FOR ONLINE PUBLICATION

# Online Supplementary Material
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# Global Coordination Challenges in the Transition to Clean Technology: Lessons from Automotive Innovation

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# A SAMPLE OF CAR MANUFACTURERS AND SUPPLIERS

# Table A.1
# List of Carmakers in Sample

| Carmaker ID | Markline Name | Orbis Name |
|---|---|---|
| 1 | Anhui Jianghuai Automotive Group | Anhui Jianghuai Automobile Group Corp., Ltd. |
| 2 | Aston Martin | Aston Martin Holdings (Uk) Limited |
| 3 | AvtoVAZ | Joint Stock Company "Avtovaz' |
| 4 | BMW Group | Bayerische Motoren Werke Aktiengesellschaft |
| 5 | BYD Auto | Byd Auto Co., Ltd. |
| 6 | Chrysler Group | Fca Us Llc |
| 7 | Changan/Chana (Changan Automobile (Group)) | China Changan Automobile Group Co., Ltd. |
| 8 | Chery Automobile | Chery Automobile Co., Ltd. |
| 9 | China National Heavy Duty Truck Group | China National Heavy Duty Truck Group Co., Ltd. |
| 10 | Daewoo Bus Corporation | Zyle Daewoo Bus Corporation |
| | | Zyle Daewoo Commercial Vehicle Company |
| 11 | Guilin Daewoo Bus | Guilin Daewoo Bus Co., Ltd. |
| 12 | Daimler Group | Daimler Ag |
| 13 | Dongfeng (Dongfeng Motor Corp.) | Dongfeng Automobile Co., Ltd. |
| | | Dongfeng Motor Co., Ltd. |
| | | Dongfeng Motor Group Co., Ltd. |
| | | Dongfeng Motor Group Company |
| 14 | FAW (China FAW Group Corp.) | China Faw Group Co., Ltd. |
| | | Faw Jiefang Automotive Co., Ltd. |
| 15 | FCA | Fca Italy S.P.A., In Forma Estesa Fiat Chrysler Automobiles Italy S.P.A. |
| | | Fiat Chrysler Automobiles N.V. |
| | | Fiat Spa |
| 16 | Ford Group | Ford Motor Co |
| | | Volvo Car Ab |
| 17 | GAZ Group | Gaz Jsc |
| 18 | GM Group | Adam Opel Gmbh |
| | | General Motors Company |
| 19 | Geely Holding Group | Volvo Car Ab |
| | | Zhejiang Geely Holding Group Co., Ltd. |
| | | Zhejiang Geely New Energy Commercial Vehicles Group Co., Ltd. |
| | | Zhejiang Haoqing Automobile Manufacturing Co., Ltd. |
| 20 | Great Wall Motor Company Ltd. (GWM) | Great Wall Motor Company Limited |
| 21 | Guangzhou Automobile Group | Guangzhou Automobile Group Co., Ltd. |
| | | Guangzhou Automobile Industry Group Co., Ltd |
| 22 | Haima Automobile Group | Haima Automobile Company Limited |
| 23 | Hawtai (Huatai) Automobile Group | Huatai Automobile Group Co., Ltd. |
| 24 | Hebei Zhongxing Automobile Mfg. | Hebei Zhongxing Automobile Co., Ltd. |
| 25 | Hinduja Group | Hinduja Automotive Limited |
| 26 | Hindustan Motors | Hindustan Motors Limited |
| 27 | Honda | Honda Motor Co.,Ltd. |
| 28 | Hyundai Kia Automotive Group | Hyundai Motor Co.,Ltd. |
| 29 | Iran Khodro (IKCO) | Iran Khodro Industrial Group Company Public Joint Stock |
| 30 | Isuzu | Isuzu Motors Limited |
| 31 | Jiangling Motors Co. Group | Jiangling Motors Corporation, Ltd. |
| 32 | KAMAZ Group | Kamaz Jsc |
| 33 | Lifan Technology (Group) | Lifan Industry (Group) Co., Ltd. |
| 34 | Mahindra & Mahindra | Mahindra And Mahindra Limited |
| 35 | Mazda | Mazda Motor Corporation |
| 36 | Mitsubishi | Mitsubishi Motors Corporation |
| 37 | Navistar | Navistar International Corp |
| 38 | PSA | Peugeot |
| 39 | Paccar | Paccar Inc |
| 40 | Perodua | Perusahaan Otomobil Kedua Sdn Bhd |
| 41 | Porsche | Dr. Ing. H.C. F. Porsche Aktiengesellschaft |
| 42 | Proton | Proton Holdings Berhad |
| 43 | Qingling Motors (Group) | Qingling Auto (Group) Co., Ltd. |
| 44 | Renault | Renault |
| | | Renault |
| 45 | SAIC (Shanghai Automotive Industry Corporation (Group)) | Saic Motor Corporation Limited |
| | | Shanghai Automotive Industry Corporation (Group) |
| 46 | Shaanxi Automobile Group | Shaanxi Automobile Group Co., Ltd. |
| | | Shaanxi Automobile Holding Group Co., Ltd. |
| 47 | Sollers Group | Sollers Jsc |
| 48 | Subaru | Subaru Corporation |
| 49 | Suzuki | Suzuki Motor Corporation |
| 50 | Tata Group | Jaguar Land Rover Automotive Plc |
| | | Tata Motors Limited |
| 51 | Tesla | Tesla, Inc. |
| 52 | Toyota Group | Toyota Motor Corporation. |
| 53 | VDL Group | Vdl Groep B.V. |
| 54 | VW Group | Audi Aktiengesellschaft |
| | | Scania Aktiebolag |
| | | Volkswagen Aktiengesellschaft |
| 55 | Volvo Trucks Group | Aktiebolaget Volvo |
| 56 | Xiamen King Long Motor Group | Xiamen King Long Motor Group Co., Ltd. |
| 57 | Yulon Group | Yulon Motor Co., Ltd. |
| 58 | Yutong Bus Group | Zhengzhou Yutong Group Co., Ltd. |
| 59 | Zotye Holding Group | Zotye Holding Group Co., Ltd. |
| 60 | CNH Industrial | Cnh Industrial N.V. |
| | Fiat Industrial | Fiat Industrial S.P.A. |
| 61 | Jiangling Motors Co. Group | Jiangling Motors Corporation Limited |
| 62 | BAIC Group | Baic Motor Corporation Ltd. |
| 63 | Eicher Group | Eicher Motors Limited |
| 64 | Force Motors | Force Motors Limited |
| 65 | Fujian Motor Industry Group Co. (FJMG) | Fujian Motor Industry Group Co., Ltd. |
| 66 | Brilliance Automobile Group | Huachen Automotive Group Holdings Co., Ltd. |
| 67 | Nanjing automobile | Nanjing Automobile (Group) Corporation |
| 68 | Nissan | Nissan Motor Co.,Ltd. |
| 69 | Qoros Auto | Qoros Automotive Co., Ltd. |
| 70 | Hualing Xingma Automobile (CAMC) | Hanma Technology Group Co.,Ltd |
| 71 | Ford Otomotiv | Ford Otomotiv Sanayi Anonim Sirketi |

# Table A.2
# Carmakers Summary Statistics for Country Sales

| Carmaker ID | Name | Mean Annual Sales | Geographic Concentration | Mean Number of Countries | Mean Nbr Countries with 50% | Mean Nbr Countries with 80% | Nbr Countries in 2004 | Nbr Countries in 2018 |
|---|---|---|---|---|---|---|---|---|
| 18 | GM Group | 8,683,251 | 0.20 | 47.29 | 2 | 8 | 31 | 49 |
| 52 | Toyota Group | 8,518,115 | 0.14 | 51.82 | 2 | 12 | 31 | 61 |
| 54 | VW Group | 7,902,643 | 0.13 | 47.71 | 3 | 12 | 30 | 53 |
| 16 | Ford Group | 5,611,336 | 0.21 | 50.12 | 2 | 10 | 31 | 59 |
| 28 | Hyundai Kia Automotive Group | 5,545,649 | 0.11 | 50.18 | 3 | 12 | 28 | 60 |
| 27 | Honda | 4,071,506 | 0.20 | 50.76 | 2 | 6 | 30 | 59 |
| 68 | Nissan | 3,831,829 | 0.14 | 49.71 | 3 | 11 | 28 | 60 |
| 15 | FCA | 3,539,823 | 0.23 | 45.82 | 2 | 6 | 28 | 53 |
| 38 | PSA | 2,997,508 | 0.10 | 44.76 | 4 | 10 | 25 | 53 |
| 6 | Chrysler Group | 2,534,384 | 0.65 | 30.80 | 1 | 2 | 25 | |
| 49 | Suzuki | 2,391,608 | 0.26 | 47.88 | 2 | 5 | 27 | 55 |
| 44 | Renault | 2,285,600 | 0.10 | 41.94 | 5 | 13 | 23 | 52 |
| 12 | Daimler Group | 2,047,411 | 0.10 | 48.94 | 4 | 12 | 30 | 55 |
| 4 | BMW Group | 1,668,659 | 0.10 | 46.41 | 4 | 11 | 28 | 52 |
| 35 | Mazda | 1,282,668 | 0.11 | 46.06 | 3 | 11 | 28 | 55 |
| 7 | Changan/Chana | 993,954 | 0.94 | 8.24 | 1 | 1 | 1 | 8 |
| 36 | Mitsubishi | 949,730 | 0.06 | 49.94 | 6 | 14 | 29 | 59 |
| 19 | Geely Holding Group | 930,539 | 0.36 | 33.59 | 1 | 6 | 1 | 55 |
| 13 | Dongfeng (Dongfeng Motor Corp.) | 833,026 | 0.96 | 10.24 | 1 | 1 | 1 | 12 |
| 62 | BAIC Group | 822,977 | 0.97 | 10.88 | 1 | 1 | 1 | 15 |
| 50 | Tata Group | 813,454 | 0.37 | 40.76 | 1 | 4 | 7 | 56 |
| 48 | Subaru | 730,089 | 0.36 | 41.88 | 1 | 3 | 22 | 50 |
| 14 | FAW (China FAW Group Corp.) | 645,400 | 0.97 | 5.41 | 1 | 1 | 1 | 6 |
| 20 | Great Wall Motor Company Ltd. (GWM) | 605,416 | 0.89 | 11.00 | 1 | 1 | 1 | 11 |
| 8 | Chery Automobile | 535,783 | 0.74 | 12.94 | 1 | 1 | 2 | 10 |
| 3 | AvtoVAZ | 518,455 | 0.83 | 14.36 | 1 | 1 | 10 | |
| 1 | Anhui Jianghuai Automotive Group | 405,305 | 0.84 | 7.94 | 1 | 1 | 1 | 12 |
| 34 | Mahindra & Mahindra | 393,492 | 0.53 | 24.76 | 1 | 2 | 3 | 34 |
| 45 | SAIC | 376,961 | 0.44 | 20.82 | 1 | 3 | 20 | 16 |
| 30 | Isuzu | 359,062 | 0.20 | 32.94 | 2 | 7 | 16 | 43 |
| 5 | BYD Auto | 354,809 | 0.93 | 6.35 | 1 | 1 | 1 | 10 |
| 66 | Brilliance Automobile Group | 351,553 | 0.94 | 6.94 | 1 | 1 | 1 | 10 |
| 31 | Jiangling Motors Co. Group | 220,769 | 0.98 | 6.00 | 1 | 1 | 1 | 7 |
| 40 | Perodua | 186,799 | 0.99 | 2.88 | 1 | 1 | 3 | 2 |
| 29 | Iran Khodro (IKCO) | 183,821 | 0.97 | 2.10 | 1 | 1 | | |
| 9 | China National Heavy Duty Truck Group | 183,606 | 1.00 | 1.00 | 1 | 1 | 1 | 1 |
| 21 | Guangzhou Automobile Group | 169,364 | 0.95 | 3.24 | 1 | 1 | 1 | 3 |
| 33 | Lifan Technology (Group) | 149,430 | 0.64 | 5.53 | 1 | 2 | 1 | 6 |
| 42 | Proton | 145,310 | 0.60 | 13.82 | 1 | 2 | 11 | 5 |
| 59 | Zotye Holding Group | 125,725 | 0.94 | 3.59 | 1 | 1 | 1 | 5 |
| 55 | Volvo Trucks Group | 125,136 | 0.10 | 27.88 | 4 | 14 | 22 | 27 |
| 46 | Shaanxi Automobile Group | 109,993 | 1.00 | 1.00 | 1 | 1 | 1 | 1 |
| 39 | Paccar | 105,418 | 0.30 | 20.65 | 1 | 5 | 15 | 22 |
| 51 | Tesla | 102,470 | 0.37 | 17.00 | 1 | 2 | | 24 |
| 60 | Fiat Industrial | 94,701 | 0.13 | 24.60 | 3 | 10 | 18 | |
| 25 | Hinduja Group | 94,462 | 0.99 | 2.71 | 1 | 1 | 2 | 2 |
| 17 | GAZ Group | 93,462 | 0.77 | 5.00 | 1 | 1 | 4 | 3 |
| 60 | CNH Industrial | 89,150 | 0.10 | 31.86 | 4 | 9 | | 33 |
| 41 | Porsche | 82,454 | 0.17 | 34.67 | 2 | 9 | 24 | |
| 65 | Fujian Motor Industry Group Co. (FJMG) | 81,189 | 1.00 | 1.12 | 1 | 1 | 1 | 1 |
| 37 | Navistar | 80,275 | 0.65 | 6.88 | 1 | 2 | 6 | 6 |
| 22 | Haima Automobile Group | 66,085 | 0.96 | 2.58 | 1 | 1 | | 1 |
| 43 | Qingling Motors (Group) | 62,484 | 1.00 | 1.00 | 1 | 1 | 1 | 1 |
| 56 | Xiamen King Long Motor Group | 57,982 | 0.86 | 4.82 | 1 | 1 | 1 | 7 |
| 23 | Hawtai (Huatai) Automobile Group | 49,623 | 0.99 | 1.40 | 1 | 1 | | 2 |
| 47 | Sollers Group | 48,212 | 0.91 | 3.00 | 1 | 1 | 2 | 4 |
| 24 | Hebei Zhongxing Automobile Mfg. | 44,015 | 0.79 | 3.35 | 1 | 1 | 1 | 1 |
| 58 | Yutong Bus Group | 42,781 | 0.96 | 4.12 | 1 | 1 | 1 | 6 |
| 63 | Eicher Group | 36,410 | 1.00 | 1.24 | 1 | 1 | 1 | 2 |
| 57 | Yulon Group | 31,399 | 0.58 | 2.00 | 1 | 2 | | 2 |
| 64 | Force Motors | 20,713 | 1.00 | 1.00 | 1 | 1 | 1 | 1 |
| 26 | Hindustan Motors | 8,809 | 1.00 | 1.00 | 1 | 1 | 1 | |
| 10 | Daewoo Bus Corporation | 2,971 | 0.69 | 1.76 | 1 | 1 | 1 | 4 |
| 2 | Aston Martin | 2,397 | 0.19 | 20.77 | 2 | 7 | | 25 |
| 32 | KAMAZ Group | 810 | 0.49 | 1.14 | 1 | 2 | | 2 |
| 53 | VDL Group | 718 | 0.14 | 8.82 | 3 | 7 | 7 | 7 |

*Note:* The sales data we're looking at covers the years 2004 to 2020. Here's what the variables mean:

- "Mean Annual Sales": This is the average yearly sales across all countries.
- "Geographic Concentration": This measures how sales are spread out across countries. It is calculated like an Herfindahl-Hirschman index: $\sum_c s_{ic}^2$ when $s_{ic}$ is the share of sales that carmaker $i$ has in country $c$. The closer the result is to 1, the more a carmaker's sales are focused in just a few countries.
- "Mean Number of Countries": This tells us the average number of countries a carmaker sells in each year.
- "Mean Number of Countries with 50% (or 80%)": This shows the number of largest markets (i.e., country-level sales) which together add up to 50% (or 80%) of a carmaker's total sales. The value reflects the mean number of such markets across years.
- "Number of Countries in 2014 (or 2018)": This tells us how many countries a carmaker sold in for that specific year, either 2014 or 2018.

Table A.3
Summary Statistics of Carmakers' Suppliers

| | count | mean | sd | min | max |
|---|---|---|---|---|---|
| Nbr of suppliers connected to carmaker | 500 | 62.16 | 85.01 | 1.00 | 508.00 |
| Nbr of suppliers (from relevant industries) connected to carmaker | 500 | 44.06 | 59.00 | 1.00 | 361.00 |
| Nbr of links that the average supplier of the carmaker has | 500 | 8.92 | 3.83 | 1.00 | 30.00 |
| Nbr of links that the average supplier of the carmaker has (weighted by age) | 500 | 1.47 | 2.83 | 0.03 | 30.00 |
| Percent of suppliers shared by 10+ carmakers (%) | 500 | 42.01 | 24.81 | 0.00 | 100.00 |
| Age of the link between carmaker and its mean supplier | 500 | 2.76 | 1.24 | 1.00 | 8.00 |

*Note:* Relevant industries for suppliers are defined as the following two-digit NAICS code: 31-33 (Manufacturing), 42 (Wholesale trade), 44 (Retail trade) and 54 (Professional, Scientific, and Technical Services).

# B PATENT DATA

## B.1 Patent Classification

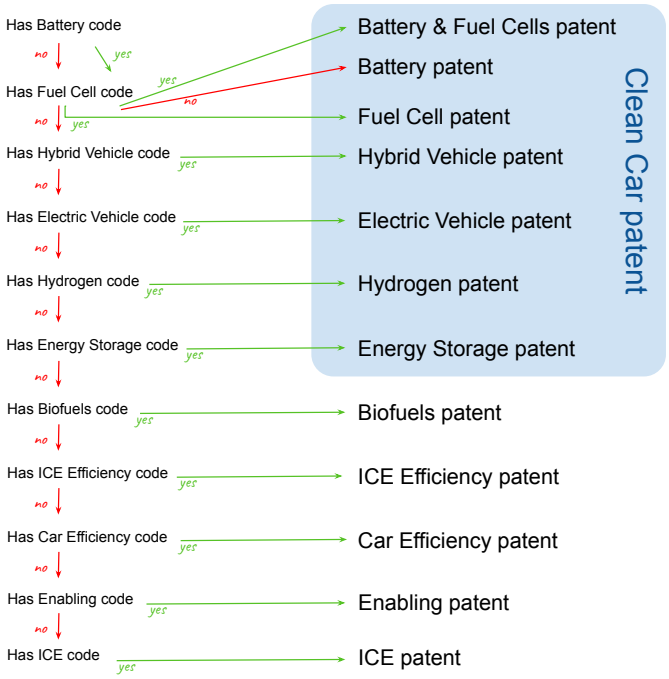



Figure B.1
Classifying Patents into Exclusive Technology Types

*Note:* This illustrates how we classify patents into exclusive categories. For example, if a patent family presents a battery and hydrogen code, it will be classified in battery only, and not in hydrogen. We do this for most patents. But if a patent mentions both batteries and fuel cells, we put it in a special category called ”Battery & Fuel Cells patent”.

Table B.1
CPC and IPC Codes for Clean Transportation Technologies

| Sub-sector | Code | Description |
|---|---|---|
| Batteries | B60L50/60 | Using power supplied by batteries |
| | B60L53 | Methods of charging batteries, specially adapted for electric vehicles; Charging stations or on-board charging equipment therefor; Exchange of energy storage elements in electric vehicles |
| | B60L53/53 | Charging stations characterised by energy-storage or power-generation means – batteries |
| | B60L58/10 | Methods or circuit arrangements for monitoring or controlling batteries or fuel cells, specially adapted for electric vehicles – batteries |
| | B60R16/033 | Characterised by the use of electrical cells or batteries |
| | B60R16/04 | Arrangement of batteries |
| | B60S5/06 | Supplying batteries to or removing batteries form |
| | Y02E60/10 | Energy storage using batteries, capacitors, Mechanical energy storage, e.g. flywheels or pressurised fluids |
| | Y02T10/70 | Energy storage for electromobility, e .g. batteries |
| | Y02T90/10 | Technologies relating to charging of electric vehicles |
| Electric Vehicles | B60K1 | Arrangement or mounting of electrical propulsion units |
| | B60K16 | Arrangements in connection with power supply of propulsion units in vehicles from forces of nature, e.g. sun or wind |
| | B60L | Propulsion of electrically-propelled vehicles |
| | B60L11 | Electric propulsion with power supplied within the vehicle |
| | B60L11/18 | Electric propulsion with power supplied within the vehicle - using power supplied from primary cells secondary cells or fuel cells |
| | B60L15 | Methods circuits or devices for controlling the traction-motor speed of electrically-propelled vehicles |
| | B60L3 | Electric devices on electrically propelled vehicles for safety purposes - monitoring operating variables e.g. speed deceleration power consumption |
| | B60L50 | Electric propulsion with power supplied within the vehicle |
| | B60L7 | Electrodynamic brake systems for vehicles in general |
| | B60L8 | Electric propulsion with power supply from forces of nature, e.g. sun or wind |
| | B60W10 | Conjoint control of vehicles sub-units of different type or different function |
| | Y02T10/64 | Electric machine technologies in electromobility |
| | Y02T10/72 | Electric energy management in electromobility |
| Enabling Technologies | Y02T90 | Technologies relating to charging of electric vehicles |
| Energy Storage | B60L53/50 | Charging stations characterised by energy-storage or power-generation means |
| | H01M | Conversion of chemical energy into electrical energy |
| Fuel Cells | B60L50/70 | Using power supplied by fuel cells |
| | B60L53/53 | Charging stations characterised by energy-storage or power-generation means – fuel cells |
| | B60L58/30 | Methods or circuit arrangements for monitoring or controlling batteries or fuel cells, specially adapted for electric vehicles – fuel cells |
| | B60W10/28 | Conjoint control of vehicle sub-units of different type or different function; including control of fuel cells |
| | H01M8/00 | Fuel cells; manufacture thereof |
| | Y02E60/50 | Fuel Cells |
| | Y02T90/40 | Application of hydrogen technology to transportation, e.g. using fuel cells |
| Hybrid Vehicles | B60K6 | Arrangement or mounting of plural diverse prime-movers for mutual or common propulsion e.g. hybrid propulsion systems comprising electric motors and internal combustion engines |
| | B60L7/20 | Regenerative braking - Braking by supplying regenerated power to the prime mover of vehicles comprising engine -driven generators |
| | B60W20 | Control systems specially adapted for hybrid vehicles |
| | Y02T10/62 | Hybrid vehicles |
| Hydrogen | Y02E60/30 | Hydrogen Technology |
| Smart Grids | Y02T90/167 | Systems integrating technologies related to power network operation and ICT for supporting the interoperability of electric or hybrid vehicles, i.e. smart grids as interface for battery charging of electric vehicles [EV] or hybrid vehicles [HEV] |
| | Y02T90/168 | Systems integrating technologies related to power network operation and ICT for supporting the interoperability of electric or hybrid vehicles, i.e. smart grids as interface for battery charging of electric vehicles [EV] or hybrid vehicles [HEV] |
| | Y02T90/169 | Systems integrating technologies related to power network operation and ICT for supporting the interoperability of electric or hybrid vehicles, i.e. smart grids as interface for battery charging of electric vehicles [EV] or hybrid vehicles [HEV] |

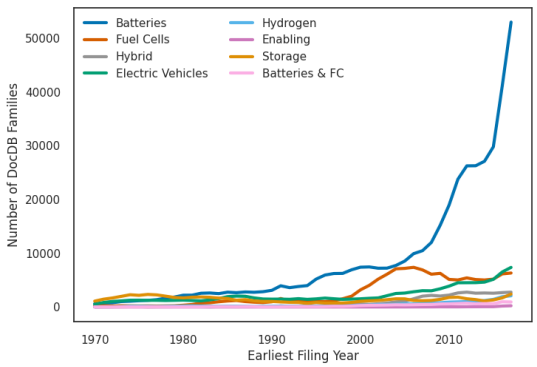
Table B.2
CPC and IPC Codes for Dirty Transportation Technologies

| Sub-sector | Code | Description |
|---|---|---|
| Internal Combustion Engine | B60K13 | Arrangement in connection with combustion air intake or gas exhaust of propulsion units |
| | B60K15 | Arrangement in connection with fuel supply of combustion engines |
| | B60K28 | Safety devices for propulsion-unit control, specially adapted for, or arranged in, vehicles, e.g. preventing fuel supply or ignition in the event of potentially dangerous conditions |
| | B60K5 | Arrangement or mounting of ICE |
| | F02B | Internal-combustion piston engines; combustion engines in general |
| | F02D | Controlling combustion engines |
| | F02F | Cylinders pistons or casings for combustion engines; arrangement of sealings in combustion engines |
| | F02M | Supplying combustion engines with combustiles mixtures or constituents thereof |
| | F02N | Starting of combustion engines |
| | F02P | Ignition (other than compression ignition) for internal-combustion engines |

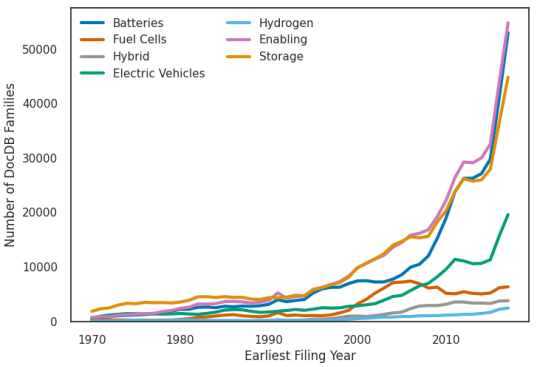
Table B.3
CPC and IPC Codes for Grey Transportation Technologies

| Sub-sector | Code | Description |
|---|---|---|
| Biofuels | B67D7/0498 | Apparatus or devices for transferring liquids from bulk storage containers or reservoirs into vehicles or into portable containers; Arrangements specially adapted for transferring biofuels |
| | F02D19/0652 | Controlling engines characterised by pluralities of fuels; Biofuels |
| | Y02E50 | Technologies for the production of fuel of non-fossil origin (Biofuels, e.g. bio-diesel, Fuel from waste, e.g. synthetic alcohol or diesel) |
| | Y02T10/30 | Use of alternative fuels, e.g. biofuels |
| | Y02T70/5218 | Maritime or waterways transport; Less carbon-intensive fuels, e.g. natural gas, biofuels |
| Biomass and Waste | F02B43/08 | Engines or plants operating on gaseous fuel generated from solid fuel, e.g. wood |
| Car Efficiency | Y02T10/80 | Technologies aiming to reduce greenhouse gasses emissions common to all road transportation technologies |
| ICE Efficiency | F02B1/12 | Engines characterised by fuel-air mixture compression ignition |
| | F02B11 | Engines characterised by both fuel-air mixture compression and air compression, or characterised by both positive ignition and compression ignition, e.g. in different cylinders |
| | F02B13/02 | Engines characterised by the introduction of liquid fuel into cylinders by use of auxiliary fluid; Compression ignition engines using air or gas for blowing fuel into compressed air in cylinder |
| | F02B3/06 | Engines characterised by air compression and subsequent fuel addition; with compression ignition |
| | F02B47/06 | Methods of operating engines involving adding non-fuel substances or anti-knock agents to combustion air fuel or fuel-air mixtures of engines the substances including non-airborne oxygen |
| | F02B49 | Methods of operating air – compressing compression - ignition engines involving introduction of small |
| | F02B7 | Engines characterised by the fuel-air charge being ignited by compression ignition of an additional fuel |
| | F02D41 | Electric control of supply of combustion mixture or its constituents |
| | F02M23 | Apparatus for adding secondary air to fuel-air mixture |
| | F02M25 | Engine-pertinent apparatus for adding non-fuel substances or small quantities of secondary fuel to combustion-air main fuel or fuel-air mixture |
| | F02M3 | Idling devices for carburettors preventing flow of idling fuel |
| | F02M39 | Fuel injection apparatus |
| | F02M41 | Fuel injection apparatus |
| | F02M43 | Fuel injection apparatus |
| | F02M45 | Fuel injection apparatus |
| | F02M47 | Fuel injection apparatus |
| | F02M49 | Fuel injection apparatus |
| | F02M51 | Fuel injection apparatus |
| | F02M53 | Fuel injection apparatus |
| | F02M55 | Fuel injection apparatus |
| | F02M57 | Fuel injection apparatus |
| | F02M59 | Fuel injection apparatus |
| | F02M61 | Fuel injection apparatus |
| | F02M63 | Fuel injection apparatus |
| | F02M65 | Fuel injection apparatus |
| | F02M67 | Fuel injection apparatus |
| | F02M69 | Fuel injection apparatus |
| | F02M71 | Fuel injection apparatus |
| | Y02T10/10 | Conventional vehicles (based on internal combustion engine) |
| Mitigation Air | Y02T50 | Aeronautics or air transport |
| Mitigation Maritime | Y02T70 | Maritime or waterways transport |
| Mitigation Rail | Y02T30 | Rail Transport |

## B.2 Patenting Trends at the Family Level




(a) Exclusive Classification (linear scale)

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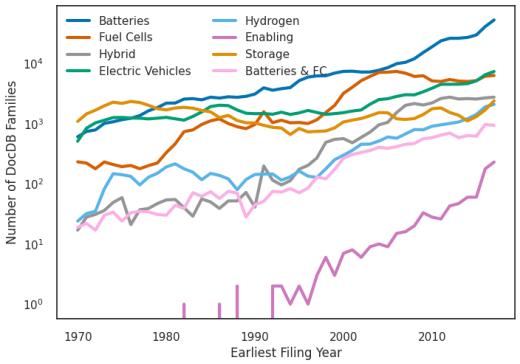


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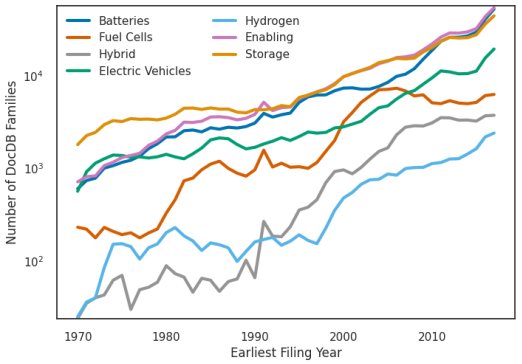
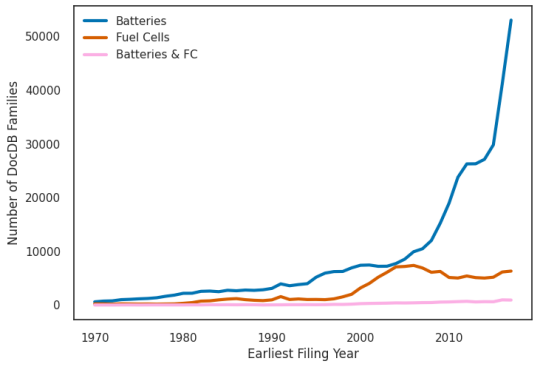


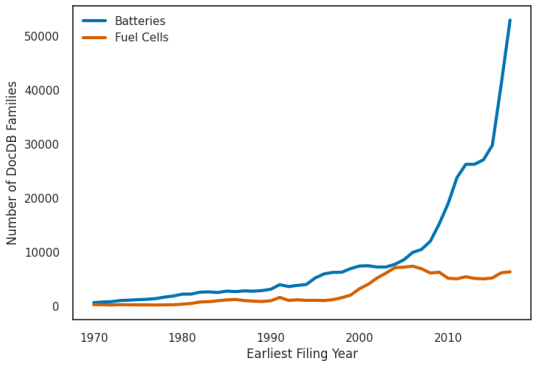

(d) Non-Exclusive Classification (log scale)

Figure B.2
Total Number of Clean Cars Patent Families in PATSTAT

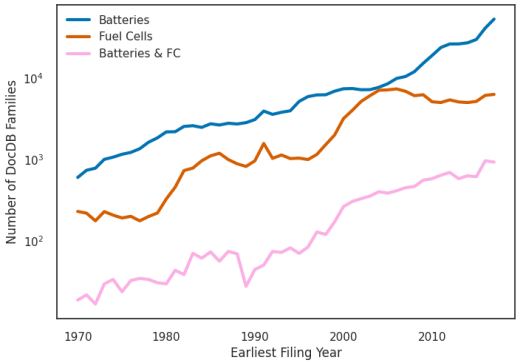
*Note:* The non-exclusive graphs use non-exclusive counts. That is, if a family has both a code for battery and a code for hybrid, it is counted in both "Batteries" and "Hybrid".



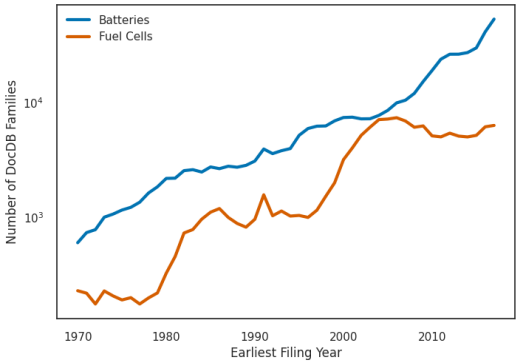

(a) Exclusive Classification (linear scale)




(b) Non-Exclusive Classification (linear scale)




(c) Exclusive Classification (log scale)




(d) Non-Exclusive Classification (log scale)

Figure B.3
Total Number of Battery and Fuel Cells Patent Families in PATSTAT

# C PATENTING TRENDS

## C.1 Patenting Trends for Carmakers

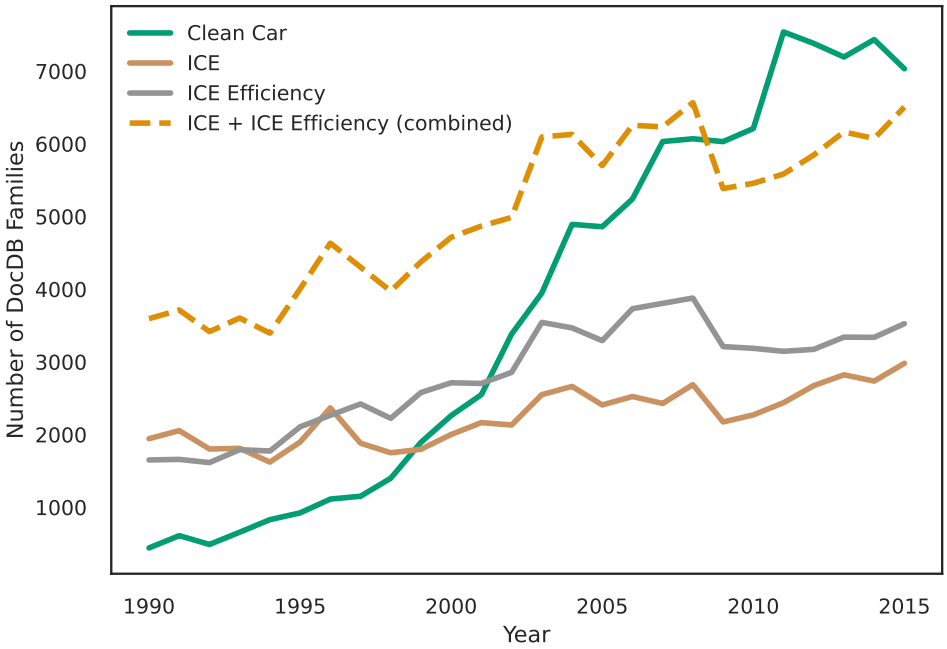
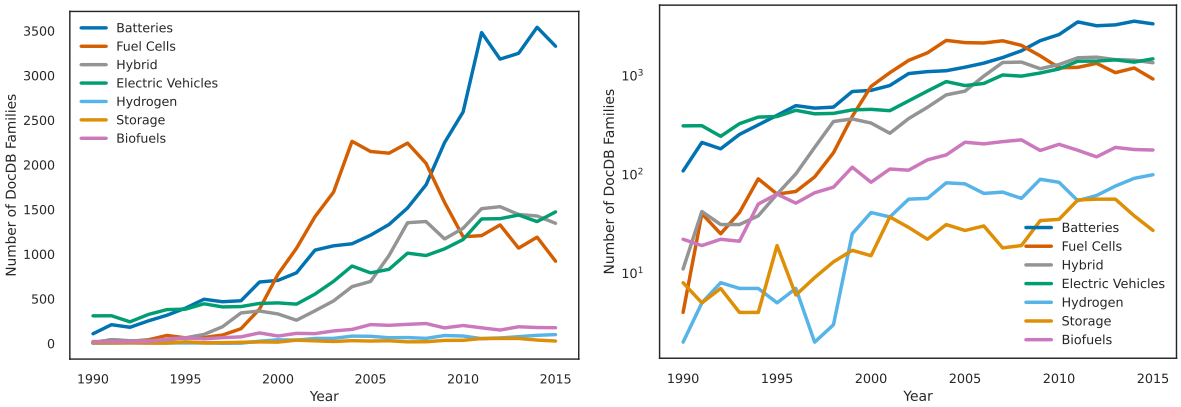



Figure C.1
Carmaker patenting on the ICE versus clean cars




(a) Linear scale

(b) Log scale

Figure C.2
Counts of Carmakers' patents by type of technology (log scale)

## C.2 Additional Graphs for Sectoral Decomposition

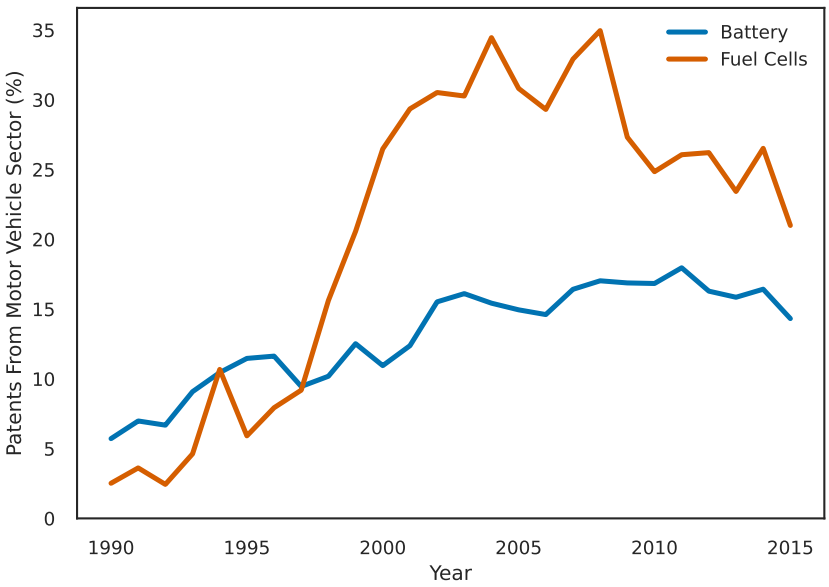



Figure C.3
Battery and Fuel Cell Patenting: Percentage of Motor Vehicles in Total

## C.3 Measuring Spillovers with Citations

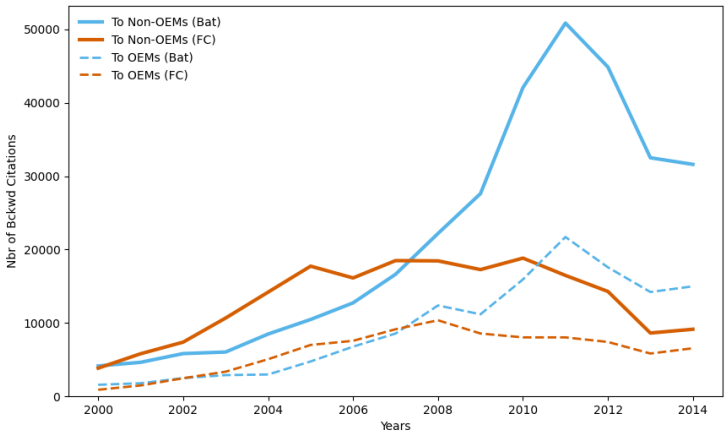



Figure C.4
Backward Citations made by Carmakers to other industries outside Motor Vehicles.

*Note:* The figure shows that car makers have been drawing more on the pool of knowledge outside of their industry than within. This highlights the importance of innovation trends in other sectors.

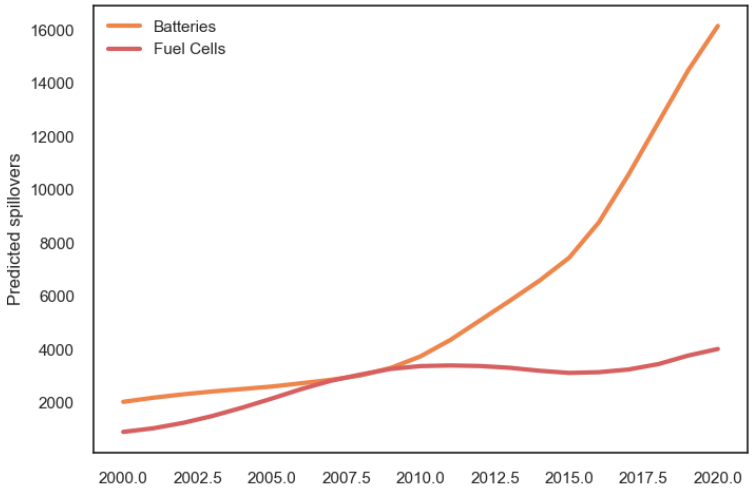



Figure C.5
Expected battery and fuel cell spillovers to OEMs from outside the industry.

*Note:* As explained in the main manuscript (see Methods), we compute a measure of expected spillovers which, unlike the basic counts of citations, control for contemporaneous changes in carmakers' patenting activity. The figure here plots the expected spillovers arising from innovation by non-OEM firms, for battery and fuel cells respectively, over time. Unlike the basic counts of citations, these expected spillovers control for contemporaneous changes in OEM's patenting activity. The figure shows that spillovers for batteries largely came to dominate those from fuel cells after 2010 due to the larger amount of available knowledge from outside the industry. This shows that the automotive industry was able to ride the wave of battery innovations happening most prominently in Electronics. For fuel cells, although OEMs were able to absorb knowledge from the outside in their work on fuel cells, there was no complementary innovation wave in other sectors to sustain cross-sectoral learning.

## C.4 Additional Information about New Suppliers

Table C.1
Top 10 New Suppliers

| Name | Region | New Supplier Battery Count | Battery Stock | Overall Stock | Nbr OEMs | % New Links |
|---|---|---|---|---|---|---|
| lg chem co ltd | KR | 37.04% | 2188 | 6054 | 8 | 0.44% |
| samsung sdi co ltd | KR | 15.13% | 2241 | 6157 | 7 | 0.39% |
| panasonic corporation | JP | 14.26% | 2046 | 49160 | 7 | 0.39% |
| toshiba corporation | JP | 6.43% | 641 | 36850 | 3 | 0.17% |
| hitachi ltd | JP | 3.21% | 541 | 18572 | 5 | 0.28% |
| yazaki corporation | JP | 2.98% | 309 | 5134 | 4 | 0.22% |
| mitsubishi electric corporation | JP | 2.46% | 326 | 27019 | 4 | 0.22% |
| nec corporation | JP | 2.42% | 369 | 16278 | 1 | 0.06% |
| sk innovation co ltd | KR | 1.92% | 348 | 829 | 3 | 0.17% |
| sharp corporation | JP | 1.59% | 294 | 24142 | 1 | 0.06% |

Table C.2
Top 10 New Suppliers from the US

| Name | Region | New Supplier Battery Count | Battery Stock | Overall Stock | Nbr OEMs | % New Links |
|---|---|---|---|---|---|---|
| boeing company the | US | 0.40% | 40 | 3643 | 2 | 0.11% |
| corning inc | US | 0.20% | 47 | 1647 | 3 | 0.17% |
| maxwell technologies inc | US | 0.12% | 16 | 26 | 7 | 0.39% |
| deere co | US | 0.09% | 20 | 1292 | 1 | 0.06% |
| raytheon company | US | 0.08% | 6 | 1466 | 2 | 0.11% |
| microsoft corporation | US | 0.07% | 10 | 12289 | 5 | 0.28% |
| exide technologies | US | 0.07% | 5 | 15 | 4 | 0.22% |
| parker hannifin corp | US | 0.02% | 3 | 339 | 7 | 0.39% |
| texas instruments inc | US | 0.02% | 7 | 3017 | 2 | 0.11% |
| basf corp | US | 0.02% | 32 | 283 | 1 | 0.06% |

# D Policy Data and Analysis

## D.1 Data Collection

Table D.1 shows how we have coded the strategic orientation of different countries over time. To infer strategic orientation, we read the text of flagship policies where possible, or accounts by other authors that provide detail of flagship policies (references are provided in the Table). Flagship policies are any laws, plans or programmes that provide an overall orientation for the automotive sector and take precedence over the programmes of agencies with narrower remit. If a policy or law has the explicit aim of furthering a particular clean vehicle technology, then we code this as the technological focus of the policy. If multiple policies co-exist with different technological foci, or if policies are explicitly technology neutral, then we infer that there is no single technological focus. If there is no overarching plan, then we code this accordingly.

Table D.1
Technological Focus of Different Countries

| Country | Period | Primary technology | Secondary technology | Strategy name | References |
|---|---|---|---|---|---|
| Japan | 1976-1986 | BEVs | | Electric Vehicles Market Expansion Plan | Åhman (2006) |
| | 1991-1997 | BEVs | | Electric Vehicles Market Expansion Plan | Åhman (2006); Pohl and Yarime (2012) |
| | 1997-2001 | All types | | Electric Vehicles Market Expansion Plan | Åhman (2006); Pohl and Yarime (2012) |
| | 2001-2010 | FCEVs | | Policy Study Group on Fuel Cell Commercialization (2001); Fuel Cell Conference of Japan (FCCJ): inter-industry and government coordination body; Roadmap for PEFCs, targeting penetration by 2010 | Maeda (2003);Ishitani and Baba (2008) |
| | 2010-2020 | PHEVs, BEVs | FCEVs | Next Generation Automotive Strategy; EV and PHV roadmap | METI (2011);METI (2018) |
| China | 1995-2000 | All types | | 9th YP | Gong, M. Q. Wang, and H. Wang (2013);ICCT (2021) |
| | 2000-2010 | Equal focus on FCEVs, BEVs and HEVs | | Numerous plans: 10th YP; 11th YP; Development Policy of Auto Industry; Energy Saving Medium and Long-term Plan; Electric Vehicle Special Project under the Tenth YP (2001-2005); National High-Tech R&D Program (863 Program) | Gong, M. Q. Wang, and H. Wang (2013);ICCT (2021) |
| | 2010-2020 | BEVs | FCEVs | 12th YP; Auto Industry Adjustment and Revitalization Plan; Decisions on Accelerating the Cultivation and Development of Emerging Strategic Industries in October 2010; Options on Accelerating the Development of Energy Savings and Environmental Protection Industry; Energy-Saving and New Energy Vehicle Development Plan (2012-2020); Medium and Long-Term Development Plan for the Automotive Industry (2017) | Gong, M. Q. Wang, and H. Wang (2013);ICCT (2021) |
| Korea | 2003-2010 | FCEVs | | 10-Year National Plan for Energy Technology Development; National Vision for Hydrogen | Leflaive (2008);M.-K. Kim, J.-H. Park, K. Kim, et al. (2020) |
| | 2010-2016 | BEVs | | Green Car Promotion Strategy; Green Car Industry Stimulation Plan | Hwang (2015) |
| | 2016- | BEVs | FCEVs | June 3 Measures; Net-Zero pledge; Hydrogen Economy Roadmap (2020) | |
| France | 1992-1999 | BEVs | | Accord-cadre sur le developpement du vehicule electrique | Calef and Goble (2007) |
| | 1999-2008 | No clear strategy | | French inter-ministry committee for clean vehicles | CIVP (2000) |
| | 2009-2020 | BEVs, PHEVs | | Plan national pour le développement des véhicules électriques et hybrides rechargeables (Plan Véhicules Décarbonés); Pacte Automobile | |
| UK | 2002-2017 | All types (technology neutral) | | Power Future Vehicles Strategy; ULEV strategy; Driving the Future Today | DfT UK (2002);OLEV (2013) |
| | 2017-2020 | BEVs, PHEVs | FCEV | Road to Zero strategy; Automated and Electric Vehicles Bill | DfT UK (2018) |
| Germany | -2008 | No clear strategy | | German Federal Government's 3rd Transport Research Programme on Mobility and Transport Technologies; National Innovation Programme Hydrogen and Fuel Cell Technology | BMWi (2008);BMDV (2016) |
| | 2008 | BEV | | German Federal Government's Economic Stimulus Package II | |
| | 2009-2020 | BEV | FCEV | National Electromobility Development Plan; Nationale Plattform Elektromobilität | Bundesregierung (2009) |
| USA | 1988-2001 | Biofuels | | Alternative Motor Fuels Act | Liu and Helfand (2009) |
| | 2001-2009 | FCEVs | BEV (as plan B) | President's National Energy Policy; Energy Policy Act of 2005; Hydrogen Posture Plan | DOE (2002);DOE (2006);NRC (2005) |
| | 2008-2016 | PHEVs, BEVs | FCEV for heavy-duty | American Recovery and Reinvestment Act; The EV Everywhere Grand Challenge Blueprint | DOE (2013);Canis (2013) |
| | 2016-2020 | no clear strategy | | No large-scale policy targeting a particular technology or nation-wide target. State-level market-pull initiatives. | |

Table D.2
RD&D Funding Data Sources for Years

| Country | Period | Technology | Source |
|---|---|---|---|
| France | 1995-2001 | Hydrogen fuel cells | OECD (2006) |
| | 2001-2020 | Both technologies | IEA database |
| Korea | 1995-2002 | Hydrogen fuel cells | OECD (2006) |
| | 2004-2020 | Both technologies | IEA database |
| Japan | 1995-2001 | Hydrogen fuel cells | Maeda (2003) |
| | 2002-2006 | Hydrogen fuel cells | Ishitani and Baba (2008) |
| | 1992-2002 | Other energy storage | Åhman (2006) |
| | 2004-2020 | Both technologies | IEA database |
| USA/DOE | 1995-2003 | Both technologies | Kelly S Gallagher and Anadon (2021) |
| | 2004-2015 | Both technologies | IEA database |
| | 2016-2020 | Both technologies | Kelly S Gallagher and Anadon (2021) |
| China | 1995-2000 | Both technologies | Zhang, Kelly Sims Gallagher, Myslikova, et al. (2021) |

## D.2 Firm-Level Regressions

Table D.3
Exposure to National Orientations and Battery/FC Focus

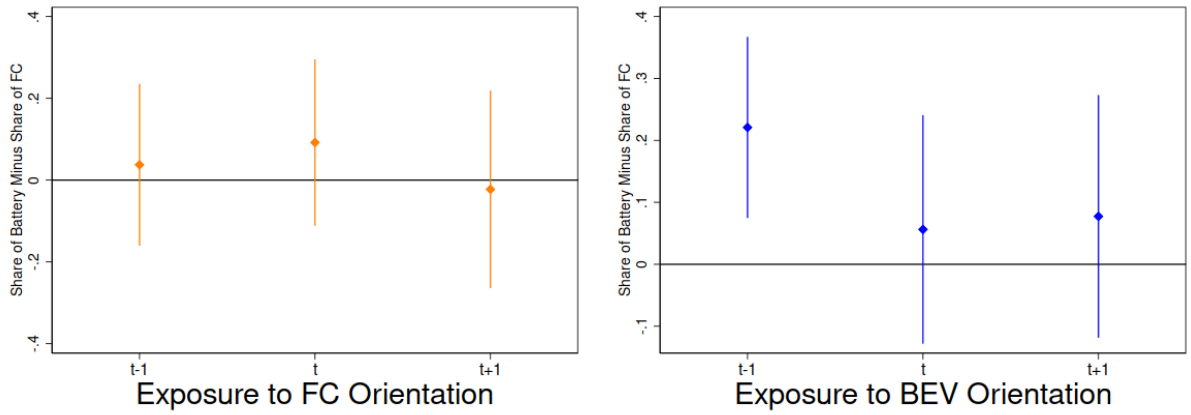
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FC Orientation t-1 | -0.03 | -0.11 | -0.19 | -0.23 | | | | | 0.10 | 0.04 | -0.04 | -0.10 |
| | (0.09) | (0.08) | (0.17) | (0.15) | | | | | (0.11) | (0.10) | (0.23) | (0.18) |
| FC Orientation | 0.05 | 0.04 | 0.17 | 0.11 | | | | | 0.11 | 0.09 | 0.20 | 0.11 |
| | (0.08) | (0.07) | (0.17) | (0.16) | | | | | (0.11) | (0.10) | (0.21) | (0.21) |
| FC Orientation t+1 | -0.27*** | -0.30*** | 0.11 | 0.09 | | | | | 0.04 | -0.02 | 0.11 | 0.07 |
| | (0.08) | (0.09) | (0.16) | (0.14) | | | | | (0.13) | (0.12) | (0.19) | (0.16) |
| BEV Orientation t-1 | | | | | 0.25*** | 0.21*** | 0.37** | 0.26* | 0.28*** | 0.22*** | 0.37* | 0.23 |
| | | | | | (0.06) | (0.06) | (0.15) | (0.14) | (0.08) | (0.07) | (0.19) | (0.16) |
| BEV Orientation | | | | | -0.01 | 0.00 | -0.05 | -0.06 | 0.06 | 0.06 | 0.08 | 0.00 |
| | | | | | (0.07) | (0.07) | (0.10) | (0.09) | (0.10) | (0.09) | (0.11) | (0.12) |
| BEV Orientation t+1 | | | | | 0.13* | 0.10 | -0.01 | -0.10 | 0.13 | 0.08 | 0.10 | -0.04 |
| | | | | | (0.07) | (0.07) | (0.20) | (0.19) | (0.10) | (0.10) | (0.25) | (0.23) |
| Year FEs | | | X | X | | | X | X | | | X | X |
| Firm FEs | | X | | X | | X | | X | | X | | X |
| Firm Clusters (SEs) | 44 | 41 | 44 | 41 | 44 | 41 | 44 | 41 | 44 | 41 | 44 | 41 |
| R2 | 0.04 | 0.49 | 0.18 | 0.56 | 0.18 | 0.54 | 0.20 | 0.56 | 0.20 | 0.54 | 0.21 | 0.56 |
| Observations | 456 | 453 | 456 | 453 | 456 | 453 | 456 | 453 | 456 | 453 | 456 | 453 |

Dependent variable: Difference between Share of Battery and FC.
OLS. Cluster-robust standard errors in parentheses. * p<0.10, ** p<0.05, *** p<0.01

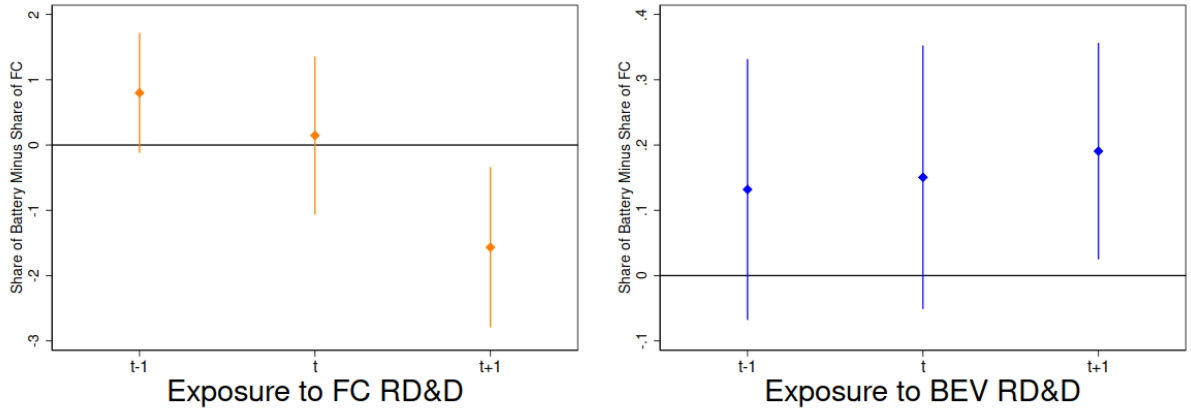
Table D.4
Exposure to RD&D Funding and Battery/FC Focus

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FC R&D t-1 | 0.78 | 0.82* | -0.14 | 0.01 | | | | | 0.45 | 0.74* | -0.25 | 0.18 |
| | (0.51) | (0.46) | (0.58) | (0.66) | | | | | (0.48) | (0.41) | (0.59) | (0.64) |
| FC R&D | -0.08 | -0.43 | -0.09 | -0.66 | | | | | -0.27 | -0.50 | -0.21 | -0.61 |
| | (0.72) | (0.65) | (0.73) | (0.72) | | | | | (0.70) | (0.68) | (0.74) | (0.75) |
| FC R&D t+1 | -2.24*** | -2.09*** | -0.85 | -1.14 | | | | | -1.44** | -1.76*** | -0.58 | -1.47 |
| | (0.58) | (0.56) | (0.73) | (0.77) | | | | | (0.68) | (0.64) | (0.86) | (0.95) |
| BEV R&D t-1 | | | | | 0.33*** | 0.39*** | -0.01 | 0.08 | 0.10 | 0.06 | -0.04 | -0.17 |
| | | | | | (0.08) | (0.10) | (0.10) | (0.12) | (0.10) | (0.10) | (0.13) | (0.15) |
| BEV R&D | | | | | 0.20*** | 0.18** | 0.21 | 0.06 | 0.15** | 0.10 | 0.22* | 0.07 |
| | | | | | (0.06) | (0.08) | (0.13) | (0.15) | (0.06) | (0.08) | (0.13) | (0.15) |
| BEV R&D t+1 | | | | | 0.17* | 0.08 | 0.05 | -0.25 | 0.16* | 0.05 | 0.04 | -0.14 |
| | | | | | (0.10) | (0.09) | (0.15) | (0.16) | (0.09) | (0.09) | (0.14) | (0.15) |
| Year FEs | | | X | X | | | X | X | | | X | X |
| Firm FEs | | X | | X | | X | | X | | X | | X |
| Firm Clusters (SEs) | 44 | 41 | 44 | 41 | 44 | 41 | 44 | 41 | 44 | 41 | 44 | 41 |
| R2 | 0.13 | 0.50 | 0.20 | 0.56 | 0.10 | 0.47 | 0.19 | 0.55 | 0.15 | 0.51 | 0.21 | 0.56 |
| Observations | 456 | 453 | 456 | 453 | 456 | 453 | 456 | 453 | 456 | 453 | 456 | 453 |

Dependent variable: Difference between Share of Battery and FC.
OLS. Cluster-robust standard errors in parentheses. * p<0.10, ** p<0.05, *** p<0.01




(a) Coefficients for Column 10 in Table D.3




(b) Coefficients for Column 10 in Table D.4

Figure D.1
Fuel Cells vs. BEV Policies

*Note:* Figure D.1a plots the coefficients from regression (10) in Table D.3, while Figure D.1b plots the coefficients from regression (10) in Table D.4.

# E OTHER ADDITIONAL INFORMATION

Table E.1
Data Sources for Fuel Cell Prices

| Year | Source |
|---|---|
| 1996 | Barbir, F., and T. Gómez. 1997. "Efficiency and Economics of Proton Exchange Membrane (PEM) Fuel Cells." International Journal of Hydrogen Energy 22 (10): 1027–37. |
| 2000 | US Department of Energy. 2000. "Cost Analysis of Fuel Cell." https://afdc.energy.gov/files/pdfs/baseline_cost_model.pdf. |
| 2002 | US Department of Energy. 2010. "Overview of Hydrogen and Fuel Cell Activities." https://www.hydrogen.energy.gov/pdfs/htac_oct1410_overview.pdf. |
| 2006-2017 | US Department of Energy. 2017. "Fuel Cell Technologies Office Record 17007: Fuel Cell System Cost." https://www.hydrogen.energy.gov/pdfs/17007_fuel_cell_system_cost_2017.pdf. |

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