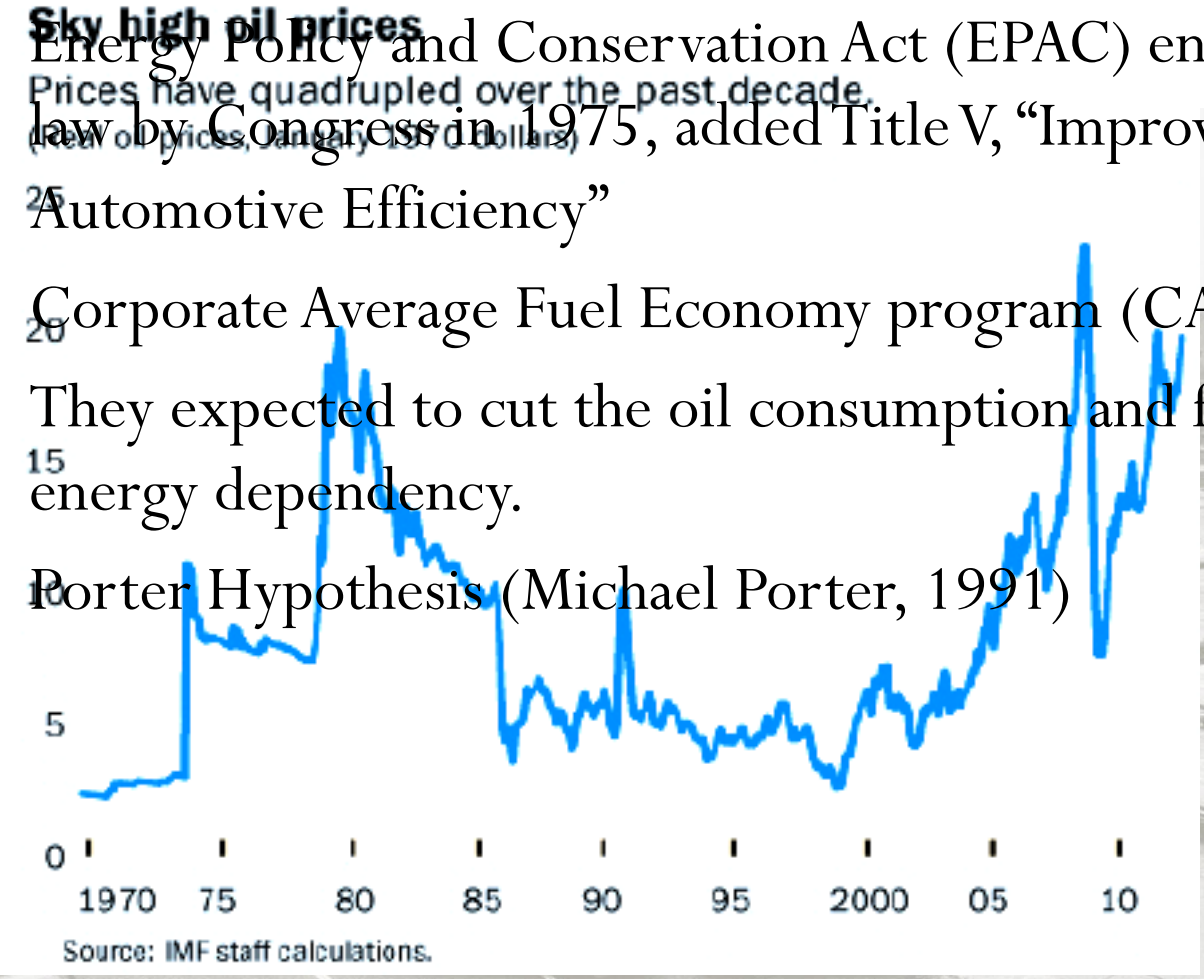
Induced Innovation from CAFE Standards in the Automotive Industry: Evidence using Patent Data

December 5th 2014

BC (Guang) Zhong
Elaine F. Frey
Department of Economics
California State University, Long Beach

Overview

- 1973 oil embargo and 1979 Iranian revolution
- Energy Policy and Conservation Act (EPAC) enacted into law by Congress in 1975, added Title V, "Improving Automotive Efficiency"
- Corporate Average Fuel Economy program (CAFE)
- They expected to cut the oil consumption and foreign energy dependency.
- Porter Hypothesis (Michael Porter, 1991)

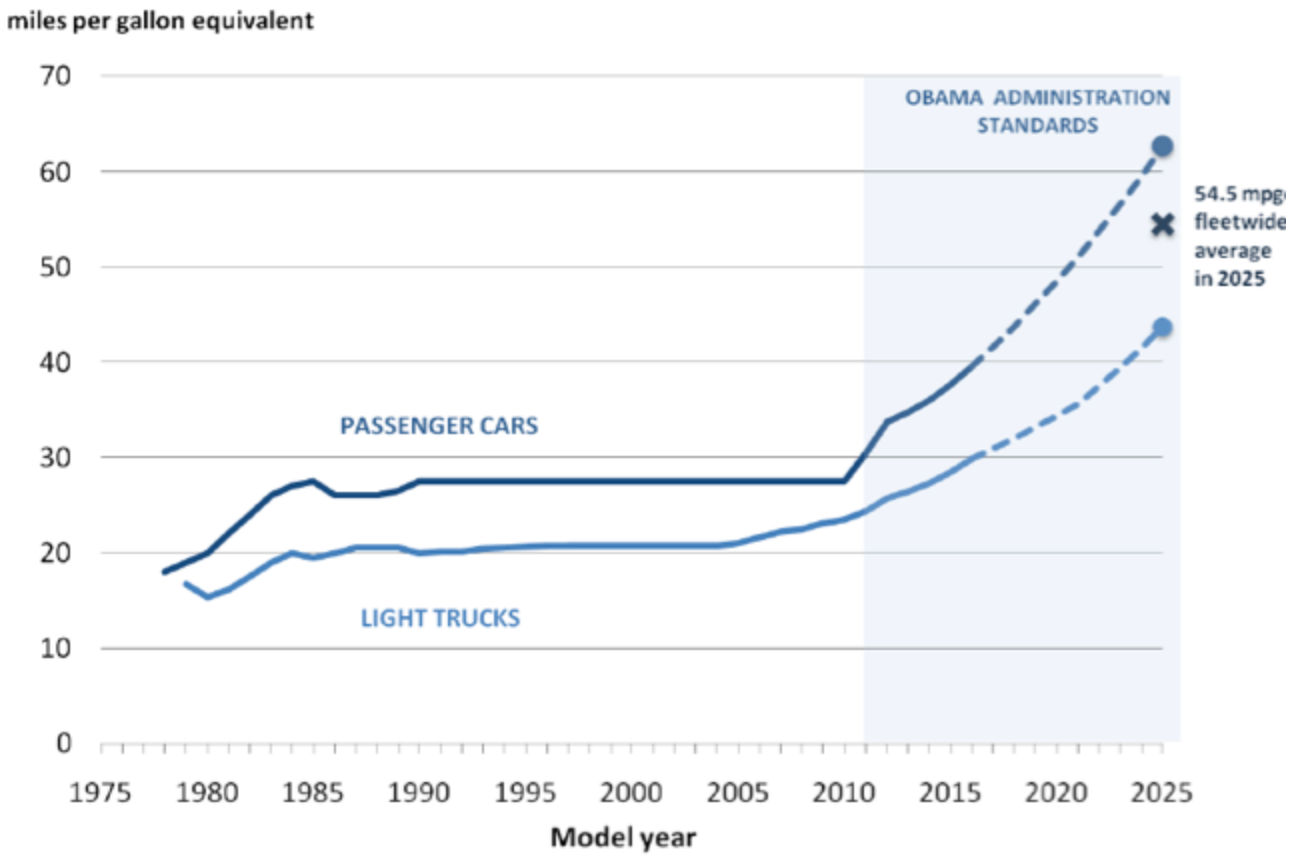


U.S. CAFE Standards

- Environmental Protection Agency (EPA) is responsible for calculating the average fuel economy
- National Highway Traffic Safety Administration (NHTSA) is responsible for enforcing the CAFE program
- Targeting – sales weighted average fuel economy in miles per gallon (mpg) of a fleet of passenger cars or light trucks with a gross vehicle weight rating of 8500 lbs or less. Combustion vehicle only.
- Fuel efficiency requirement—one universal standard for a fleet of cars (take the average mpg based on sales volume)

U.S. CAFE Standards

- Light-duty vehicle fuel economy standards, 1978-2025

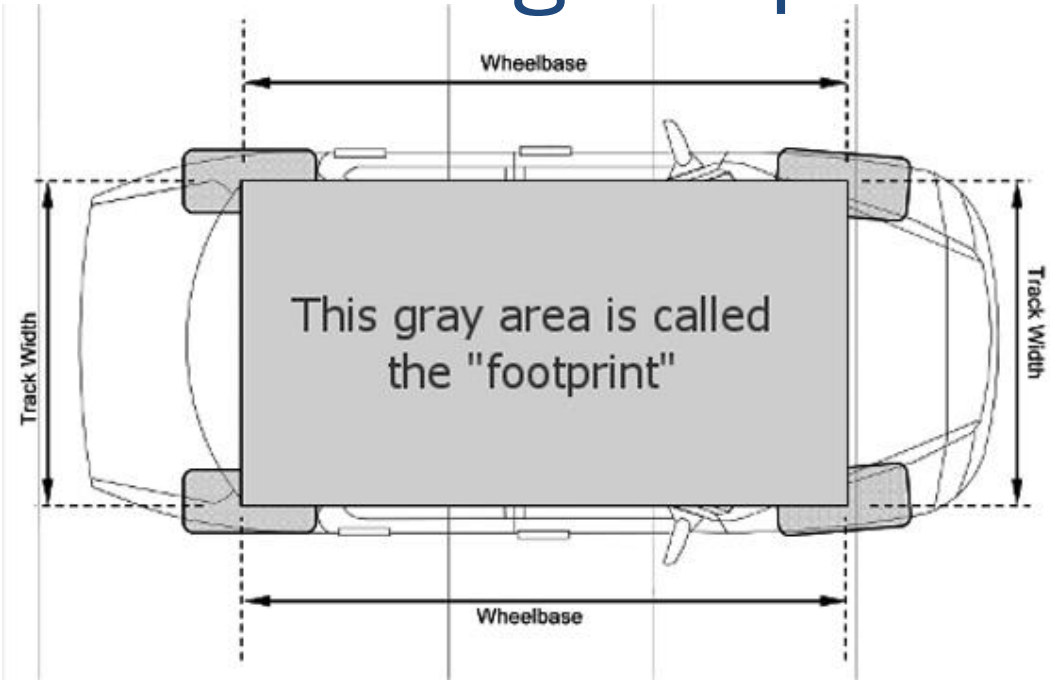


Graph Source: Shrink That Footprint

U.S. CAFE Standards

- Penalty – $5.50 per 1/10 of mpg lower than the requirement
- Total penalty collected from automobile firms until 2010: $818,724,551 (data updated 2012)
- CAFE Credit is non tradable before 2007
- Energy Independence and Security Act (EISA), originally named the Clean Energy Act of 2007, regulates environment standards for the automotive industry. Under this Act, CAFE program renewed– with higher target and more scientific and flexibility way.
- 2007 changes to CAFE:
  - Transferable credit
  - Add CO2 and green house gas (GHG) in regulation system
  - Add electric powered vehicle (EV) incentive
  - Footprint model for new fuel efficiency calculation

CAFE Target Equation (since 2008)



$$TARGET = \frac{1}{MIN[MAX\left(c \times FOOTPRINT + d, \frac{1}{a}\right), \frac{1}{b}]}$$

Where

TARGET=the fuel economy target (in mpg) applicable to vehicles of a given footprint (in square feet)

a=the function's upper limit (in mpg) for all vehicles

b = the function's lower limit (in mpg) for all vehicles

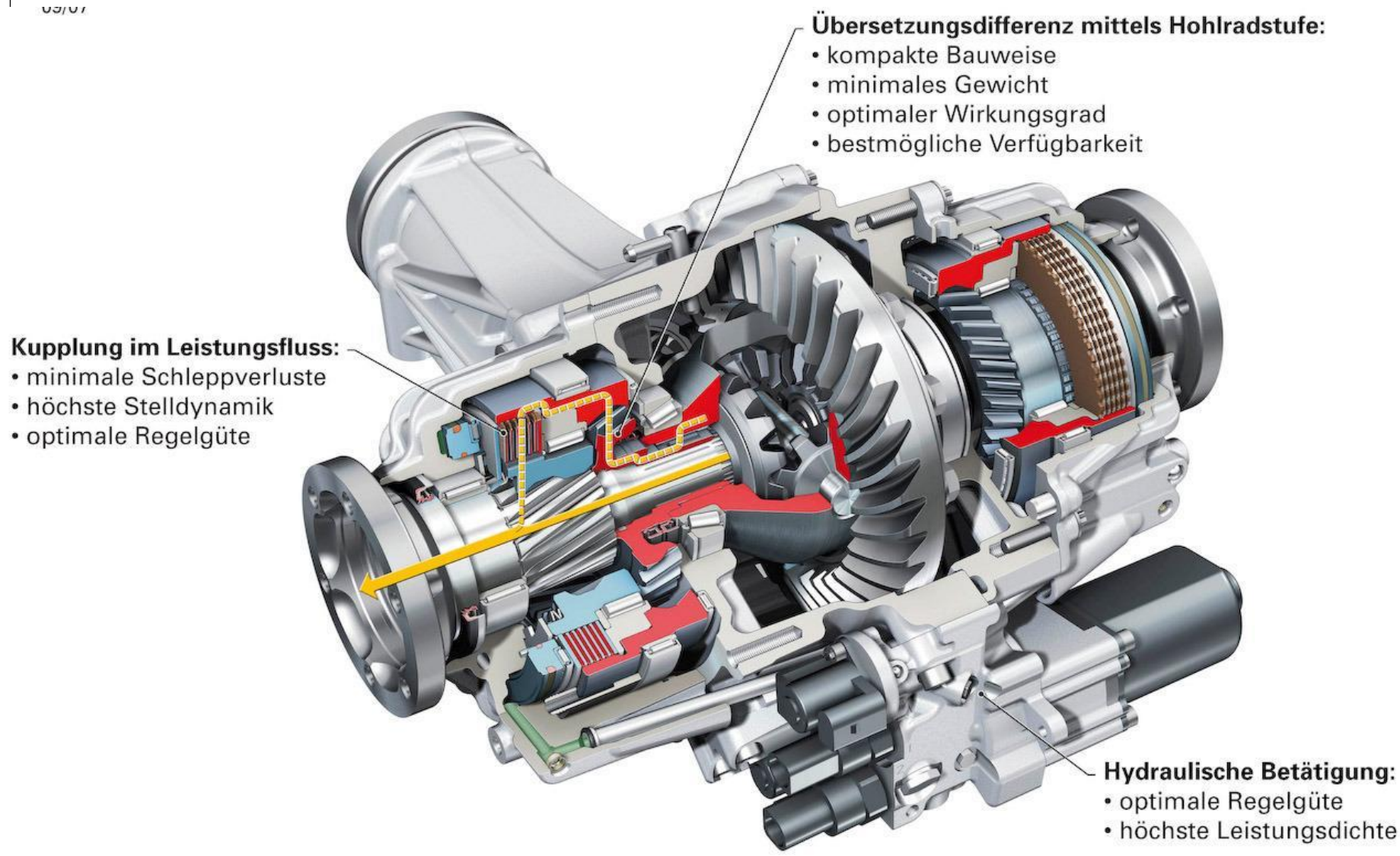
c = the slope (in gpm per square foot) of the sloped portion of the function,

d = the intercept (in gpm) of the sloped portion of the function

Source of footprint graph: blogs.cars.com

Battery

Vehicle Fuel Efficiency Related Technology Development Overview



Vehicle Fuel Efficiency Related Technology Development Overview

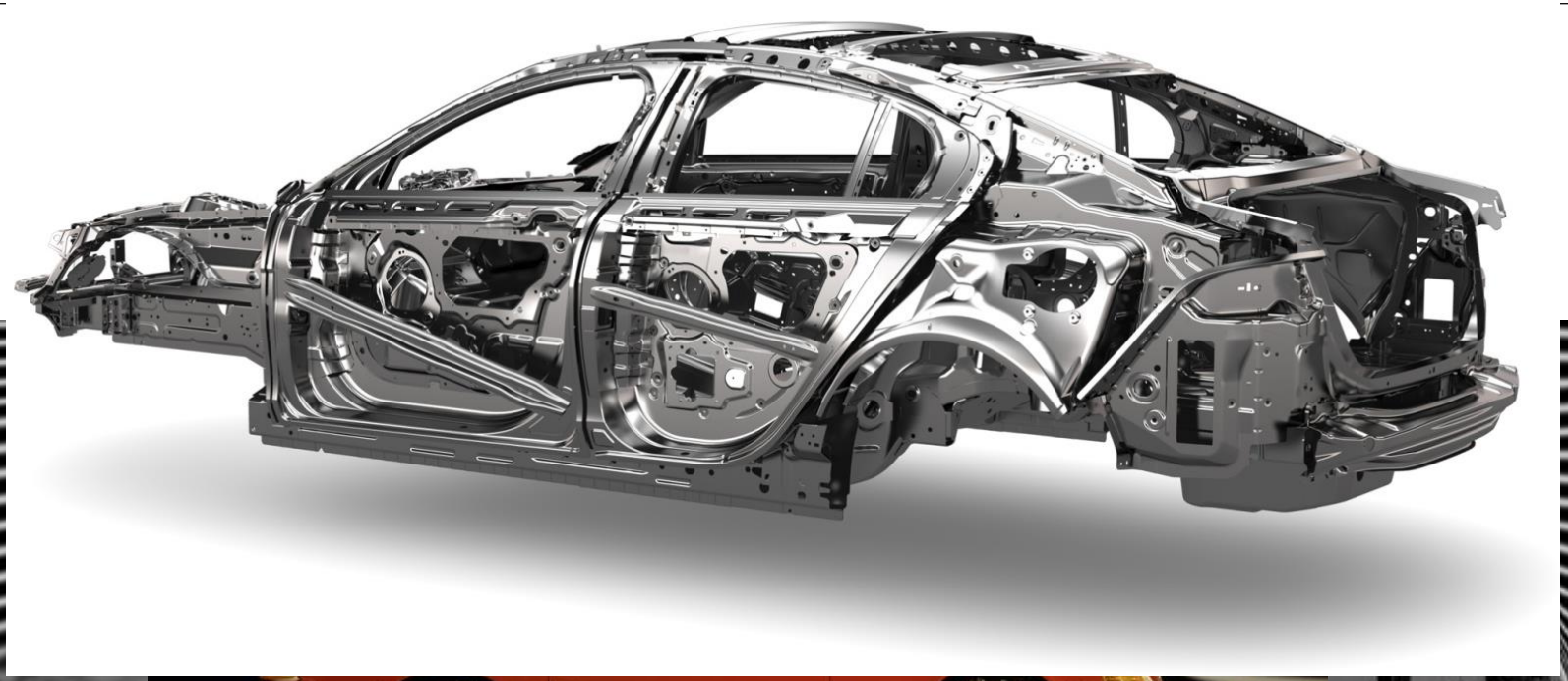
Audi Matrix LED-Scheinwerfer

Audi Matrix LED headlight

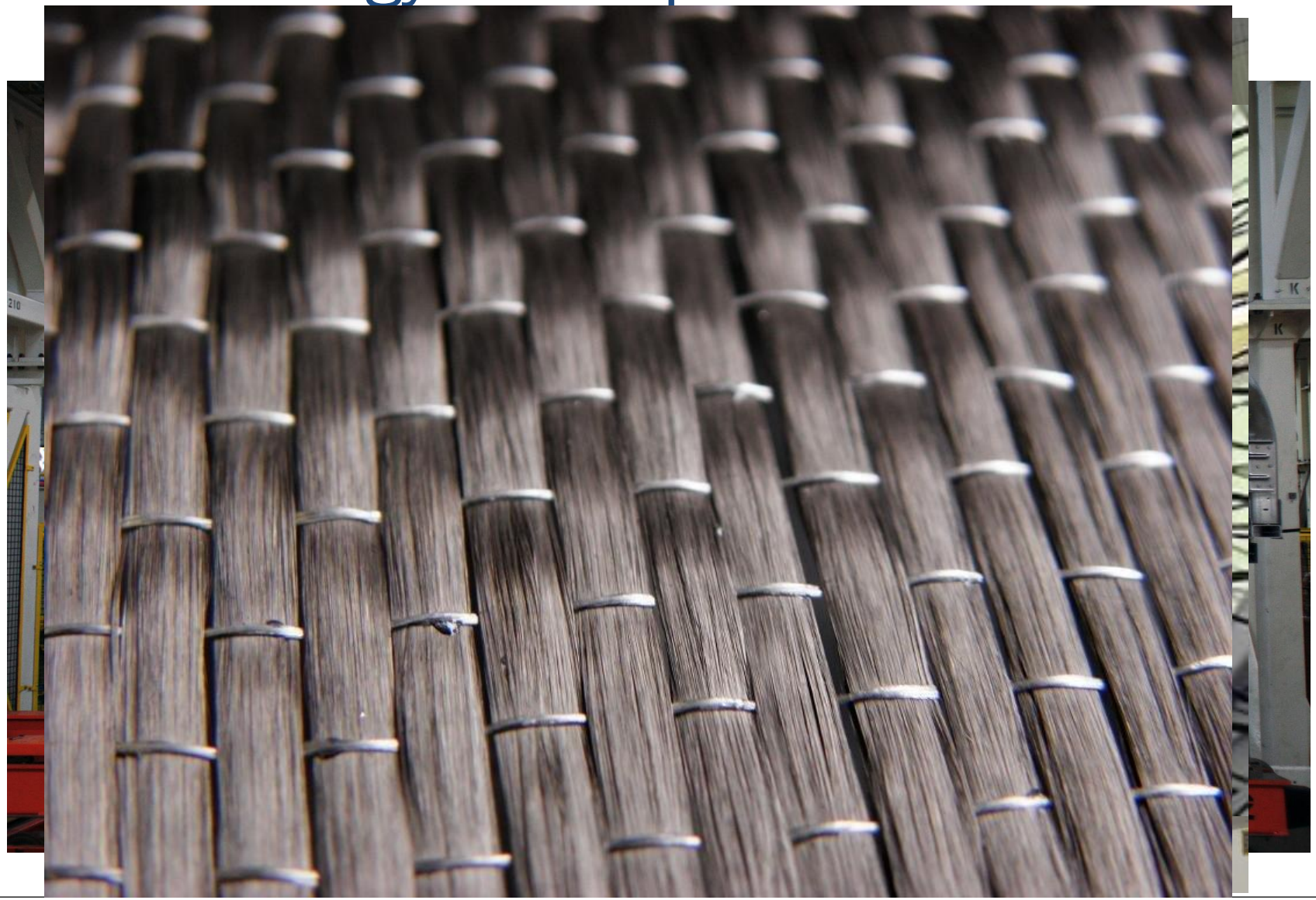
10/13

Vehicle Fuel Efficiency Related Technology Development Overview

- Power unit (Engine, EV, hybrid)
- Power distribution unit (transmission, gear)
- Sub Electronic components
- Software control and support system
  - Engine control unit (ECU)
  - Electronic stability control (ESC)
  - Traction control system (TCS)
  - Electronic Vale Timing (EVT)
  - Idle stop/start
  - And many more…



Vehicle Fuel Efficiency Related Technology Development Overview



Patent Study

- Patent is an exclusive right to intellectual property
- It's a better way to measure innovation improvement
  - Patent approval system guarantees the degree of innovation in the new patent
  - Data availability
  - Clear information
- I'm looking for fuel efficient related patents
- Group into six by classification and functionality

USPTO Patent

(54) **EXHAUST PURIFICATION SYSTEM FOR INTERNAL COMBUSTION ENGINE**

(75) Inventors: **Hideki Matsunaga**, Saitama (JP); **Yuji Yasui**, Saitama (JP); **Eiji Hashimoto**, Saitama (JP); **Hisao Haga**, Saitama (JP); **Naohiro Sato**, Saitama (JP); **Masafumi Sakota**, Saitama (JP)

(73) Assignee: **Honda Motor Co., Ltd.**, Tokyo (JP)

(51) **Int. Cl.**
F01N 3/00 (2006.01)
F01N 3/10 (2006.01)

(Continued)

(52) **U.S. Cl.**
CPC ***F02D 41/0055*** (2013.01); *Y02T 10/24* (2013.01); *Y02T 10/47* (2013.01); ***F01N 3/106*** (2013.01); *F01N 2370/04* (2013.01); ***F01N 13/0097*** (2013.01); ***F01N 3/208*** (2014.06);

(57) **ABSTRACT**

An exhaust purification system for an internal combustion engine is provided that can steadily maintain a NOx purification rate of a selective reduction catalyst to be high without allowing the fuel economy or marketability to deteriorate. The exhaust purification system includes a NO_2—NOx ratio adjustment mechanism that causes a NO_2—NOx ratio to

US008875497B2

(12) **United States Patent**
Matsunaga et al.

(10) **Patent No.: US 8,875,497 B2**
(45) **Date of Patent: Nov. 4, 2014**

(54) **EXHAUST PURIFICATION SYSTEM FOR INTERNAL COMBUSTION ENGINE**

(75) Inventors: **Hideki Matsunaga**, Saitama (JP); **Yuji Yasui**, Saitama (JP); **Eiji Hashimoto**, Saitama (JP); **Hisao Haga**, Saitama (JP); **Naohiro Sato**, Saitama (JP); **Masafumi Sakota**, Saitama (JP)

(73) Assignee: **Honda Motor Co., Ltd.**, Tokyo (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 238 days.

(21) Appl. No.: **13/439,434**
(22) Filed: **Apr. 4, 2012**
(65) **Prior Publication Data**
US 2012/0255286 A1 Oct. 11, 2012
(30) **Foreign Application Priority Data**
Apr. 5, 2011 (JP) 2011-083960

(51) **Int. Cl.**
F01N 3/00 (2006.01)
F01N 3/10 (2006.01)

(Continued)

(52) **U.S. Cl.**
CPC ***F02D 41/0055*** (2013.01); *Y02T 10/24* (2013.01); *Y02T 10/47* (2013.01); ***F01N 3/106*** (2013.01); *F01N 2370/04* (2013.01); ***F01N 13/0097*** (2013.01); ***F01N 3/208*** (2014.06); *F02D 2041/1468* (2013.01); ***F01N 3/0814*** (2013.01); *B01D 53/9418* (2013.01); *B01D 2255/912* (2013.01); *B01D 2255/50* (2013.01); *F02D 41/1446* (2013.01); *F01N 2560/026* (2013.01); *F02D 2200/0806* (2013.01); ***F02D 41/10*** (2013.01); *F02D 2200/0802* (2013.01); *F02D 41/146* (2013.01); *B01D 53/944* (2013.01); *F02D 41/0275* (2013.01); *B01D 2255/91* (2013.01); ***F01N 13/009*** (2014.06); *F01N 2570/14* (2013.01); ***B01D 53/9477*** (2013.01); ***F01N 3/2066*** (2013.01)
USPC **60/295**; 60/285; 60/286; 60/301; 60/303

(58) **Field of Classification Search**
CPC F01N 3/106; F01N 3/2066; F01N 3/208; F01N 2560/026; F01N 2570/14; F01N 2610/02; F02D 41/146; F02D 2200/0806; Y02T 10/47
USPC 60/285, 286, 287, 295, 299, 301, 303
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2010/0139250 A1* 6/2010 Andersson et al. 60/285
2011/0000189 A1* 1/2011 Mussmann et al. 60/274

(Continued)

FOREIGN PATENT DOCUMENTS

JP 2008-231950 A 10/2008

OTHER PUBLICATIONS

Notice of Reasons for Rejection issued in DE Application No. 102012205736.6, mailed Jul. 31, 2012.

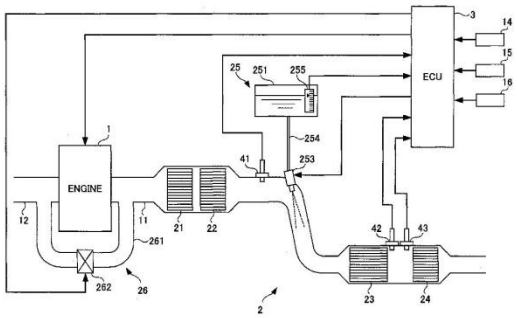
(Continued)

Primary Examiner — Audrey K Bradley
(74) *Attorney, Agent, or Firm* — Squire Patton Boggs (US) LLP

(57) **ABSTRACT**

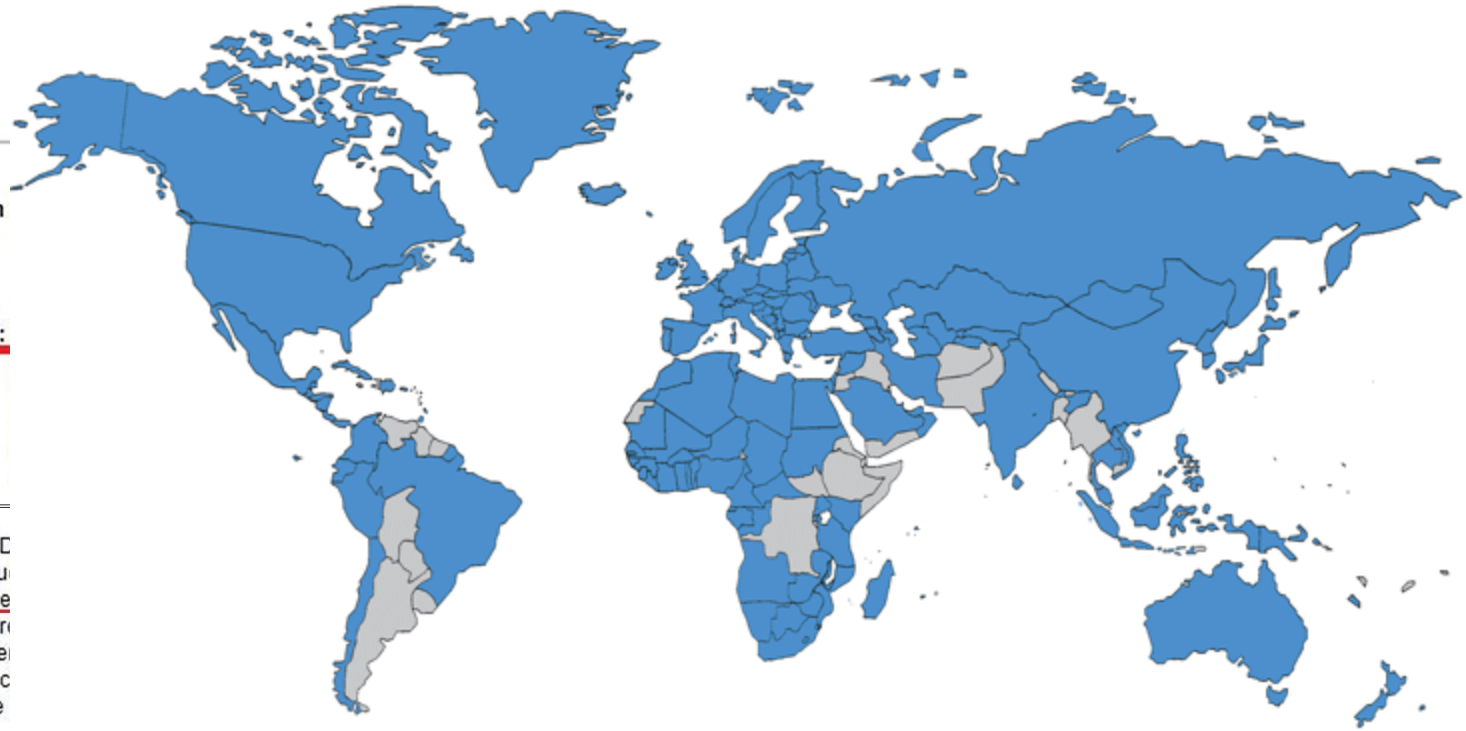
An exhaust purification system for an internal combustion engine is provided that can steadily maintain a NOx purification rate of a selective reduction catalyst to be high without allowing the fuel economy or marketability to deteriorate. The exhaust purification system includes a NO_2—NOx ratio adjustment mechanism that causes a NO_2—NOx ratio to change; and a NO_2—NOx ratio perturbation controller that executes NO_2—NOx ratio perturbation control so that a NO_2 balance of the selective reduction catalyst in a predetermined time period, with NO_2 adsorption being positive and NO_2 release being negative, is 0. Herein, NO_2—NOx ratio perturbation control is defined as control that alternately executes NO_2 increase control to cause the NO_2—NOx ratio to be greater than a reference value near 0.5, and NO_2 decrease control to cause the NO_2—NOx ratio to be less than the reference value.

15 Claims, 20 Drawing Sheets



WIPO patent

- Provide patent right in 148 contracting States



WIPO PATENTSCOPE

Search International and National Patent Collections

WORLD INTELLECTUAL PROPERTY ORGANIZATION

Search | Browse | Translate | Options | News | Login | Help

1. (WO2014178225) HYBRID VEHICLE CONTROL DEVICE

PCT Biblio. Data | Full Text | National Phase | Notices | Drawings | Documents

Latest bibliographic data on file with the International Bureau

Pub. No.: WO/2014/178225 International Application No.: PCT/JP2014/055661
Publication Date: 06.11.2014 International Filing Date: 05.03.2014
IPC: B60W 10/06 (2006.01), B60K 6/48 (2007.10), B60K 6/547 (2007.10), B60L 11/14 (2006.01), B60W 10/02 (2006.01), B60W 10/08 (2006.01), B60W 10/10 (2012.01), B60W 20/00 (2006.01)
Applicants: NISSAN MOTOR CO., LTD. [JP/JP]; 2, Takaracho, Kanagawa-ku, Yokohama-shi, Kanagawa 2210023 (JP)
Inventors: UENO, Munetoshi; (JP).
YAMADA, Tetsu; (JP).

Pub. No.:
Publication
IPC:
Applicants:
Inventors:
Agent:

Abstract: (EN)D
frequ
fuel e
contr
gene
that c
drive

Designated States: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.
African Regional Intellectual Property Org. (ARIPO) (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW)

African Regional Intellectual Property Org. (ARIPO) (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW)
Eurasian Patent Organization (EAPO) (AM, AZ, BY, KG, KZ, RU, TJ, TM)
European Patent Office (EPO) (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR)
African Intellectual Property Organization (OAPI) (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Publication Language: Japanese (JA)
Filing Language: Japanese (JA)

Porter Hypothesis

- Porter's idea from 1991
- Win-win solution
- Benefits from regulation
  1. Diminishing inefficiency consumption in limited resource
  2. Raising awareness
  3. Promote investment in environmental improvement
  4. Create pressure that motivate innovation and progress
  5. Increase firms' competitiveness

Literature Review

- Porter Hypothesis (Palmer et al, 1995; Oates et al, 1993; Ambec et al,2013; Oates and Portney, 1993; Lanoie et el;2010)
- Regulation and innovation (Gray et al. 1998; Jaffe et al, 1995; Berman and Bui, 2001; ;Popp,2003,2006;Lanjouw and Mody, 1996; Arimura et el., 2007;Van den Hoed et al, 2005;)
- CAFE and its effectiveness (Greene 1990; Liu and Green, 2014; Parry et al, 2005; Austin and Dinan, 2005; Goldberg, 1998;)

Data

- Variable source (patent): World Intellectual Property Organization (WIPO); Number of patents from WIPO: 2314
- Variable source (patent): United States Patent and Trademark Office (USPTO); Number of patents from USPTO: 6076
- Market Share source: Wardsauto.com
- Number of firms: Firms from the US and international that sell car to the US market, Ford, TOYOTA, BMW… (20 firms)
- Year used in panel data range from 1965-2013
- Omitted firm: Aston Martin, Lotus, Ferrari, Maserati, Spyker, Sterling, Vector Aeromotive, Callaway Cars, and few small coach building company

Summary Statistic

Variables	Mean	Std.Dev	Min	Max
Market Share (%)	4.85	9.18	0.001	49.59
CAFE Standard (mpg)	20.32	12.71	0	37
Change of CAFE Standard (mpg)	0.77	2.61	-1.5	18
CAFE Penalty (in Million USD)	0.83	3.28	0	30.26
CAFE Penalty Dummy	0.14	0.35	0	1
Total number of patents	8.56	27.25	0	301
Software patent	0.46	2.29	0	34
Power source patents	4.55	13.83	0	113
Power transform patents	2.55	9.92	0	151
Architechture patents	0.32	1.19	0	12
Sub electric patents	0.17	0.81	0	9
Other patents	0.52	2.29	0	27
Observations: 980				

Fixed Effects Panel Model

- Dependent Variable: log (market share of auto firms)
- Independent Variables:
  - Number of patents
  - Number of patents in six groups
  - CAFE standard (in mpg)
  - Level change of CAFE standard (in mpg)
  - CAFE penalty dummy
- STATA estimation: xtset, xtreg, fe
- Fix effects using: brands of automobile manufacturers

Patent Data Analysis Results –Fixed Effects

	(1)	(2)	(3)
VARIABLES	log MarketShare	log MarketShare	log MarketShare
CAFE requirement	0.0279***		
	(0.00229)		
Change in CAFE from Last year		-0.00195	-0.00112
		(0.0102)	(0.0104)
CAFE Penalty Dummy	-0.362***	-0.0471	-0.0469
	(0.0841)	(0.0873)	(0.0890)
Lag total patent			0.00327***
			(0.000997)
Lag software patents	-0.0584***	-0.0709***	
	(0.0186)	(0.0202)	
Lag power source patents	0.0154***	0.0246***	
	(0.00463)	(0.00497)	
Lag transmission patents	0.00166	0.00427	
	(0.00410)	(0.00445)	
Lag architecture patents	-0.0638*	-0.0254	
	(0.0341)	(0.0369)	
Lag sub-electric patents	0.0395	0.0130	
	(0.0481)	(0.0523)	
Lag other patents	-0.0515***	-0.0639***	
	(0.0188)	(0.0204)	
Observations	835	835	835
R-squared	0.203	0.057	0.013
Number of Brand	20	20	20

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Result

- Every mpg increase in CAFE standards will increase market share by 2.79 percentage points
- Every additional new patent in a year will increase market share 0.327 percentage points
- Increase patents in more seeable way by consumer will increase market share (power source); but increase in patents in less noticeable areas will reduce market share (software, architectures, and other)

Implications

- My study supports the Porter hypothesis. Increased innovation helps firms increase market share.
- Increases in future CAFE standards will promote increases in market share for those who innovate.
- Increases in the penalty level will force firms to increase innovation under the threat of loosing market share.

Next Steps

- Combine market analysis results
- Eliminate other factors may change market share to robust the results of this paper.
- Collect data from R&D and compare result
- Better data from market share
- Use other measures for market performance measuring, robust my result . (like profit, marketing expenditures, market segments)

Thank you for your time!
Question?

Source: Tesla Motors; msnbc