AVC* increases more quickly than *AFC* is decreasing.



4. Characterize Short-Run Market Equilibrium

Section 4 Outline

- We now apply the theory of perfect competition to characterize the short-run market equilibrium of the trucking service market.
  - Step 1: Assume perfectly competitive market
  - Step 2: Assume firms are price takers
  - Step 3: Consider Firm Profit Maximization
  - Step 4: Calculate firm supply function
  - Step 5: Calculate market supply function
  - Step 6: Construct market demand function
  - Step 7: Calculate short-run equilibrium
  - Step 8: Calculate consumer surplus
  - Step 9: Calculate producer surplus
  - Step 10: Calculate social surplus
  - Step 11: Calculate industry employment

Step 1: Assume Perfectly Competitive Market

- Recall that a perfectly competitive market is a situation where many firms sell identical products to many buyers.

- In trucking industry, there are about 1.2 million companies.
  - http://www.trucking.org/News_and_Information_Reports_Industry_Data.aspx

- Furthermore, the 50 largest companies account for less than 30 percent of the market.
  - http://www.dot.ca.gov/hq/tpp/offices/ogm/key_reports_files/National,%20Technical%20studies/Trucking_industry_overview.pdf

- Thus we assume trucking industry as perfectly competitive.

Step 2: Assume Price Taker

- Recall that, in a perfectly competitive market, firms are price takers
  = a firm does not have the power to negotiate the price
  = a firm accepts the market price as given

- In reality,
  - "More shippers are putting more of their business out to bid to multiple carriers, rather than going through extensive one-on-one negotiations with individual carriers"
  - "If all you're doing is arguing rates, you'll only get so far," Broadhurst said. "You hit the point of diminishing return."
    - https://www.transplace.com/2017/01/31/joc_us_shippers_rethink_truck_contract_pricing-2/

- Thus we assume firms are price takers.

Step 3: Consider Firm Profit Maximization

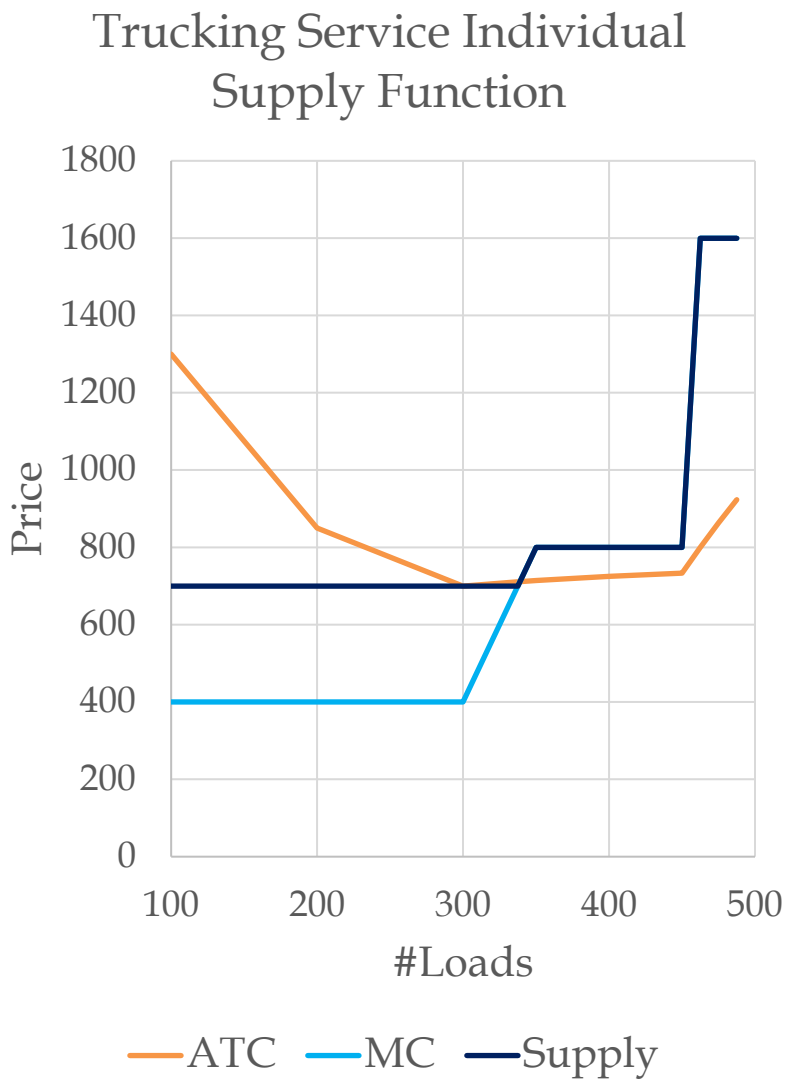
- Recall that the firm's objective is to maximize its profit.

- Then, a firm first compares price and marginal cost and,
  - if the price is above the marginal cost, produce and go to the next unit
  - if price is equal to the marginal cost, stop

- Then the firm compares price and average total cost and,
  - if the price is above the average total cost, produce up to that unit
  - if the price is below the average total cost, do not produce

Step 4: Derive Firm Supply Function

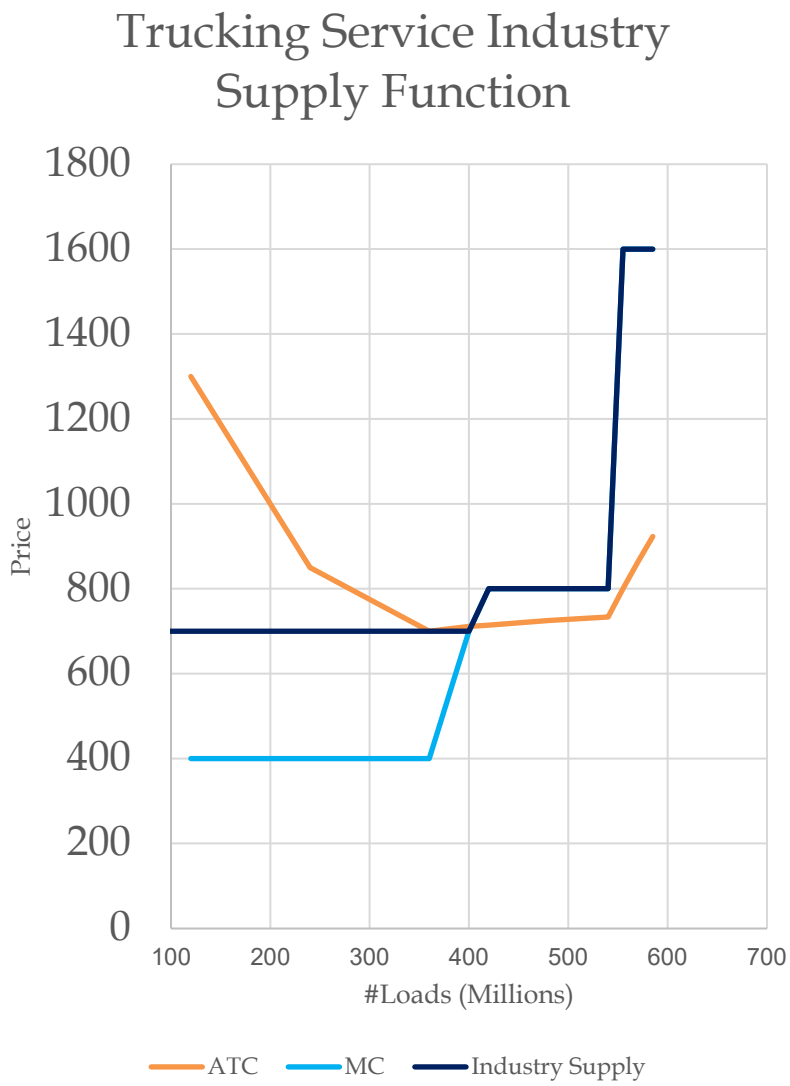
- Derive a firm supply function as
  - If the price is less than the minimum of the average total cost, a firm will not supply,
  - For prices higher than the minimum of AVC, the firm will supply till the marginal cost equals to the price.



Step 5: Drive Market Supply Function

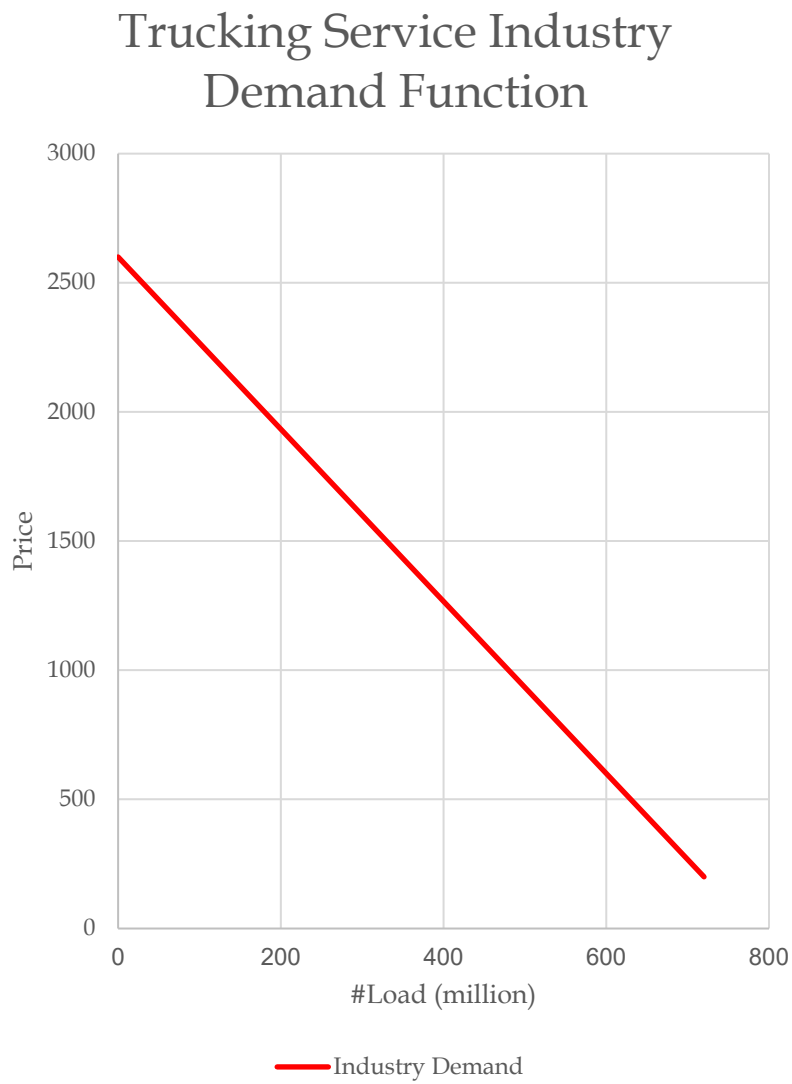
- Recall that there are 1.2 million firms in the industry.
  - http://www.trucking.org/News_and_Information_Reports_Industry_Data.aspx

- Calculate the industry supply function by horizontally summing up individual supply at each price.



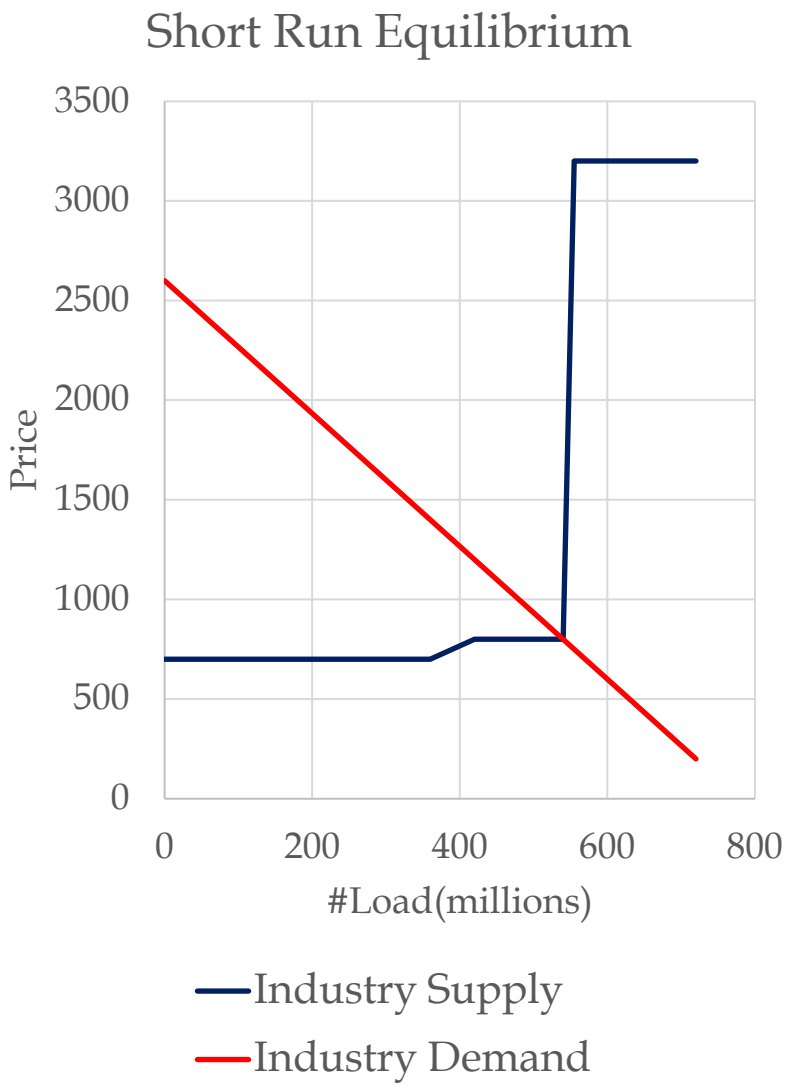
Step 6: Construct Market Demand Function

- Recall that the current market has
  - load rate $800
  - 540 million yearly loads.
- Assume linear demand.
- Assume that the demand is inelastic with price elasticity -0.46 (West et al. (2005))
  - Weak competition from air and railroad.
  - Uber demand elasticity -0.36 (Cohen et al. (2016))



Step 7: Derive the Short- Market Equilibrium

- Recall that the short-run equilibrium is the shipping rate that the demand will be equal to supply.
- Find that the equilibrium load rate is $800 and #load is 540M.



Step 8: Calculate Consumer Surplus

- Recall that the consumer surplus is the sum of marginal benefits minus price summed over quantities.

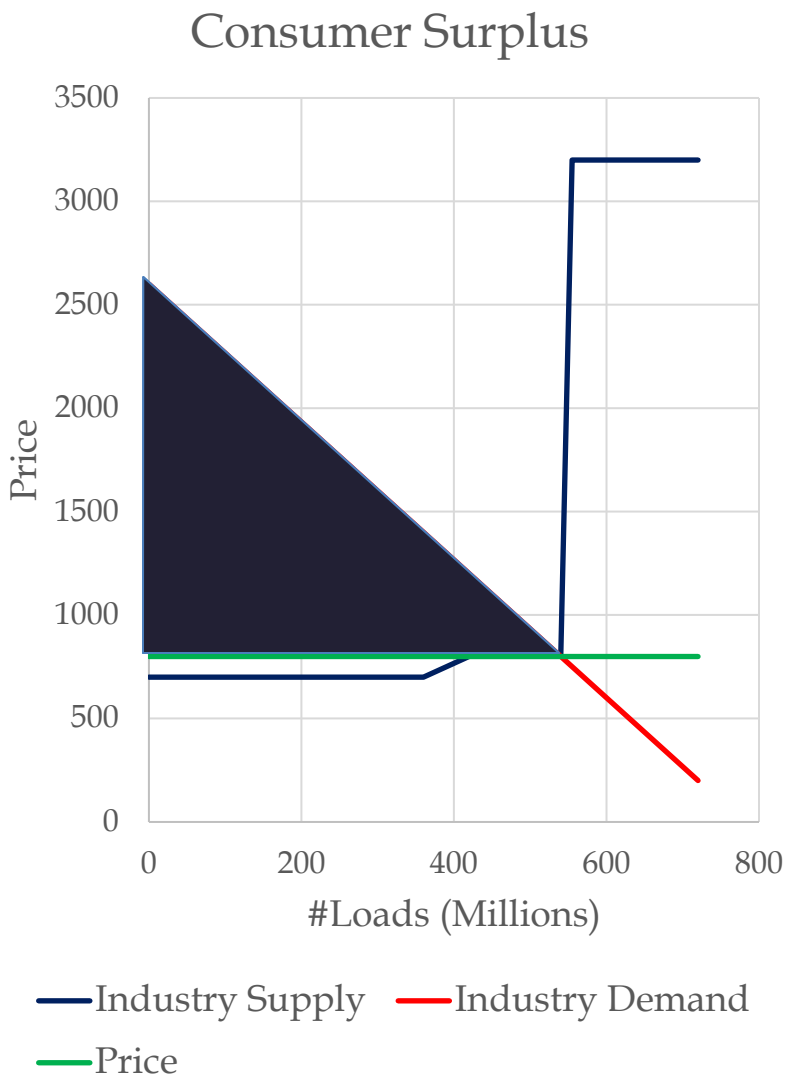
- Calculate

  Consumer Surplus

  =(1/2)*(2600-800)*540M

  = 486 Billion

- Consistent with the data that Trucking industry revenues are 676.2 Billion
  - http://www.trucking.org/article/ATA-American-Trucking-Trends-2017



Step 9: Calculate Producer Surplus

- Recall that the producer surplus is the price minus marginal cost summed over the quantities.

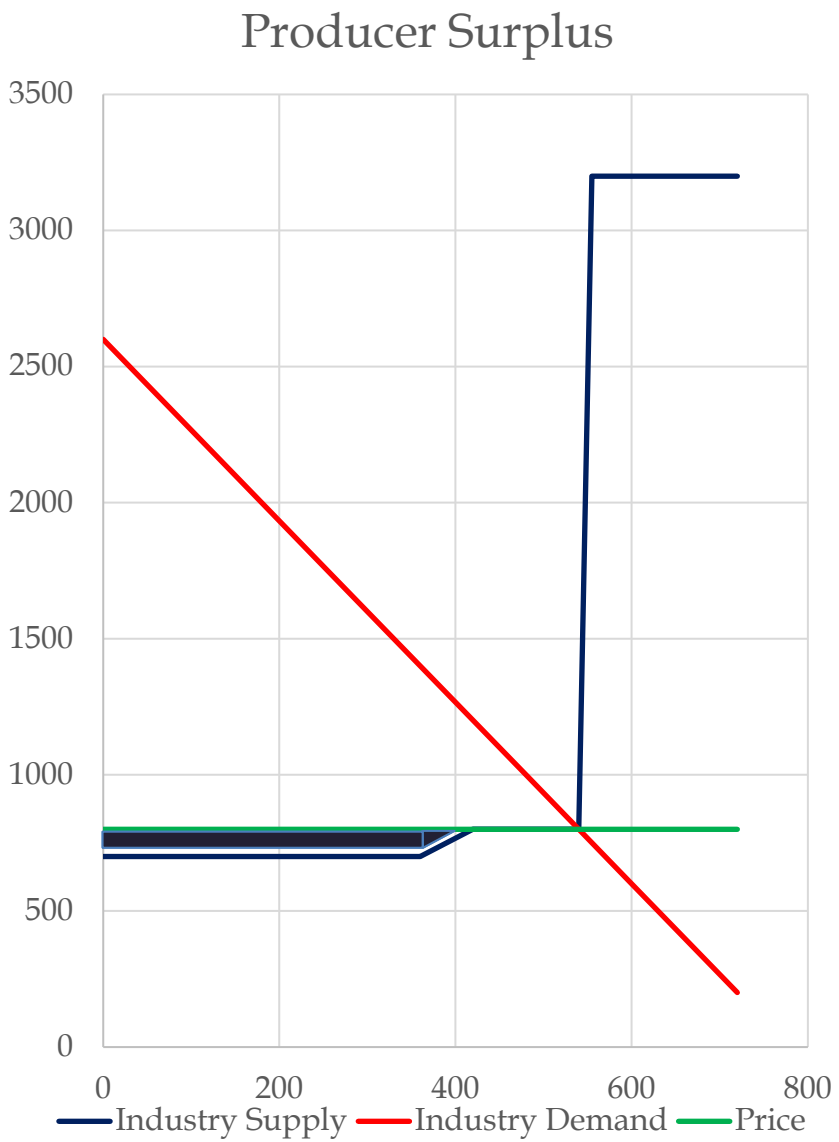
- Calculate

  Producer Surplus

  =(1/2)*(360M+450M)*100

  =45 Billion

- Consistent with the data that Trucking industry revenues are 676.2 Billion and the expense ratio is <8%
  - http://www.trucking.org/article/ATA-American-Trucking-Trends-2017



Step 10: Calculate Social Surplus

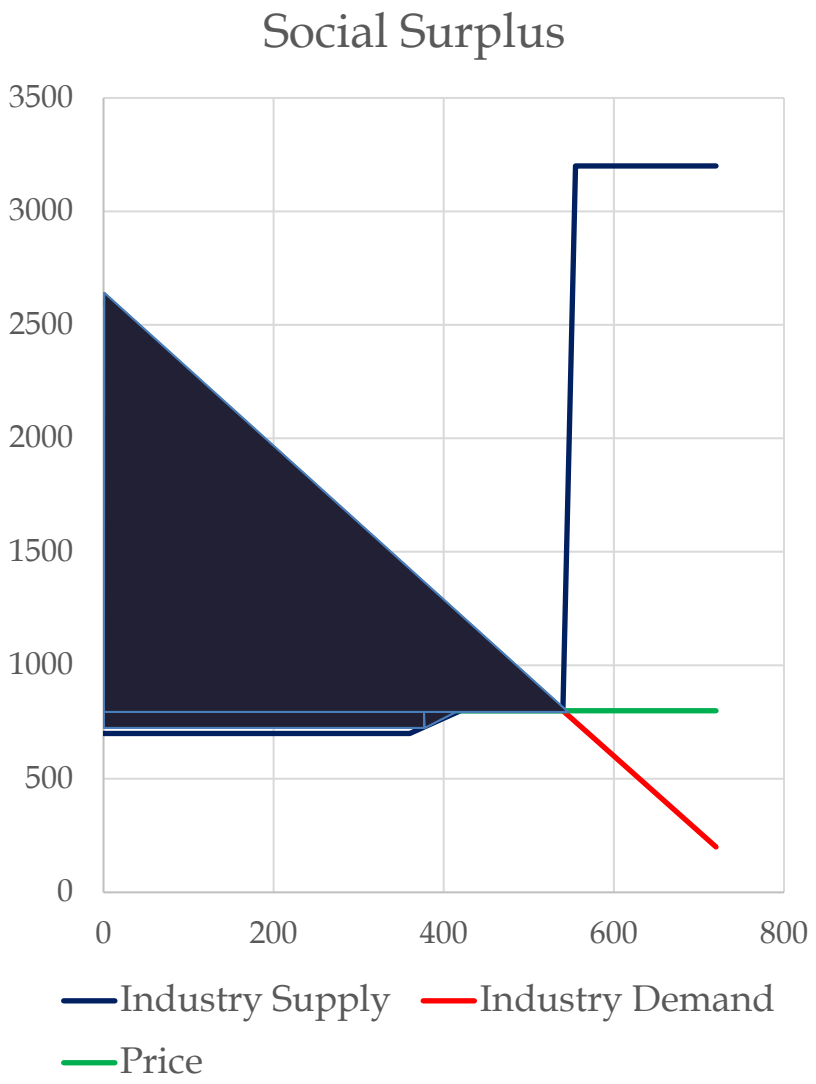
- Recall that social surplus is the sum of consumer surplus and producer surplus.

- Calculate

  Social surplus

  = 486 Billion+45 Billion

  = 531 Billion



Step 11: Calculate Industry Employment

- In equilibrium, each firm will hire 6 employees.
  - Two employees (including back-office) for one truck.
  - Trucking business operates close to full capacity.
  - Trucks operate Monday-Saturday.

- This will lead to employment of 7.2 million people.

- Consistent with the industry statistics: 7.3 million people employed throughout the economy in jobs that relate to trucking activity
  - http://www.trucking.org/News_and_Information_Reports_Industry_Data.aspx

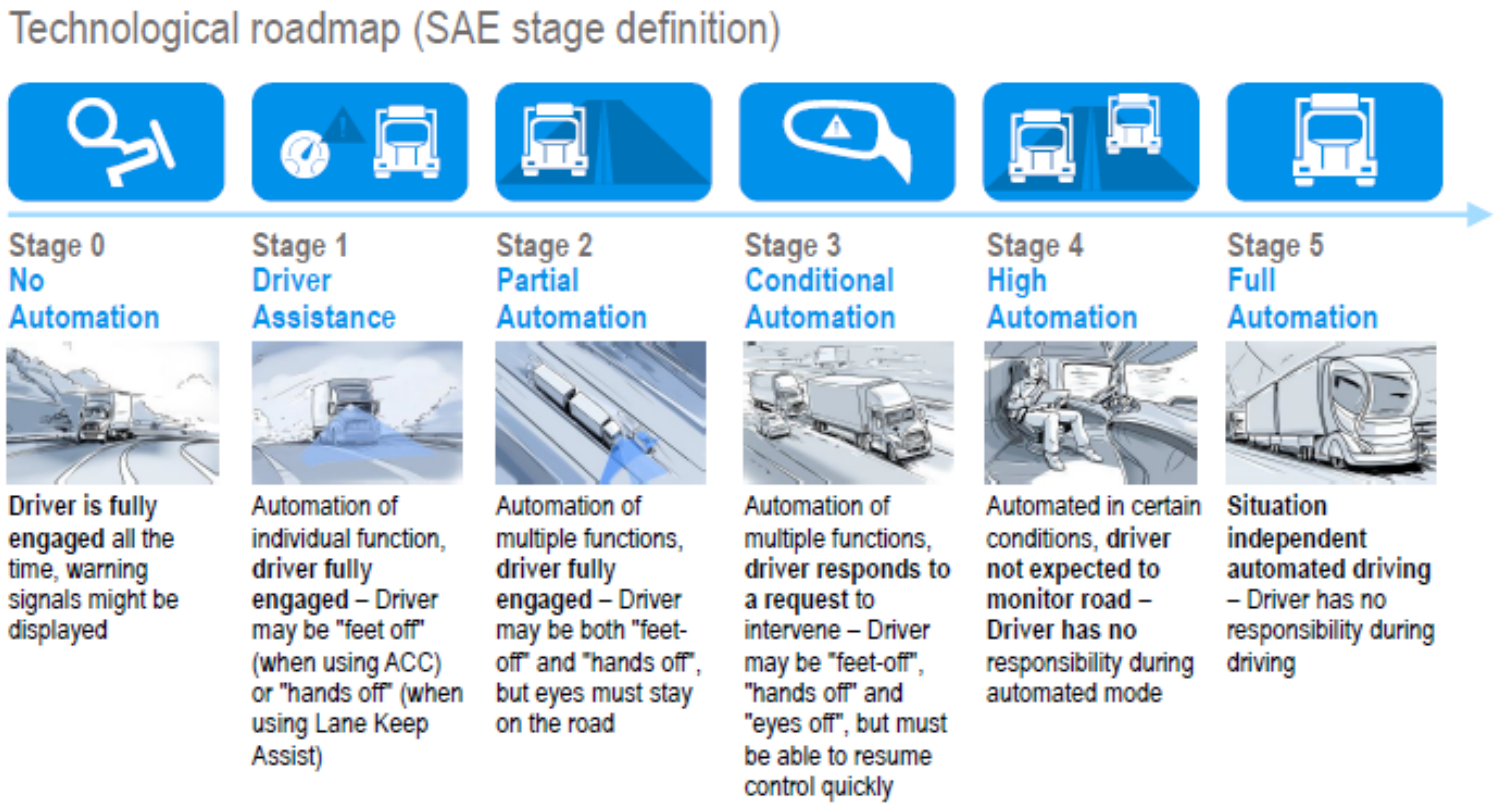
5. Autonomous Vehicle Technology Overview

Section 5 Outline

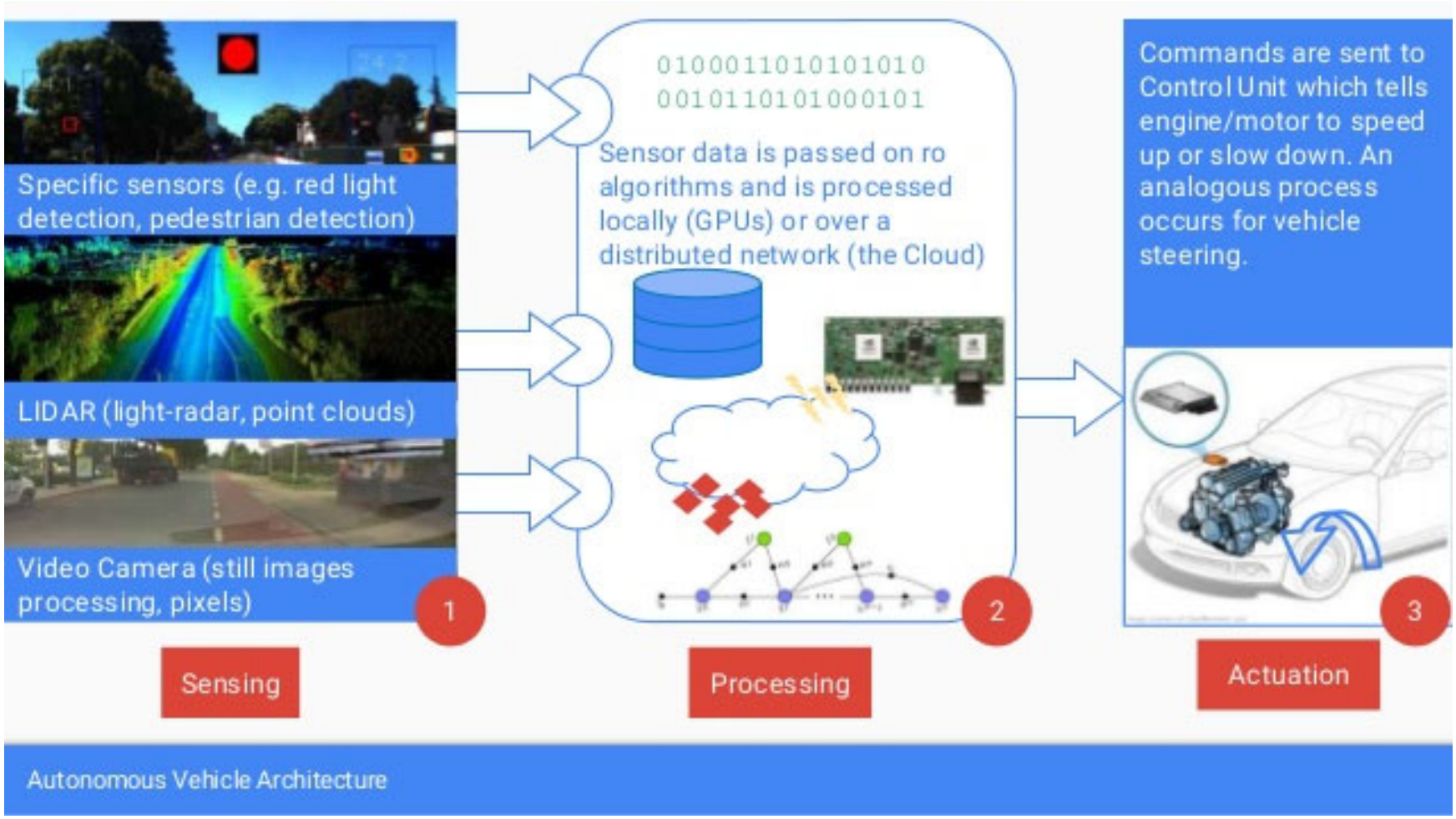
- We now briefly review the autonomous vehicle (AV) technology and identify its economic benefits and costs.
  - Step 1: Define AV technology
  - Step 2: Explain the mechanics of AV technology
  - Step 3: Identify economic benefits of AV technology
  - Step 4: Identify economic costs of AV technology

Step 1: Define AV technology

- An autonomous vehicle (also known as a driverless car, self-driving car, robotic car, autos) is a vehicle that is capable of sensing its environment and navigating without human input.



Step 2: Explain the mechanics of AV technology



Step 2-1: Sensor System

- The sensor system uses a pulsed laser to amass detailed data about the truck's surroundings.

Video Clip: Velodyne's LiDAR Laser System for Autonomous Driving (Click the Screen to Play the Video)

(https://www.youtube.com/watch?v=EBgdskiWlO8&t=20s)

Step 2-2: Feed the Data into Algorithms

- Computers feed the sensor data into algorithms to adjust braking and steering.

Video Clip: Controlling Self Driving Cars (Click the Screen to Play the Video)

(https://www.youtube.com/watch?v=4Y7zG48uHRo&index=2&list=PLGvDOHlOvH_L1XjOf3pLjlqxgeuc5KnqW)

Step 3: Identify Economic Benefits of AV

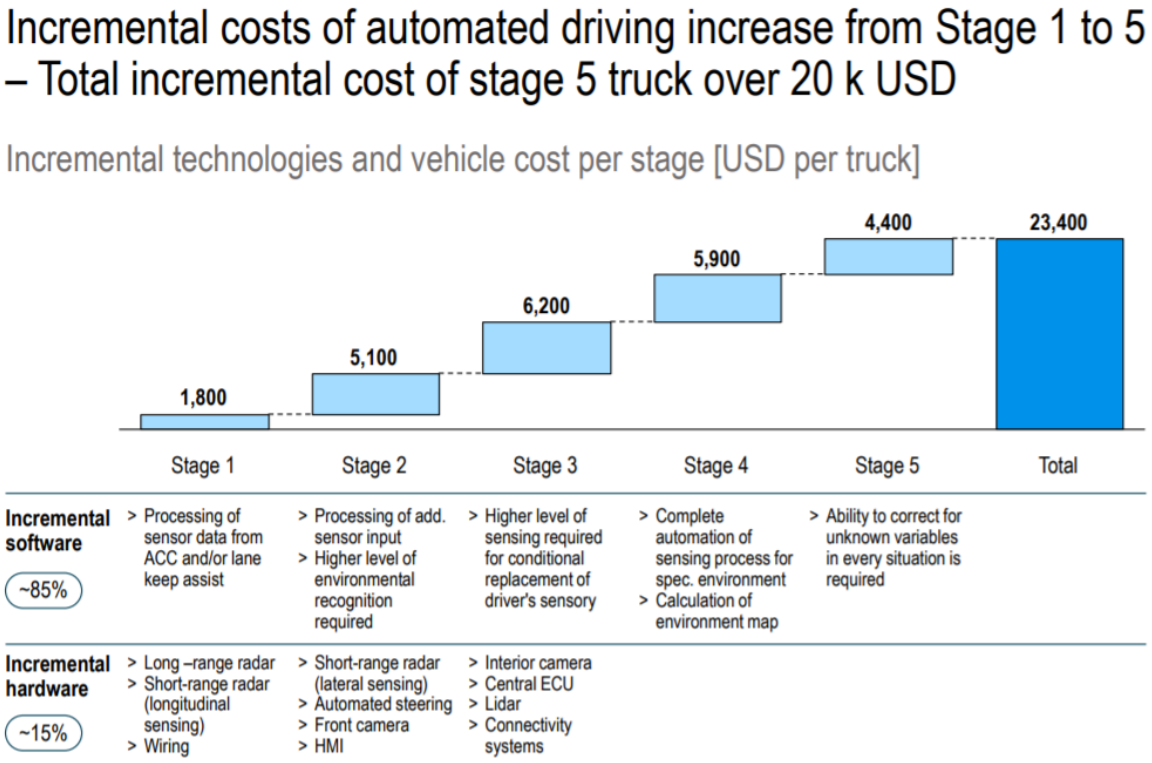
- "In fact, Otto insists it has no plans to release products intended to operate trucks without a driver in the cab. But Otto does expect to free up the driver during highway cruising to remain in the back of the cab.

- And therein lies the strongest part of the economic case for self-driving trucks. Drivers are legally restricted to 11 hours of driving a day and 60 hours a week. Given that a new big rig goes for about $150,000, and taking into account the vast delays that pulling over to rest injects into the movement of goods, trucks that can cruise nearly 24/7 could dramatically lower freight costs."

  - https://www.technologyreview.com/s/603493/10-breakthrough-technologies-2017-self-driving-trucks/

Step 4: Identify Economic Costs of AV

- Any tractor built after 2013 with automated transmissions can be modified or retrofitted into an autonomous truck.



(https://www.rolandberger.com/en/press/Automated-Trucks-%E2%80%93-The-next-big-disrupter-in-the-automotive-industry.html)

6. Autonomous Vehicles Technology Production Functions and Cost Functions

Section 6 Outline

- We now formulate AV technology and cost functions and compare with the traditional technology studies in Section 3.
  - Step 1: Formulate AV production technology assumptions
  - Step 2: Formulate AV production plans
  - Step 3: Calculate AV production function
  - Step 4: Calculate AV marginal product
  - Step 5: Calculate AV average product
  - Step 6: Calculate AV fixed cost
  - Step 7: Calculate AV variable cost
  - Step 8: Calculate AV total cost
  - Step 9: Calculate AV marginal cost
  - Step 10: Calculate AV average fixed cost
  - Step 11: Calculate AV average variable cost
  - Step 12: Calculate AV average total cost

Step 1: Formulate AV production technology assumptions

- **Fixed: Trucks with AV**
- Consider a trucking company with 3 trucks.
- We assume that # of trucks is fixed with 3 to focus on the effect of AV technology.
- We equip each truck with AV technology that costs 20K.
- **Variable Inputs: Skilled Drivers.**
- A production of a load requires a combination of an AV truck and a skilled driver.
  - Assume that a driver is assigned to one truck.
- We assume that AV technology will double productivity for a skilled driver.
  - "Trucks that can cruise nearly 24/7"
  - "Trucks that do not need to park at the destination overnight."

Step 2: Formulate AV production plans

- Observe that the AV technology will increase a driver outputs.
  - "Trucks that can cruise nearly 24/7"

Driver	Previous-Output	AV Output
0	0	0
1	100	200
2	200	400
3	300	600
4	350	700
5	400	800
6	450	900
7	475	950
8	500	1000
9	525	1050

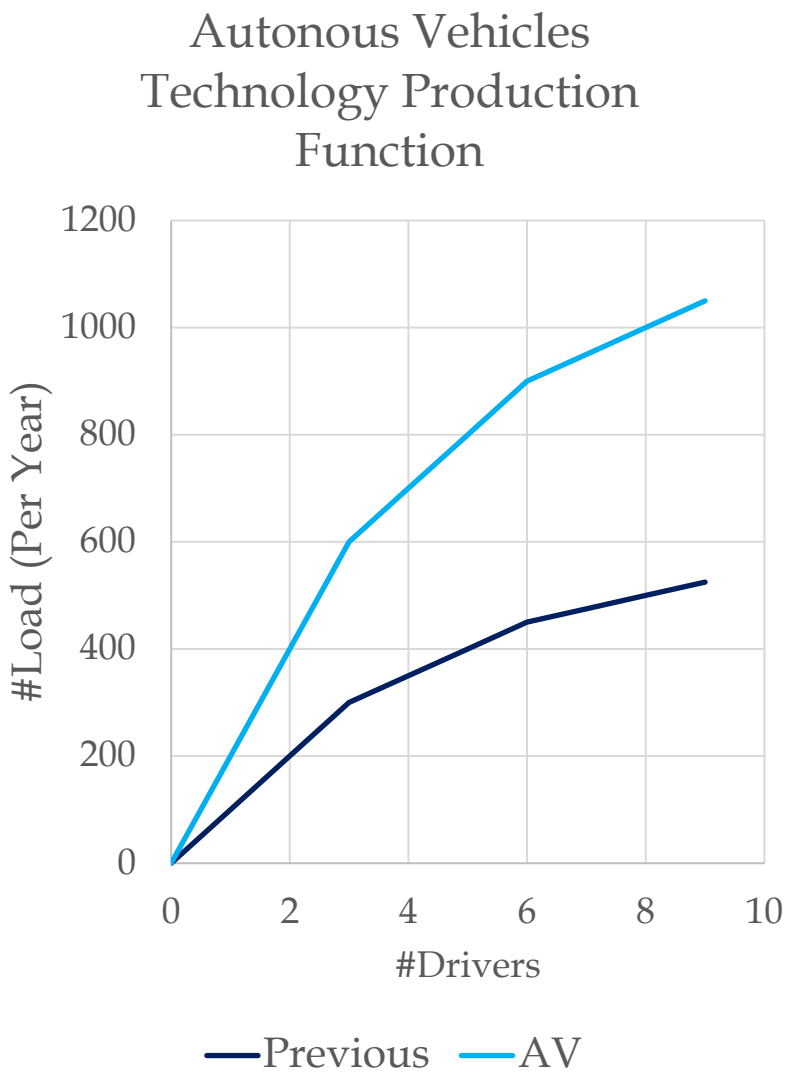
First driver for each car

Second driver for each car

Third driver for each car

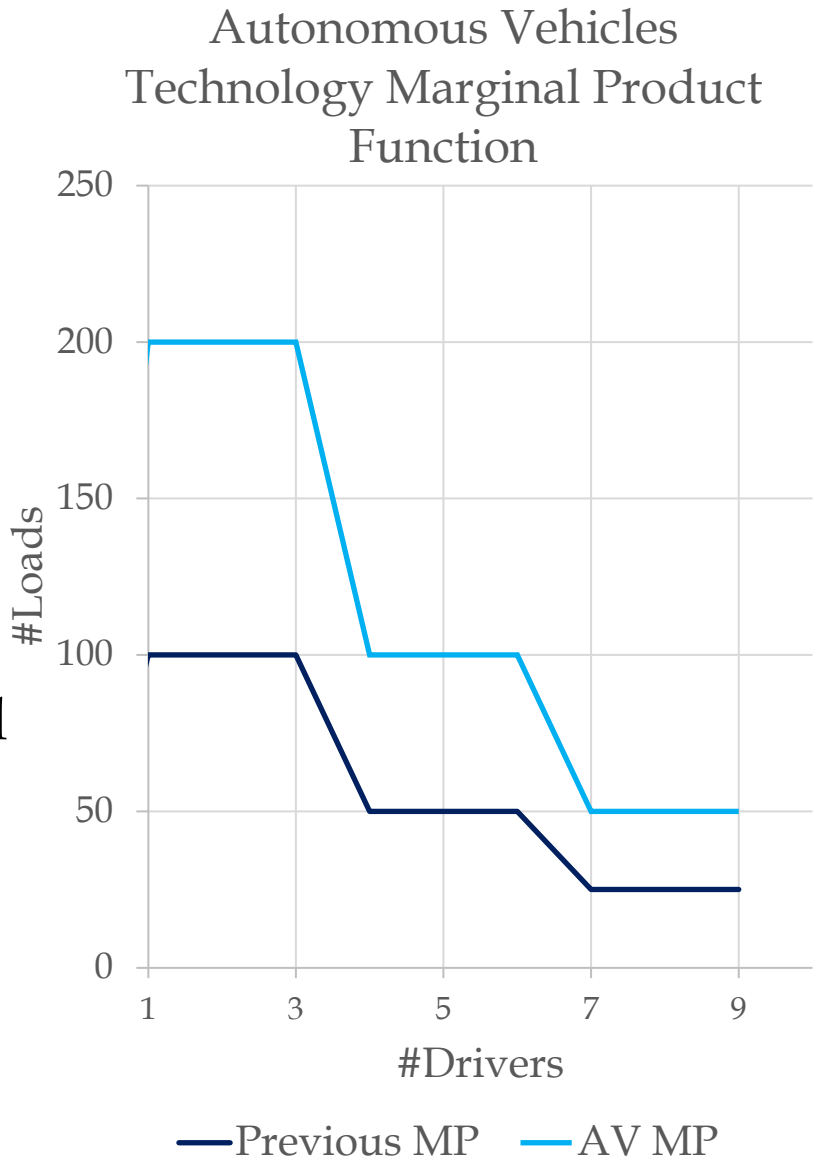
Step 3: Calculate AV Production Function

- Observe
  - AV technology enables each drivers to operate vehicle more efficiently
  - the output increases compared with the previous technology.



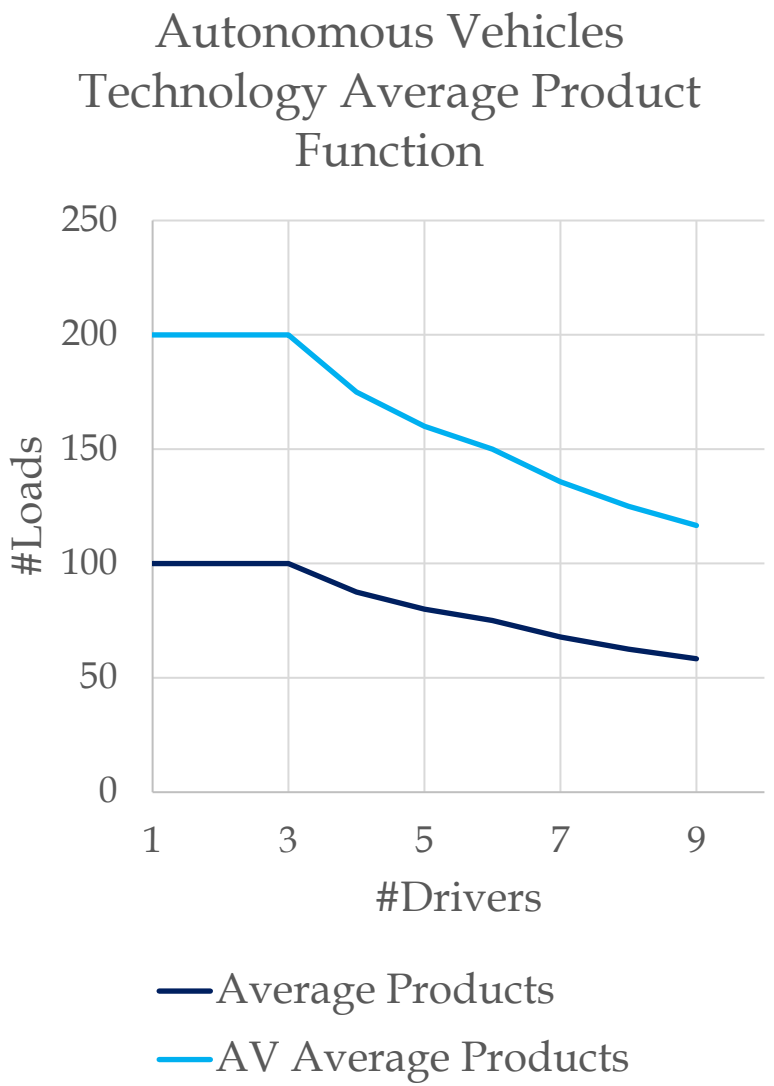
Step 4: Calculate AV Marginal Product

- Calculate marginal product as the change in output (loads) resulting from employing one more unit of labor (driver).
- Observe that AV technology increases skilled driver productivity
  - "skill-biased technological change"



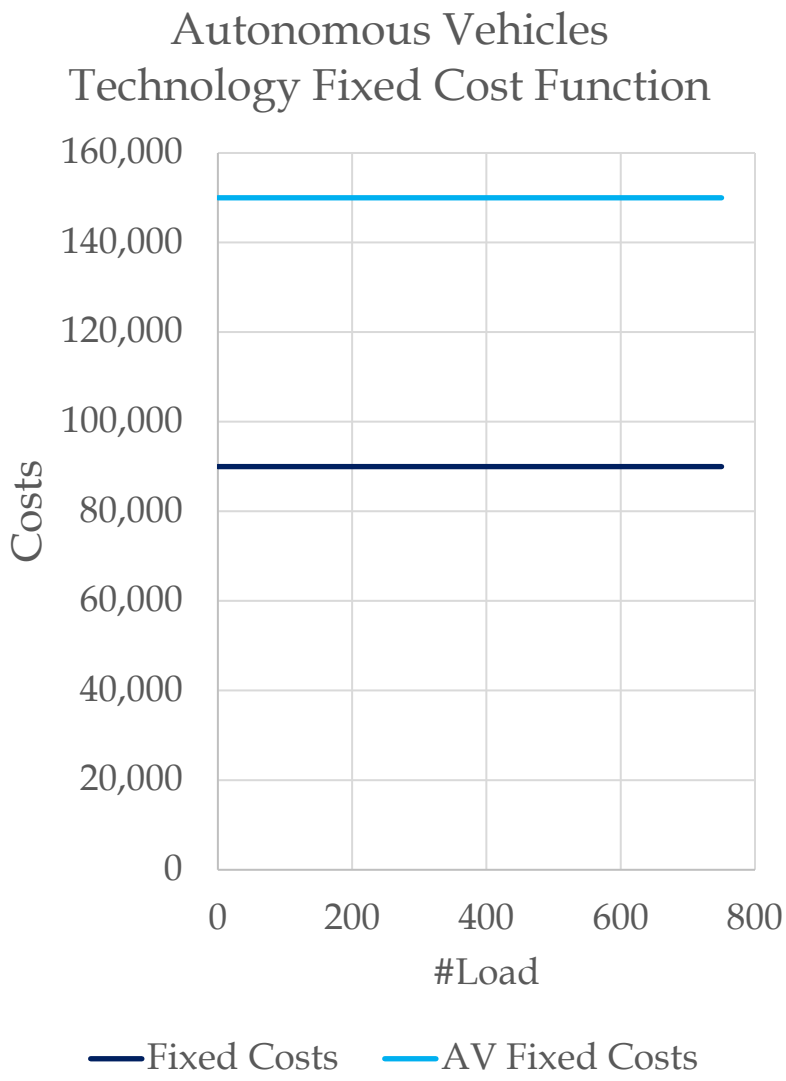
Step 5: Calculate AV Average Product

- Observe that AV technology increases average productivity of skilled drivers.



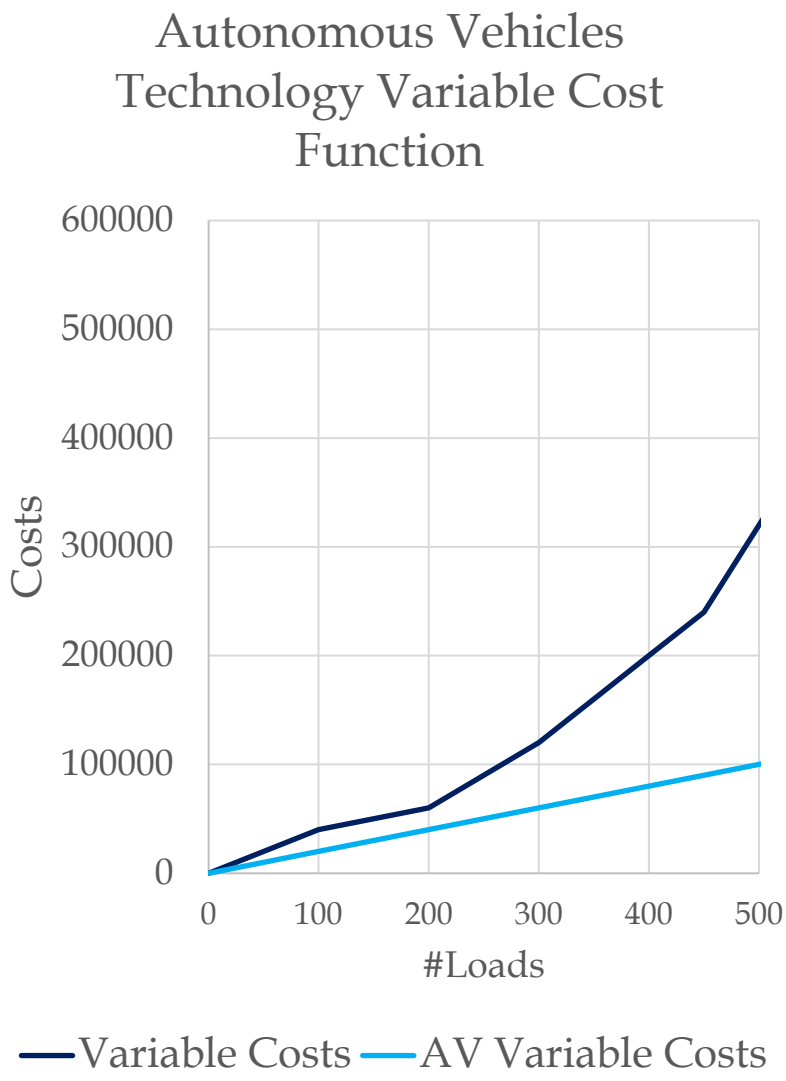
Step 6: Calculate AV Fixed Cost

- Recall that fixed cost is the cost of the firm's fixed inputs.
- Observe that AV technology requires higher initial capital improvements for hardware and software upgrades.



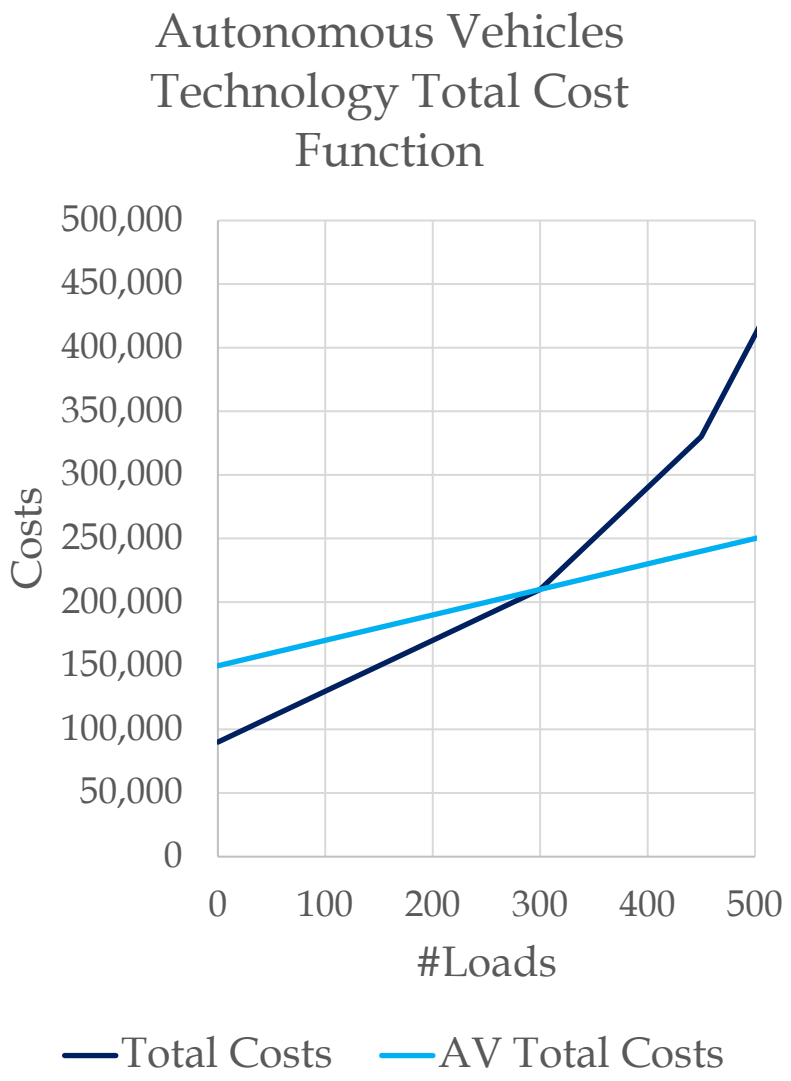
Step 7: Calculate AV Variable Cost

- Recall that variable cost is the cost of the firm's variable inputs.
- Observe that AV technology reduces variable costs significantly.



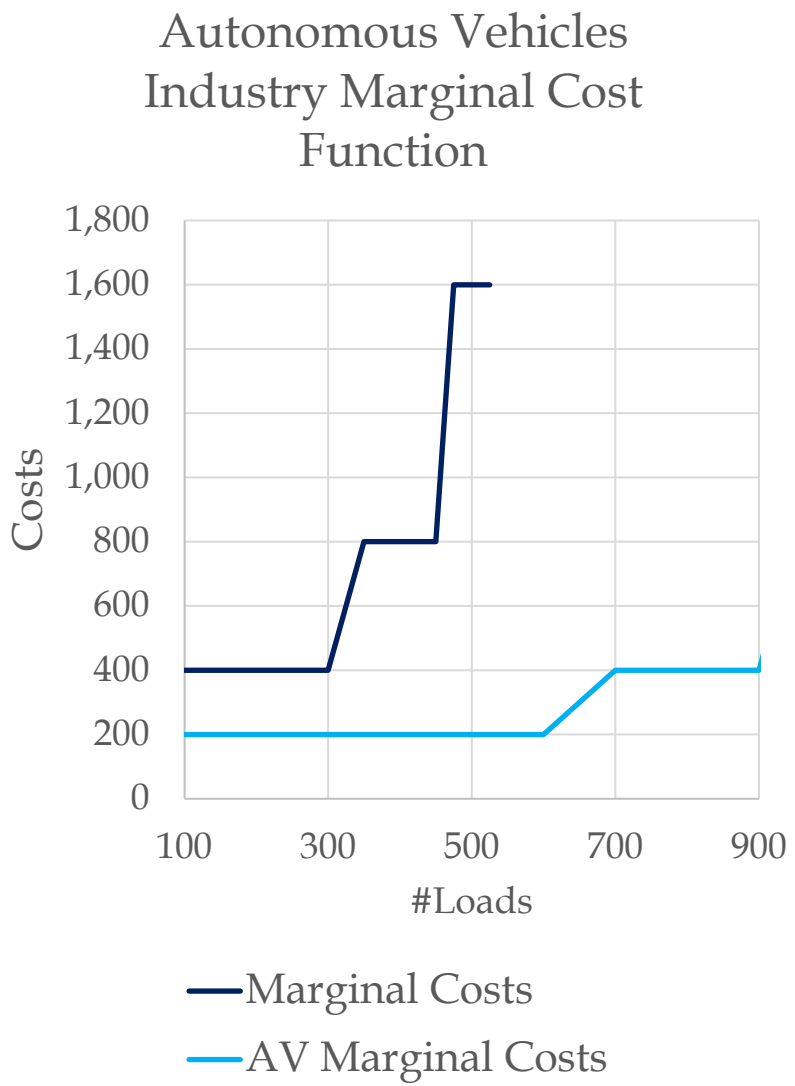
Step 8: Calculate AV Total Cost

- Observe that
  - Due to higher capital investment, the AV total cost would be higher initially
  - But as the load increases, the productivity improvement kicks in and the AV technology will have cost advantage.



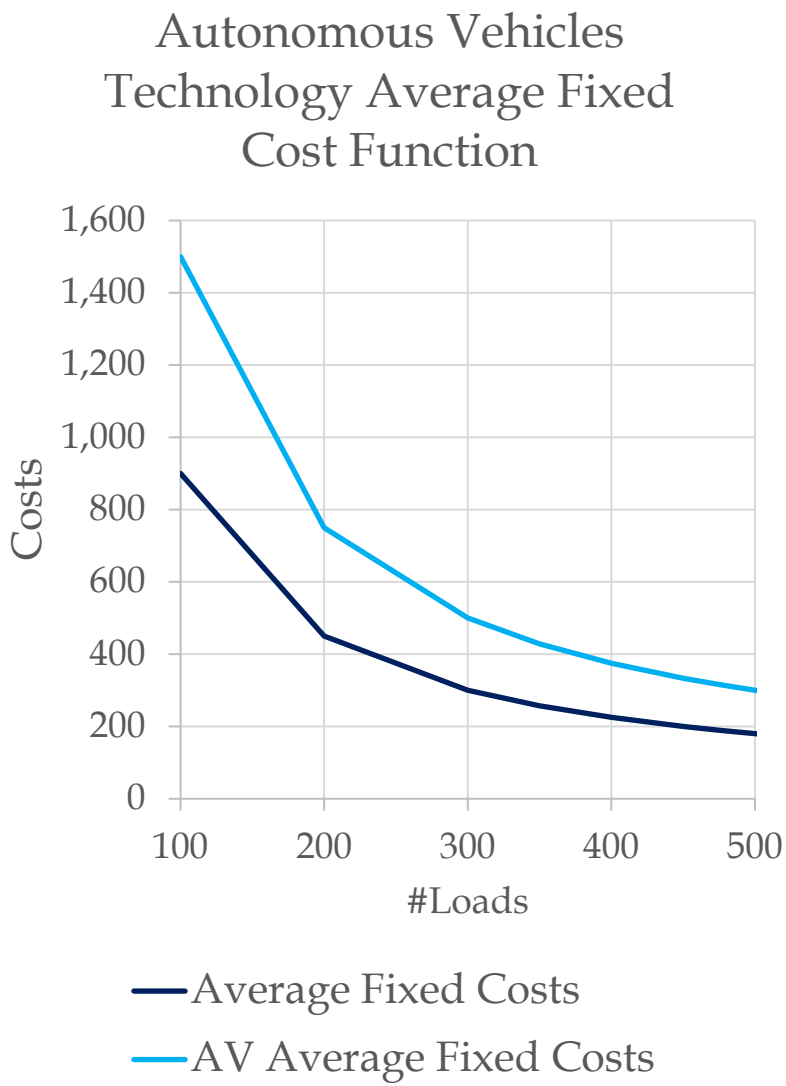
Step 9: Calculate AV Marginal Cost

- Recall that marginal cost is the increase in the total cost from a one-unit increase in output.
- Observe that AV technology reduces marginal costs through automation.



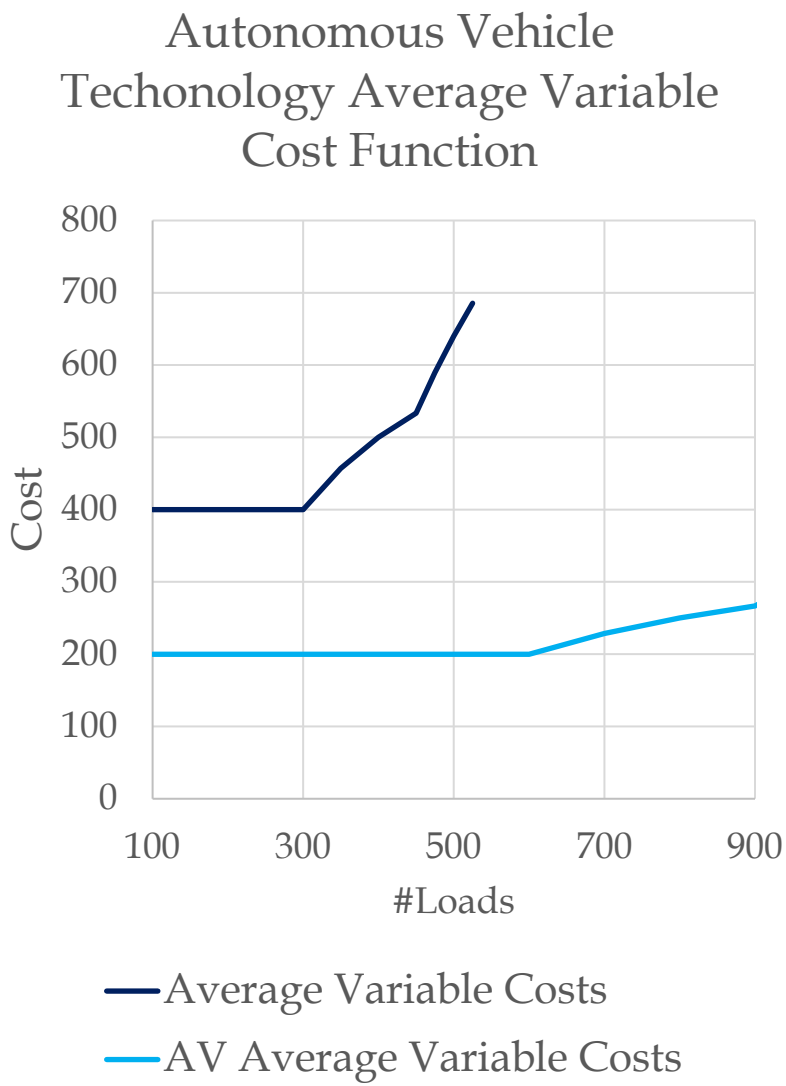
Step 10: Calculate AV Average Fixed Cost

- Recall that average fixed cost is the fixed cost per unit of output.
- Observe that, due to higher capital investment, AV technology would have a higher AFC.



Step 11: Calculate AV Average Variable Cost

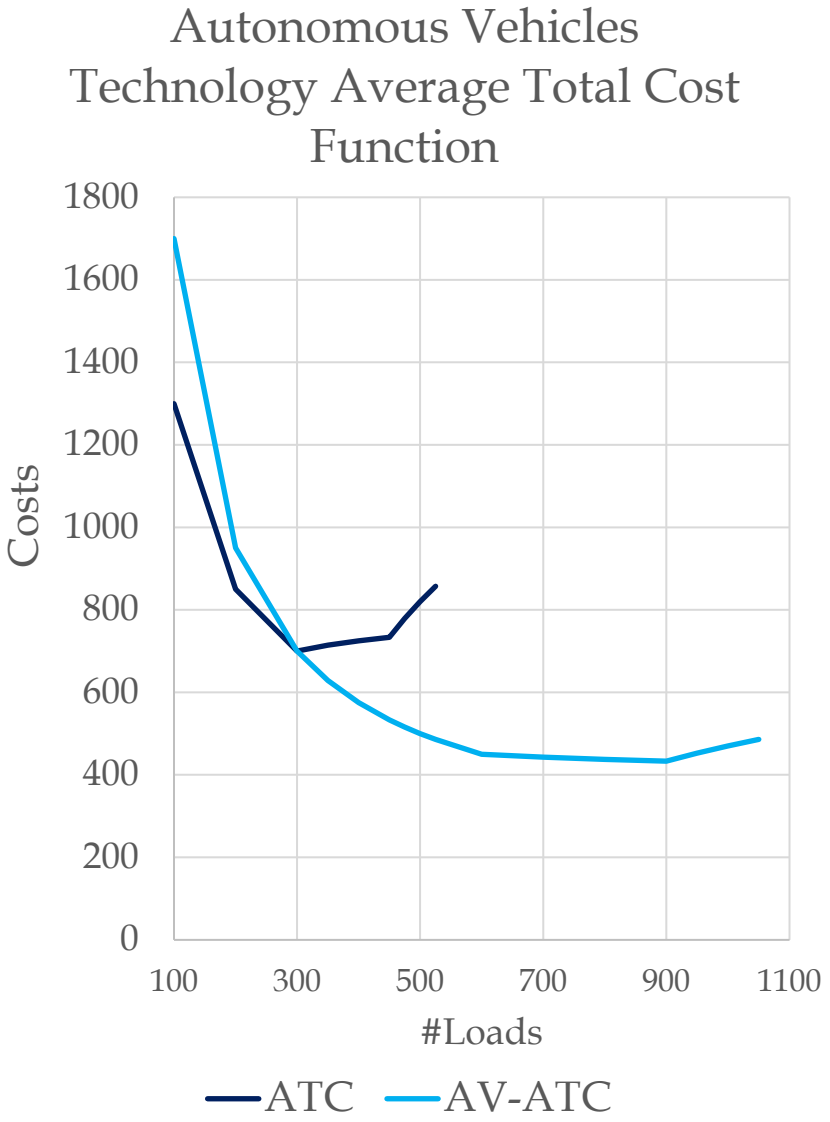
- Recall that Average variable cost is the variable cost per unit.
- Observe that, due to higher driver productivity, AV technology would have lower average variable costs.



Step 12: Calculate AV Average Total Costs

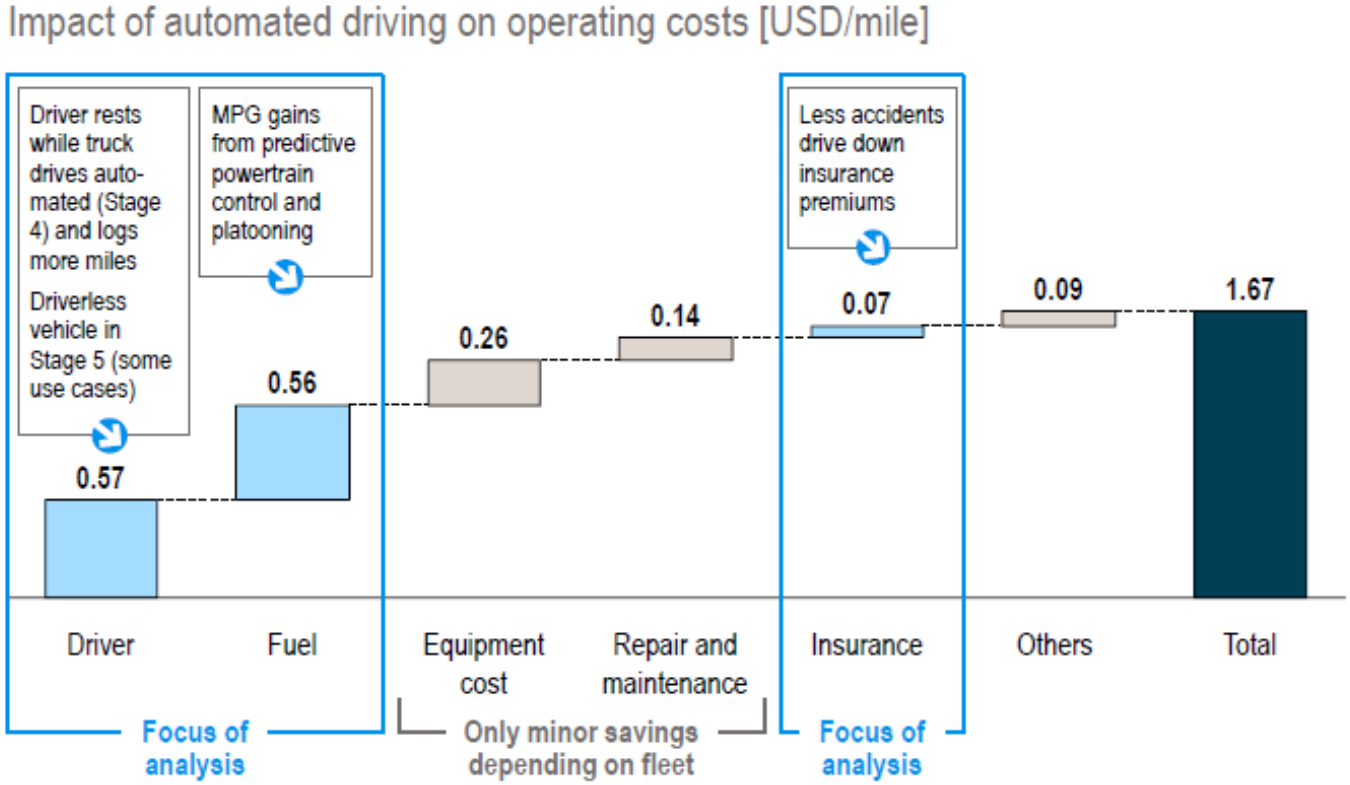
- Observe that
  - AV technology would have a higher ATC initially due to capital investment in AV technology
  - AV technology will lead to lower ATC as the technology kicks in.

- Thus AV firms will enter the market over traditional firms.



Sanity check: significant cost savings from AV Technology

Driver and fuel are the largest cost items and will be impacted by automated driving – Additional savings on insurance cost possible



(https://www.rolandberger.com/en/press/Automated-Trucks-%E2%80%93-The-next-big-disrupter-in-the-automotive-industry.html)

7. Long-Run Trucking Industry Equilibrium

Section 7 Outline

- We now characterize the long-run market equilibrium with AV firms.
  - Step 1: Define Long-Run Competitive Equilibrium
  - Step 2: Derive Individual Firm Supply Function
  - Step 3: Calculate AV firm supply function
  - Step 4: Calculate AV market supply function
  - Step 5: Construct market demand function
  - Step 6: Calculate AV long-run equilibrium
  - Step 7: Calculate AV consumer surplus
  - Step 8: Calculate AV producer surplus
  - Step 9: Calculate AV social surplus
  - Step 10: Calculate AV industry employment

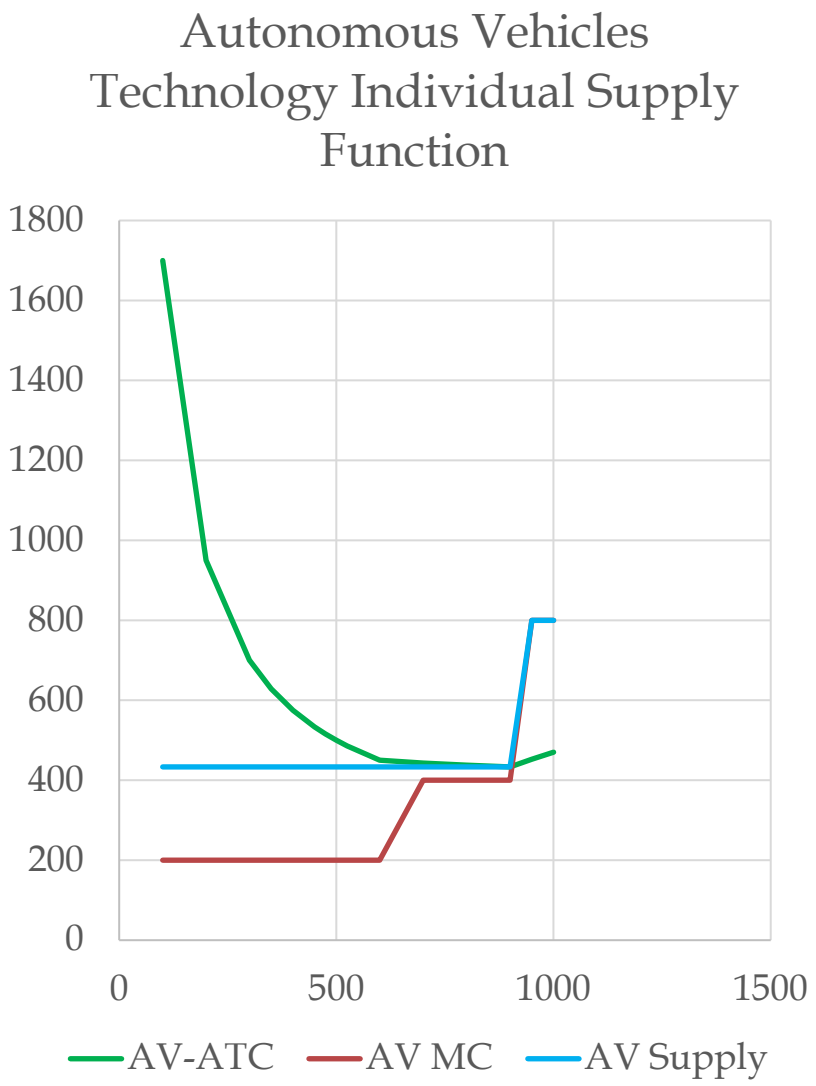
Step 1: Define Long-Run Competitive Equilibrium

- Recall that a long run equilibrium is a situation where no firm in the industry wants to leave and no potential firm wants to enter.

- Assuming that the technology (and hence cost functions) of every firm are the same, in a long run equilibrium every firm's maximal profit is zero, the price is equal to minimum average total cost.

Step 2: Derive Individual Firm Supply Function

- Firm supply function
  - If the price is less than the minimum of the average total cost, a firm will not supply,
  - For prices higher than the minimum of ATC, the firm will supply till the marginal cost equals to the price.



Step 3: Derive AV Long-Run Equilibrium Price

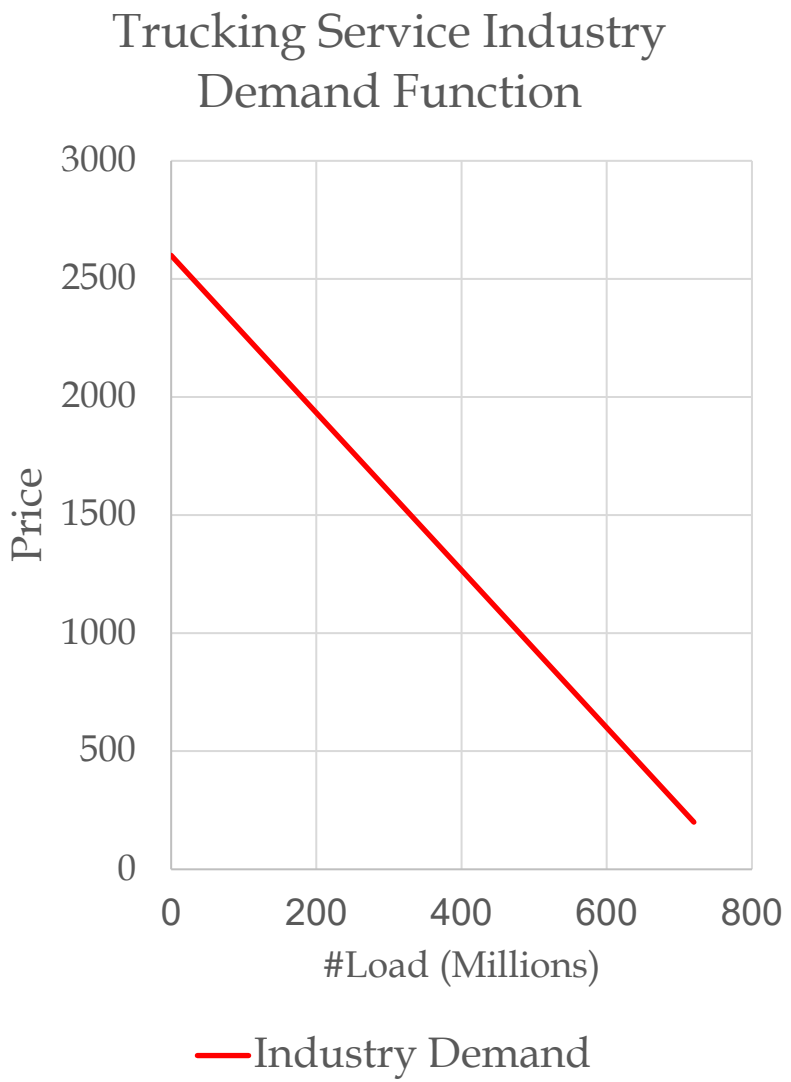
- Deduce, from the zero profit condition,
  - the AV equilibrium price is $433
  - each firm supplies 900 loads per year.

- Recall that
  - the current equilibrium load rate is $800
  - each firm supplies 450 loads per year.

- Observe
  - AV technology firm will be able to supply more services with lower costs.
  - This will lead to exit of traditional trucking firms.

Step 4: Derive Long-Run Demand

- Deduce, from the industry demand function, the demand at the price 433 is about 660M loads.
- Recall that previous equilibrium has 540 million yearly loads.
- Observe that AV higher productivity leads to lower prices and higher loads.

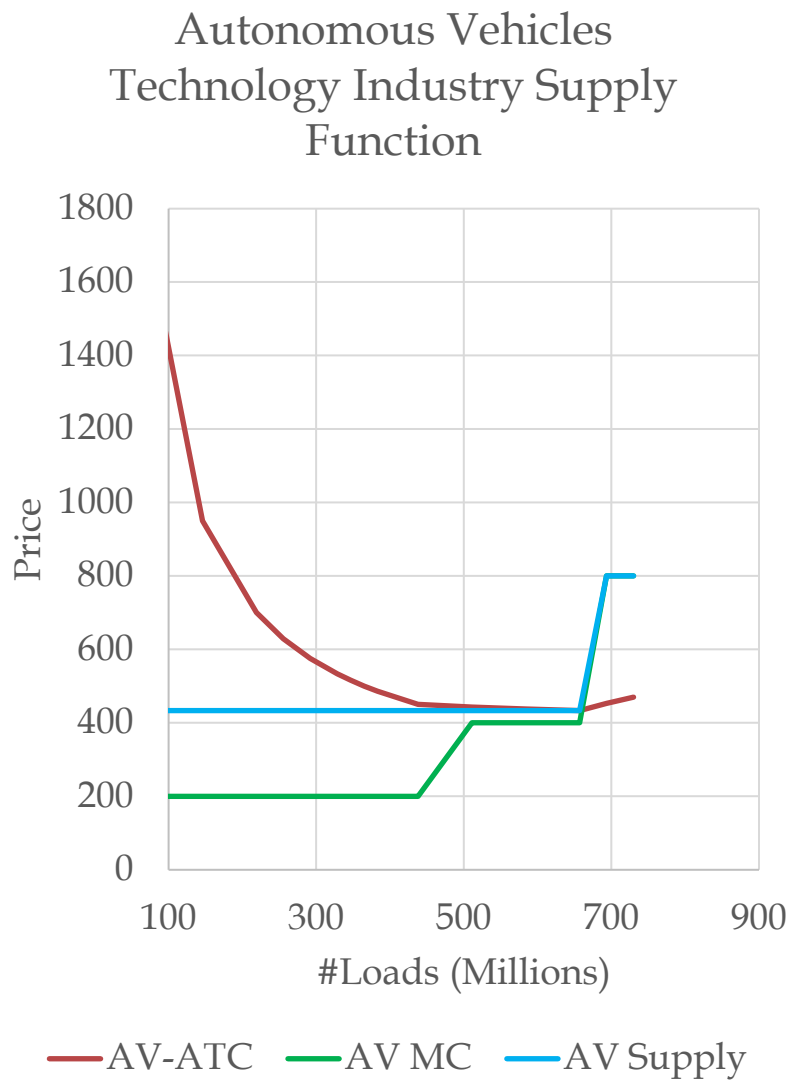


Step 5: Derive Long-Run # of Firms

- Since each firm will deliver 900 loads, there will be about 733,000 trucking firms in the industry.
- Recall that currently there are 1.2 million firms.
- Deduce that about 40% of current firms will exit from the industry.

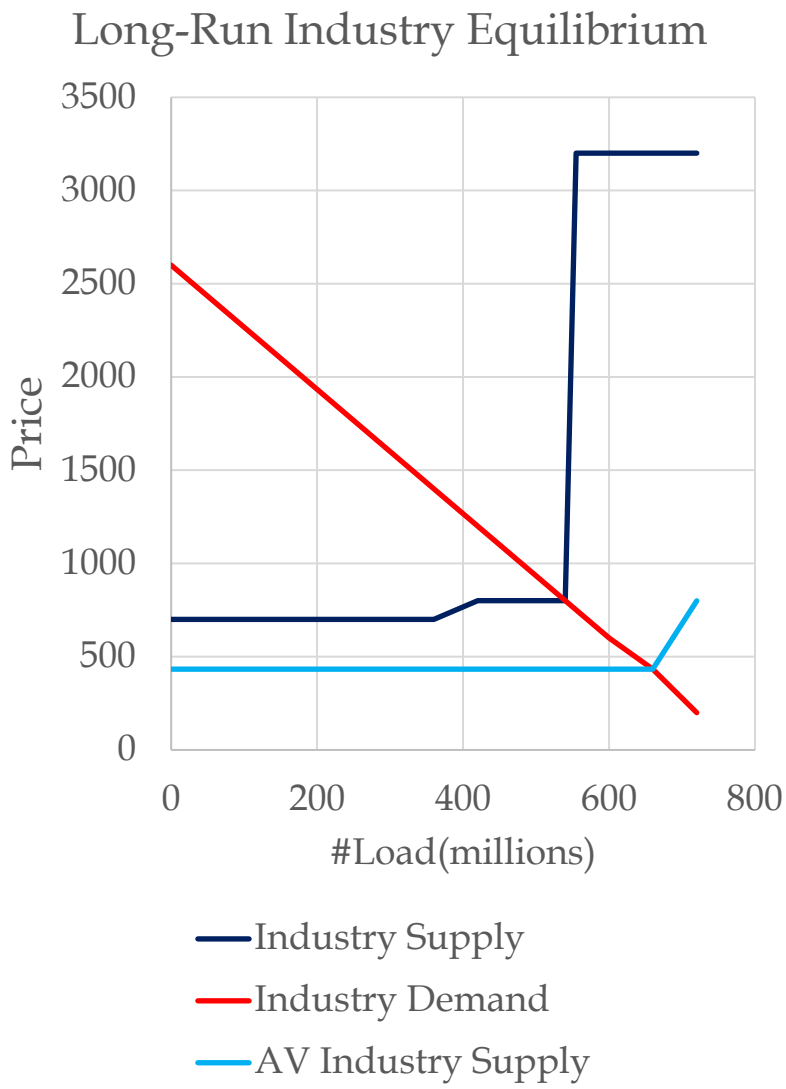
Step 6: Derive Long-Run Industry Supply Function

- We calculate the industry supply function by summing up individual supply function for 733,300 firms.



Step 7: Derive Long-Run Market Equilibrium

- In summary, the AV technology
  - reduces the load rate by 45%
  - increases the load by 22%
  - reduces the number of firms by 40%.



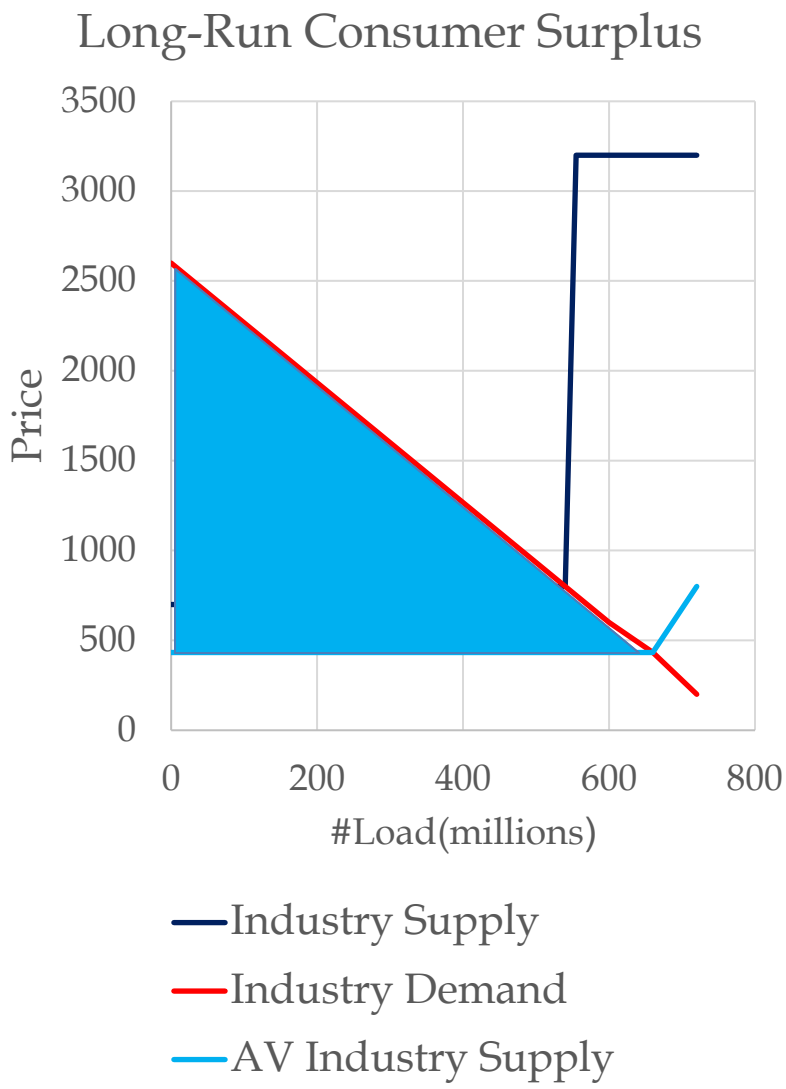
Step 8: Calculate AV Consumer Surplus

- Calculate

  AV Consumer Surplus
  =(1/2)*(2600-433)*660M
  = 714B

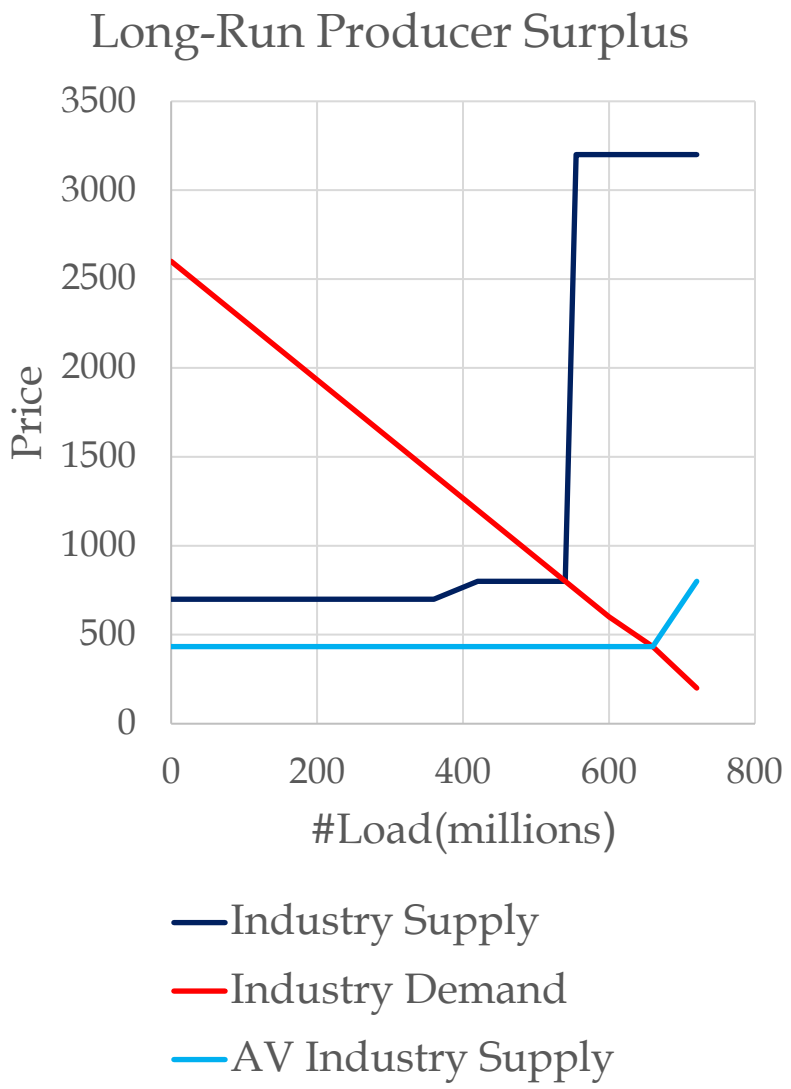
- The current consumer surplus s is 486B

- The AV technology increases the consumer benefits by 228B



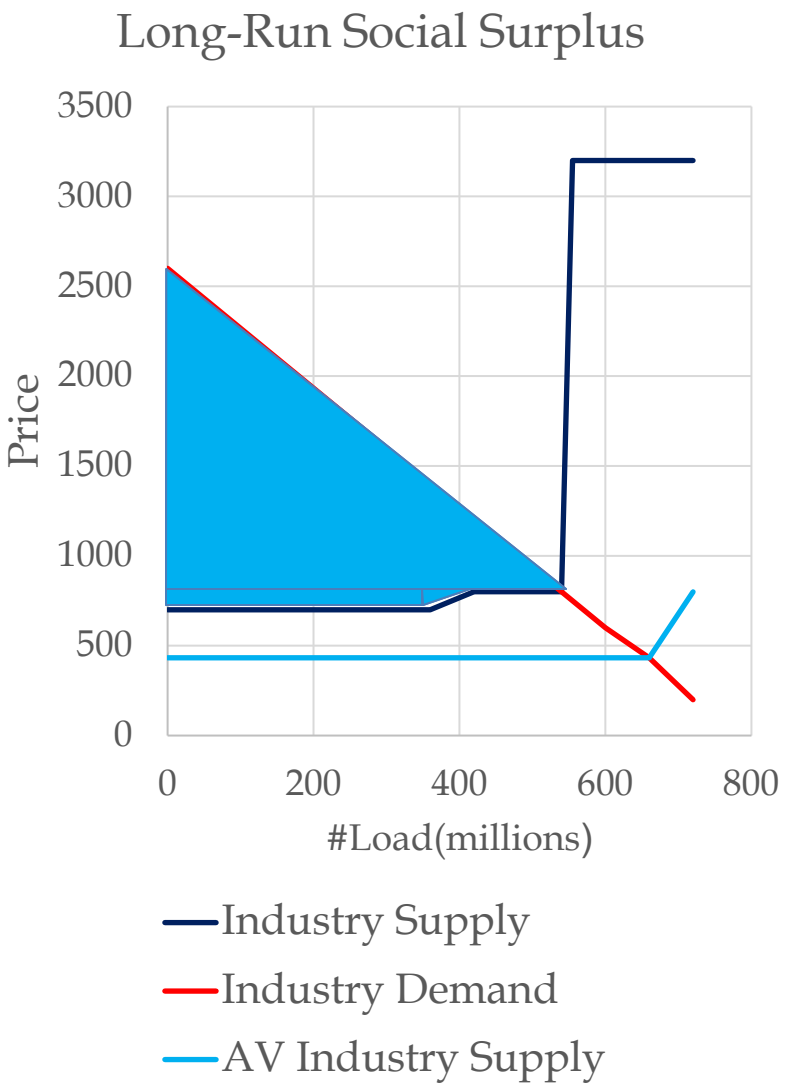
Step 9: Calculate AV Producer Surplus

- In the long-run equilibrium, the firms will earn zero profits.
- Sales increase and cost reduction will lead to profit increases.
- But firms would need to pay for the initial investments.
- Furthermore, entries by new firms will make the market further competitive.



Step 10: Calculate AV Social Surplus

- With zero profit condition, AV Technology Social Surplus is close to 714B.
- Previous social surplus was 531B.
- Increase in the social surplus through higher efficiency with the new automation technology.



Step 11: Calculate AV Equilibrium Employment

- Observe
  - each firm will employ 6 employees.
  - now there are 733,000 firms.

- Deduce that the total industry employee is 733,000*6=4.4M.

- Recall that currently there are 7.2M employment.

- Deduce 7.2M-4.4M=2.8M loss of employment.

- Consistent with the CEA estimate that 2.2 to 3.1M existing part- and full-time U.S. jobs may be threatened or substantially altered by AV technology.
  - https://www.whitehouse.gov/sites/whitehouse.gov/files/images/EMBARGOED%20AI%20Economy%20Report.pdf

8. Policy Counterfactuals

Section 8 Outline

- We now examine possible policy responses to AV:
  - Step 1: Define the role of government in economy policy
  - Step 2: Policy Option 1: Robot Tax
  - Step 3: Model Robot Tax
  - Step 4: Analyze the Effect of Tax on Industry
  - Step 5: Policy Option 2: Universal Basic Income (UBI)
  - Step 6: Model UBI
  - Step 7: Analyze the Effect of UBI on Industry
  - Step 8: Policy Option 3: AV Subsidy
  - Step 9: Model AV Subsidy
  - Step 10: Analyze the Effect of AV Subsidy
  - Step 11: Policy Option 4: Entrepreneurship that Enhances Transportation Demand
  - Step 12: Model Increasing Demand
  - Step 13: Analyze the Effect of Demand Enhancement

Step 1: Recall the Role of Government in Market

- The primary role of economic policy is to deal with the market failure to restore efficiency and equity.
- We consider a partial equilibrium analysis.
- The main idea:
  - AV is a shift of the production function
  - AV is not a market failure
- Note: this is a partial equilibrium (industry) analysis

Step 2: Consider Policy 1: Robot Tax

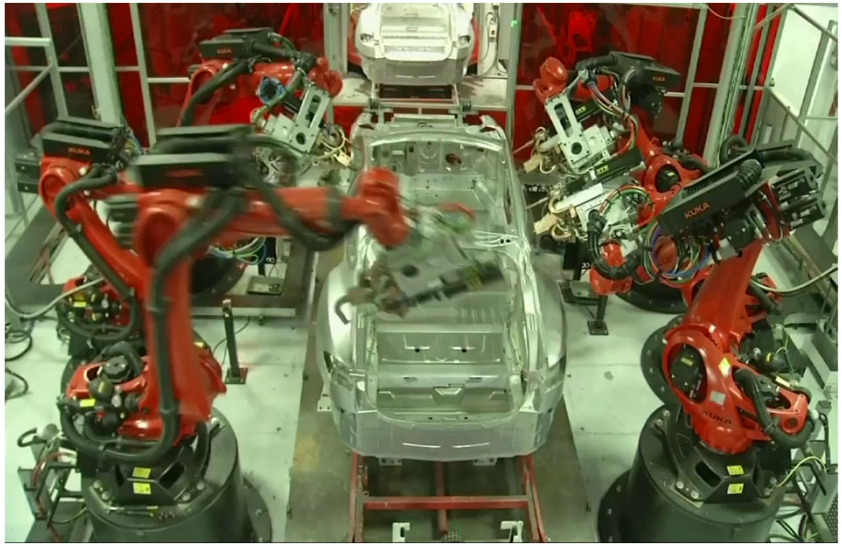
- Recall

  robot tax

  = owners should pay taxes for employing a robot instead of workers

Video Clip: SF Seeks 'Robot Tax' to Help Laid Off Workers (Click the Screen to Play the Video)

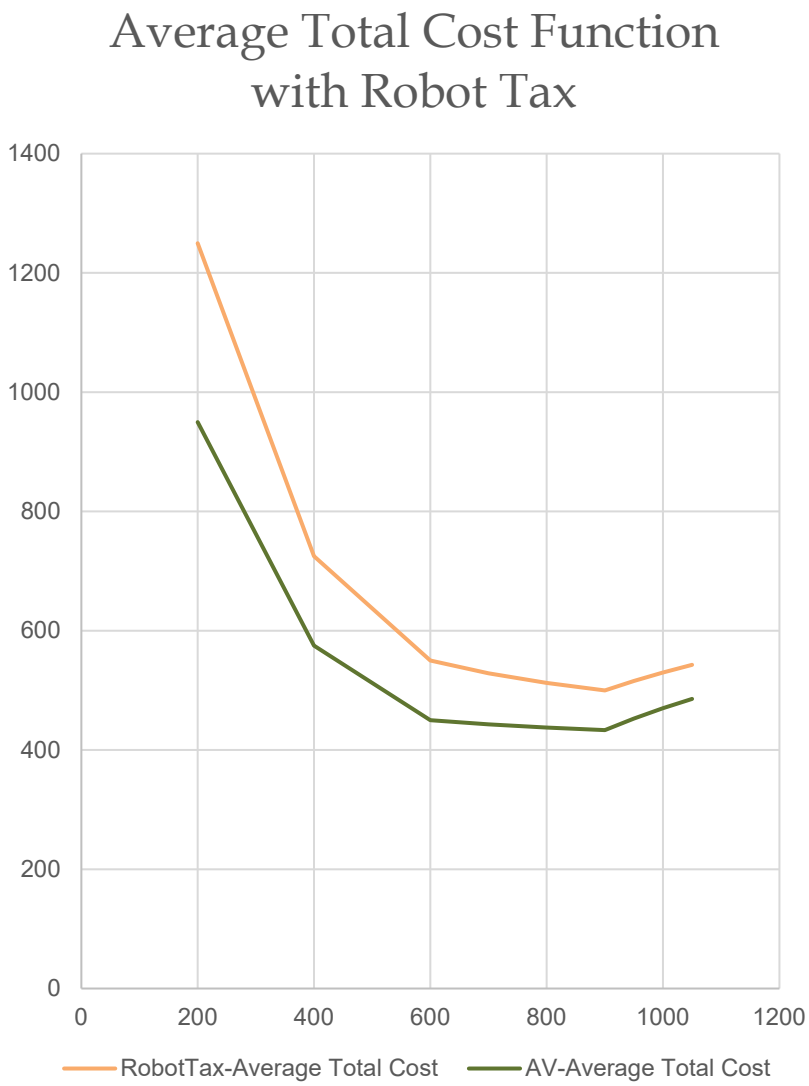
(https://www.youtube.com/watch?v=nccryZOcrUg)



Step 3: Model Robot Tax

- Assume that
  - there will be 100% robot tax to the AV manufacturer.
  - the manufacturer shifts 100% of taxes to the AV price.
- Observe that
  - AV introduction now costs 40K instead of 20K.

- Consideration of other assumptions will not change qualitative conclusions of the analysis.



Step 4: Examine the Effect of Tax on Industry

- Observe robot tax leads to
  - higher rates
  - lower loads
  - lower CS
  - lower # of firms
  - lower employment

- Conclude robot tax
  - lowers the adoption of AV and lead to distortion
  - redistribution to the unemployed

	Current	AV	RoboTax
Load Rate	800	443	500
#Loads	540M	660M	636M
CS	486M	714B	668M
#Firms	1.2M	0.73M	0.71M
#Employees	7.2M	4.4M	4.2M

Step 5: Consider Policy Option 2: Universal Basic Income

- Recall

  universal basic income (UBI)

  = everyone will receive a regular unconditional amount as a social safety net

- State of Hawaii Resolution of UBI

HOUSE OF REPRESENTATIVES
TWENTY-NINTH LEGISLATURE, 2017
STATE OF HAWAII

H.C.R. NO. 89

HOUSE CONCURRENT RESOLUTION

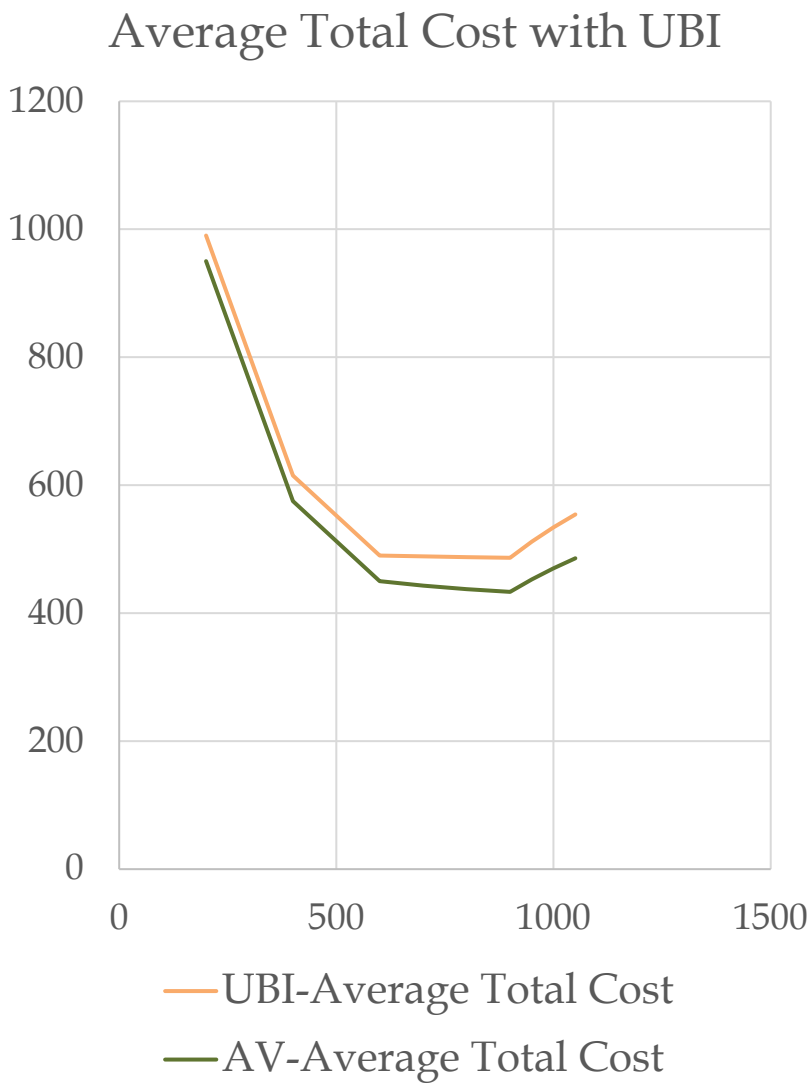
REQUESTING THE DEPARTMENT OF LABOR AND INDUSTRIAL RELATIONS AND THE DEPARTMENT OF BUSINESS, ECONOMIC DEVELOPMENT, AND TOURISM TO CONVENE A BASIC ECONOMIC SECURITY WORKING GROUP.

WHEREAS, while the United States is the wealthiest nation in the world, many families, individuals, and businesses in Hawaii have been struggling to keep pace with the increasing cost of living as economic inequality widens the gap between a few top earners and the middle and lower class, the latter of which has seen its overall share of income decline in recent decades; and

WHEREAS, efforts to increase wages, benefits, and working conditions are important steps to assist local families in the short-term, but a paradigm shift in policy will soon be necessary as automation, innovation, and disruption begin to rapidly worsen economic inequality by displacing significant numbers of jobs in Hawaii's transportation, food service, tourism, retail, medical, legal, insurance, and other sectors; and

Step 6: Model UBI

- Observe "although the magnitudes vary across these papers, taken together the results provide fairly clear evidence to policymakers that unconditional cash transfer programs in developed countries will likely reduce aggregate labor supply by a meaningful amount."
  - http://voxeu.org/article/labour-supply-responses-lottery-winners
- Assume
  - UBI increases the wage 20%, from 40K to 48K.



Step 7: Discuss the Effect of UBI on Industry

- Observe UBI leads to
  - higher rates
  - lower loads
  - lower CS
  - lower # of firms
  - lower employment
- Conclude UBI leads to
  - lower AV adoption
  - distortion
  - redistribution to the unemployed

	Current	AV	AV+UBI
Load Rate	800	443	486
#Loads	540M	660M	640M
CS	486M	714B	677B
#Firms	1.2M	0.73M	0.71M
#Employees	7.2M	4.4M	4.3M

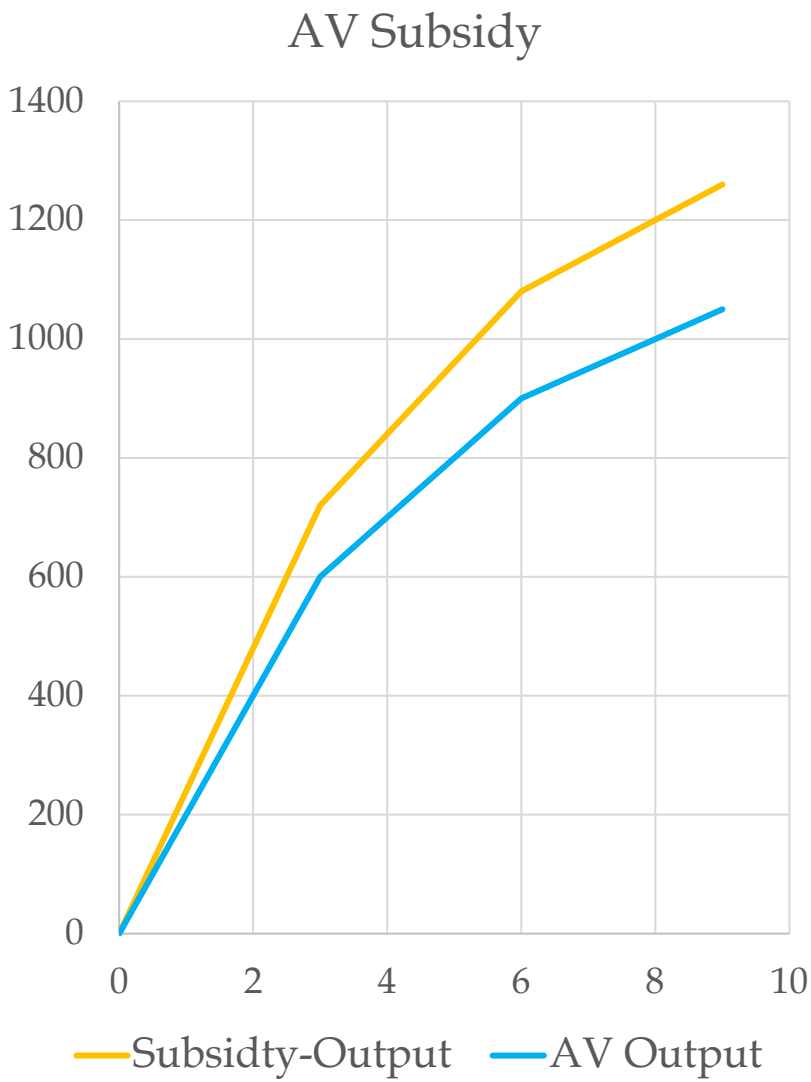
Step 8: Consider Policy Option 3: AV subsidy

- Idea: subsidy to increase a driver productivity with AV technology.

- Consider the effect of subsidy to increase worker AV productivity.

Step 9: Model AV Subsidy

- Assume that
  - AV subsidy increases the driver productivity by 50%.



Step 10: Analyze the Effect of AV Subsidy

- Observe that AV subsidy leads to
  - lower rate, higher #load, and higher CS
    - there will be new work
  - but lower #firms and #employees
    - existing firms will take all the new work
- Conclude that
  - the effect of mere productivity improvement is limited without new demand creation
- Consideration of alternative assumptions will not change qualitative conclusions of the analysis.

	Current	AV	AV+AV Subsidy
Load Rate	$800	$443	$361
#Loads	540M	660M	678M
CS	486B	714B	759B
#Firms	1.2M	0.73M	0.63M
#Employees	7.2M	4.4M	3.8M

Step 11: Consider Policy Option 4: MaaS Entrepreneurship to Enhance Demand

- Recall

  the main obstacle for job creation

  = inelastic demand for transportation service

  = demand does not increase even with lower costs

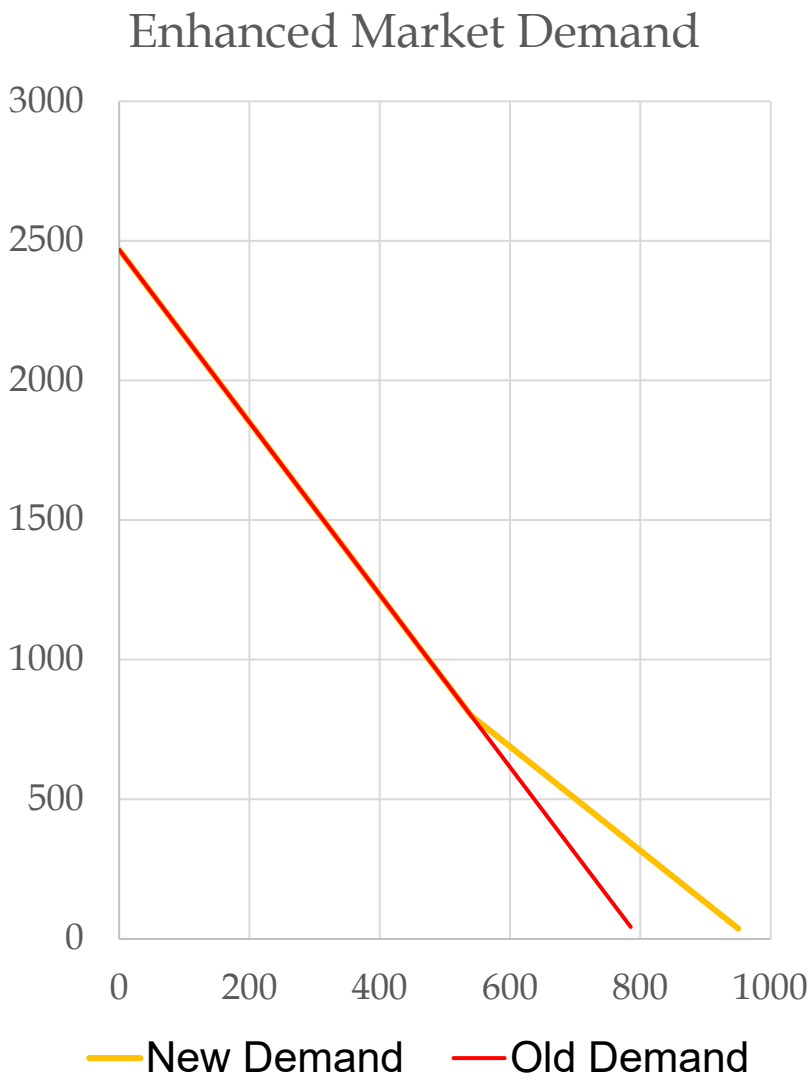
- Consider the effect of MaasS ("Mobility-as-a-Service"), entrepreneurship to enhance demand for AV transportation service.

- Example: with AV lower cost and MaaS, consumers prefer ride sharing with autonomous vehicles because it frees up driving time
  - "self-driving cars are poised to open up a whole new economic chapter in what Intel and research firm Strategy Analytics are calling the Passenger Economy, valued at $7 trillion in revenue by 2050."
    - https://newsroom.intel.com/news-releases/intel-predicts-autonomous-driving-will-spur-new-passenger-economy-worth-7-trillion/

Step 12: Model Demand Enhancement Effect

- Assume the transportation demand elasticity below the current price 800 is now -0.8.

- Observe
  - More demand for transportation service for lower prices due to MaaS



Step 13: Analyze the Effect of MaaS Demand

- Observe that MaaS demand enhancement leads to
  - lower rate, higher #load, and higher CS
    - new work
  - more #firms and #employee
    - new jobs
    - truck drivers now work as new MaaS services
- Conclude that
  - Transportation demand enhancement is the key for job creation

	Current	AV	AV+MaaS
Load Rate	800	443	443
#Loads	540M	660M	678M
CS	486M	714B	740B
#Firms	1.2M	0.73M	0.81M
#Employees	7.2M	4.4M	4.9M

9. Conclusion

Conclusion

- This lecture studies the theory of perfect competition through the analysis of the effect of autonomous vehicles on trucking service industry.

- The autonomous vehicle technology has two effects: (1) substitution of traditional labors (drivers) but (2) increased productivity of drivers who adapt to the new technology.

- Based on industry data, we estimate changes in consumer surplus, producer surplus, and labor employment when firms adopt the autonomous vehicle technology.
  - These results are consistent with the industry statistics and the CEA estimate of employment impacts.

- Furthermore, the perfect competition framework enables us to analyze the effect of proposed policies such as robot tax, basic income, subsidy, and new industry demand.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