

## Assessing and quantifying the impacts of vehicle automation, electrification, and connectivity on highway expenditures, revenues, and user equity.

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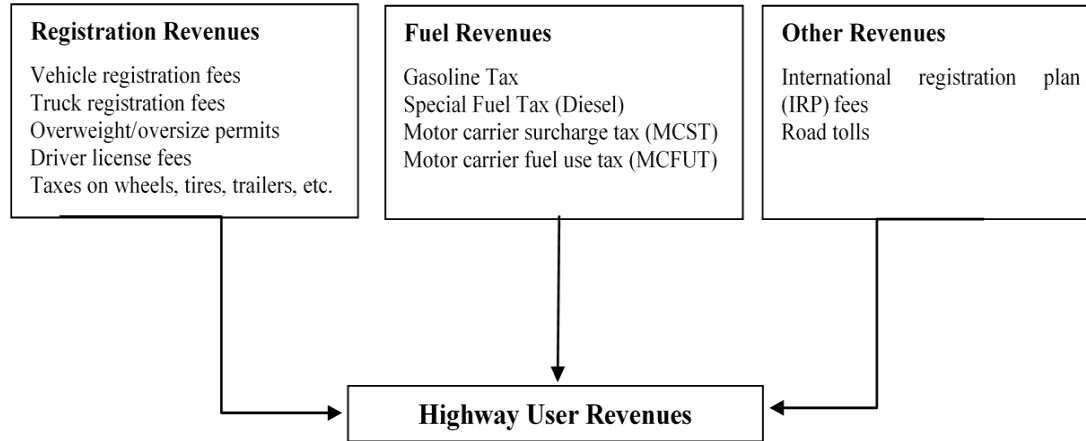
CENTER FOR CONNECTED AND  
 AUTOMATED TRANSPORTATION

## Overview

- The Big Picture
  - Highway Financing: Where the money comes from, what is it used for, and what are some challenges currently facing the system?
- Study Motivation
  - Research gaps
- Emerging Vehicle Technologies
  - Market Penetrations of technologies, impacts on travel, expenditures, revenues and equity.
- Revising the User Fee Structure
  - Novel funding frameworks, updates to current systems.
- Conclusions

## The Big Picture

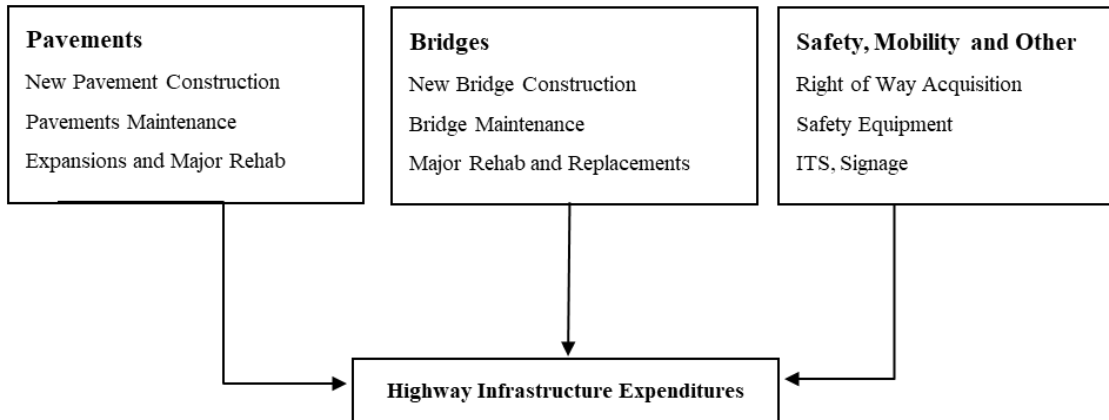
### Highway Revenues



- User Revenues
  - Paid by highway as fees and taxes
- Non-User Revenues
  - Government grants, stimulus, general fund transfers, etc.

## The Big Picture

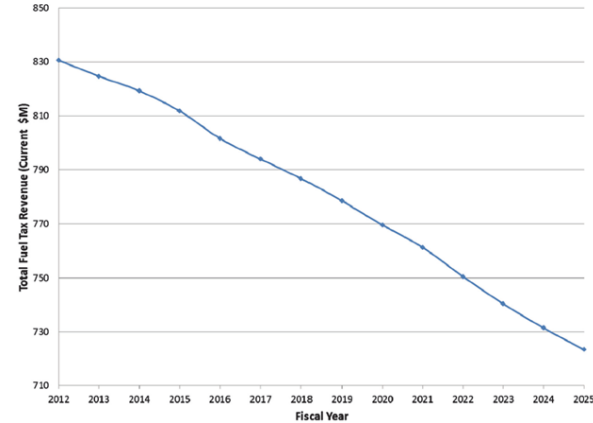
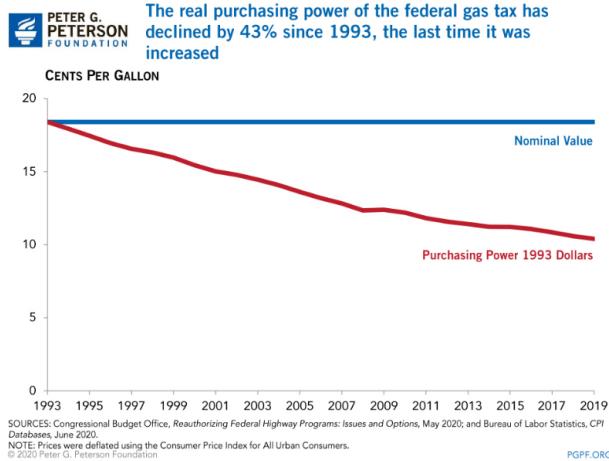
### Highway Expenditures



- Infrastructure expenditures
  - Pavements, bridges, safety, etc.
- Non-Infrastructure expenditures
  - Administration, law enforcement, research, etc.

## The Big Picture

### Problems with Highway Financing



adapted from (Agbelie et al., 2012)

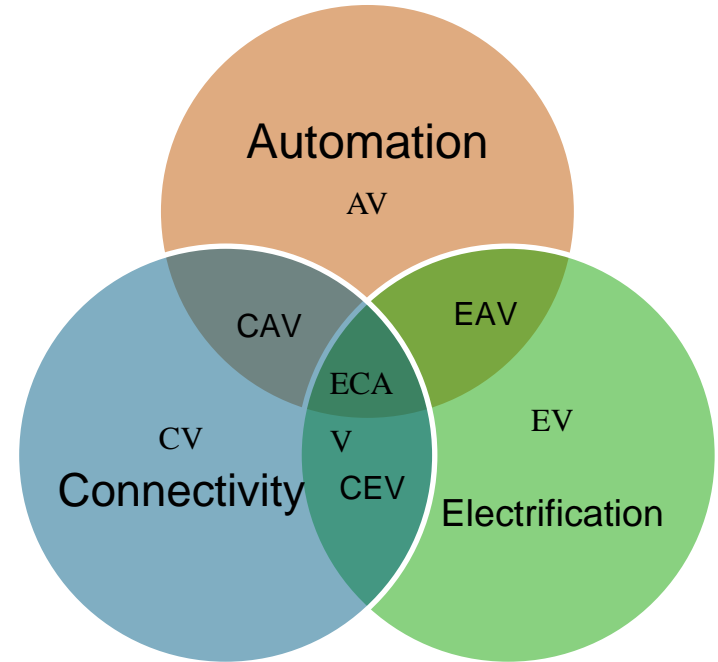
- Increased fuel efficiency
- Prominence of alternative fuels
- Inflation
- New Vehicle Technologies

## Study Motivation

Study	Cost Allocation	Revenue Attribution	Novel Revenue Alternatives	Impacts of ECAVs
(Agbelie et al., 2016)	✓	✓	✓	✗
(Agbelie et al., 2012)	✗	✓	✓	✗
(Agbelie et al., 2010)	✗	✓	✓	✗
(Oh & Sinha, 2008)	✗	✓	✓	✗
(ECONorthwest, 2014)	✓	✓	✓	✗
(Gupta & Chen, 2012)	✓	✓	✓	✗
(P Balducci et al., 2009)	✓	✓	✓	✗
(Kumar Dubey, 2017)	✓	✗	✗	✗
<b>This Study</b>	✓	✓	✓	✓

## Emerging Vehicle Technologies

- Vehicle Automation, Electrification and Connectivity.
  - Each combination of technology and market penetration rate will have different infrastructure requirements
  - Requirements include connectivity equipment, network infrastructure, charging stations, computation and cloud storage, smart highways.
  - May alter highway travel patterns e.g ride sharing and mobility as a service, increased travel due to ghost trips, etc.
  - May raise equity and access issues



## Emerging Vehicle Technologies

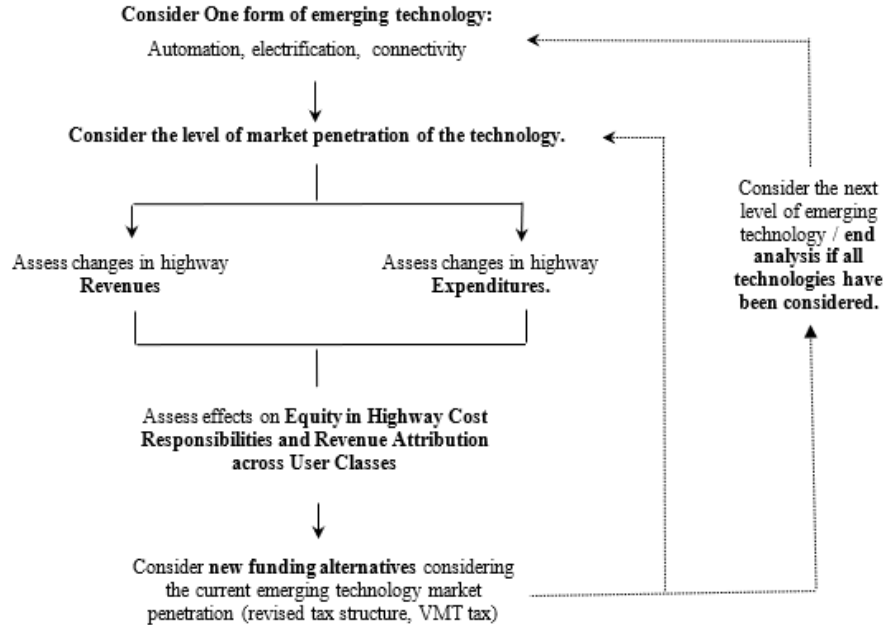
### Scenarios Analyzed

Scenario	Supply	Demand	Timeline (Year)
1	Connectivity	Low	2030
2		Moderate	2040
3		High	2050
4	Automation	Low	2050
5		Moderate	2060
6		High	2070
7	Electrification without Automation	Low	2040
8		Moderate	2050
9		High	2060
10	Automation and Electrification	Low	2050
11		Moderate	2060
12		High	2070
13	Connectivity and Automation	Low	2050
14		Moderate	2060
15		High	2070
16	Connectivity, Automation, and	Low	2050
17	Electrification	Moderate	2060
18		High	2070



## Emerging Vehicle Technologies

### Study Framework



## Emerging Vehicle Technologies

### Sample Results – Expenditures (State of Indiana)

Vehicle Class	Common Costs	Attributable Costs	Total
<b>Base Case – reference year 2070</b>			
Passenger Cars	\$380,999,293	\$715,469,377	\$1,096,468,670
Light Duty Trucks	\$158,211,809	\$1,782,835,478	\$1,941,047,287
Heavy Duty Trucks	\$60,293,921	\$1,562,696,954	\$1,622,990,874
Total	\$599,505,022	\$4,061,001,809	\$4,660,506,831
<b>Expenditures adjusted for ECAVs at high market penetration</b>			
Passenger Cars	\$527,413,228	\$859,510,291	\$1,386,923,519
Light Duty Trucks	\$216,601,548	\$2,121,310,140	\$2,337,911,688
Heavy Duty Trucks	\$83,480,162	\$1,882,338,462	\$1,965,818,624
Total	\$827,494,938	\$4,863,158,893	\$5,690,653,831

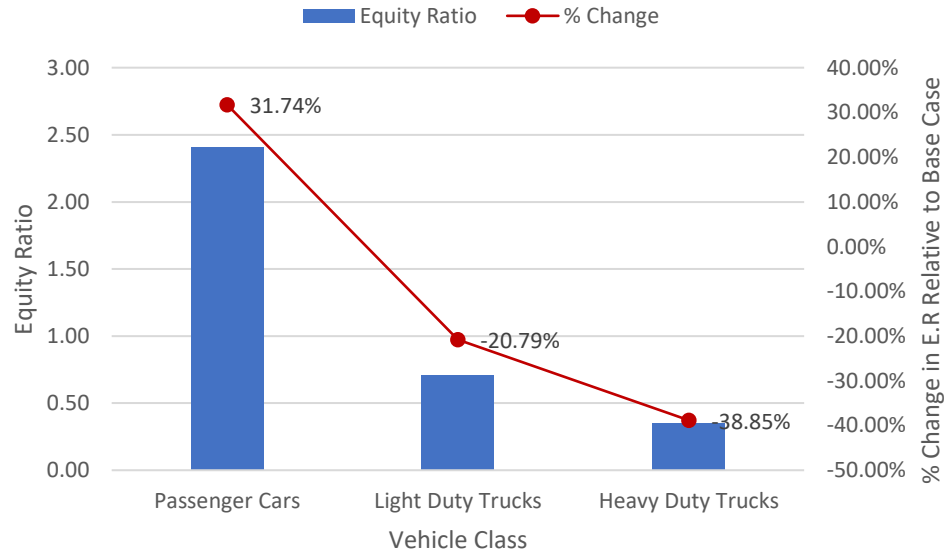
## Emerging Vehicle Technologies

### Sample Results – Revenues (State of Indiana)

Vehicle Class	Non-Fuel	Federal Fuel	State Fuel	Fuel Total	Total Revenues
<b>Base Case – reference year 2070</b>					
Passenger Cars	\$1,469,412,753	\$364,611,119	\$349,386,458	\$713,997,576	\$2,183,410,330
Light Duty Trucks	\$627,691,412	\$735,621,092	\$517,729,871	\$1,253,350,963	\$1,881,042,375
Heavy Duty Trucks	\$237,767,795	\$461,852,485	\$310,676,127	\$772,528,612	\$1,010,296,406
<b>Total</b>	<b>\$2,334,871,959</b>	<b>\$1,562,084,696</b>	<b>\$1,177,792,455</b>	<b>\$2,739,877,151</b>	<b>\$5,074,749,111</b>
<b>Revenues adjusted for ECAVs at high market penetration</b>					
Passenger Cars	\$1,983,707,217	\$49,222,501	\$47,167,172	\$96,389,673	\$2,080,096,889
Light Duty Trucks	\$847,383,406	\$99,308,847	\$69,893,533	\$169,202,380	\$1,016,585,786
Heavy Duty Trucks	\$320,986,523	\$62,350,085	\$41,941,277	\$104,291,363	\$425,277,885
<b>Total</b>	<b>\$3,152,077,145</b>	<b>\$210,881,434</b>	<b>\$159,001,981</b>	<b>\$369,883,415</b>	<b>\$3,521,960,560</b>

## Emerging Vehicle Technologies

### Sample Results - User Equity



## Revising the User Fee Structure

$$R_{i,k} = \left( \frac{VMT_i}{e_{i,k}} \right) \times T_k \times p_{i,k} \tag{1}$$

$$ER_i = \frac{RCP_i}{CRP_i} \tag{2}$$

$$ER_i = \frac{RCP_i}{CRP_i} = \frac{\sum_k \left( \frac{VMT_i}{e_{i,k}} \times T_k \times p_{i,k} \right) + y_i}{\sum_i \sum_k \left( \frac{VMT_i}{e_{i,k}} \times T_k \times p_{i,k} \right) + y_i} \times \frac{C_i}{\sum_i C_i} \tag{3}$$

## Revising the User Fee Structure

$$ER_i = \frac{\left( \sum_k \left( \frac{VMT_i}{e_{i,k}} \right) \times T_{i,k} \times p_{i,k} \right) + y_i + x_i}{\frac{C_i}{\sum_i C_i}} = 1.00 \quad (4)$$

$$T_{i,k} \leq \mu \quad (5)$$

$$x_i \leq \lambda \quad (6)$$

$$T_{i,k}, x_i \geq 0 \quad (7)$$

$$\sum_i \left( \sum_k \left( \frac{VMT_i}{e_{i,k}} \right) \times T_{i,k} \times p_{i,k} \right) + y_i + x_i \geq \sum_i C_i \quad (8)$$

## Revising the User Fee Structure

### Variable Tax Scheme

Vehicle Class	Fuel Tax Rate (\$ / Gallon)				VMT Tax (\$ / mile)	Equity ratio
	Fed Diesel	State Diesel	Fed Gas	State Gas		
Low ECAV Market Penetration						
<b>Passenger Cars</b>	0.01	0.01	0.01	0.01	0.0001	1.05
<b>Light Duty Trucks</b>	0.50	0.01	0.01	0.01	0.1342	1.00
<b>Heavy Duty Trucks</b>	0.50	0.50	0.50	0.50	0.2000	0.97
Moderate ECAV Market Penetration						
<b>Passenger Cars</b>	0.01	0.01	0.01	0.01	0.0001	1.06
<b>Light Duty Trucks</b>	0.01	0.01	0.01	0.01	0.1081	1.00
<b>Heavy Duty Trucks</b>	0.50	0.50	0.50	0.50	0.1500	0.96
High ECAV Market Penetration						
<b>Passenger Cars</b>	0.01	0.01	0.01	0.01	0.0011	1.00
<b>Light Duty Trucks</b>	0.01	0.01	0.01	0.01	0.0974	1.00
<b>Heavy Duty Trucks</b>	0.50	0.50	0.50	0.50	0.1841	1.00

## Conclusions

- Results show that emerging vehicle technologies will impact
  - Highway expenditures – increased due to changing travel patterns, increased infrastructure needs
  - Highway revenues – reduced due to increased fuel efficiency, vehicle electrification
  - User equity – increased inequity due to changing expenditures and revenues.
- Variable Tax Scheme:
  - In the near-term increases system efficiency and improves user equity through variable fuel tax.
  - In the long term introduces a distance-based tax applicable to electric vehicles.



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