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The economic benefits of early green innovation: evidence from the automotive sector

Environment Working Paper No. 209

By Alberto Agnelli (1), Hélia Costa (1) and Damien Dussaux (1)

(1) OECD Environment Directorate

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Keywords: Green Technology, Technological Change, Firm Performance, Fuel prices, Fuel taxation, Price Salience

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Abstract

The economic consequences for firms investing in green innovation, and therefore their incentives to innovate, are not well understood. This paper empirically assesses the economic returns on innovation in cleaner vehicles. The analysis uses data on passenger car market shares and patents for car manufacturers operating in eight countries for the period 2005-2021. The results show that, when vehicle fuel prices increase, firms having previously successfully filed patents related to both electric and hybrid vehicles and fuel efficiency experience an increase in their market share. This increase takes place between 7 and 8 years after the patent stock is accumulated for patents related to electric and hybrid vehicles and between 8 and 15 years for patents related to fuel efficiency. The analysis also finds that in contexts where fuel price salience is high, price increases generate larger and earlier competitiveness returns for firms having previously invested in cleaner technologies.

Keywords: Green Technology, Technological Change, Firm Performance, Fuel prices, Fuel taxation, Price Salience

JEL Codes : Q55, O30, Q48

Résumé

Les conséquences économiques pour les entreprises qui investissent dans les technologies vertes, et donc leurs incitations à innover, ne sont pas encore bien comprises. Ce papier évalue empiriquement les bénéfices économiques de l'innovation dans les véhicules plus propres. L'analyse utilise des données sur les parts de marché des voitures particulières et les brevets des constructeurs automobiles opérant dans huit pays sur la période 2005-2021. Les résultats montrent que, lorsque le prix des carburants augmente, les entreprises ayant précédemment déposé avec succès des brevets liés aux véhicules à moteurs électriques et hybrides et des brevets liés à l'efficacité énergétique des moteurs thermiques voient leur part de marché augmenter. Cette augmentation a lieu entre 7 et 8 ans après l'accumulation du stock de brevets liés aux véhicules électriques et hybrides et entre 8 et 15 ans pour les brevets liés à l'efficacité énergétique des moteurs thermiques. L'analyse révèle également que dans les contextes où la saillance des prix des carburants est élevée, les augmentations de prix génèrent des augmentations de parts de marché plus importantes et plus précoces pour les entreprises ayant précédemment investi dans des technologies plus propres.

Mots-clés : Technologie Verte, Changement Technique, Performance des Entreprises, Prix des Carburants, Taxation des Carburants, Saillance des Prix

Classification JEL: Q55, O30, Q48

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Executive summary

Innovation is critical for a transition towards a low-carbon economy. While there is ample empirical evidence that environmental regulation spurs investment in green technologies, the economic consequences for firms investing in green innovation, and therefore their incentives to innovate, are less well understood. The dynamics of these economic consequences are particularly important, as it might take time for innovation to pay off.

This paper empirically assesses the economic returns on innovation in cleaner vehicles and how these returns depend on price signals in the form of increased fuel prices. The analysis uses newly collected data on passenger car market shares, a proxy for economic performance, and patents for the most important car manufacturers operating in eight countries (France, Germany, Italy, Japan, Poland, Portugal, Spain, United States) for the period 2005-2021. The paper investigates various time lags between innovation and economic returns (0 to 20 years) as well as different types of innovation, namely clean (electric, hybrid, and hydrogen vehicles), grey (fuel efficiency of internal combustion engines) and dirty (all other technologies related to internal combustion engines).

The econometric analysis yields several findings. First, the paper shows that a surge in fuel price today increases the market share of firms that had accumulated more knowledge in clean and grey technologies in the past relative to other technologies. On the contrary, fuel price increases harm the market share of firms whose past innovation focused relatively more on dirty technologies. This result suggests that consumers respond to fuel price increases on the extensive margin by switching to more fuel-efficient vehicles and to electric or hybrid vehicles.

Second, these positive and negative effects on the economic performance of firms occur over different time horizons depending on the type of technology considered. Firms realise improvements in economic performance when fuel prices increase 7 to 8 years after knowledge in clean technologies is accumulated. In comparison, the positive effects of grey innovation on market share materialise 8 to 15 years after the stock of knowledge is built. In contrast, the negative impacts from dirty innovation on market share take more time to hit and materialise only 17 to 18 years after knowledge is accumulated.

Third, the firms' economic benefit of innovating in fuel efficient (grey) car technologies under increasing fuel prices is twice as large as the economic benefit of innovating in electric or hybrid (clean) technologies. These differences in timing and magnitude across the various types of car technologies might derive from several non-exclusive explanations. First, the process between innovation and commercialisation of products can be lengthy. This commercialisation lag likely varies between clean, grey and dirty technologies. Second, the factors determining the purchase of cleaner vehicles, more fuel-efficient internal combustion engine cars and dirty internal combustion engine cars differ. Notably, the weight that fuel prices have, among other factors, on the purchase decision of consumers is relatively more important for internal combustion engine cars than for hybrid or electric vehicles.

An additional explanation is that the estimated effects depend on the salience of the information regarding fuel prices for consumers. Low salience can delay price internalisation and therefore weaken or postpone impact on consumption decisions. The paper investigates this hypothesis by estimating the role of attention to fuel prices, measured by the volume of Google searches across countries and years. The analysis shows that high fuel price salience generates larger and earlier competitiveness returns for firms having previously invested in fuel-efficiency technologies while it has no statistically significant effect on returns from investing in electric and hybrid vehicles.

Finally, the paper highlights the important role of public policies on the economic benefits of green innovation. The analysis shows that fuel taxes explain 75% to 81% of the estimated effect of fuel prices including taxes on market share for various levels of past green innovation.

These results have important policy implications. First, governments should put in place or maintain strong price signals over time to reinforce the incentives of firms to innovate in cleaner technologies, as consumers respond to fuel price increases by switching to more fuel-efficient vehicles and to electric or hybrid vehicles. This is particularly important since it takes several years for firms to reap the benefits of investing in green technology.

Second, governments should incorporate the positive effect that fuel price salience has on the adoption of cleaner cars and on promoting green innovation when communicating on policies affecting fuel prices. Regulating and communicating around fuel prices represents a difficult equation for governments, as they often face conflicting incentives to increase or decrease fuel prices. On the one hand, governments are advised to increase the carbon taxation of fuels to meet their climate and environmental goals. On the other hand, the political acceptability of such measures is notoriously low, especially when the non-tax component of fuel prices is high.

Governments have two major tools to ease the fuel price equation that are also relevant to green innovation. First, governments should provide and support the dissemination of information on fuel taxation in the short and long run. Predictability and stability of carbon price signals have been found to be key to encourage investment in clean technologies. Second, governments should simultaneously disseminate information on the progressive use of revenues from carbon taxation to increase its political acceptability. For example, governments could increase the diffusion of information on well targeted bonus malus systems that help credit-constrained household purchase cleaner cars.

1 Introduction

Achieving net zero greenhouse gas emissions by 2050 requires both an acceleration in the deployment of available clean technologies and substantial innovation efforts bringing new clean technologies to the market (IEA, 2021[1]). Innovation efforts in clean technologies can be effectively supported through tailored policy packages. A growing body of research supports the view that environmental policies such as standards and carbon pricing induce green innovation (e.g. Aghion et al. (2016[2]); Calel and Dechezleprêtre (2016[3]); Haščič et al. (2009[4]); Popp (2002[5])).[1]

Yet, the economic consequences for firms investing in green innovation are still not well understood. The Porter Hypothesis predicts that, by decreasing inefficiencies, innovations brought about by stringent environmental policy increase productivity and profitability (Porter and van der Linde, 1995[6]; Porter, 1991[7]), but empirical research is less conclusive. While some studies find a positive effect of some types of green innovation on profitability and productivity (Rexhäuser and Rammer, 2014[8]; Van Leeuwen and Mohnen, 2017[9]), others find no significant effect (Dechezleprêtre and Kruse, 2022[10]). An important dimension missing from these studies is the dynamic aspect, the fact that it might take time for innovation to lead to better economic performance (Ambec et al., 2013[11]).

Determining the private returns to firms' green innovation is important because they can provide incentives to innovate in addition to public policies. Data shows that innovation in low-carbon technologies has slowed down in recent years despite the overall level of innovation continuing to increase (Dechezleprêtre, 2016[12]). The literature suggests that to influence the direction of innovation towards green technologies, carbon taxes should be accompanied by other incentives, such as subsidies for research and development (R&D) (Acemoglu et al., 2012[13]). Private returns could offer a substitute to subsidies and generate incentives for greater innovation, which coupled with adoption of low-carbon vehicles would in turn decrease carbon emissions per distance travelled. Understanding the size and conditions under which these returns occur is therefore important.

This paper investigates empirically the impact of green innovation on car manufacturers' market share. Its main contribution is to focus on the medium and long run, up to 20 years after innovation takes place. In particular, it estimates the return to innovation in technologies that reduce vehicle fuel use per distance travelled in the years after knowledge is accumulated. The present analysis estimates how these returns depend on price signals in the form of increased fuel prices. When fuel prices increase, either because of market fluctuations or carbon pricing, consumers may respond along the *intensive margin* by reducing the distance driven, and along the *extensive margin* by purchasing a more fuel-efficient car when making a purchasing decision (Alberini and Horvath, 2021[14]). The latter benefits manufacturers that have invested in greener technologies. However, investment in innovation as a response to regulatory intervention is likely to generate competitiveness benefits only with a time lag, due to the time necessary for commercialising new technologies (Gross et al., 2018[15]), and it may require complementary and continued policy interventions to pay off.

This study focuses on the automotive sector, and in particular on passenger cars, for two reasons. First, road transportation continues to be one of the main contributors to greenhouse gas emissions, with

[1] We use the terms "green innovation" and "low-carbon innovation" interchangeably, to mean innovation in technologies that aim at reducing emissions of greenhouse gases.

passenger cars accounting for almost 10% of CO_2 emissions worldwide in 2019 (Statista, 2021[16]; IEA, 2020[17]). To achieve net zero by 2050, significant increases in the deployment of electric vehicles are required, from 4.6% of total sales in 2020 to 60% in 2030 (IEA, 2021[1]). Second, major environmental innovation has taken place in past years in the automobile sector (Lee and Berente, 2013[18]; Haščič et al., 2009[4]). Large multinational final producers, such as General Motors or Toyota, are particularly active in innovative activities related to emission control, which are instrumental to meeting net zero CO_2 emissions scenario requirements (Dechezleprêtre, Neumayer and Perkins, 2015[19]).

The analysis uses data on market shares obtained from national car manufacturer associations. The data include firms covering over 95% of the market across eight countries (France, Germany, Italy, Japan, Poland, Portugal, Spain, and the United States) over the period 2005-2021 that accounted for over 37% of worldwide CO_2 emissions from road transportation in 2018 (Statista, 2020[20]). The countries in the sample cover a large share of the world's green innovation in the automotive sector.[2] Market shares are an important measure of firms' relative economic performance within a sector, as they allow firms to have higher profit margins by taking advantage of market power and quality signalling (Buzzell, Gale and Sultan, 1975[21]; Bhattacharya, Morgan and Rego, 2022[22]; Edeling and Himme, 2018[23]).

Innovation is measured using the stock of patents accumulated by each firm. Patent-based measures of innovation have the benefit of being available and comparable across countries, reflecting the outputs of innovation, and allowing to disaggregate innovation by technology field (Haščič and Migotto, 2015[24]). In particular, this paper differentiates between technologies for fuel efficiency (grey innovation), those related to electric or hybrid vehicles (clean innovation), and all other patents (dirty innovation) related to internal combustion engines (ICE) following the classification by Aghion et al. (2016[2]). More specifically, the present paper uses the shares of grey, clean, and dirty innovation out of total innovation to understand the relative benefits for firms of each when prices increase, net of any overall increases of innovation.

Several key results emerge from the econometric analysis. First, an increase in fuel price today raises the market share of firms that had accumulated more knowledge in clean and grey technologies in the past relative to other technologies. On the contrary, fuel price increases harm the market share of firms whose past innovation focused relatively more on dirty technologies. This suggests that consumers respond to current fuel price increases on the extensive margin by switching to more fuel-efficient vehicles and to electric or hybrid vehicles as supported by previous research (Anderson, Kellogg and Sallee, 2013[25]; Grigolon, Reynaert and Verboven, 2018[26]; Alberini and Horvath, 2021[14]).[3]

Second, the paper finds that the economic benefits, as measured by increased market shares, for firms innovating in grey technologies (improving the fuel efficiency of ICE) are twice as large as the economic benefits for firms innovating in clean (electric or hybrid) technologies when fuel prices increase. One potential explanation could be that the factors determining the purchase of a clean car and the purchase of a more fuel-efficient ICE cars differ. Notably, expected fuel cost is likely to be more important for the purchase of a more fuel-efficient ICE car than for the purchase of an electric or hybrid vehicle where considerations such as the availability of charging stations are likely to be more important.

Third, the analysis reveals that the positive and negative effects of past innovation on the economic performance of firms in the context of higher fuel prices occur over different time horizons depending on

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[2] This innovation is highly concentrated, with Germany, Japan and the United States accounting for its largest shares (Dechezleprêtre, Neumayer and Perkins, 2015[19]).

[3] Alberini and Horvath (2021[14]) show that consumers respond to fuel price increases on the extensive margin by switching to more fuel-efficient vehicles and also to electric or hybrid vehicles. Grigolon, Reynaert and Verboven (2018[26]) find that consumers only modestly undervalue future fuel costs when making vehicle purchases. If consumers correctly anticipate fuel prices and base their expectations of future prices on current prices as shown by Anderson, Kellogg and Sallee (2013[25]), then current prices should affect their choice of vehicle, increasing the importance of maintained pricing signals.

the type of technology considered. Economic benefits are accrued by firms 7 to 8 years after knowledge in clean technologies is accumulated. In comparison, the positive effects of grey innovation on market share materialise 8 to 15 years after the stock of knowledge is built. In contrast, the negative impacts from dirty innovation on market share take more time to hit and materialise only 17 to 18 years after knowledge is accumulated. The erosion of the effects of innovation in fuel efficient technologies after 15 years might be explained by the obsolescence of knowledge. While early knowledge in green technologies can provide an economic advantage, the knowledge developed very early is at some point no longer relevant for the current market. However, the speed of knowledge obsolescence is likely to be different across technologies, partially explaining the differences in timing found between the effects of clean, grey and dirty technology.[4]

Moreover, the large lag between the time innovative knowledge is accumulated and the time of economic returns could be due to several factors. First, the process between innovation and commercialisation of products can be lengthy (Gross et al., 2018[27]). This commercialisation lag likely varies between clean, grey and dirty technologies. Second, the time gap could also arise from the low salience of the information regarding fuel prices for consumers, delaying its internalisation and therefore weakening or postponing impact on consumption decisions (Alberini, Khymych and Ščasný, 2020[28]; Huse and Koptyug, 2022[29]). The present analysis investigates the latter hypothesis using the intensity of Google searches for fuel price information, which has been shown to be adequately proxy fuel price salience (Mellon, 2013[30]; Huse and Koptyug, 2022[29]). The estimation shows that when fuel price salience is high, fuel price increases generate larger and earlier competitiveness returns for firms having previously invested in fuel-efficiency technologies.

Finally, the private economic benefits of early green innovation are large and the role of environmental policy, in the form of fuel taxation, is key. For example, ten years after the stock of grey patents is accrued, going from the median grey innovation share to the 75th percentile (i.e., from a share of 3% to a share of 5%) is associated with an increase of approximately 0.5 percentage points in market share for median fuel prices. This is a large effect considering that 0.5 percentage points correspond to one fifth of the median market share of firms in the sample, which is 2.5. The analysis also shows that fuel taxes explain 75% to 81% of the estimated effect of fuel prices (including taxes) on market share for various levels of past green innovation.

These results have important policy implications. First, they indicate that it takes time to reap the benefits of investing in green technology but that consumers respond to fuel price increases by switching to more fuel-efficient vehicles and to electric or hybrid vehicles.[5] The findings also suggest that green innovation that will directly benefit the environment can also produce benefits for firms in the medium and long run if price signals are strong. Competitiveness benefits for firms could be a strong incentive for investment in green innovation. If these economic benefits depend on consumer behaviour, it is important for governments to put in place or maintain price signals that reinforce firms' incentives to innovate.

The second important policy implication of this work is that the salience of fuel prices has an important role to play in the adoption of cleaner cars. Regulating and communicating around fuel prices represents a difficult equation for governments to solve as they often face conflicting incentives to increase or decrease fuel prices. On the one hand, governments are advised to increase the carbon taxation of fuels and to phase out fossil fuel subsidies in order to meet their climate and environmental goals. On the other hand, the political acceptability of such measures is notoriously low, especially when the non-tax component of fuel prices is high.

[4] Notably, the clean car technologies evolved rapidly over the last decades.

[5] Consistent with previous findings, this suggests that understanding the private returns to green innovation requires a longer time perspective (Ambec et al., 2013[11]).

Governments have two major tools to ease the fuel price equation that are also relevant to green innovation. First, they should provide and support the dissemination of information on fuel taxation in the short and long run. While it is not empirically tested in this paper, predictability and stability of carbon price signals have been found to be key to encourage investment in clean technologies (OECD and World Bank, 2015[31]). Second, governments should simultaneously disseminate information on the progressive use of revenues from carbon taxation to improve its political acceptability. Studies show that reliance on cars is an important determinant of public support for climate change policies including carbon taxes, but that a progressive use of revenues increases their support (Dechezleprêtre et al., 2022[32]). For example, governments could increase the diffusion of information on well targeted bonus malus systems that help credit-constrained household purchase cleaner cars.

The remainder of the paper is structured as follows. Section 2 presents the empirical analysis on the effects of green innovation on economic performance in the car manufacturing sector. Section 3 expands the empirical model to estimate the change in the effect of green innovation on economic performance for different levels of fuel price salience at the country level. Section 4 provides a discussion of the results and concluding remarks.

2 Empirical analysis of the effects of past innovation on economic performance

2.1 Data

The analysis uses newly collected annual data covering 19 car manufacturers operating across eight countries (France, Germany, Italy, Japan, Poland, Portugal, Spain, and the United States) over the period 2005-2021. The data used include information measuring economic outcomes for firms, innovation by these firms (environmentally friendly or otherwise), and country-level fuel prices. The following subsections focus on each of these in turn.

2.1.1 Economic outcomes

The economic performance of firms can be assessed using several different indicators. Common measures include operating profit margin, return on assets, return on investment, revenue per employee and market share. The return on assets and the operating profit margin[6] - - are considered superior to market shares because they measure how well a company uses its inputs and assets to generate income.

However, measures such as return on assets, return on investment, or revenue per employee present in financial reports, in the case of multinational companies such as the car manufacturers in our data, refer normally to the parent company and not to countries where sales are made. While revenue data per firm and per country can be found, attributing part of the global firm's assets or costs to sales made in a specific market is nearly impossible. On the contrary, market shares in a given country can be directly linked to the level of fuel prices in this country, allowing to test for the effect of country-specific policy-induced fuel price variations on firms' economic performance.

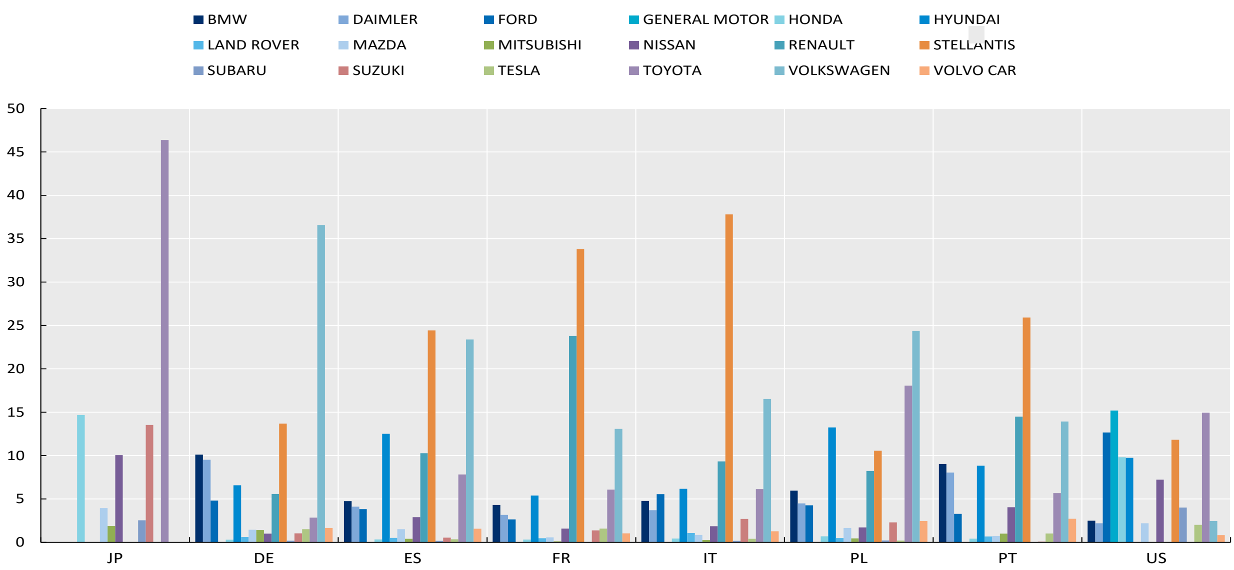
Therefore, to measure firms' economic performance, information on market shares at the firm and country level is collected. As a measure of economic performance, market shares have the benefit of being available and comparable across firms and countries. Additionally, research has shown that market shares tend to be related to indicators of firm profitability such as higher profit margins, lower marketing costs as a percentage of sales and higher prices (Buzzell, Gale and Sultan, 1975[21]; Edeling and Himme, 2018[23]), through their impact on market power and quality signalling (Bhattacharya, Morgan and Rego, 2022[22]). This is particularly the case for products that are purchased infrequently. In the automotive industry, market share objectives are so important that executive compensation is often tied to the achieved market share (Ritz, 2008[33]).

[6] Return on assets is a financial ratio measuring a company's profitability in relation to its total assets. The operating profit margin is the ratio between operating income and revenue, where the operating income is equal to net sales minus costs of goods minus selling, general and administrative and other operating expenses.

The analysis focuses on the sales of passenger cars[7], which capture the response of consumers – rather than businesses – to fuel (gasoline and diesel) price increases and vehicle characteristics better than commercial or heavy vehicles. Data on the number of car sales for each manufacturer were collected from the automobile manufacturers' association of each country.[8] The market shares were computed for each firm, country and year. The data covers over 95% of each country's market across the eight countries analysed. Since the industry has undergone several mergers and acquisitions that modified the ownership structure of many car manufacturing firms, market shares were computed based on the latest ownership structure.[9] This ensures a comparable unit of observations for the entire observation period.

The data shows that market shares vary markedly by country and throughout the period of analysis. While manufacturers like Land Rover have market shares of around 1%, others like Toyota, Volkswagen and Stellantis (which includes Abarth, Alfa Romeo, Chrysler, Citroën, Dodge, DS, Fiat, Fiat Professional, Jeep, Lancia, Maserati, Mopar, Opel, Peugeot, Ram and Vauxhall) reach between 40% and 50%. Figure 2.1 shows the variation of market shares across countries in two different time periods, 2005 and 2021 and Figure 2.2 the variation in market share of a sample of firms in Poland from 2005 to 2021.

Figure 2.1. Variation in market share by country and firm



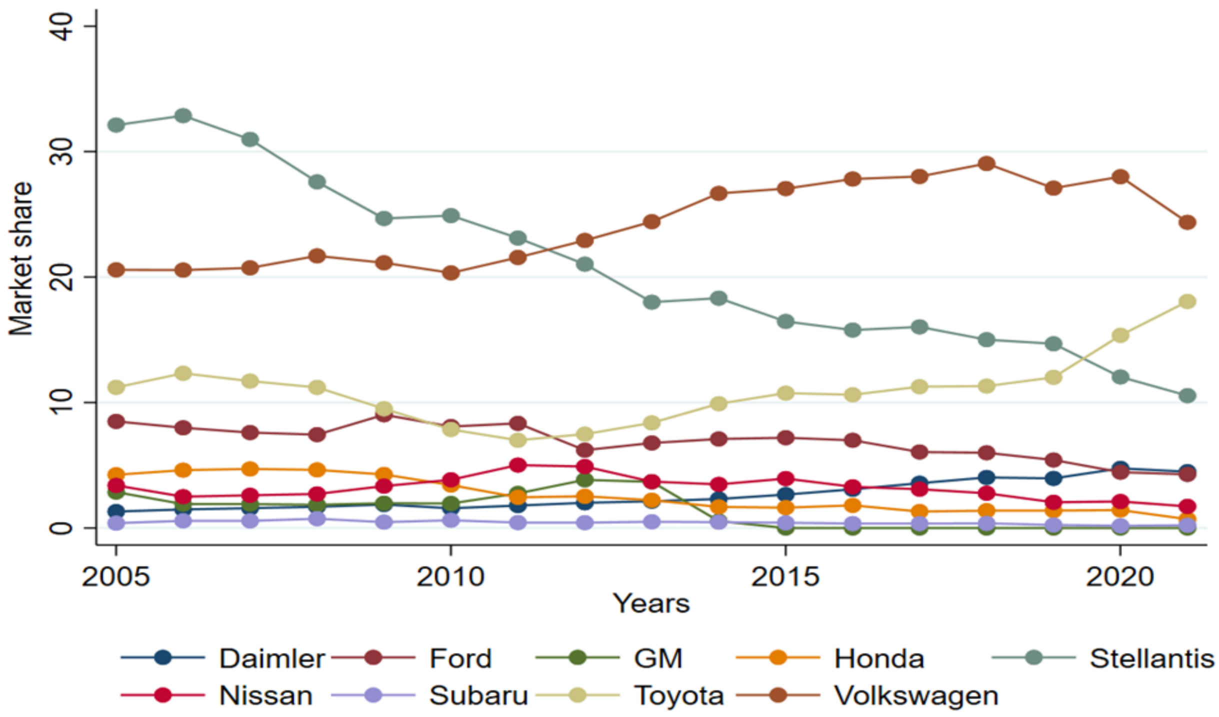
Source: Data from Comité des Constructeurs Français d'Automobiles (France), Kraftfahrt-Bundesamt (Germany), Associazione Nazionale Filiera Industria Automobilistica (Italy), Japan Automobile Manufacturers Association (Japan), Polski Związek Przemysłu Motoryzacyjnego (Poland), Associação Automóvel de Portugal (Portugal), Instituto de Estudios de Automoción – IDEAUTO (Spain), and GoodCarBadCar.net (United States).

[7] M1 vehicles only are considered as defined in United Nations Economic Commission for Europe's Consolidated Resolution on the Construction of Vehicles (R.E.3). These are defined as vehicles used for the carriage of passengers, with no more than eight seats in addition to the driver seat, also known as passenger cars.

[8] Sources of car sales data are: Comité des Constructeurs Français d'Automobiles (France), Kraftfahrt-Bundesamt (Germany), Associazione Nazionale Filiera Industria Automobilistica (Italy), Japan Automobile Manufacturers Association (Japan), Polski Związek Przemysłu Motoryzacyjnego (Poland), Associação Automóvel de Portugal (Portugal), Instituto de Estudios de Automoción – IDEAUTO (Spain), and GoodCarBadCar.net (United States).

[9] 2021 ownership structure for car companies was obtained from the European Automobile Manufacturers' Association (ACEA).

Figure 2.2. Market share of sample firms in Poland, 2005-2021



Source: Polski Związek Przemysłu Motoryzacyjnego

2.1.2 *Innovation*

Several approaches exist to measuring innovation, and in particular green innovation. These include measures based on R&D spending, number of scientific personnel, survey-based measures, and measures based on patents granted (OECD, 2010[34]).[10] R&D spending and number of scientific personnel often lack coverage and disaggregation by technology and reflect inputs to the innovation process rather than outputs. Surveys, in turn, tend to be costly, difficult to compare, and subject to known problems with self-reporting.

Patent-based measures have advantages compared to other measures of innovation, in that patent information tends to be widely available, reflects outputs of innovation, and allows for disaggregation by technological fields, allowing to account for green innovation (Haščič and Migotto, 2015[24]; Dechezleprêtre et al., 2020[35]). Although some innovation may never be patented, most economically significant innovations are (Dernis, Guellec and van Pottelsberghe, 2001[36]). Accordingly, research on environmental innovation often uses patents as a measure of innovative activity (Popp, 2006[37]; Johnstone, Haščič and Popp, 2010[38]; Dechezleprêtre and Kruse, 2022[10]).

This analysis follows previous literature and uses the number of inventions that were granted a patent by each manufacturer in a given year as a proxy for firm-level innovation. Specifically, it uses the number of simple patent families, which are a collection of patent applications covering the same or similar technical content, to avoid double counting. These data are available from the OECD Science Technology and

[10] Approaches to measure innovation, however, are varied and recent research has also focused on developing new approaches to improve the measurement of innovation related to climate change mitigation (Dussaux, Es-Sadki and Agnelli, Forthcoming[49]).

Innovation (STI) Micro-data Lab's Intellectual Property Database that uses information from the World Patent Statistical Database (PATSTAT) maintained by the European Patent Office (OECD, 2022[39]).

The database reports the name of the applicant filing the patent, which was used to attribute patents to each car manufacturer.[11] The analysis uses all the patents filed in any office in the world, but the results are robust to using only patents filed in at least one of the main three offices: the European Patent Office (EPO), the Japan Patent Office (JPO), and the US Patents and Trademark Office (USPTO). Inventors of high value innovations are more likely to protect them in one of the main offices (Dechezleprêtre, Ménière and Mohnen, 2017[40]). One key limitation of this metric is that it only measures patents filed by the car manufacturer itself. Car manufacturers rely, to varying degrees, on suppliers from outside their corporate families for key inputs. For instance, turbocharging has played an important role in reducing both diesel and gasoline internal combustion engines' fuel consumption and CO_2 emissions but it is unlikely that automobile manufacturers hold patents related to their suppliers' turbochargers. This limitation introduces a measurement error which further research could contribute to reduce.

The analysis focuses on measuring emission-reducing, or green, innovation, as well as dirty innovation (innovation related to internal combustion engines that does not involve emission reduction). Using the International Patent Classification (IPC), it follows the distinction by Aghion et al. (2016[2]), based on the work by Haščič et al. (2009[4]) and Vollebergh (2010[41]). Patents are separated into: i) clean patents, which include technology for electric, hybrid, and hydrogen vehicles; ii) grey patents, including technologies to improve fuel efficiency of internal combustion engines; and iii) dirty patents, which cover all other technologies related to internal combustion engines. It is worth noting that some patents filed under dirty patents correspond to technologies addressing regulatory requirements to reduce conventional pollutants. Nonetheless, patents classified under dirty in this paper correspond to technologies that mainly do not improve the fossil fuel efficiency of cars and contribute to internal combustion engine vehicles, Table 2.1 provides a broad description of the technologies covered in these three main categories and Table A.1 in Appendix A shows the IPC codes used to identify the types of technologies.[12]

Table 2.1. Defining clean, grey and dirty car technologies

Clean patents	Grey patents	Dirty patents
Electric vehicles technologies	Fuel efficiency of internal combustion engines	Internal combustion engine technologies
Hybrid vehicles technologies		
Regenerative braking technologies		
Hydrogen vehicles		
Fuel cells		

Source: Aghion et al. (2016[2])

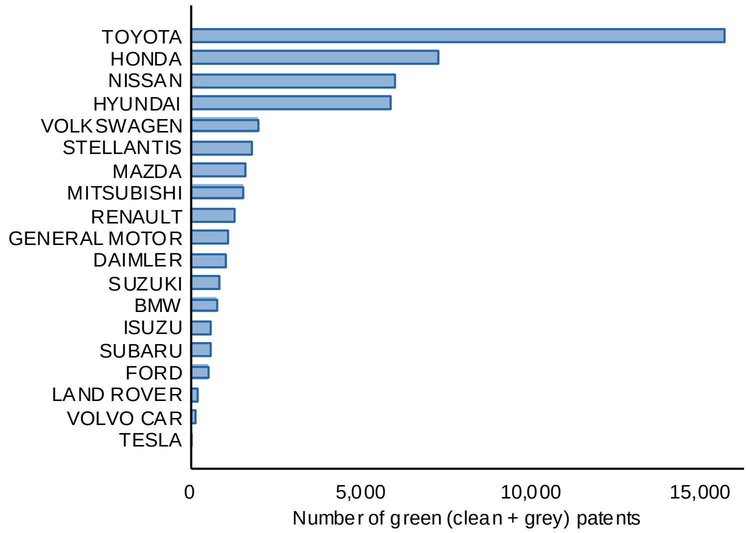
[11] Applicants' names were linked to car manufacturers using the field "person name" available in PATSTAT. Individual patents were manually traced back to individual car manufacturers using a keyword search followed by manual verification. A search was run on PATSTAT's applicant names using car manufactures' official names as keywords. Multiple variations of the name were included in the search such as previous company names and names of subsidiaries

[12] Classification of "green," "grey," and "dirty" patents involve some degree of arbitrariness. In particular, many of the categories listed as "dirty" encompass technological innovations that in specific cases could overall reduce conventional and greenhouse gas emissions while some of the specific examples of "green" and "grey" innovation may not be necessarily benign. In addition, aerodynamic efficiency, tire rolling resistance, and vehicle mass are all important determinants of energy efficiency for both electric and internal combustion powered vehicles but they are outside the scope of the study.

This information is collected for the years 1980-2020. Figure 2.3 summarises the total number of emission-reducing patents for the period. There are sharp differences in patenting activity between manufacturers, with frontrunners like Toyota, Honda, Nissan and Hyundai having the largest number of patents. Of these, Toyota has filed more than double the number of green patents filed by Honda over the period 1980-2020.

Figure 2.3. Patenting activity varies markedly by manufacturer

Total number of clean and grey patents filed by manufacturers, 1980-2020



Note: The bars represent the number of green (clean and grey) patent families filed by each manufacturer (or people associated with the manufacturer) in any office worldwide during the period 1980-2020.
Source: Authors with data from OECD, STI Micro-data Lab: Intellectual Property Database, http://oe.cd/ipstats , May 2022.

To assess firms' stock of knowledge in clean, grey and dirty technologies at a given point in time, while also considering that patented knowledge becomes obsolete over time, the Perpetual Inventory Method (PIM) is used to compute the discounted stock of granted patents. This stock equals the sum of the discounted flow of patents granted in all years since 1980.[13] The discount rate was chosen to be 15%, between the values of 10% (Peri, 2005[42]) and 20% (Aghion et al., 2016[2]) used in previous literature.[14]

To measure past innovation in clean, grey and dirty technologies for each firm, this paper uses the stock of clean, grey and dirty patents as shares of the total stock of patents. For example, the share of clean patent stock equals the stock of clean patents granted to the firm divided by the stock of all patents granted to the firm. Shares of patent stock are used rather than absolute stocks of clean, grey and dirty patents for several reasons.

First, shares capture better than stocks the degree of greenness of technologies invented and commercialised by firms. Suppose firm A has a clean patent stock that is twice as large as the clean patent stock of firm B. Suppose also that firm A has a dirty patent stock that is five times the size of that of firm B. In that case, firm A has a lower share of clean patent stock. It is expected that firm B will perform better than firm A if fuel prices increase in the near future because firm B innovated relatively more in cleaner vehicles. This green specialisation should be reflected in the cars sold in the following years and influences

[13] Mathematically, the discounted stock of patent equals $Stock_{it} = Patent_{it} + \gamma Stock_{it-1}$ where $Patent_{it}$ is the number of patents granted to firm i in year t and $Stock_{i1980} = Patent_{i1980}$.

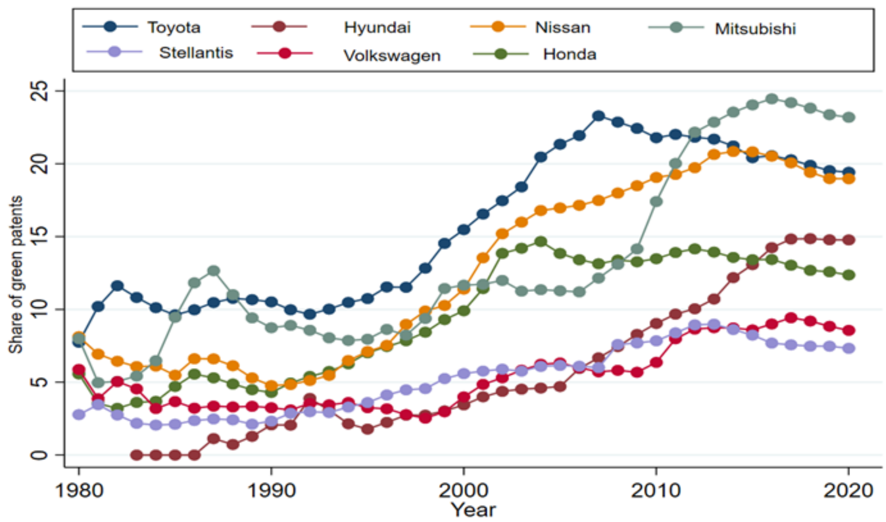
[14] Alternative estimations using 10% and 20% depreciation rates did not carry substantially different results (Table B.3 and Table B.4 in Annex B).

relative market shares. Second, using shares rather than stocks allows to control for firms' propensity to patent. Firms do not rely on the same appropriation strategy when it comes to protect their intellectual property. Usually, firms use both patents and trade secrets to protect their technology, but they rely on those to varying degrees. Therefore, absolute patent stocks are not directly comparable across firms. Third, having the stock of clean, grey and dirty patents generates a multicollinearity issue due to a scale effect. The larger the firms, the higher the stock of patents in all categories, making them highly correlated with one another.[15] This multicollinearity leads to spurious estimates and does not occur when using shares of clean, grey and dirty patents.

In 2020, the share of green (grey and clean) patent stock was on average 11% for the 19 car manufacturers in the sample Figure 2.4 depicts the evolution of the share of green patent stocks for the top six innovators. While there was an increasing trend in the share of innovation in green technologies, it has stalled or slightly decreased since the early 2010's. Some explanations offered for this are the low oil prices observed in this period and insufficient public research funding (Dechezleprêtre, 2016[12]). The share of green patent stocks also varies between and within manufacturer (Figure 2.4). For example, Hyundai surpassed several other manufacturers between 1990 and 2020 while Mitsubishi's stock share varied from levels just above 5% in the 90s to almost 25% of all patent stocks in 2016.

Figure 2.4. The share of green knowledge has been generally increasing in the last decades

Share of stock of patents that is clean or grey for top innovators, 1980-2020



Note: Note: The share of the stock green patents is the sum of the share of the stocks of clean and grey patents. The stock of patents is estimated through the PIM with a depreciation rate of 15%.
Source: Authors with data from OECD, STI Micro-data Lab: Intellectual Property Database, http://oe.cd/ipstats , May 2022

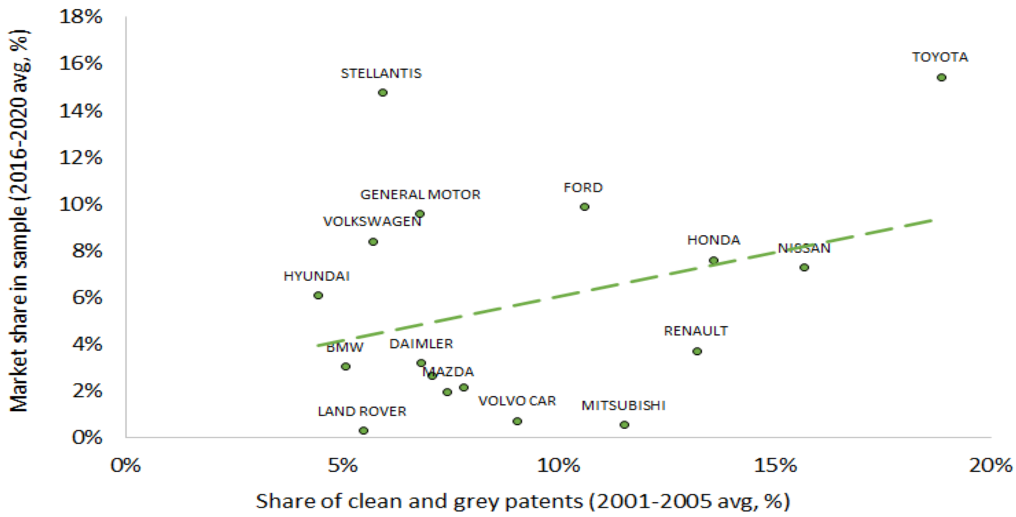
The past share of green innovation is positively correlated with market share at the firm level ten years later (Figure 2.5, Panel A). For example, Toyota that had the largest share of green innovation between 2001 and 2005 also had the highest market share between 2016 and 2020. Growth in past share of green

[15] The pairwise correlation between the interactions of fuel prices with past patent stocks vary between 0.94 and 0.99 for a lag of 12 years and between 0.90 and 0.99 for a lag of 15 years. In comparison, the correlation coefficient between interactions of fuel prices with past patent stocks shares vary between 0.49 and 0.82. The multicollinearity issue with using patent stocks is further demonstrated by the high student t-statistics reported in Table B.1 of Appendix B, which take into account the various fixed-effects and other relevant controls.

innovation is also correlated positively with growth in future market share (Figure 2.5, Panel B).[16] For instance, Land Rover and Hyundai experienced an increase in their market share between 2010 and 2020 that is proportionate to their increase in past share of green innovation between 2005 and 1995. While this relationship could signal a positive effect of green innovation on car manufacturers' economic performance, this relationship is weak. As an illustration, Stellantis has a past share of green innovation that is four times smaller than Toyota (see Figure 2.5, Panel A). Yet the market share of the two companies is relatively similar. Moreover, this correlation cannot be interpreted as a causal effect since many confounding factors could drive the relationship, including firm-level characteristics such as size, the markets in which firm operate and country-level regulatory settings. Controlling for these confounders is needed to further investigate empirically the effect of past green innovation behaviour on future economic performance.

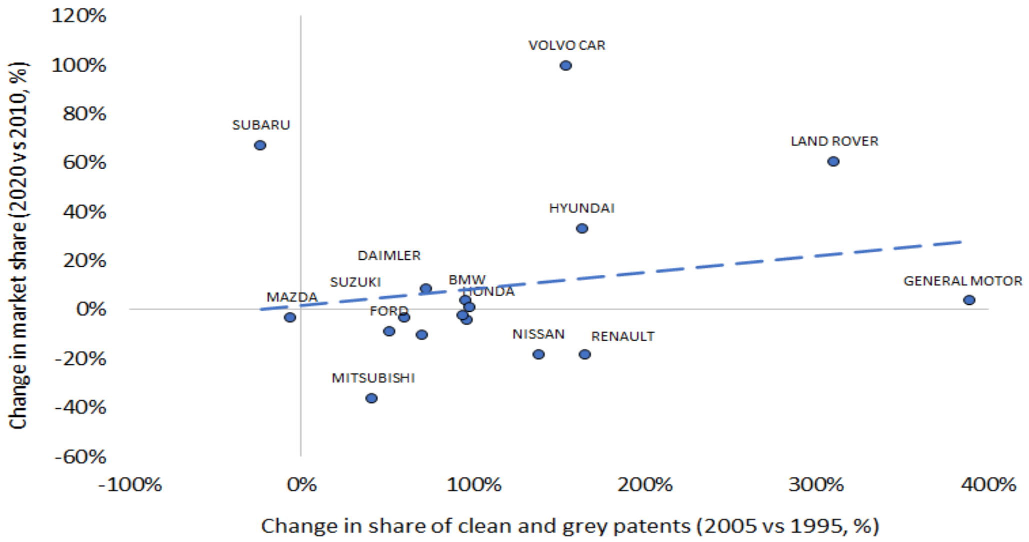
Figure 2.5. Correlation between market share and green innovation

Panel A. Correlation between past share of green patents and future market share



[16] Tesla is absent from these figures because the company was created in 2003 and cannot be compared to other car manufacturers graphically.

Panel B. Correlation between change in share of green patents and change in market share



Note: the market share is computed among the eight countries included in the sample only; the share of green patents is firm specific and does not change between markets.

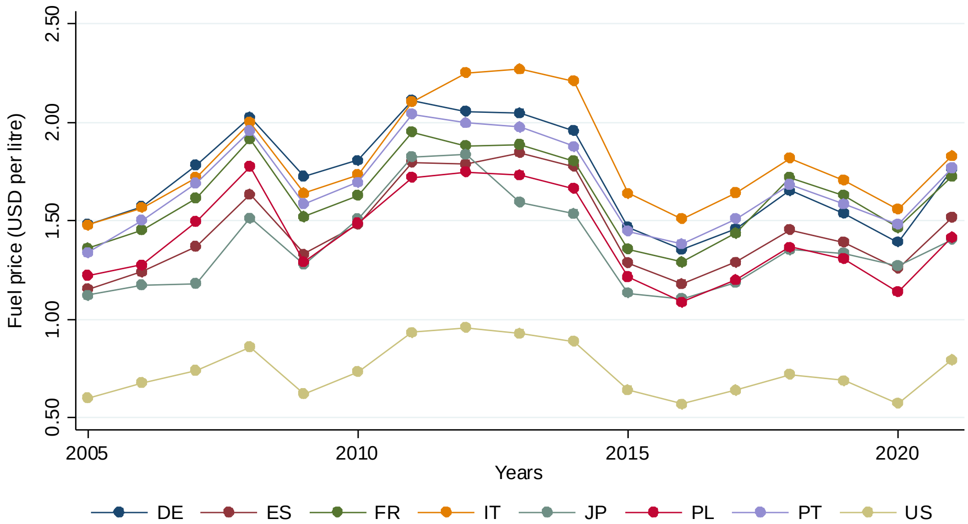
2.1.3 *Fuel prices*

In order to estimate an indicator of each country's automobile fuel prices, this analysis uses a sum of gasoline prices and diesel prices, in current USD per litre, weighted by the share of gasoline and diesel cars in each country's fleet of passenger cars.[17] Information on fuel prices are retrieved from the OECD.Stat database, which collates information from IEA (2021[43]). These prices are inclusive of taxation and therefore also capture price signals that can be modified by governments. The resulting values are depicted in Figure 2.6 Panel A. Although prices across countries seem to share a trend, there are relative changes during the period of analysis. To better portray the fuel price variation between countries, Figure 2.6 Panel B shows the residuals obtained from regressing fuel prices on country and year fixed effects. Residuals represent country-specific variations of fuel prices over time cleaned of time invariant country-specific factors and cleaned of factors that influence all countries over time such as variation in the international oil price.

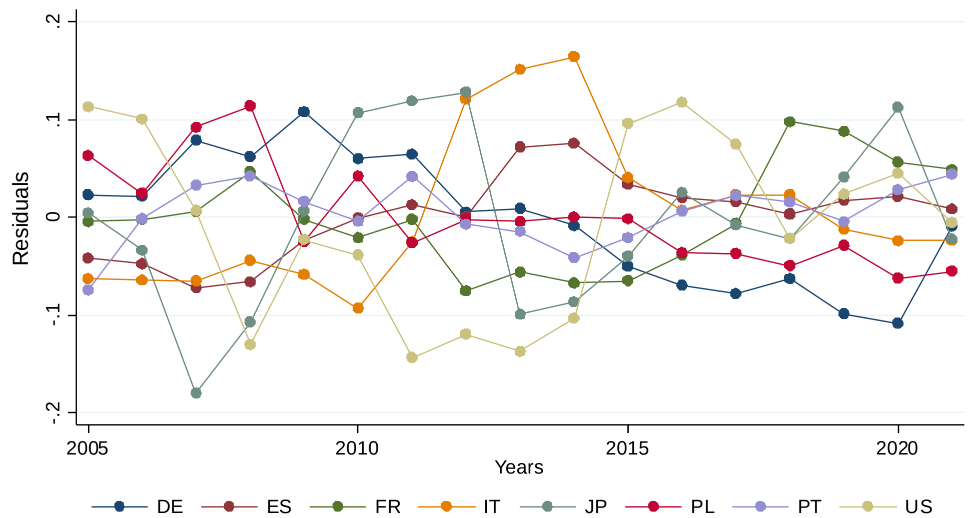
[17] The price of premium unleaded 95 was used as the gasoline price for all countries except the US and Japan, where the price of unleaded regular was used, as it is the main gasoline used.

Figure 2.6. Fuel price evolution

Panel A. Fuel prices across countries 2005-2021



Panel B. Residuals across countries 2005-2021



Note: The price of fuel for each country is a weighted sum of gasoline and diesel prices, weighted by the fleet fuel input. In Panel B, the residuals depicted are from regressing fuel prices on country and year fixed effects.
Source: OECD.Stat with information from IEA (2021[43]).

2.2 Empirical specification

The analysis investigates the relative gains of previous green innovation in the presence of continued price signals. The following equation is estimated for the baseline results:

$$\begin{aligned} mkt\ share_{ict} &= \alpha_1 fuel_{ct} \times grey_{it-k} + \alpha_2 fuel_{ct} \times clean_{it-k} + \alpha_3 fuel_{ct} \times dirty_{it-k} \\ &+ \alpha_4 fuel_{ct} \times \ln(all_{it-k}) + \beta_1 fuel_{ct} \times initial_{ic} + \beta_2 trend_t \times initial_{ic} \\ &+ \rho_{it} + \sigma_{ci} + \varphi_{ct} + \varepsilon_{ict}, \\ & k = \{0, \dots, 20\} \qquad (1) \end{aligned}$$

where $mkt\ share_{ict}$ is the market share of car manufacturer i in country c in year t, $fuel_{ct}$ is the log of the tax-inclusive fuel prices in country c and year t, and $grey_{it-k}$, $clean_{it-k}$ and $dirty_{it-k}$ are respectively the grey, clean, and dirty stock of patents as a share of total patents accumulated by firm i in year $t-k$, where $k = \{0, \dots, 20\}$, while all_{it-k} is the log of the stock of all patents accumulated by firm i in year $t-k$.[18] The total stock of patents accounts for the overall stock of knowledge of the firm.[19]

Additionally, $initial_{ic}$ is the log of the number of vehicles sold by firm i in country c in 2005, included to account for the initial size of manufacturers in a given market. The first interaction, with fuel prices, measures whether fuel price effects depend on initial size, and the second, of initial size interacted with a linear time trend, whether firms' market shares vary over time depending on initial size of the firm in a given market. This last term captures the effect of historical commercial presence. The larger the initial commercial presence, the higher the market share over time due for example to learning by doing and to more developed commercial relations. Finally, ρ_{it}, σ_{ci}, and φ_{ct} are respectively firm-year, country-firm, and country-year fixed effects, included in order to control for firm-specific trends, such as changes in management, characteristics of firms in each country, such as the firms' nationality, and country-level shocks, like environmental regulations, taxation or subsidies, which could be correlated with the error term and the regressors of interest. Examples of environmental regulations that country-year fixed effects allow to control for include country-specific fuel economy standards, such as the United States Corporate Average Fuel Economy (CAFE) standards, which incentivise the use of cleaner car by introducing penalties on automakers building inefficient vehicles. At last, ε_{ict} is the error term. Robust standard errors are clustered at the firm-country level.[20]

The suite of fixed effects included allows to control for several unobservable factors, and therefore to decrease endogeneity concerns – arising, for example, because firms with better management could have both a larger share of green innovation and more market share. However, it also implies that the estimation is only able to identify the combined marginal effect of innovation and fuel prices, and not the total effects of innovation or fuel prices.

The use of lagged innovation stocks decreases the concern of reverse causality between economic performance and green innovation. The higher the economic performance of a firm, the more it can invest in green innovation. Research shows that most of the positive effects of energy prices on green innovation tends to occur within five years of the price increases (Popp, 2002[5]; Newell, Jaffe and Stavins, 1999[44]). So, while there could be some concerns with endogeneity for estimations using the first lags of innovation

[18] Where the stock of patents is estimated as indicated in Section 2.1.2.

[19] Clean, grey and dirty patents account for on average 22% of the entire stock of patents. Excluding these patents from the variable all_{it-k} does not change the results.

[20] Additionally clustering standard errors at the firm-year and country-year levels does not change the results, except for marginally increasing coefficients' significance levels.

stocks, this is less likely to be the case the longer the period considered between innovation and price changes.

The main coefficients of interest are α_1, α_2, and α_3. They allow to estimate marginal effects such as the average gain, in percentage points of market share, for firm *i* in year *t* of having accumulated 1 additional percentage point of share of innovation in respectively grey, clean, and dirty technology in the years $t-k$, when fuel prices increase. Accordingly, the gains of different types of innovation are measured relative to other firms, to fuel prices, and to the overall stock of innovation.

2.3 Results

2.3.1 Main results

Table 2.2 and Table 2.3 present the baseline estimation results. Columns (0)-(20) present the estimation of Eq. (1) for shares of stocks of innovation accrued respectively in t to $t-20$.The results show that, when fuel prices increase, the market share of firms that had previously innovated more in clean and grey technologies increases more relative to those that had not made similar investments. Conversely, firms that innovated more in dirty car technologies experience a decrease in their market share when fuel prices increase. More specifically, when fuel prices increase, there is a positive and significant effect of the share of clean patent stock between 7 and 8 years after the stock is accumulated. For grey patents, this effect takes place between 8 and 15 years after and is twice as large. For dirty patents, the effect is negative and takes place between 17 and 18 years after.

That firms innovating more in green car technologies experience an increase in their market share implies that consumers are switching to cleaner vehicles when fuel prices increase. That consumers respond to fuel price increases on the extensive margin is consistent with previous research (Alberini and Horvath, 2021[14]). The findings are also consistent with Grigolon, Reynaert and Verboven (2018[26]) that find that consumers do not undervalue future fuel costs much when making decision about their vehicle purchases. If consumers correctly anticipate fuel prices and base their expectations of future prices on current prices (Anderson, Kellogg and Sallee, 2013[25]), then current prices should affect their choice of vehicle, increasing the importance of maintaining pricing signals over time.

The present analysis finds that the size of the economic benefit for firms innovating in fuel efficient ICE (grey) cars is twice as large as the benefit for firms innovating in electric or hybrid (clean) cars. One potential explanation could be that the factors determining the purchase of a clean (electric or hybrid) car and the purchase of a more fuel-efficient ICE cars differ. Notably, expected fuel cost is likely to be more important for the purchase of a more fuel-efficient ICE car than for the purchase of an electric or hybrid vehicle. Previous research has shown that buyers of cleaner cars do not respond to information on fuel prices in the same fashion as buyers of intermediately-efficient cars (Alberini and Horvath, 2021[14]).For cleaner cars, considerations such as the environmental benefit of cleaner car use (Jensen, Cherchi and Mabit, 2013[45]; Cui et al., 2021[46]; Sobiech-Grabka, Stankowska and Jerzak, 2022[47]) and the availability of charging stations are likely to be more important (Cole et al., 2021[48]). The significantly higher fixed capital cost of cleaner cars implies that disposable income has more important role than expected fuel cost in the purchase of electric and hybrid cars.

In addition, the present analysis finds that the erosion of economic benefits when fuel prices increase across clean and grey technologies takes place at different times. The obsolescence of knowledge might explain the finding that innovating more in fuel efficient technologies more than 15 years before has no statistically significant impact on market share when fuel prices increase. While early knowledge in grey technologies can provide an economic advantage, the knowledge developed very early becomes at some point no longer relevant for the current market. The same logic could apply to clean and dirty technologies. However, the speed of knowledge obsolescence is likely to be different across these technologies, partially explaining the differences in timing found. Notably, the clean car technologies evolved rapidly over the last decades. This is reflected in the number of patent families related to clean cars granted to firms in the estimation sample, which increased by 4% every year between 2003 and 2016.

The present analysis also finds that the time lag between economic benefits and innovation is quite large and varies significantly across clean, grey and dirty technologies. This large gap could be driven both by supply-side and demand-side factors. On the supply side, it could be the result of the time it takes between innovation and commercialisation of products (Gross et al., 2018[27]). Patents are filed by companies to appropriate intellectual property on technologies that at the time may not be fully operational at scale. For example, Dussaux, Es-Sadki and Agnelli (Forthcoming[49]) show that there is a lag of between 4 and 9 years between the increase in cleaner cars patenting and the increase in the share of cleaner cars sold in the United States. This lag is consistent with the findings of this paper. Moreover, this commercialisation lag likely varies between clean, grey and dirty technologies. Since electric and hybrid cars embed more recent technologies than fuel efficient or dirty cars, it would be expected that they require more time to be commercialised. However, the time lag is shorter for cleaner cars. Therefore, other factors are likely to be at play.

On the demand side, two factors could explain the estimated time lags. First, consumers do not immediately react to changes in fuel prices and to changes in the catalogue of cars available to purchase. There is a sunk cost of purchasing a new car and this decision has implications for several years. For example, American households keep their car for around 12 years on average. For cleaner cars, this purchasing decision could be made more rapidly because clean cars exhibit new green attributes that are more visible and therefore more attractive than those of fuel-efficient cars.

The second demand side factor that could explain the estimated time lags is the low salience of the information regarding fuel prices for consumers, delaying its internalisation and therefore weakening or postponing impact on consumption decisions (Alberini, Khymych and Ščasný, 2020[28]; Huse and Koptyug, 2022[29]). While it is not possible to test all the different interpretations of the results presented above, the role of fuel price salience is investigated in Section 3.

Table 2.2. The effect of fuel price changes on market share for various types of past innovation (between 0 and 10 years)

	Dependent variable: Market share of car manufacturer i in country c in year t										
	k = 0	k = 1	k = 2	k = 3	k = 4	k = 5	k = 6	k = 7	k = 8	k = 9	k = 10
Fuel price in country c and year t	-0.037	-0.023	0.02	0.074	0.148	0.201*	0.243*	0.271**	0.263**	0.238*	0.214
× Share of *clean* patent stock of firm i in year $t-k$	(0.155)	(0.147)	(0.132)	(0.116)	(0.109)	(0.116)	(0.126)	(0.127)	(0.129)	(0.132)	(0.138)
Fuel price in country c and year t	-0.459	-0.446	-0.342	-0.157	-0.029	0.093	0.237	0.354	0.455**	0.503**	0.543***
× Share of *grey* patent stock of firm i in year $t-k$	(0.407)	(0.403)	(0.380)	(0.343)	(0.308)	(0.290)	(0.275)	(0.246)	(0.213)	(0.197)	(0.185)
Fuel price in country c and year t	0.113	0.105	0.065	0.008	-0.032	-0.062	-0.09	-0.1	-0.092	-0.083	-0.087
× Share of *dirty* patent stock of firm i in year $t-k$	(0.140)	(0.129)	(0.113)	(0.097)	(0.094)	(0.094)	(0.092)	(0.094)	(0.103)	(0.113)	(0.121)
Fuel price in country c and year t	0.295	-0.002	-0.289	-0.564	-0.818	-0.965	-1.003	-0.966	-0.856	-0.685	-0.534
× Log(stock of all patents of firm i in year $t-k$)	(0.743)	(0.734)	(0.755)	(0.796)	(0.827)	(0.832)	(0.808)	(0.759)	(0.718)	(0.687)	(0.650)
Fuel price in country c and year t	0.011	0.028	0.042	0.053	0.076	0.096	0.105	0.112	0.092	0.078	0.02
× Log(vehicles sold by firm i in country c in 2005)	(0.357)	(0.373)	(0.373)	(0.375)	(0.376)	(0.373)	(0.370)	(0.368)	(0.365)	(0.366)	(0.371)
Time trend in year t	-0.039	-0.040*	-0.040*	-0.041*	-0.042*	-0.042*	-0.042*	-0.043**	-0.043**	-0.043**	-0.045**
× Log(vehicles sold by firm i in country c in 2005)	(0.024)	(0.023)	(0.023)	(0.023)	(0.023)	(0.023)	(0.022)	(0.021)	(0.019)	(0.018)	(0.018)
Constant	19.683**	21.041**	21.747**	22.486**	23.268**	23.555**	23.626**	23.473***	23.148***	22.798***	23.258***
	(9.237)	(8.979)	(9.300)	(9.659)	(9.814)	(9.721)	(9.259)	(8.506)	(7.926)	(7.518)	(7.325)
Observations	1946	2067	2067	2067	2067	2067	2067	2067	2067	2067	2067
Number of firms	123	123	123	123	123	123	123	123	123	123	123
F-statis	0.73	0.72	0.63	0.57	0.70	0.88	1.27	1.95	2.36	2.61	2.98

Note: The dependent variable is the market share of firm i in year t. All estimations include firm-country, country-year, and firm-year fixed effects. Standard errors clustered at the firm-country level are provided in parentheses. Innovation stock shares are the share of accumulated stock of patents of grey, clean, and dirty technologies over the total stock of patents of a given firm. Results from estimating Eq. (1) for lags of innovation between 0 and 10 years.

Table 2.3. The effect of fuel price changes on market share for various types of past innovation (between 11 and 20 years)

	Dependent variable: Market share of car manufacturer i in country c in year t									
	k = 11	k = 12	k = 13	k = 14	k = 15	k = 16	k = 17	k = 18	k = 19	k = 20
Fuel price in country c and year t	0.194	0.183	0.154	0.13	0.098	0.08	0.06	0.018	-0.087	-0.23
× Share of *clean* patent stock of firm i in year $t-k$	(0.145)	(0.153)	(0.160)	(0.160)	(0.156)	(0.163)	(0.180)	(0.191)	(0.204)	(0.247)
Fuel price in country c and year t	0.570***	0.590***	0.564***	0.492**	0.423**	0.361*	0.291	0.208	0.081	-0.013
× Share of *grey* patent stock of firm i in year $t-k$	(0.184)	(0.188)	(0.193)	(0.198)	(0.201)	(0.211)	(0.215)	(0.211)	(0.210)	(0.208)
Fuel price in country c and year t	-0.145	-0.206	-0.224	-0.22	-0.205*	-0.200*	-0.203**	-0.187**	-0.144	-0.114
× Share of *dirty* patent stock of firm i in year $t-k$	(0.132)	(0.140)	(0.149)	(0.141)	(0.122)	(0.106)	(0.098)	(0.091)	(0.088)	(0.086)
Fuel price in country c and year t	-0.321	-0.168	-0.044	-0.034	-0.026	-0.02	0.058	0.118	0.102	0.093
× Log(stock of all patents of firm i in year $t-k$)	(0.581)	(0.540)	(0.525)	(0.489)	(0.416)	(0.322)	(0.269)	(0.236)	(0.209)	(0.192)
Fuel price in country c and year t	-0.046	-0.061	-0.064	-0.046	-0.023	-0.003	-0.023	-0.038	-0.031	-0.032
× Log(vehicles sold by firm i in country c in 2005)	(0.394)	(0.418)	(0.438)	(0.445)	(0.439)	(0.431)	(0.429)	(0.428)	(0.423)	(0.424)
Time trend in year t	-0.048**	-0.051**	-0.052**	-0.052**	-0.051**	-0.050**	-0.049**	-0.048**	-0.046**	-0.045**
× Log(vehicles sold by firm i in country c in 2005)	(0.019)	(0.020)	(0.021)	(0.021)	(0.021)	(0.021)	(0.022)	(0.021)	(0.021)	(0.021)
Constant	24.410***	25.243***	25.563***	25.439***	25.363***	24.998***	24.665***	24.151***	23.530***	23.407***
	(7.680)	(7.961)	(8.112)	(8.051)	(7.967)	(7.879)	(7.865)	(7.826)	(7.786)	(7.714)
Observations	2067	2067	2067	2067	2067	2067	2067	2067	2067	2067
Number of firms	123	123	123	123	123	123	123	123	123	123
F-statis	2.79	2.55	2.25	1.90	1.69	1.64	1.54	1.45	1.25	1.20

Note: The dependent variable is the market share of firm i in year t. All estimations include firm-country, country-year, and firm-year fixed effects. Standard errors clustered at the firm-country level are provided in parentheses. Innovation stock shares are the share of accumulated stock of patents of grey, clean, and dirty technologies over the total stock of patents of a given firm. Results from estimating Eq. (1) for lags of innovation between 11 and 20 years.

2.3.2 Magnitude

The estimated effect reported in Table 2.2 and Table 2.3 are not straightforward to interpret. Therefore, the marginal effects of past investment in clean and grey technology on a firm's market share when fuel prices increase are presented in this section to better illustrate the magnitude of the estimated effects.

Panel A of Figure 2.7 illustrates the estimated marginal effects of past investment in clean technology on a firm's market share throughout the years at the median fuel price level. The average effect is maximum after 7 years of accruing clean patent stock. An increase in the share of clean patent stock of 1 percentage point (pp) is associated with a 0.13 pp increase in market share 7 years later at the median fuel price level. Panel B of Figure 2.7 illustrates the estimated marginal effects of past investment in grey technology on a firm's market share throughout the years at the median fuel price level. The average effect is maximum after 12 years of accruing grey patent stock. An increase in the share of grey patent stock of 1 pp is associated with a 0.28 pp increase in market share 12 years later at the median fuel price level.

Figure 2.8 illustrates how the marginal effects of a 1 pp increase in the share of clean and grey patent stocks 8 years before vary with fuel prices.[21] The marginal effects for clean and grey are respectfully equal to 0.06 and 0.10 for the 20th percentile of fuel price. For the 80th percentile, the marginal effects for clean and grey are respectfully equal to 0.15 and 0.26.

To better illustrate the economic magnitude of these effects, the marginal effect of a movement from the median share of clean patent stock (8.6%) to the 75th percentile share (12%) at median fuel prices on market share is estimated. This movement is associated with an increase of 0.37 pp in market share 8 years later. This corresponds to a 14% increase from the median market share. Similarly, going from the median share of grey patent stock (2.5%) to the 75th percentile share (3.6%) at median fuel prices is associated 8 years later with an increase of 0.21 pp (8% increase from the median) in market share is associated with an increase of 0.21 pp (8% increase from the median) in market share 8 years later.

Finally, it is useful to look at the effects of an increase in fuel prices on market share for various percentiles of share of clean and grey patents stocks. Panel A of Figure 2.9 shows the marginal gain in market shares following a 25-cent per litre increase in fuel prices by percentiles of share of clean patent stocks 8 years before.[22] This increase in fuel prices leads to a 0.2 pp gain in market share for firms at the 10th percentile (5 % of their patent stock is clean) while the same increase leads to a 0.45 pp gain in market share for firms at the 75th percentiles (12% of their patent stock is clean). Panel B of Figure 2.9 shows the marginal gain in market shares following a 25-cent per litre increase in fuel prices by percentiles of share of grey patent stocks 12 years before.[23] This increase in fuel prices leads to a 0.17 pp gain in market share for firms at the 10th percentile (2 % of their patent stock is grey) while the same increase leads to a 0.32 pp gain in market share for firms at the 75th percentiles (4% of their patent stock is grey).

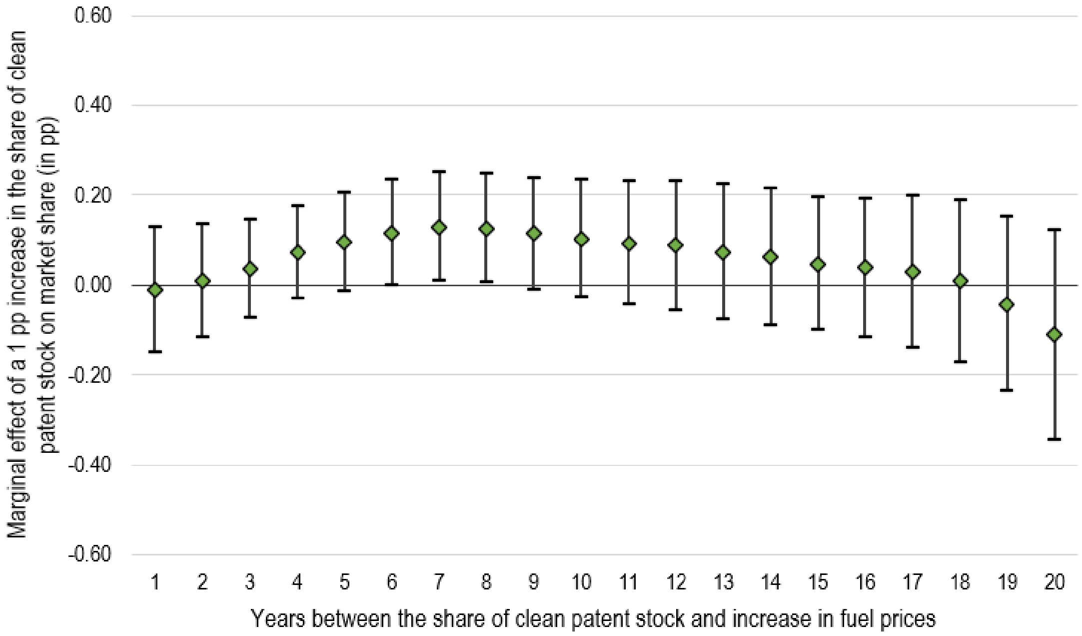
[21] Marginal effects are computed for an 8-year lag because both clean and grey innovation has a positive and statistically significant effect on market share 8 years later.

[22] This 25-cent increase starts from the median fuel price in 2021 equal to USD 1.62 per litre. The 25-cent increase was chosen because it is a realistic increase that is economically meaningful to car drivers. 20 cents or 30 cents could have also been used. The 8-year lag corresponds to the maximum effect estimated for the share of clean patent stock.

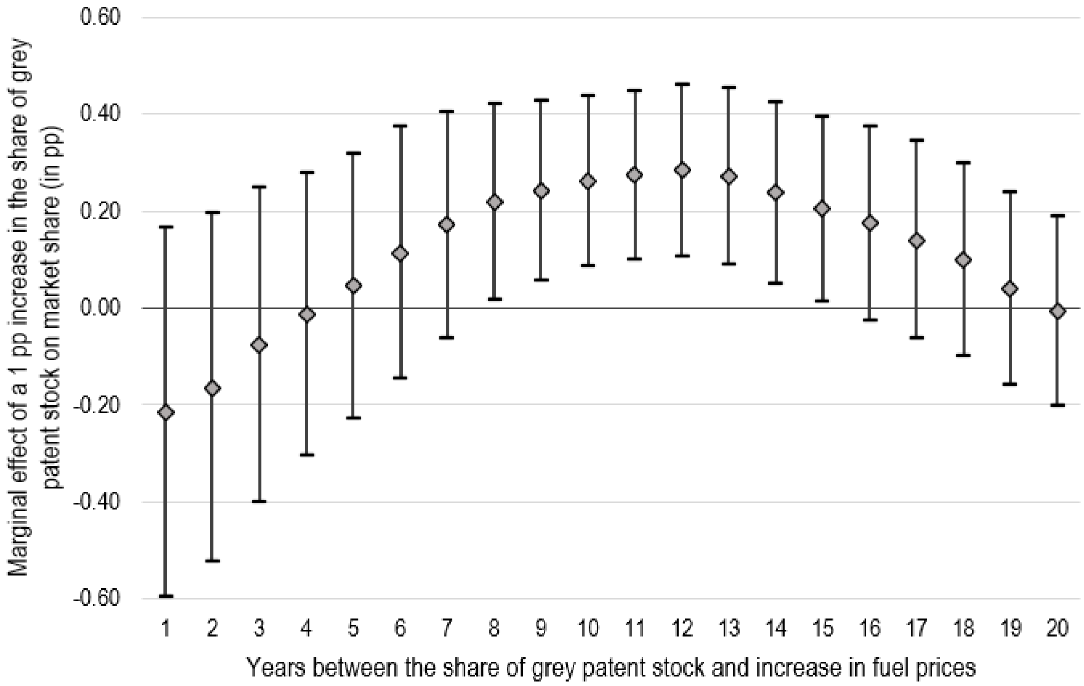
[23] 12 years lag corresponds to the maximum effect estimated for the share of grey patent stock.

Figure 2.7. Marginal effect of past innovation on firm market share for median fuel prices across years

Panel A. Effects of innovating in electric and hybrid (clean) car technologies



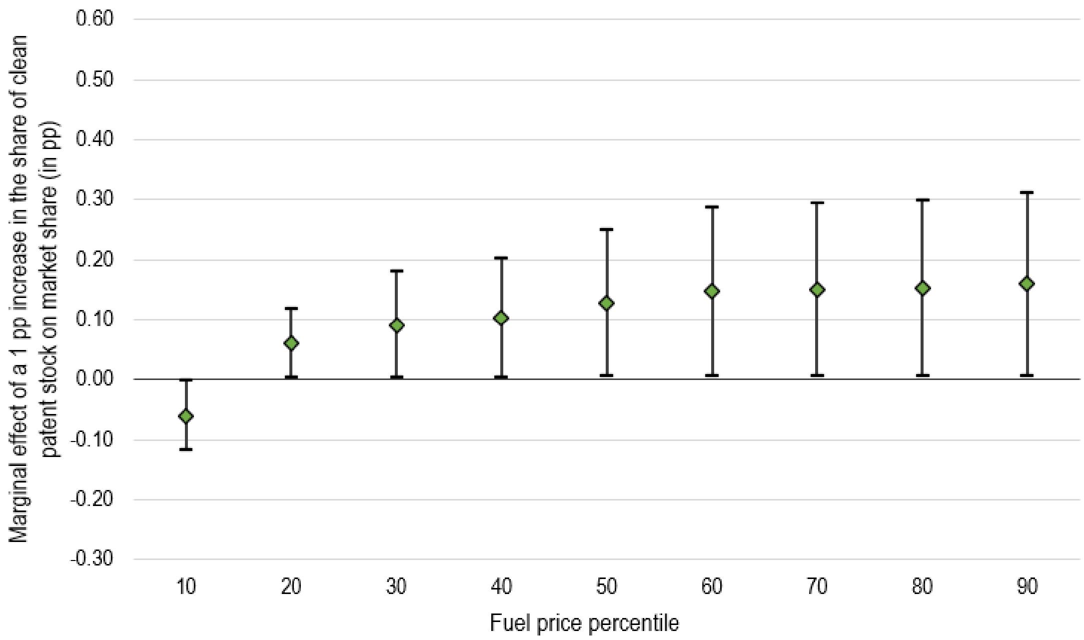
Panel B. Effects of innovating in fuel efficient (grey) car technologies



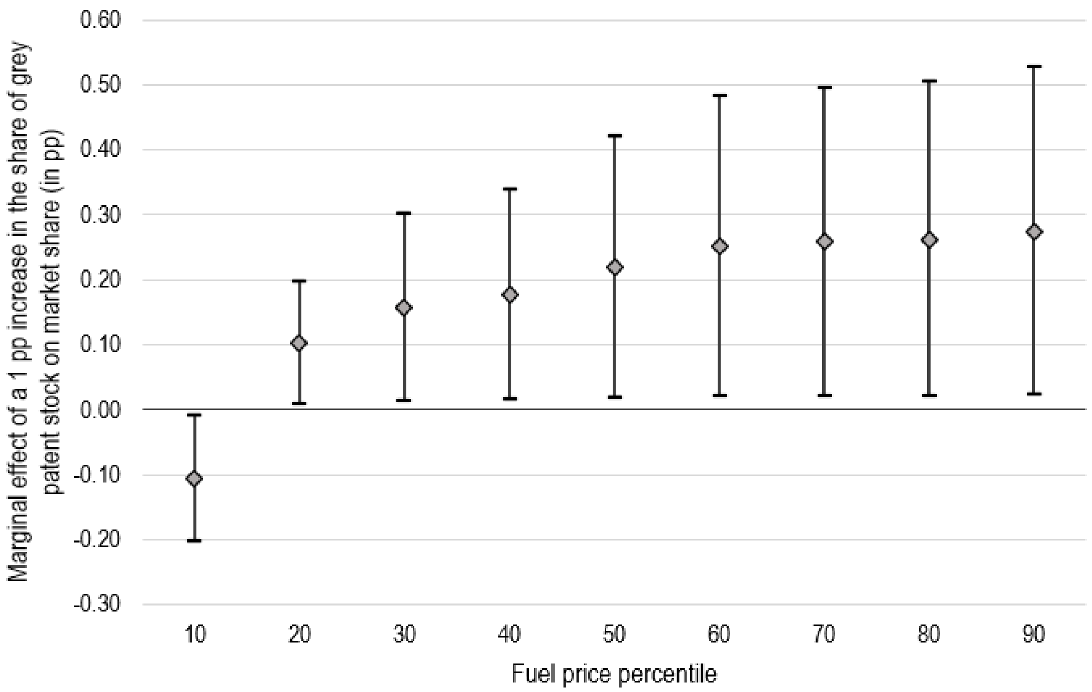
Note: Marginal effects estimated by eq. (1). Panel A and B illustrates the marginal effect (in percentage points of market share) of a 1 percentage point (pp) increase in the stock of clean and grey patents (as a share of total firm patent stocks) on market share (in percentage points) for years 1-20 after the stock is accumulated assuming the median fuel price in the sample in 2021. Points represent marginal effects and the vertical bars represent 95% confidence intervals.

Figure 2.8. Marginal effect on firm market share after 8 years by percentiles of fuel prices

Panel A. Effects of innovating in electric and hybrid (clean) car technologies



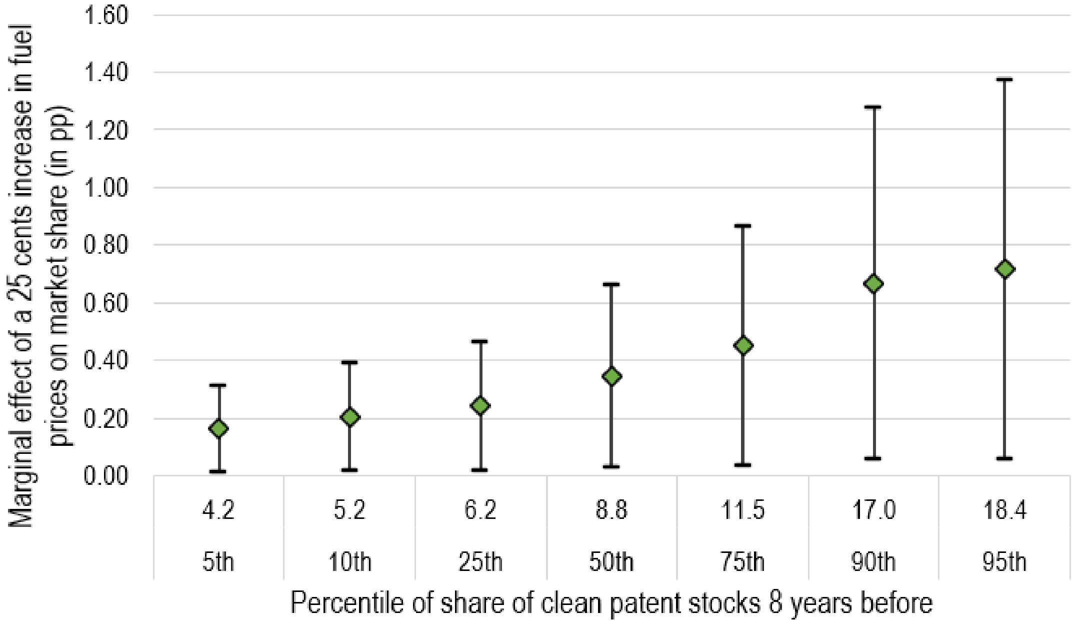
Panel B. Effects of innovating in fuel efficient (grey) car technologies



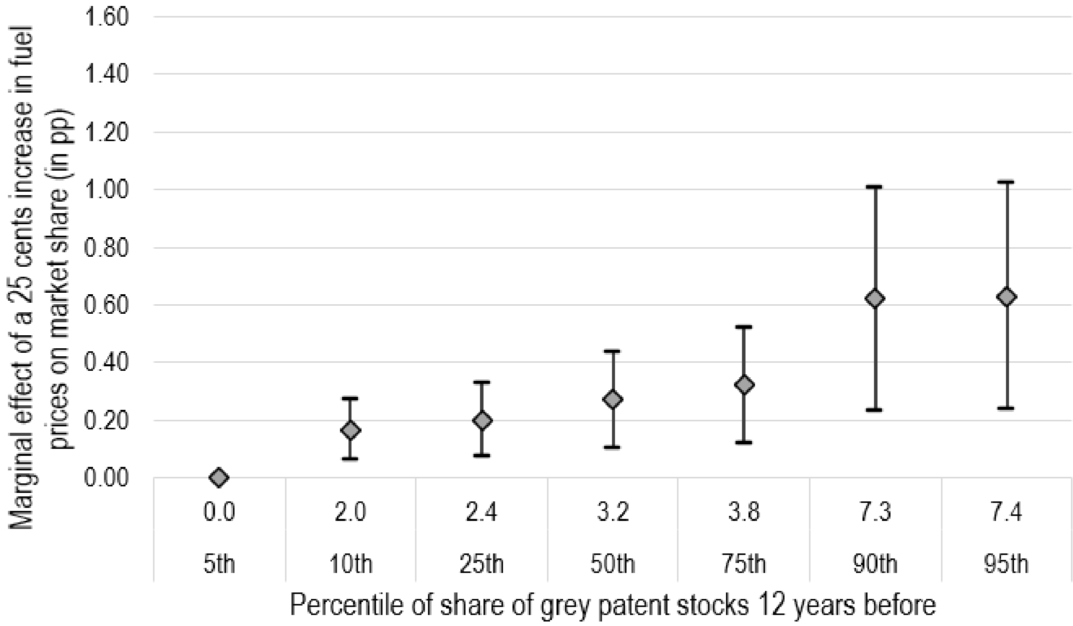
Note: Marginal effects estimated by eq. (1). Panel A and B illustrate the marginal effect of a 1 percentage point (pp) increase in the stock of clean and grey patents (as a share of total firm patent stock) on market share (in pp) 8 years after the stock is accrued at different percentiles of fuel prices in the sample. Points represent marginal effects and the vertical bars represent 95% confidence intervals.

Figure 2.9. Effects of a 25-cent increase in fuel prices by percentile of share of clean and grey patent stocks

Panel A: Effects of innovating in electric and hybrid (clean) car technologies



Panel B. Effects of innovating in fuel efficient (grey) car technologies



Note: Marginal effects estimated by eq. (1). Panel A and B illustrate the marginal effect of a 25-cent per litre increase in fuel prices (from the median value in 2021) on market share (in pp) by percentile of share of clean and grey patent stock. Points represent marginal effects and the vertical bars represent 95% confidence intervals. Numbers above the percentile bin are the share of grey patent stocks (in pp) corresponding to that percentile.

2.3.3 Robustness

The baseline estimation presented above is robust to various robustness checks. First, the main results are robust to changes in the list of control variables. Columns (1)-(7) of Table B.2 in Annex B show the estimation results for k = 8, which corresponds to the lag where the economic benefits of clean innovation are at their maximum. Column (1) of Table B.2 provides the baseline estimation results for comparison. Columns (2)-(7) of Table B.2 in Annex B show the estimation when one regressor at a time is removed from the baseline specification. The estimated coefficients for the interaction between fuel prices and share of clean patent stock are highly similar to the baseline estimate regardless of the removed control. The only exception is for column (4) where the interaction between fuel prices and the share of grey patent stock is omitted. In that case, the coefficient is similar, but it is not possible to reject the null hypothesis that past clean innovation has no statistically significant effect on market share when interacted with fuel prices.

Columns (8)-(14) in Table B.2 in Annex B show the estimation results for k = 12, which corresponds to the lag where the economics benefits of grey innovation are at their maximum. Column (8) of Table B.2 provides the baseline estimation results for comparison. The estimated coefficients for the interaction between fuel prices and share of grey patent stock when one control is removed are highly similar to the baseline estimate. It is smallest when the time trend interacted with the pre-sample volume of cars sold is removed from the controls.

Additionally, the analysis is repeated for stocks of innovation estimated under alternative depreciation rates, namely 10% and 20% that have been used in previous studies (Aghion et al., 2016[2]; Peri, 2005[42]). The results for the main variables of interest are presented in Table B.3 and Table B.4 in Annex B and show that the results are largely maintained. A depreciation rate of 10% leads to a slight increase (around 20% on average) in the effects of investing in clean, grey and dirty car technology when prices increase. Conversely, a depreciation rate of 20% leads to a slight decrease (around 20% on average) in the effects of investing in clean, grey and dirty car technology when prices increase. The timing of the effects is the same as the baseline in all cases.

Finally, the role of fuel tax in the estimated baseline results is investigated in Table B.5 of Annex B. When fuel prices are replaced by fuel taxes in eq. (1), the signs, statistical significance and timing of the effects of past innovation on market share are similar to the baseline. The size of the coefficients differs because the scale of the regressors is not the same. However, the proportion of the effects across types of technologies is maintained. Figure B.1 of Annex B provides the marginal effects of a 25-cent per litre in fuel taxes on market shares by percentile of share of clean and grey patent stock.[24] Similar to the baseline, being an early leader in clean technologies brings economic benefits when fuel taxes increase. However, the effects of a 25-cent per litre increase in fuel taxes is lower than the effects of a 25-cent per litre increase in fuel prices (including tax). When comparing to Figure 2.9, it is found that fuel taxes explain 75% to 81% of the effect of fuel prices (including tax).

[24] This 25-cent increase starts from the median fuel tax in 2021 equal to USD 0.86 per litre.

3 Empirical analysis of the role of fuel price salience

The paper finds that there is a large time lag between economic benefits and innovation in clean and grey car technologies under rising fuel prices. The previous section suggests that various supply and demand-side factors could explain that these gaps. While most of the hypotheses related to these factors cannot be tested, this section investigates the role of salience of fuels prices on the timing and size of returns to green innovation.

Salience is defined here as the amount of attention paid to fuel prices, particularly by consumers. For example, consumers' response to residential energy prices has been found to depend on the salience of prices (Alberini, Khymych and Ščasný, 2020[28]). If firms' private returns to innovation depend on pricing signals as well as their salience, then policy support to green innovation should be complemented by policy interventions that take into account the salience of prices.[25] To assess the role of salience of fuel prices in generating economic benefits of innovation, the analysis evaluates how the response of market shares of early innovators to fuel prices varies depending on the level of attention consumers pay to these prices.

3.1 Google Trends Data

Google Trends provides information on the volume of searches for given terms for all countries where the Google search engine is used between 2004 and the present. A large body of research has used this information to estimate a range of socioeconomic indicators, such as private demand [e.g. and Woo and Owen (2019[50])], unemployment [e.g. Maas (2020[51])], GDP [e.g. Woloszko (2020[52])], demand for financial information [e.g. Aouadi, Arouri and Roubaud (2018[53])], or investors' attitudes [e.g. Amstad et al. (2020[54])].

The information provided by Google Trends has also been used to measure the salience of issues, particularly in hard to survey population [e.g. Chykina and Crabtree (2018[55])]. Mellon (2013[30]) finds that Google Trends data provide a good measure of the salience of fuel prices in the United States between 2004-2010. This study uses Google Trends to proxy the salience of fuel prices in the analysis. This information provides a country-specific measure of the relative attention and interest consumers pay to fuel prices.

However, using information from Google Trends has its limitations. For instance, its suitability for assessing characteristics of the entire population depends on everyone having access to the internet, as well as using Google as their search engine. Figure A.1 in Annex A shows that while the percentage of people using the Internet has increased in the period of analysis, it has only been over 50% in all countries since 2010. This indicates that, while Google Trends might provide a measure of salience, its generalisation to the entire population should be done with caution particularly in early years. Figure A.2, in turn, shows the percentage of people using Google as a search engine in the last decades across countries in our sample. For the

[25] This could be particularly relevant when price changes are small. When fuel prices are already very high, governments may be under pressure to provide subsidies or another form of relief.

European countries, this percentage is always above 90%, while for the United States and Japan it is lower but still a clear majority.

The analysis uses the Google Trends *term search* for a variation of the words “fuel” and “price”, which provides a measure of the intensity of searches for any queries that include both words in any order and mixed with any other words.[26] For each country, a consultation with native speakers was conducted to understand the most commonly used words when searching for information on fuel prices. The words chosen also minimised the zero or undefined values on the Google Trends indicator.[27] Table 3.1 displays the terms chosen for each country.

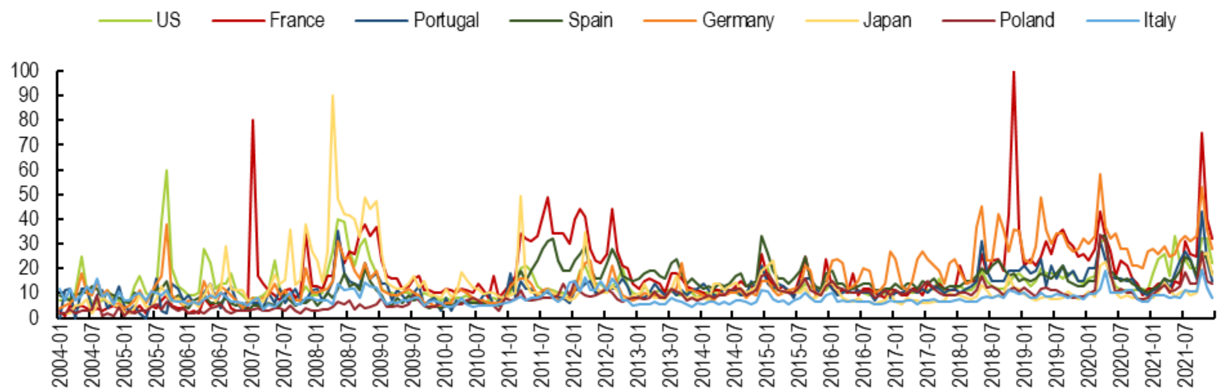
Table 3.1. Google Trends terms of search

United States	Japan	Portugal	Spain	Italy	France	Poland	Germany
gas price	ガソリン価格	preço gasolina	precio gasolina	prezzo benzina	prix carburant	cena paliwa	benzinpreis

Note: For Japan, we also use ディーゼル価格 without an effect on results.

Google Trends provides monthly indices of search volumes for a given geographical location. It provides information on a normalised scale for terms in the same query, which is capped at five search terms or five countries. A repeated search query was used (e.g. “gas” “price” for the United States) to re-scale the second search query and render the indicators comparable between countries. Therefore, the resulting indicator is a measure of relative salience, valuable for comparisons within countries throughout time and between countries, but not in absolute terms. Figure 3.1 presents the resulting indicator for all countries.

Figure 3.1. Google Trends monthly indicator of salience of automobile fuel prices, 2004-2021



Note: The Google Trends indicator measures the relative frequency with which there were Google searches for the terms “fuel” and “price” across countries and over time.
Source: Authors based on data from Google Trends

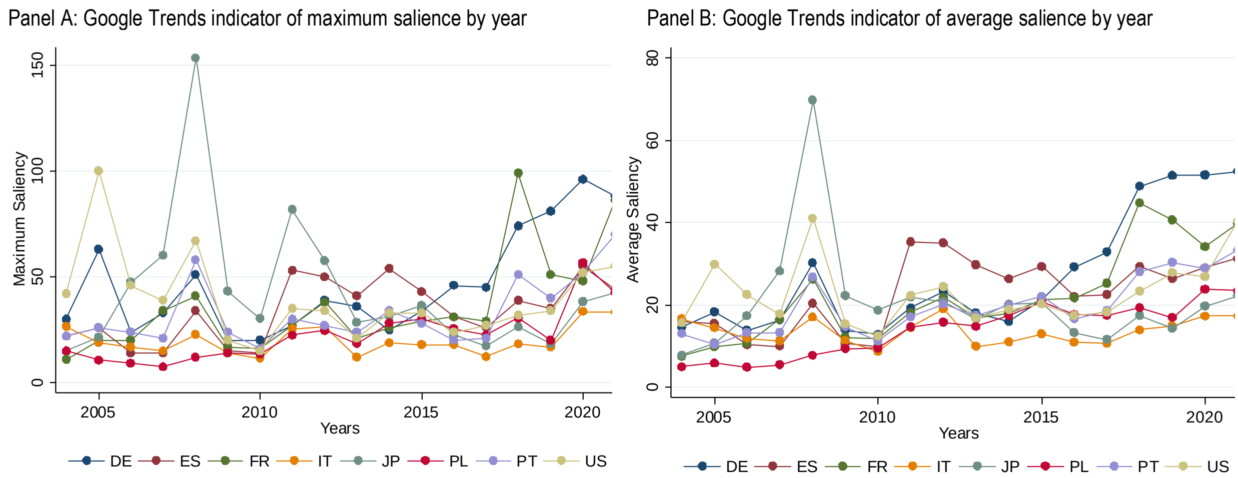
From the monthly data, two yearly indicators were constructed. The first uses the maximum value of the indicator in each year, and the second uses the average of the monthly values of each year. These indicators have an overall correlation of 0.9, varying between 0.94 for Japan and 0.7 for the United States. Figure 3.2 depicts these two indicators for each country. Given that spikes in attention might be more

26 For example, someone searching for “gasoline and diesel price” would show up in our indicator for “gasoline” and “price”, as well as someone searching “prix du carburant” would show up in our indicator for “prix” and “carburant”.

27 When the number of searches is too small, Google Trends assigns them “<1” or “0”, which then does not allow us to re-scale other values.

important for purchasing decisions than the average attention consumers pay to prices, the analysis focuses on results using the estimator of maximum salience. Results using the indicator of average salience are not qualitatively different (see Section 3.4).

Figure 3.2. Yearly indicators of salience of fuel prices



Note: Panel A presents a yearly indicator calculated as the maximum of the monthly indicator for each country-year and Panel B presents a yearly indicator calculated as the average of the monthly indicator for each country year. The correlation between these is 0.9.
Source: Authors based on data from Google Trends.

A final concern when using Google Trends indicators to measure salience of prices is that they might be capturing increases in prices, because people are more interested in fuel prices when they increase. In this case, including them in the analysis could lead to multicollinearity issues making hypothesis testing more complicated. However, the correlation coefficient between fuel prices and our Google Trends indicators overall equals 0.06 (for the maximum indicator) and -0.02 (for the average indicator), with the coefficient by country varying between -0.16 (Poland) and 0.55 (Spain) for the indicator of maximum salience. Similarly, the correlation coefficient between the Google Trends indicators and changes in prices is of 0.16 (for the maximum) and 0.09 (for the average), varying between -0.21 (Poland) to 0.45 (Japan) for the indicator of maximum salience. Figure A.3 in Annex A shows the evolution, for each country, of the Google Trends indicator of maximum salience and fuel prices (Panel A) and fuel price changes (Panel B).

3.2 Empirical specification

The following equation is estimated to understand the impacts of salience:

$$mkt\ share_{ict} = \alpha_1 fuel_{ct} \times grey_{it-k} + \alpha_2 fuel_{ct} \times clean_{it-k} + \alpha_3 fuel_{ct} \times dirty_{it-k} + \alpha_4 fuel_{ct} \times \ln(all_{it-k}) + \gamma_1 fuel_{ct} \times grey_{it-k} \times google_{ct} + \gamma_2 fuel_{ct} \times clean_{it-k} \times google_{ct} + \gamma_3 fuel_{ct} \times dirty_{it-k} \times google_{ct} + \beta_1 fuel_{ct} \times initial_{ic} + \beta_2 trend_t \times initial_{ic} + \rho_{it} + \sigma_{ci} + \varphi_{ct} + \varepsilon_{ict}$$

$$k = \{0, \ldots, 20\} \qquad (2)$$

where $google_{ct}$ is the value of the google trends indicator in country c in year t, calculated as the annual maximum of the monthly google trends indicator.[28] As before, $mkt\ share_{ict}$ is the market share of car manufacturer i in country c in year t, $fuel_{ct}$ is the log of the tax-inclusive fuel prices in country c year t, and $grey_{it-k}$, $clean_{it-k}$ and $dirty_{it-k}$ are respectively the grey, clean, and dirty stock of patents as a share of total patents accumulated by firm i in year $t-k$, where $k = \{1, \ldots, 20\}$, while all_{it-k} is the log of stock of all patents accumulated by firm i in year $t-k$. Finally, $initial_{ic}$ is the log of the number of vehicles sold by firm i in country c in 2005, ρ_{it}, σ_{ci}, and φ_{ct} are respectively firm-year, country-firm, and country-year fixed effects and ε_{ict} is the error term.

The main coefficients of interest are γ_1, γ_2 and γ_3. They measure how the salience of fuel prices affects the relationship between market share, fuel prices, and innovative stock share of, respectively, grey, clean, and dirty technologies. If consumers paying more attention to fuel prices enhances the positive relationship between emission-decreasing innovation and market shares when prices increase, then we would expect a positive coefficient of γ_1 and γ_2.

3.3 Results

Table 3.2 and Table 3.3 show the results of the estimation of eq. (2). First, the estimated coefficients for the interaction between fuel prices and past share of patent stocks are highly similar to those estimated in eq. (1) reported in Table 2.2 and Table 2.3. Second, the salience of fuel prices captured by Google Trends has a statistically significant effect for past innovation in grey car technologies but not for past innovation in clean and dirty car technologies. More specifically, the effect of fuel prices salience on market share when fuel prices increase is positive and statistically significant for grey innovation stocks accrued between 3 and 9 years prior. In other words, salient fuel prices accelerate the obtainment of economic benefits of investing in grey car technologies. This effect reaches its maximum level for a lag of 7 years.

[28] The results are similar when using the average of the monthly indicator, and are presented in Annex B.

Table 3.2. Effects of fuel price changes on market share by types of past innovation (0 to 10 years ago) as a function of fuel price salience

	Dependent variable: Market share of car manufacturer i in country c in year t										
	k = 0	k = 1	k = 2	k = 3	k = 4	k = 5	k = 6	k = 7	k = 8	k = 9	k = 10
Fuel price in country c and year t	-0.048	-0.021	0.029	0.090	0.166	0.218*	0.264**	0.299**	0.290**	0.257*	0.227
× Share of *clean* patent stock of firm i in year $t-k$	(0.158)	(0.151)	(0.136)	(0.123)	(0.117)	(0.122)	(0.127)	(0.126)	(0.128)	(0.133)	(0.141)
Fuel price in country c and year t	0.000	0.000	0.000	0.000	-0.001	-0.001	-0.001	-0.001	-0.001	0.000	0.000
× Share of *clean* patent stock of firm i in year $t-k$	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
× google trend (max) in country c and year t											
Fuel price in country c and year t	-0.563	-0.579	-0.503	-0.358	-0.272	-0.176	-0.057	0.059	0.186	0.283	0.366*
× Share of *grey* patent stock of firm i in year $t-k$	(0.409)	(0.408)	(0.386)	(0.348)	(0.321)	(0.307)	(0.287)	(0.254)	(0.228)	(0.220)	(0.214)
Fuel price in country c and year t	0.003	0.004	0.005*	0.006**	0.007**	0.007***	0.008***	0.008***	0.007***	0.006**	0.004*
× Share of *grey* patent stock of firm i in year $t-k$	(0.002)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
× google trend (max) in country c and year t											
Fuel price in country c and year t	0.079	0.085	0.050	-0.001	-0.033	-0.057	-0.076	-0.086	-0.080	-0.070	-0.082
× Share of *dirty* patent stock of firm i in year $t-k$	(0.140)	(0.131)	(0.115)	(0.102)	(0.100)	(0.100)	(0.098)	(0.098)	(0.107)	(0.116)	(0.127)
Fuel price in country c and year t	0.001	0.000	0.000	0.000	0.000	0.000	-0.001	0.000	0.000	0.000	0.000
× Share of *dirty* patent stock of firm i in year $t-k$	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
× google trend (max) in country c and year t											
Fuel price in country c and year t	0.326	-0.014	-0.320	-0.601	-0.863	-1.010	-1.047	-0.998	-0.886	-0.705	-0.558
× Log(stock of all patents of firm i in year $t-k$)	(0.739)	(0.735)	(0.758)	(0.797)	(0.826)	(0.826)	(0.792)	(0.738)	(0.706)	(0.686)	(0.662)
Fuel price in country c and year t	0.027	0.049	0.068	0.082	0.101	0.113	0.100	0.098	0.079	0.078	0.014
× Log(vehicles sold by firm i in country c in 2005)	(0.358)	(0.373)	(0.373)	(0.374)	(0.373)	(0.371)	(0.368)	(0.366)	(0.364)	(0.364)	(0.368)
Time trend in year t	-0.040	-0.041*	-0.041*	-0.041*	-0.042*	-0.043*	-0.044**	-0.045**	-0.045**	-0.044**	-0.046**
× Log(vehicles sold by firm i in country c in 2005)	(0.024)	(0.023)	(0.023)	(0.024)	(0.024)	(0.023)	(0.022)	(0.020)	(0.019)	(0.019)	(0.018)
Constant	19.880**	21.285**	22.038**	22.798**	23.679**	24.121**	24.531***	24.485***	24.073***	23.358***	23.737***
	(9.314)	(9.091)	(9.412)	(9.727)	(9.820)	(9.672)	(9.143)	(8.422)	(7.932)	(7.578)	(7.441)
Observations	1946	2067	2067	2067	2067	2067	2067	2067	2067	2067	2067
Number of firms	123	123	123	123	123	123	123	123	123	123	123
F-stat	0.7	0.6	0.7	0.9	1.3	1.6	2.2	2.8	2.8	2.6	2.4

Note: All estimations include firm-country, country-year, and firm-year fixed effects. Standard errors clustered at the firm-country level. Innovation stock shares are the share of accumulated stock of patents of grey, clean, and dirty technologies over the total stock of patents of a given firm. Results from estimating Eq. (2) for lags of innovation between 0 and 10 years.

Table 3.3. Effects of fuel price changes on market share by types of past innovation (11 to 20 years ago) as a function of fuel price salience

	Dependent variable: Market share of car manufacturer i in country c in year t									
	k = 11	k = 12	k = 13	k = 14	k = 15	k = 16	k = 17	k = 18	k = 19	k = 20
Fuel price in country c and year t	0.214	0.218	0.204	0.202	0.179	0.162	0.140	0.103	0.013	-0.080
× Share of *clean* patent stock of firm i in year $t-k$	(0.149)	(0.159)	(0.171)	(0.173)	(0.171)	(0.188)	(0.212)	(0.235)	(0.260)	(0.309)
Fuel price in country c and year t	0.000	-0.001	-0.001	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.003
× Share of *clean* patent stock of firm i in year $t-k$	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)	(0.003)	(0.004)
× google trend (max) in country c and year t										
Fuel price in country c and year t	0.449**	0.515**	0.510**	0.450*	0.370	0.285	0.201	0.102	-0.032	-0.136
× Share of *grey* patent stock of firm i in year $t-k$	(0.212)	(0.210)	(0.223)	(0.231)	(0.236)	(0.245)	(0.249)	(0.239)	(0.234)	(0.218)
Fuel price in country c and year t	0.003	0.002	0.002	0.001	0.002	0.002	0.002	0.003*	0.004**	0.004***
× Share of *grey* patent stock of firm i in year $t-k$	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.001)
× google trend (max) in country c and year t										
Fuel price in country c and year t	-0.151	-0.223	-0.246	-0.245	-0.231*	-0.219*	-0.216*	-0.199**	-0.154*	-0.126
× Share of *dirty* patent stock of firm i in year $t-k$	(0.143)	(0.155)	(0.166)	(0.158)	(0.139)	(0.120)	(0.111)	(0.101)	(0.092)	(0.087)
Fuel price in country c and year t	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.000
× Share of *dirty* patent stock of firm i in year $t-k$	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
× google trend (max) in country c and year t										
Fuel price in country c and year t	-0.350	-0.188	-0.057	-0.048	-0.033	-0.030	0.037	0.105	0.085	0.077
× Log(stock of all patents of firm i in year $t-k$)	(0.602)	(0.552)	(0.528)	(0.486)	(0.408)	(0.315)	(0.260)	(0.230)	(0.204)	(0.186)
Fuel price in country c and year t	-0.054	-0.070	-0.073	-0.059	-0.037	-0.018	-0.036	-0.052	-0.045	-0.044
× Log(vehicles sold by firm i in country c in 2005)	(0.390)	(0.415)	(0.436)	(0.443)	(0.437)	(0.429)	(0.427)	(0.426)	(0.421)	(0.421)
Time trend in year t	-0.049**	-0.052**	-0.053**	-0.053**	-0.053**	-0.052**	-0.051**	-0.050**	-0.048**	-0.048**
× Log(vehicles sold by firm i in country c in 2005)	(0.019)	(0.020)	(0.021)	(0.022)	(0.022)	(0.022)	(0.022)	(0.022)	(0.021)	(0.021)
Constant	24.847***	25.694***	26.010***	26.005***	26.026***	25.697***	25.403***	25.026***	24.505***	24.409***
	(7.847)	(8.148)	(8.316)	(8.291)	(8.218)	(8.090)	(8.044)	(7.953)	(7.838)	(7.743)
Observations	2067	2067	2067	2067	2067	2067	2067	2067	2067	2067
Number of firms	123	123	123	123	123	123	123	123	123	123
F-stat	2.0	1.7	1.5	1.4	1.2	1.3	1.3	1.4	1.5	1.7

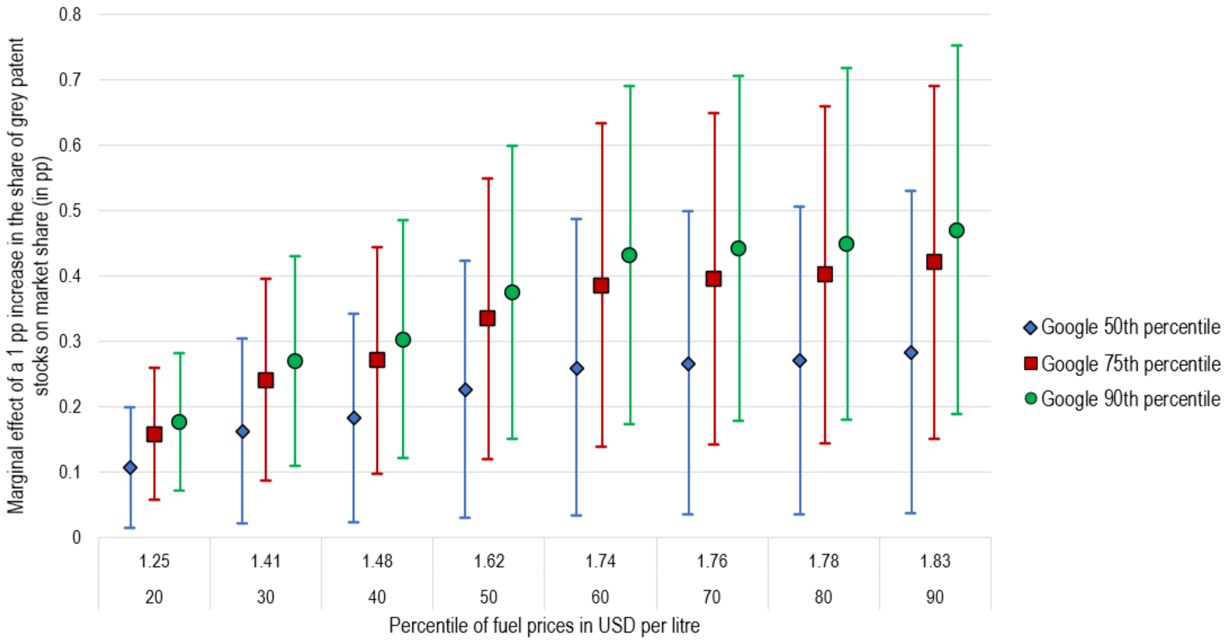
Note: All estimations include firm-country, country-year, and firm-year fixed effects. Standard errors clustered at the firm-country level. Innovation stock shares are the share of accumulated stock of patents of grey, clean, and dirty technologies over the total stock of patents of a given firm. Results from estimating Eq. (2) for lags of innovation between 11 and 20 years.

These results support the hypothesis mentioned in Section 2.3 that fuel prices constitute a more important driver for the adoption of fuel-efficient cars than for the adoption of clean or dirty cars. This is consistent with research that finds that buyers of the cleanest vehicles process new information on prices in a different manner than buyers of average fuel-efficient cars (Alberini and Horvath, 2021[14]).

Figure 3.3 illustrates the magnitude of the effect of the salience of fuel prices on the economic benefits of innovating in fuel efficient car technologies 7 years before when fuel prices increase. The figure shows the economic gains in terms of market share percentage points of increasing the share of grey patent stock by 1 pp by percentiles of fuel prices for three different levels of salience. At the 20th percentile of fuel prices, increasing salience from the 50th percentile to the 75th percentile increases the economic benefits of grey innovation by 0.05 pp. At the 80th percentile of fuels prices, the difference is greater and equal to 0.13 pp. This is not surprising. The higher the salience, the more the magnitude of the fuel price level is incorporated by consumers in their car purchase decision.

Figure 3.3. The more attention to fuel prices is paid, the larger the positive effect of grey innovation on market shares as fuel prices increase

Marginal effects on market share of a percentage point increase in the share of grey innovation by decile of fuel prices for different levels of maximum attention (7 years after stock is accrued)



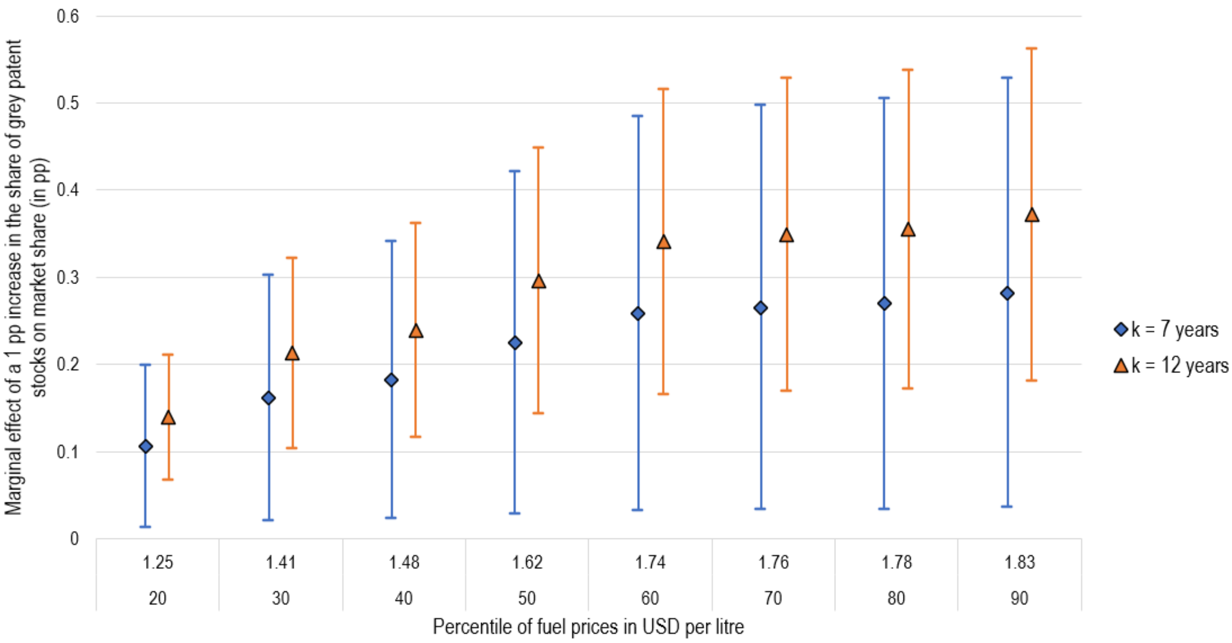
Note: Marginal effects estimated through Equation (2). The figure illustrates the marginal effect of a 1 percentage point (pp) increase in the share of fuel-efficiency (grey) patent stocks on market share (in percentage points) 7 years after the stock is accrued at different percentiles of fuel prices in the sample. It is represented for different levels of salience of fuel prices (namely, the median, the 75th and the 90th percentile of salience in the sample). Points represent marginal effects and the vertical bars represent 90% confidence intervals. Numbers above the percentile bin are the fuel price in USD/litre corresponding to that percentile.

High fuel prices salience accelerates the economic returns of innovating in fuel efficient car technologies. However, the economic returns of innovating in these technologies 12 years before is higher than the economic returns of innovating in the same technologies 7 years before even after fuel price salience has been accounted for. Figure 3.4 shows the economic gains of increasing the share of grey patent stock 7 and 12 years before by 1 pp by percentiles of fuel prices at the 50th percentile level of fuel prices salience.

The economic returns of investing 12 years in advance is systematically higher than the economic returns of investing 7 years in advance. For example, it is 32% higher at the median fuel prices.

Figure 3.4. The earlier the investment in fuel efficient car technologies, the larger the economic benefits when fuel prices increase

Marginal effects on market share of a percentage point increase in the share of grey innovation by decile of fuel prices for different levels of maximum attention (7 years and 12 years after stock is accrued)



Note: Marginal effects estimated through Equation (2). The figure illustrates the marginal effect of a 1 percentage point (pp) increase in the share of fuel-efficiency (grey) patent stocks on market share (in percentage points) 7 years after the stock is accrued at different percentiles of fuel prices in the sample. It is represented for different levels of salience of fuel prices (namely, the median, the 75th and the 90th percentile of salience in the sample). Points represent marginal effects and the vertical bars represent 90% confidence intervals. Numbers above the percentile bin are the fuel price in USD/litre corresponding to that percentile.

3.4 Robustness

The results presented in this section are not sensitive to the way monthly values of the Google Trends indicator are aggregated at the year level. Table B.6 and Table B.7 in Annex B indicates that the results are similar when using an indicator based on the average number of searches as opposed to the maximum number of searches.

These results are also robust to changes in the list of control variables. Table B.8 in Annex B shows in columns (1)-(6) the estimation results for k = 7 that corresponds to the lag where the effect of fuel prices salience on the economic benefits of grey innovation are maximum. Column (1) of Table B.8 provides the baseline estimation results for comparison. The estimated coefficients for the interaction between fuel price, share of clean patent stock and fuel prices salience when one control is removed are highly similar to the baseline estimate.

4 Discussion

This paper analyses the returns on green innovation in terms of market shares in the presence of fuel price signals. The analysis shows that innovation in green technologies pays off in the presence of increased price signals in the medium and long run. Particularly, the results show that when fuel prices increase, car manufacturers who accrued a larger share of knowledge in fuel-efficiency technologies, with respect to other technologies, in the past 8-15 years tend to have increased market shares. Similarly, those who accumulated a larger share of knowledge in technologies related to hybrid or electric vehicles in the past 7-8 years tend to have increased market shares when fuel prices increase. Conversely, the paper shows that firms having previously invested in dirty car technologies 17 to 18 years before experience a decrease in their market share when fuel prices increase

Further focusing on the gap between the time of accumulation of innovative knowledge and the time of economic returns, the paper attempts to test one of its possible causes: consumers having less salient information on prices. Using Google Trends information to gauge the salience of fuel prices across countries, this paper presents evidence that the returns to fuel-efficiency technologies are larger and take place earlier relative to the time of innovation in situations where fuel prices are salient.

These results complement other OECD research in analysing returns to innovation, e.g. Dechezleprêtre and Kruse (2022[10]) by focusing on dynamic aspects of these returns. In order to fully assess the benefits for firms of directing innovation towards fuel-efficient technologies, it is necessary to look at longer timespans. The results are also relevant for research investigating incentives for green innovation. If fuel price salience can help enhance private benefits to innovation, then information provision should accompany carbon taxes and other pricing instruments. Since increased tax and fuel prices have generally low political acceptability, information on fuel tax and fuel prices could be accompanied by information on the progressive use of revenues from carbon taxation.

Some caveats remain and highlight areas for future research. First, previous research has shown that different types of innovation – namely, product- and process-based innovation – can lead to different returns. The same is true for incremental and breakthrough innovation. This analysis does not disentangle these properties but instead focuses on the aggregate effects. Second, the analysis does not identify whether the link between green innovation and market share is due to actual increase in fuel efficiency of the available fleet, or perceived “greenness” of firms. Further work could collect data on the fuel efficiency of each manufacturer’s fleet to assess the former channel. Third, while this paper looks at the fuel prices channel linking green innovation and economic performance, another important policy instrument employed by many countries is the use of fuel economy standards, which incentivise the purchase of more efficient cars by increasing the price of inefficient cars through penalties on car manufacturers. Future research could explore further the impact of fuel economy standards in strengthening the link between green innovation and firms’ economic performance.

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Annex A. Additional descriptive statistics

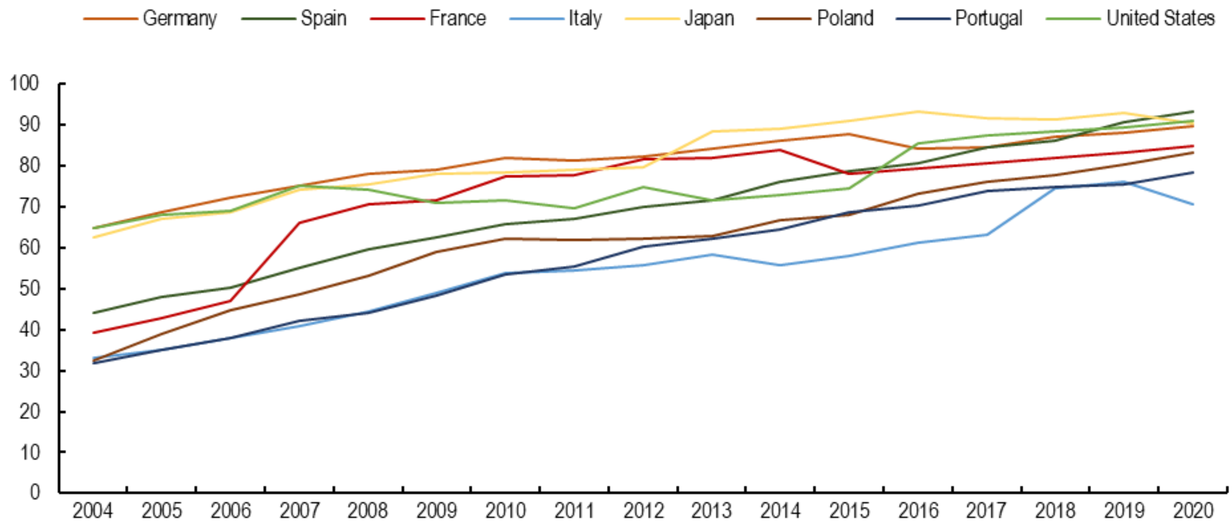
Table A.1. Definition of clean, grey, and dirty patent IPC codes

Clean Patents	
	IPC codes
Electric vehicles:	
Electric propulsion with power supplied within the vehicle	B60L 11
Electric devices on electrically propelled vehicles for safety purposes; monitoring operating variables, e.g., speed, deceleration, power consumption	B60L 3
Methods, circuits, or devices for controlling the traction motor speed of electrically propelled vehicles	B60L 15
Arrangement or mounting of electrical propulsion units	B60K 1
Conjoint control of vehicle subunits of different type or different function/including control of electric propulsion units, e.g., motors or generators/including control of energy storage means/for electrical energy, e.g., batteries or capacitors	B60W 10/08, 24, 26
Hybrid vehicles:	
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	B60K 6
Control systems specially adapted for hybrid vehicles, i.e., vehicles having two or more prime movers of more than one type, e.g., electrical and internal combustion motors, all used for propulsion of the vehicle	B60W 20
Regenerative braking:	
Dynamic electric regenerative braking	B60L 7/1
Braking by supplying regenerated power to the prime mover of vehicles comprising engine-driven generators	B60L 7/20
Hydrogen vehicles/fuel cells:	
Conjoint control of vehicle subunits of different type or different function; including control of fuel cells	B60W 10/28
Electric propulsion with power supplied within the vehicle using power supplied from primary cells, secondary cells, or fuel cells	B60L 11/18
Fuel cells; manufacture thereof	H01M 8
Grey Patents	
Fuel efficiency of internal combustion engines:	
Fuel injection apparatus	F02M39-71
Idling devices for carburettors preventing flow of idling fuel	F02M3/02-05
Apparatus for adding secondary air to fuel-air mixture	F02M23
Engine-pertinent apparatus for adding nonfuel substances or small quantities of secondary fuel to combustion-air, main fuel, or fuel-air mixture	F02M25
Electrical control of supply of combustible mixture or its constituents	F02D41
Methods of operating engines involving adding nonfuel substances or antiknock agents to combustion air, fuel, or fuel-air mixtures of engines, the substances including non-airborne oxygen	F02B47/06
Dirty Patents	
Internal combustion engine:	
Internal combustion piston engines; combustion engines in general	F02B
Controlling combustion engines	F02D
Cylinders, pistons, or casings for combustion engines; arrangement of sealings in combustion engines	F02F
Supplying combustion engines with combustible mixtures or constituents thereof	F02M
Starting of combustion engines	F02N
Ignition (other than compression ignition) for internal combustion engines	F02P

Source: (Aghion et al., 2016[2]).

Figure A.1. The use of the Internet has increased in the sample countries

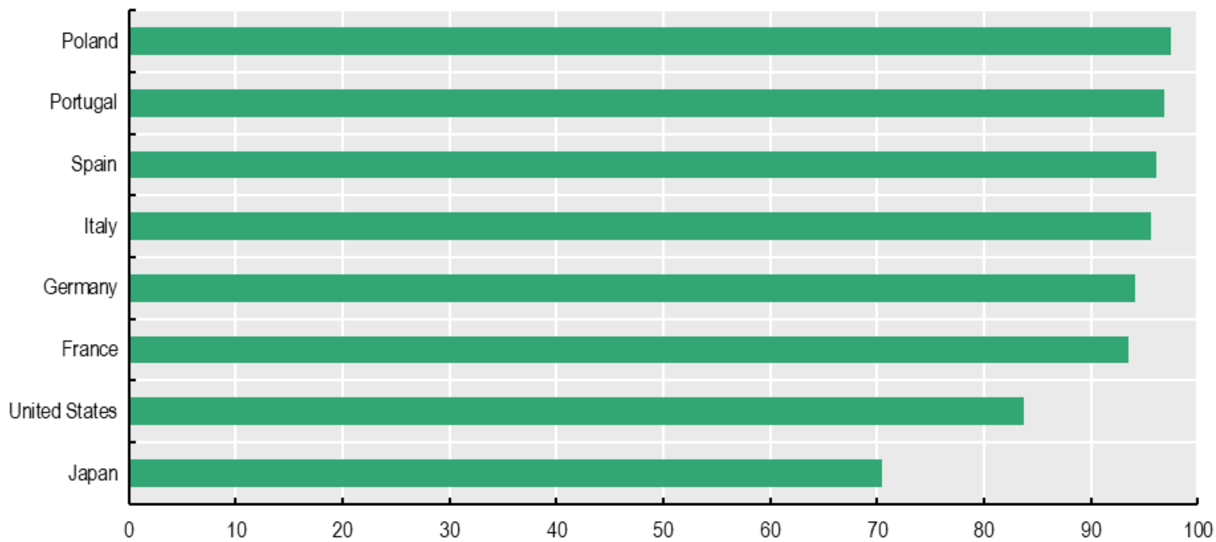
Share of individuals using the internet (as a percentage of the total population)



Note: Internet users are individuals who have used the Internet in the last 3 months. The Internet can be used via a computer, mobile phone, personal digital assistant, games machine, digital TV etc.
Source: Data from World Development Indicators (International Telecommunication Union (ITU) World Telecommunication/ICT Indicators Database).

Figure A.2. Most people use Google as a search engine

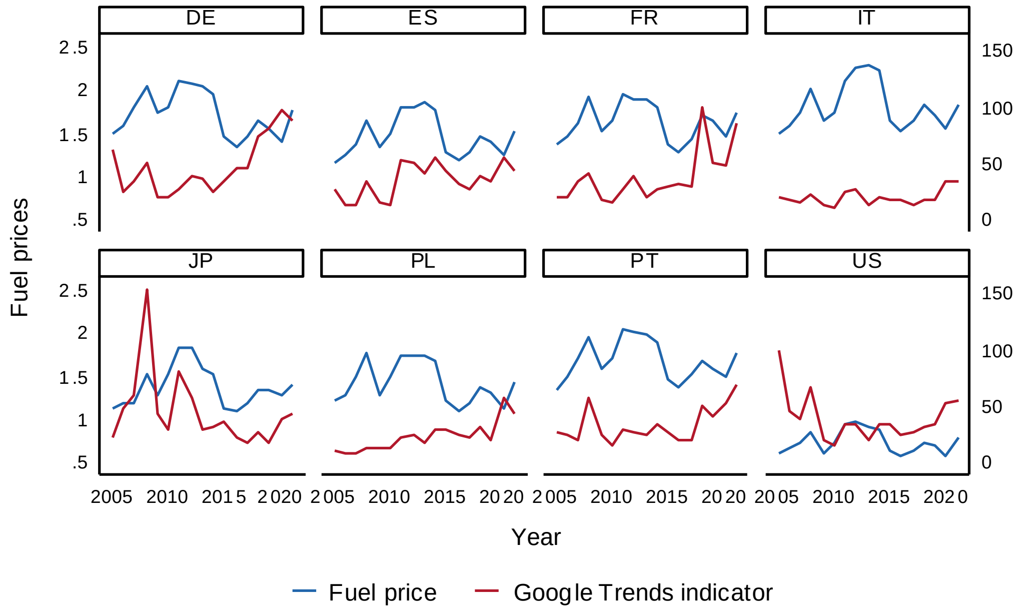
Market share of Google among all search engines, average 2009-2021



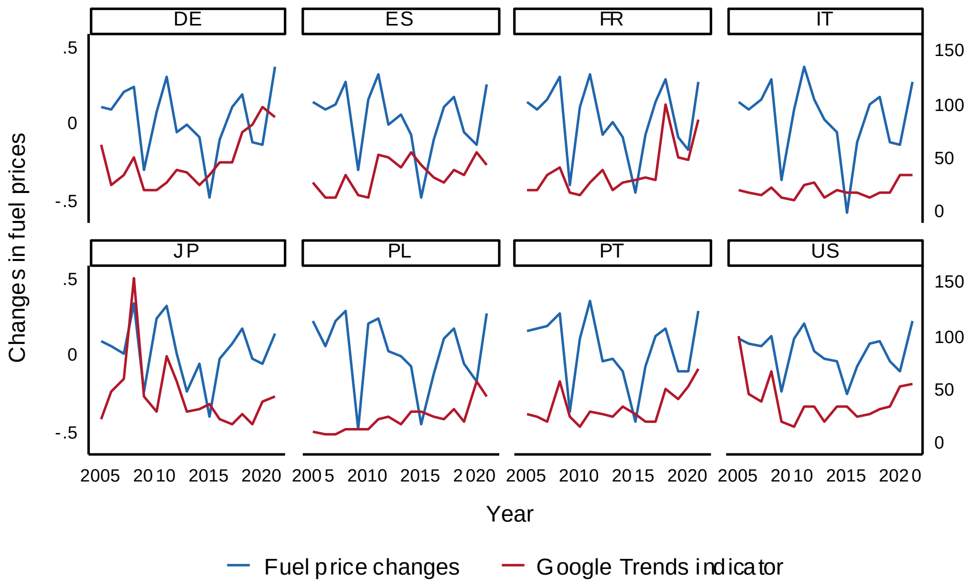
Note: Market share includes all platforms (desktop, tablet, and mobile). They represent the average from January 2009 (the first month where data is available) to December 2021.
Source: Data from StatCounter Global Stats

Figure A.3. Google Trends indicator of maximum salience and fuel prices

Panel B: Evolution of fuel prices and the Google Trends indicator of maximum salience



Panel B: Evolution of changes in fuel prices and the Google Trends indicator of maximum salience



Note: The indicator for maximum salience is calculated as the maximum value of the monthly indicator.

Annex B. Robustness checks

Table B.1. Using patent stocks generates multicollinearity issues

Panel A: lags of innovation between 0 and 10 years

		Dependent variable: Fuel price in country c and year t × Share of *clean* patent stock of firm i in year $t-k$										
		k = 0	k = 1	k = 2	k = 3	k = 4	k = 5	k = 6	k = 7	k = 8	k = 9	k = 10
Fuel price in country c and year t	t-stat	-0.70	-0.84	-0.92	-0.73	-0.45	0.01	0.33	0.19	-0.05	-0.34	-0.58
× Share of *grey* patent stock of firm i in year $t-k$	Coeff.	-0.27	-0.34	-0.38	-0.31	-0.17	0.00	0.09	0.05	-0.01	-0.07	-0.11
	Std. Err.	(0.380)	(0.402)	(0.415)	(0.426)	(0.380)	(0.309)	(0.265)	(0.251)	(0.235)	(0.220)	(0.196)
Fuel price in country c and year t	t-stat	1.39	2.07	2.71	2.87	2.98	3.05	3.05	3.19	3.56	3.97	4.60
× Share of *dirty* patent stock of firm i in year $t-k$	Coeff.	0.61	0.854**	1.070***	1.150***	1.125***	0.960***	0.848***	0.882***	0.893***	0.921***	0.963***
	Std. Err.	(0.443)	(0.413)	(0.395)	(0.401)	(0.377)	(0.315)	(0.278)	(0.277)	(0.251)	(0.232)	(0.210)
Fuel price in country c and year t	t-stat	6.37	6.42	4.87	2.59	1.07	0.30	-0.25	-0.58	-0.63	-0.42	-0.22
× Log(stock of all patents of firm i in year $t-k$)	Coeff.	1.035***	0.850***	0.651***	0.407**	0.19	0.06	-0.05	-0.13	-0.14	-0.08	-0.03
	Std. Err.	(0.163)	(0.132)	(0.134)	(0.157)	(0.178)	(0.197)	(0.217)	(0.233)	(0.218)	(0.179)	(0.148)
Fuel price in country c and year t	t-stat	0.18	0.23	0.33	-0.13	-0.57	-1.11	-1.39	-1.19	-1.03	-0.67	-0.32
× Log(vehicles sold by firm i in country c in 2005)	Coeff.	0.01	0.01	0.02	-0.01	-0.03	-0.05	-0.06	-0.05	-0.04	-0.03	-0.02
	Std. Err.	(0.036)	(0.043)	(0.046)	(0.047)	(0.045)	(0.044)	(0.046)	(0.045)	(0.040)	(0.045)	(0.048)
Time trend in year t	t-stat	2.55	2.76	3.00	3.15	3.19	2.96	2.46	1.79	0.64	-0.98	-2.35
× Log(vehicles sold by firm i in country c in 2005)	Coeff.	0.009**	0.010***	0.011***	0.011***	0.010***	0.008***	0.006**	0.004*	0.00	0.00	-0.004**
	Std. Err.	(0.004)	(0.004)	(0.004)	(0.004)	(0.003)	(0.003)	(0.002)	(0.002)	(0.002)	(0.001)	(0.002)
Constant	t-stat	-4.10	-4.31	-4.67	-4.59	-4.08	-3.16	-2.01	-1.15	-0.09	0.91	1.56
	Coeff.	-5.118***	-5.492***	-5.680***	-5.203***	-4.410***	-3.171***	-1.900**	-0.96	-0.06	0.61	1.26
	Std. Err.	(1.248)	(1.273)	(1.216)	(1.133)	(1.082)	(1.003)	(0.944)	(0.833)	(0.696)	(0.661)	(0.805)
Observations		1 946	1 946	1 946	1 946	1 946	1 946	1 946	1 940	1 934	1 928	1 922
Number of firms		123	123	123	123	123	123	123	123	123	123	123
F-stat		80.82	78.95	90.86	70.04	35.38	18.41	12.14	9.32	7.78	7.91	9.16

Note: All estimations include firm-country, country-year, and firm-year fixed effects. Standard errors clustered at the firm-country level are provided in parentheses.

Panel B: lags of innovation between 11 and 20 years

		Dependent variable: Fuel price in country c and year t × Share of *clean* patent stock of firm i in year $t-k$									
		k = 11	k = 12	k = 13	k = 14	k = 15	k = 16	k = 17	k = 18	k = 19	k = 20
Fuel price in country c and year t	t-stat	-1.15	-2.32	-4.26	-5.86	-8.13	-6.18	-4.65	-3.39	-2.28	0.48
× Share of *grey* patent stock of firm i in year $t-k$	Coeff.	-0.19	-0.279**	-0.393***	-0.395***	-0.475***	-0.501***	-0.500***	-0.433***	-0.363**	0.19
	Std. Err.	(0.167)	(0.120)	(0.092)	(0.067)	(0.058)	(0.081)	(0.108)	(0.128)	(0.159)	(0.391)
Fuel price in country c and year t	t-stat	5.50	6.86	7.84	9.29	10.86	9.57	6.73	3.89	2.73	0.12
× Share of *dirty* patent stock of firm i in year $t-k$	Coeff.	1.001***	0.995***	0.986***	0.955***	0.963***	0.873***	0.781***	0.620***	0.495***	0.03
	Std. Err.	(0.182)	(0.145)	(0.126)	(0.103)	(0.089)	(0.091)	(0.116)	(0.160)	(0.181)	(0.207)
Fuel price in country c and year t	t-stat	0.03	0.60	0.96	0.97	1.24	1.39	1.02	0.72	0.44	2.53
× Log(stock of all patents of firm i in year $t-k$)	Coeff.	0.00	0.08	0.12	0.12	0.18	0.27	0.24	0.20	0.14	1.457**
	Std. Err.	(0.148)	(0.139)	(0.126)	(0.123)	(0.141)	(0.192)	(0.239)	(0.283)	(0.326)	(0.575)
Fuel price in country c and year t	t-stat	0.32	1.15	1.78	2.23	2.62	2.81	2.48	1.56	0.86	1.73
× Log(vehicles sold by firm i in country c in 2005)	Coeff.	0.02	0.07	0.106*	0.109**	0.099***	0.131***	0.141**	0.08	0.05	0.229*
	Std. Err.	(0.051)	(0.063)	(0.060)	(0.049)	(0.038)	(0.047)	(0.057)	(0.052)	(0.053)	(0.132)
Time trend in year t	t-stat	-2.84	-2.81	-2.27	-1.91	-1.46	-1.02	-0.66	-0.84	-0.83	1.57
× Log(vehicles sold by firm i in country c in 2005)	Coeff.	-0.006***	-0.007***	-0.006**	-0.006*	-0.01	0.00	0.00	0.00	0.00	0.03
	Std. Err.	(0.002)	(0.002)	(0.003)	(0.003)	(0.004)	(0.004)	(0.005)	(0.005)	(0.005)	(0.016)
Constant	t-stat	1.81	1.61	1.15	0.95	0.60	0.21	0.05	0.45	0.61	-1.82
	Coeff.	1.677*	1.65	1.28	1.29	0.90	0.37	0.09	0.92	1.35	-11.361*
	Std. Err.	(0.926)	(1.025)	(1.111)	(1.357)	(1.502)	(1.793)	(1.936)	(2.049)	(2.207)	(6.229)
Observations		1 916	1 910	1 904	1 884	1 864	1 844	1 824	1 804	1 777	1 946
Number of firms		123	123	123	123	123	123	123	123	123	123
F-stat		14.96	24.49	28.52	34.99	48.17	39.20	25.21	12.26	6.65	6.13

Note: All estimations include firm-country, country-year, and firm-year fixed effects. Standard errors clustered at the firm-country level are provided in parentheses.

Table B.2.Effects of shares of innovation stocks on market shares under different specifications

	Dependent variable: Market share of car manufacturer i in country c in year t													
	k = 8							k = 12						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Fuel price in country c and year t	0.271**	0.227**		0.235	0.246**	0.268**	0.246**	0.183	0.177		0.056	0.104	0.181	0.236
× Share of *clean* patent stock of firm i in year $t-k$	(0.127)	(0.110)		(0.147)	(0.123)	(0.127)	(0.112)	(0.153)	(0.143)		(0.151)	(0.141)	(0.152)	(0.155)
Fuel price in country c and year t	0.354	0.402	0.216		0.278	0.361	0.177	0.590***	0.597***	0.475***		0.493***	0.588***	0.359**
× Share of *grey* patent stock of firm i in year $t-k$	(0.246)	(0.249)	(0.265)		(0.273)	(0.242)	(0.264)	(0.188)	(0.188)	(0.180)		(0.156)	(0.190)	(0.156)
Fuel price in country c and year t	-0.1	-0.087	-0.022	-0.04		-0.101	-0.026	-0.206	-0.202	-0.107	-0.073		-0.204	-0.156
× Share of *dirty* patent stock of firm i in year $t-k$	(0.094)	(0.106)	(0.085)	(0.114)		(0.095)	(0.099)	(0.140)	(0.136)	(0.117)	(0.131)		(0.141)	(0.131)
Fuel price in country c and year t	-0.966		-0.626	-1.06	-0.932	-0.94	-1.102	-0.168		-0.03	-0.322	-0.101	-0.176	-0.415
× Log(stock of all patents of firm i in year $t-k$)	(0.759)		(0.704)	(0.799)	(0.749)	(0.787)	(0.885)	(0.540)		(0.530)	(0.608)	(0.558)	(0.555)	(0.574)
Fuel price in country c and year t	0.112	0.019	0.028	0.162	0.121		0.292	-0.061	-0.074	-0.002	0.012	-0.004		0.107
× Log(vehicles sold by firm i in country c in 2005)	(0.368)	(0.394)	(0.382)	(0.363)	(0.372)		(0.393)	(0.418)	(0.427)	(0.405)	(0.400)	(0.424)		(0.415)
Time trend in year t	-0.043**	-0.044**	-0.040*	-0.039*	-0.041**	-0.043**		-0.051**	-0.051**	-0.053**	-0.038*	-0.049**	-0.051**	
× Log(vehicles sold by firm i in country c in 2005)	(0.021)	(0.022)	(0.021)	(0.022)	(0.020)	(0.021)		(0.020)	(0.021)	(0.021)	(0.023)	(0.020)	(0.020)	
Observations	2 067	2 067	2 067	2 067	2 067	2 067	2 067	2 067	2 067	2 067	2 067	2 067	2 067	2 067
Number of firms	123	123	123	123	123	123	123	123	123	123	123	123	123	123
F-stat	2.36	2.36	1.80	0.83	2.73	2.82	2.33	2.98	2.99	2.71	0.67	3.66	3.47	2.72

Note: Results from estimating Eq. (1). All estimations include firm-country, country-year, and firm-year fixed effects. Standard errors clustered at the firm-country level are provided in parentheses. The coefficients and standard errors for the constant are not reported for clarity.

Table B.3. The effect of past innovation on market share using a 10% depreciation rates to compute patent stocks

Panel A: lags of innovation between 0 and 10 years

	Dependent variable: Market share of car manufacturer i in country c in year t										
	k = 0	k = 1	k = 2	k = 3	k = 4	k = 5	k = 6	k = 7	k = 8	k = 9	k = 10
Fuel price in country c and year t	0.016	0.023	0.071	0.138	0.221	0.275*	0.312*	0.329**	0.311**	0.277*	0.249
× Share of *clean* patent stock of firm i in year $t-k$	(0.207)	(0.197)	(0.176)	(0.156)	(0.152)	(0.160)	(0.164)	(0.159)	(0.157)	(0.159)	(0.164)
Fuel price in country c and year t	-0.429	-0.37	-0.205	0.048	0.218	0.364	0.501	0.598**	0.675***	0.697***	0.709***
× Share of *grey* patent stock of firm i in year $t-k$	(0.554)	(0.532)	(0.494)	(0.445)	(0.408)	(0.384)	(0.347)	(0.299)	(0.256)	(0.232)	(0.214)
Fuel price in country c and year t	0.077	0.058	0.009	-0.054	-0.095	-0.123	-0.142	-0.142	-0.128	-0.127	-0.148
× Share of *dirty* patent stock of firm i in year $t-k$	(0.149)	(0.136)	(0.120)	(0.107)	(0.109)	(0.113)	(0.114)	(0.120)	(0.132)	(0.145)	(0.153)
Fuel price in country c and year t	0.217	-0.085	-0.385	-0.672	-0.934	-1.068	-1.097	-1.057	-0.938	-0.766	-0.633
× Log(stock of all patents of firm i in year $t-k$)	(0.774)	(0.789)	(0.827)	(0.882)	(0.924)	(0.935)	(0.911)	(0.866)	(0.835)	(0.808)	(0.765)
Fuel price in country c and year t	0.003	0.024	0.035	0.039	0.059	0.073	0.077	0.079	0.065	0.058	0.001
× Log(vehicles sold by firm i in country c in 2005)	(0.356)	(0.372)	(0.374)	(0.375)	(0.373)	(0.369)	(0.366)	(0.364)	(0.362)	(0.362)	(0.369)
Time trend in year t	-0.04	-0.041*	-0.041*	-0.041*	-0.042*	-0.042*	-0.043**	-0.044**	-0.045**	-0.046**	-0.048**
× Log(vehicles sold by firm i in country c in 2005)	(0.024)	(0.023)	(0.023)	(0.023)	(0.023)	(0.023)	(0.021)	(0.020)	(0.019)	(0.018)	(0.018)
Constant	19.999**	21.355**	22.122**	22.975**	23.768**	24.118**	24.371***	24.432***	24.270***	24.132***	24.816***
	(9.771)	(9.472)	(9.739)	(10.013)	(10.082)	(9.862)	(9.287)	(8.560)	(8.077)	(7.772)	(7.679)
Observations	1 946	2 067	2 067	2 067	2 067	2 067	2 067	2 067	2 067	2 067	2 067
Number of firms	123	123	123	123	123	123	123	123	123	123	123
F-statis	0.63	0.61	0.55	0.62	0.85	1.12	1.59	2.25	2.65	2.84	3.02

Note: Results from estimating Eq. (1) for lags of innovation between 1 and 20 years, using alternative depreciation rates for estimating the stock of accumulated knowledge: 10% instead of 15%. All estimations include firm-country, country-year, and firm-year fixed effects. Standard errors clustered at the firm-country level are provided in parentheses.

Panel B: lags of innovation between 11 and 20 years

	Dependent variable: Market share of car manufacturer i in country c in year t									
	k = 11	k = 12	k = 13	k = 14	k = 15	k = 16	k = 17	k = 18	k = 19	k = 20
Fuel price in country c and year t	0.223	0.205	0.165	0.132	0.094	0.065	0.032	-0.026	-0.149	-0.309
× Share of *clean* patent stock of firm i in year $t-k$	(0.171)	(0.176)	(0.179)	(0.179)	(0.179)	(0.190)	(0.207)	(0.220)	(0.239)	(0.292)
Fuel price in country c and year t	0.710***	0.707***	0.643***	0.538**	0.447*	0.365	0.279	0.185	0.047	-0.052
× Share of *grey* patent stock of firm i in year $t-k$	(0.210)	(0.215)	(0.225)	(0.237)	(0.241)	(0.251)	(0.250)	(0.240)	(0.234)	(0.229)
Fuel price in country c and year t	-0.221	-0.279*	-0.284*	-0.270*	-0.249*	-0.234*	-0.228**	-0.203*	-0.152	-0.118
× Share of *dirty* patent stock of firm i in year $t-k$	(0.160)	(0.161)	(0.163)	(0.150)	(0.133)	(0.119)	(0.111)	(0.104)	(0.100)	(0.095)
Fuel price in country c and year t	-0.423	-0.257	-0.091	-0.057	-0.022	-0.007	0.073	0.126	0.11	0.1
× Log(stock of all patents of firm i in year $t-k$)	(0.677)	(0.616)	(0.573)	(0.502)	(0.408)	(0.312)	(0.265)	(0.238)	(0.215)	(0.201)
Fuel price in country c and year t	-0.064	-0.074	-0.072	-0.055	-0.032	-0.01	-0.026	-0.038	-0.034	-0.039
× Log(vehicles sold by firm i in country c in 2005)	(0.394)	(0.418)	(0.435)	(0.441)	(0.435)	(0.427)	(0.427)	(0.427)	(0.424)	(0.426)
Time trend in year t	-0.051**	-0.053**	-0.054**	-0.053**	-0.052**	-0.050**	-0.049**	-0.047**	-0.046**	-0.045**
× Log(vehicles sold by firm i in country c in 2005)	(0.020)	(0.020)	(0.021)	(0.021)	(0.021)	(0.021)	(0.021)	(0.021)	(0.021)	(0.020)
Constant	26.017***	26.643***	26.563***	26.149***	25.773***	25.201***	24.710***	24.106***	23.501***	23.401***
	(8.039)	(8.206)	(8.230)	(8.064)	(7.892)	(7.764)	(7.724)	(7.685)	(7.654)	(7.606)
Observations	2067	2067	2067	2067	2067	2067	2067	2067	2067	2067
Number of firms	123	123	123	123	123	123	123	123	123	123
F-statis	2.82	2.63	2.23	1.83	1.69	1.67	1.55	1.44	1.26	1.26

Note: Results from estimating Eq. (1) for lags of innovation between 1 and 20 years, using alternative depreciation rates for estimating the stock of accumulated knowledge: 10% instead of 15%. All estimations include firm-country, country-year, and firm-year fixed effects. Standard errors clustered at the firm-country level are provided in parentheses.

Table B.4. The effect of past innovation on market share using a 20% depreciation rates to compute patent stocks

Panel A: lags of innovation between 0 and 10 years

	Dependent variable: Market share of car manufacturer i in country c in year t										
	k = 0	k = 1	k = 2	k = 3	k = 4	k = 5	k = 6	k = 7	k = 8	k = 9	k = 10
Fuel price in country c and year t	-0.073	-0.053	-0.014	0.03	0.095	0.144*	0.185*	0.216**	0.215**	0.198*	0.182
× Share of *clean* patent stock of firm i in year $t-k$	(0.126)	(0.119)	(0.107)	(0.092)	(0.082)	(0.085)	(0.094)	(0.099)	(0.104)	(0.109)	(0.115)
Fuel price in country c and year t	-0.385	-0.414	-0.362	-0.232	-0.145	-0.057	0.071	0.184	0.29	0.352**	0.412**
× Share of *grey* patent stock of firm i in year $t-k$	(0.311)	(0.315)	(0.303)	(0.280)	(0.254)	(0.238)	(0.228)	(0.208)	(0.180)	(0.169)	(0.161)
Fuel price in country c and year t	0.102	0.109	0.083	0.037	0.003	-0.024	-0.053	-0.067	-0.063	-0.053	-0.049
× Share of *dirty* patent stock of firm i in year $t-k$	(0.127)	(0.119)	(0.106)	(0.092)	(0.086)	(0.084)	(0.079)	(0.079)	(0.084)	(0.090)	(0.095)
Fuel price in country c and year t	0.369	0.058	-0.217	-0.465	-0.708	-0.866	-0.924	-0.897	-0.798	-0.636	-0.483
× Log(stock of all patents of firm i in year $t-k$)	(0.723)	(0.698)	(0.704)	(0.732)	(0.754)	(0.759)	(0.742)	(0.696)	(0.650)	(0.614)	(0.575)
Fuel price in country c and year t	0.016	0.025	0.041	0.056	0.083	0.107	0.121	0.134	0.111	0.094	0.035
× Log(vehicles sold by firm i in country c in 2005)	(0.358)	(0.374)	(0.374)	(0.375)	(0.377)	(0.377)	(0.375)	(0.371)	(0.368)	(0.368)	(0.373)
Time trend in year t	-0.039	-0.040*	-0.040*	-0.040*	-0.041*	-0.042*	-0.042*	-0.042*	-0.041**	-0.041**	-0.042**
× Log(vehicles sold by firm i in country c in 2005)	(0.024)	(0.023)	(0.023)	(0.023)	(0.023)	(0.023)	(0.023)	(0.021)	(0.020)	(0.019)	(0.018)
Constant	19.292**	20.763**	21.454**	22.106**	22.951**	23.275**	23.261**	22.947***	22.456***	21.917***	22.155***
	(8.814)	(8.616)	(8.971)	(9.382)	(9.596)	(9.597)	(9.276)	(8.579)	(7.974)	(7.495)	(7.194)
Observations	1946	2067	2067	2067	2067	2067	2067	2067	2067	2067	2067
Number of firms	123	123	123	123	123	123	123	123	123	123	123
F-statis	0.83	0.81	0.71	0.61	0.67	0.79	1.06	1.70	2.09	2.28	2.80

Note: Results from estimating Eq. (1) for lags of innovation between 1 and 20 years, using alternative depreciation rates for estimating the stock of accumulated knowledge: 20% instead of 15%. All estimations include firm-country, country-year, and firm-year fixed effects. Standard errors clustered at the firm-country level are provided in parentheses.

Panel B: lags of innovation between 11 and 20 years

	Dependent variable: Market share of car manufacturer i in country c in year t									
	k = 11	k = 12	k = 13	k = 14	k = 15	k = 16	k = 17	k = 18	k = 19	k = 20
Fuel price in country c and year t	0.167	0.157	0.134	0.117	0.09	0.082	0.071	0.043	-0.047	-0.177
× Share of *clean* patent stock of firm i in year $t-k$	(0.123)	(0.131)	(0.139)	(0.143)	(0.136)	(0.142)	(0.158)	(0.168)	(0.179)	(0.216)
Fuel price in country c and year t	0.457***	0.488***	0.481***	0.437**	0.389**	0.344*	0.291	0.219	0.1	0.01
× Share of *grey* patent stock of firm i in year $t-k$	(0.161)	(0.165)	(0.170)	(0.171)	(0.172)	(0.182)	(0.187)	(0.188)	(0.191)	(0.191)
Fuel price in country c and year t	-0.088	-0.137	-0.16	-0.167	-0.16	-0.165*	-0.176**	-0.170**	-0.133*	-0.107
× Share of *dirty* patent stock of firm i in year $t-k$	(0.105)	(0.115)	(0.130)	(0.129)	(0.111)	(0.095)	(0.087)	(0.080)	(0.077)	(0.077)
Fuel price in country c and year t	-0.265	-0.11	-0.005	-0.009	-0.027	-0.034	0.039	0.104	0.092	0.085
× Log(stock of all patents of firm i in year $t-k$)	(0.509)	(0.471)	(0.470)	(0.462)	(0.414)	(0.327)	(0.271)	(0.234)	(0.203)	(0.184)
Fuel price in country c and year t	-0.029	-0.046	-0.051	-0.035	-0.012	0.005	-0.019	-0.039	-0.029	-0.028
× Log(vehicles sold by firm i in country c in 2005)	(0.394)	(0.419)	(0.440)	(0.449)	(0.443)	(0.434)	(0.432)	(0.430)	(0.422)	(0.423)
Time trend in year t	-0.046**	-0.048**	-0.050**	-0.050**	-0.050**	-0.050**	-0.049**	-0.048**	-0.046**	-0.046**
× Log(vehicles sold by firm i in country c in 2005)	(0.019)	(0.020)	(0.021)	(0.021)	(0.021)	(0.022)	(0.022)	(0.022)	(0.022)	(0.021)
Constant	23.106***	23.920***	24.427***	24.542***	24.775***	24.639***	24.495***	24.100***	23.490***	23.373***
	(7.463)	(7.763)	(7.978)	(7.992)	(7.992)	(7.948)	(7.965)	(7.940)	(7.907)	(7.823)
Observations	2067	2067	2067	2067	2067	2067	2067	2067	2067	2067
Number of firms	123	123	123	123	123	123	123	123	123	123
F-statis	2.78	2.50	2.20	1.92	1.70	1.63	1.53	1.46	1.24	1.16

Note: Results from estimating Eq. (1) for lags of innovation between 1 and 20 years, using alternative depreciation rates for estimating the stock of accumulated knowledge: 20% instead of 15%. All estimations include firm-country, country-year, and firm-year fixed effects. Standard errors clustered at the firm-country level are provided in parentheses.

Table B.5. The effect of past innovation on market share when fuel taxes increase

Panel A: lags of innovation between 0 and 10 years

	Dependent variable: Market share of car manufacturer i in country c in year t										
	k = 0	k = 1	k = 2	k = 3	k = 4	k = 5	k = 6	k = 7	k = 8	k = 9	k = 10
Fuel tax in country c and year t	-0.057	-0.045	-0.021	0.01	0.048	0.074	0.096*	0.115**	0.119**	0.120*	0.117
× Share of *clean* patent stock of firm i in year $t-k$	(0.061)	(0.058)	(0.052)	(0.045)	(0.043)	(0.046)	(0.050)	(0.052)	(0.055)	(0.062)	(0.071)
Fuel tax in country c and year t	-0.296	-0.29	-0.23	-0.145	-0.083	-0.023	0.058	0.121	0.179*	0.209**	0.237***
× Share of *grey* patent stock of firm i in year $t-k$	(0.191)	(0.197)	(0.188)	(0.173)	(0.153)	(0.141)	(0.135)	(0.124)	(0.105)	(0.091)	(0.083)
Fuel tax in country c and year t	0.09	0.08	0.053	0.019	-0.005	-0.022	-0.041	-0.048	-0.046	-0.047	-0.05
× Share of *dirty* patent stock of firm i in year $t-k$	(0.065)	(0.059)	(0.053)	(0.046)	(0.043)	(0.044)	(0.042)	(0.040)	(0.041)	(0.047)	(0.054)
Fuel tax in country c and year t	-0.07	-0.225	-0.353	-0.47	-0.557	-0.604	-0.606	-0.59	-0.53	-0.475	-0.403
× Log(stock of all patents of firm i in year $t-k$)	(0.326)	(0.332)	(0.354)	(0.391)	(0.408)	(0.417)	(0.417)	(0.406)	(0.384)	(0.374)	(0.352)
Fuel tax in country c and year t	0	0	0	0	0	0	0	0	0	0	0
× Log(vehicles sold by firm i in country c in 2005)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Time trend in year t	-0.041*	-0.042*	-0.042*	-0.042*	-0.043*	-0.044*	-0.045*	-0.045**	-0.046**	-0.046**	-0.047**
× Log(vehicles sold by firm i in country c in 2005)	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)	(0.022)	(0.021)	(0.020)	(0.019)
Constant	21.267**	21.315**	20.741**	20.412**	20.625**	20.802**	21.223**	21.696***	22.115***	22.418***	23.038***
	(8.799)	(8.648)	(8.583)	(8.589)	(8.549)	(8.428)	(8.128)	(7.666)	(7.271)	(6.980)	(6.836)
Observations	1946	2067	2067	2067	2067	2067	2067	2067	2067	2067	2067
Number of firms	123	123	123	123	123	123	123	123	123	123	123
F-statis	1.07	0.97	0.82	0.72	0.75	0.89	1.40	2.06	2.37	2.63	3.07

Note: The dependent variable is the market share of firm i in year t. All estimations include firm-country, country-year, and firm-year fixed effects. Standard errors clustered at the firm-country level are provided in parentheses. Innovation stock shares are the share of accumulated stock of patents of grey, clean, and dirty technologies over the total stock of patents of a given firm. Results from estimating Eq. (1) for lags of innovation between 0 and 10 years.

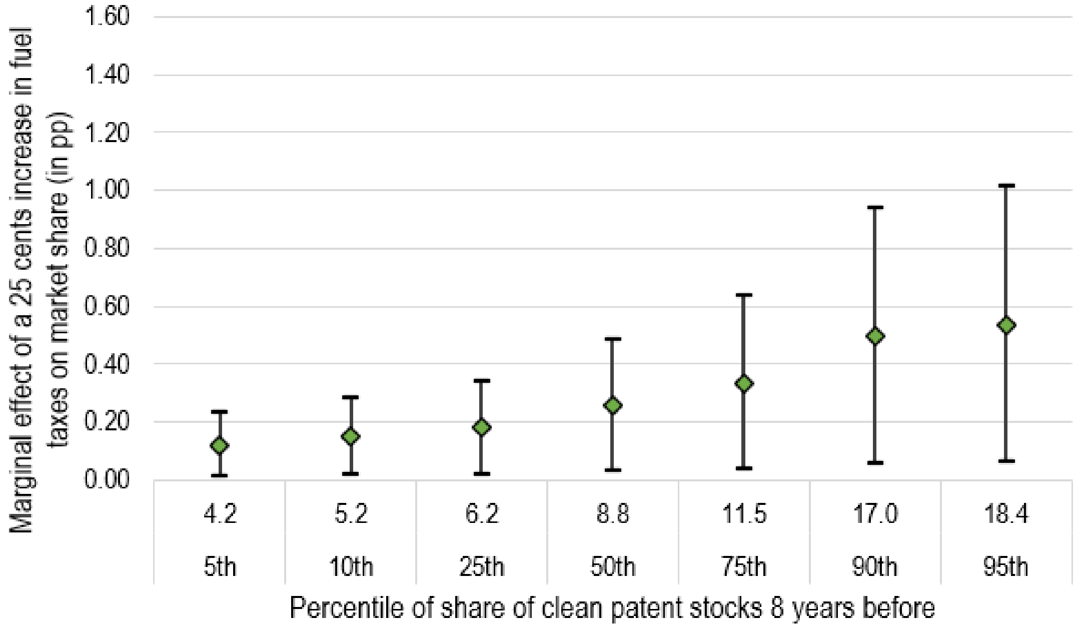
Panel B: lags of innovation between 11 and 20 years

	Dependent variable: Market share of car manufacturer i in country c in year t									
	k = 11	k = 12	k = 13	k = 14	k = 15	k = 16	k = 17	k = 18	k = 19	k = 20
Fuel tax in country c and year t	0.111	0.104	0.087	0.07	0.048	0.034	0.017	-0.007	-0.058	-0.129
× Share of *clean* patent stock of firm i in year $t-k$	(0.080)	(0.084)	(0.085)	(0.083)	(0.080)	(0.083)	(0.088)	(0.094)	(0.097)	(0.114)
Fuel tax in country c and year t	0.259***	0.271***	0.257***	0.222***	0.182**	0.145	0.107	0.069	0.011	-0.032
× Share of *grey* patent stock of firm i in year $t-k$	(0.083)	(0.084)	(0.085)	(0.083)	(0.086)	(0.094)	(0.100)	(0.104)	(0.108)	(0.105)
Fuel tax in country c and year t	-0.083	-0.112	-0.121	-0.116*	-0.102*	-0.093*	-0.088**	-0.080*	-0.062	-0.05
× Share of *dirty* patent stock of firm i in year $t-k$	(0.063)	(0.068)	(0.073)	(0.069)	(0.058)	(0.049)	(0.043)	(0.041)	(0.042)	(0.041)
Fuel tax in country c and year t	-0.257	-0.124	-0.021	0.003	0.008	0.008	0.044	0.07	0.065	0.064
× Log(stock of all patents of firm i in year $t-k$)	(0.309)	(0.288)	(0.283)	(0.265)	(0.215)	(0.160)	(0.132)	(0.112)	(0.098)	(0.088)
Fuel tax in country c and year t	0	0	0	0	0	0	0	0	0	0
× Log(vehicles sold by firm i in country c in 2005)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Time trend in year t	-0.050**	-0.052**	-0.053**	-0.052**	-0.052**	-0.051**	-0.050**	-0.049**	-0.047**	-0.047**
× Log(vehicles sold by firm i in country c in 2005)	(0.020)	(0.020)	(0.021)	(0.021)	(0.021)	(0.022)	(0.022)	(0.022)	(0.022)	(0.022)
Constant	24.022***	24.920***	25.434***	25.183***	25.048***	24.597***	24.263***	23.963***	23.476***	23.383***
	(6.960)	(7.128)	(7.323)	(7.476)	(7.716)	(7.854)	(7.968)	(8.067)	(8.092)	(8.061)
Observations	2067	2067	2067	2067	2067	2067	2067	2067	2067	2067
Number of firms	123	123	123	123	123	123	123	123	123	123
F-statis	3.01	2.66	2.26	1.93	1.68	1.54	1.38	1.25	1.11	1.09

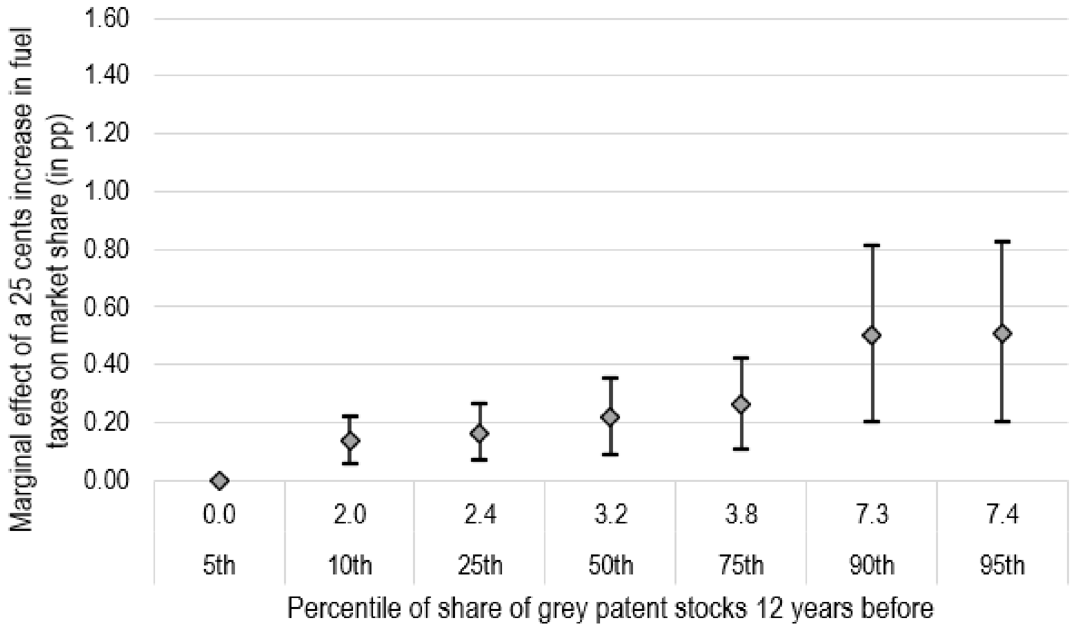
Note: The dependent variable is the market share of firm i in year t. All estimations include firm-country, country-year, and firm-year fixed effects. Standard errors clustered at the firm-country level are provided in parentheses. Innovation stock shares are the share of accumulated stock of patents of grey, clean, and dirty technologies over the total stock of patents of a given firm. Results from estimating Eq. (1) for lags of innovation between 11 and 20 years.

Figure B.1. Effects of a 25-cent increase in fuel taxes by percentile of share of clean patent stocks

Panel A: Effects of innovating in electric and hybrid (clean) car technologies



Panel B. Effects of innovating in fuel efficient (grey) car technologies



Note: Marginal effects estimated by eq. (1). Panel A and B illustrate the marginal effect of a 25-cent per litre increase in fuel taxes on market share (in pp) by percentile of share of clean and grey patent stock. Points represent marginal effects and the vertical bars represent 95% confidence intervals. Numbers above the percentile bin are the share of grey patent stocks (in pp) corresponding to that percentile.

Table B.6. The effect of fuel price changes on market share by types of past innovation as a function of averaged fuel price salience, lag 0-10

	Dependent variable: Market share of car manufacturer i in country c in year t										
	k = 0	k = 1	k = 2	k = 3	k = 4	k = 5	k = 6	k = 7	k = 8	k = 9	k = 10
Fuel price in country c and year t	-0.016	0.021	0.07	0.134	0.212*	0.258**	0.295**	0.323**	0.307**	0.274*	0.24
× Share of *clean* patent stock of firm i in year $t-k$	(0.156)	(0.151)	(0.141)	(0.130)	(0.126)	(0.129)	(0.132)	(0.132)	(0.135)	(0.140)	(0.149)
Fuel price in country c and year t	-0.001	-0.002	-0.002	-0.003	-0.003	-0.003	-0.003	-0.003	-0.002	-0.002	-0.001
× Share of *clean* patent stock of firm i in year $t-k$	(0.002)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
× google trend (average) in country c and year t											
Fuel price in country c and year t	-0.664	-0.673*	-0.571	-0.399	-0.28	-0.15	-0.01	0.107	0.238	0.338	0.431*
× Share of *grey* patent stock of firm i in year $t-k$	(0.406)	(0.402)	(0.382)	(0.349)	(0.323)	(0.310)	(0.289)	(0.264)	(0.241)	(0.231)	(0.222)
Fuel price in country c and year t	0.012**	0.014**	0.014**	0.015**	0.015**	0.014**	0.015***	0.014***	0.012**	0.008	0.006
× Share of *grey* patent stock of firm i in year $t-k$	(0.006)	(0.007)	(0.006)	(0.006)	(0.006)	(0.006)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
× google trend (average) in country c and year t											
Fuel price in country c and year t	0.115	0.114	0.075	0.02	-0.019	-0.043	-0.059	-0.067	-0.061	-0.056	-0.07
× Share of *dirty* patent stock of firm i in year $t-k$	(0.147)	(0.137)	(0.122)	(0.109)	(0.107)	(0.107)	(0.103)	(0.103)	(0.111)	(0.120)	(0.130)
Fuel price in country c and year t	-0.001	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.001	-0.001	-0.001
× Share of *dirty* patent stock of firm i in year $t-k$	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
× google trend (average) in country c and year t											
Fuel price in country c and year t	0.247	-0.101	-0.387	-0.65	-0.888	-1.003	-1.006	-0.953	-0.834	-0.657	-0.51
× Log(stock of all patents of firm i in year $t-k$)	(0.744)	(0.738)	(0.761)	(0.801)	(0.831)	(0.831)	(0.800)	(0.752)	(0.718)	(0.693)	(0.657)
Fuel price in country c and year t	0.03	0.04	0.051	0.054	0.069	0.084	0.083	0.089	0.075	0.074	0.013
× Log(vehicles sold by firm i in country c in 2005)	(0.359)	(0.375)	(0.375)	(0.376)	(0.376)	(0.374)	(0.369)	(0.366)	(0.364)	(0.365)	(0.368)
Time trend in year t	-0.040*	-0.041*	-0.041*	-0.042*	-0.043*	-0.043*	-0.044**	-0.044**	-0.045**	-0.044**	-0.046**
× Log(vehicles sold by firm i in country c in 2005)	(0.024)	(0.023)	(0.023)	(0.023)	(0.023)	(0.023)	(0.022)	(0.020)	(0.019)	(0.019)	(0.019)
Constant	20.078**	21.684**	22.426**	23.219**	24.007**	24.203**	24.287***	24.148***	23.750***	23.180***	23.554***
	(9.307)	(9.040)	(9.375)	(9.704)	(9.833)	(9.703)	(9.179)	(8.462)	(7.957)	(7.575)	(7.426)
Observations	1946	2067	2067	2067	2067	2067	2067	2067	2067	2067	2067
Number of firms	123	123	123	123	123	123	123	123	123	123	123
F-stat	1.0	1.1	1.1	1.2	1.4	1.6	1.9	2.4	2.3	2.2	2.1

Note: All estimations include firm-country, country-year, and firm-year fixed effects. Standard errors clustered at the firm-country level. Innovation stock shares are the share of accumulated stock of patents of grey, clean, and dirty technologies over the total stock of patents of a given firm. Results from estimating Eq. (2) for lags of innovation between 0 and 10 years.

Table B.7. The effect of fuel price changes on market share by types of past innovation as a function of averaged fuel price salience, lag 11-20

	Dependent variable: Market share of car manufacturer i in country c in year t									
	k = 11	k = 12	k = 13	k = 14	k = 15	k = 16	k = 17	k = 18	k = 19	k = 20
Fuel price in country c and year t	0.228	0.241	0.235	0.243	0.22	0.21	0.192	0.156	0.07	-0.028
× Share of *clean* patent stock of firm i in year $t-k$	(0.159)	(0.172)	(0.185)	(0.188)	(0.188)	(0.208)	(0.237)	(0.265)	(0.294)	(0.353)
Fuel price in country c and year t	-0.001	-0.002	-0.003	-0.004	-0.004	-0.004	-0.004	-0.005	-0.005	-0.007
× Share of *clean* patent stock of firm i in year $t-k$	(0.003)	(0.004)	(0.004)	(0.004)	(0.004)	(0.005)	(0.005)	(0.006)	(0.007)	(0.009)
× google trend (average) in country c and year t										
Fuel price in country c and year t	0.502**	0.562**	0.559**	0.486**	0.403*	0.324	0.247	0.142	0.002	-0.117
× Share of *grey* patent stock of firm i in year $t-k$	(0.217)	(0.218)	(0.230)	(0.235)	(0.237)	(0.248)	(0.253)	(0.247)	(0.244)	(0.238)
Fuel price in country c and year t	0.003	0.001	0.001	0.001	0.001	0.002	0.002	0.004	0.004	0.006
× Share of *grey* patent stock of firm i in year $t-k$	(0.006)	(0.005)	(0.005)	(0.005)	(0.005)	(0.006)	(0.005)	(0.005)	(0.004)	(0.004)
× google trend (average) in country c and year t										
Fuel price in country c and year t	-0.135	-0.204	-0.23	-0.229	-0.215	-0.205*	-0.203*	-0.184*	-0.14	-0.11
× Share of *dirty* patent stock of firm i in year $t-k$	(0.142)	(0.151)	(0.161)	(0.151)	(0.132)	(0.115)	(0.106)	(0.098)	(0.091)	(0.088)
Fuel price in country c and year t	-0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
× Share of *dirty* patent stock of firm i in year $t-k$	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
× google trend (average) in country c and year t										
Fuel price in country c and year t	-0.296	-0.143	-0.02	-0.005	0.003	0.005	0.076	0.133	0.116	0.105
× Log(stock of all patents of firm i in year $t-k$)	(0.585)	(0.540)	(0.525)	(0.489)	(0.416)	(0.325)	(0.273)	(0.241)	(0.214)	(0.195)
Fuel price in country c and year t	-0.054	-0.071	-0.077	-0.065	-0.037	-0.014	-0.033	-0.046	-0.034	-0.029
× Log(vehicles sold by firm i in country c in 2005)	(0.390)	(0.415)	(0.436)	(0.444)	(0.438)	(0.430)	(0.428)	(0.427)	(0.422)	(0.423)
Time trend in year t	-0.049**	-0.052**	-0.053**	-0.053**	-0.053**	-0.052**	-0.051**	-0.049**	-0.048**	-0.047**
× Log(vehicles sold by firm i in country c in 2005)	(0.020)	(0.020)	(0.021)	(0.022)	(0.022)	(0.022)	(0.022)	(0.022)	(0.022)	(0.021)
Constant	24.675***	25.539***	25.893***	25.934***	25.909***	25.566***	25.172***	24.680***	24.035***	23.832***
	(7.795)	(8.089)	(8.274)	(8.285)	(8.232)	(8.122)	(8.072)	(8.006)	(7.915)	(7.825)
Observations	2067	2067	2067	2067	2067	2067	2067	2067	2067	2067
Number of firms	123	123	123	123	123	123	123	123	123	123
F-stat	1.9	1.8	1.6	1.4	1.2	1.2	1.1	1.1	1.1	1.1

Note: All estimations include firm-country, country-year, and firm-year fixed effects. Standard errors clustered at the firm-country level. Innovation stock shares are the share of accumulated stock of patents of grey, clean, and dirty technologies over the total stock of patents of a given firm. Results from estimating Eq. (2) for lags of innovation between 11 and 20 years.

Table B.8. The role of fuel price salience under different specifications

	Dependent variable: Market share of car manufacturer i in country c in year t					
	k = 7					
	(1)	(2)	(3)	(4)	(5)	(6)
Fuel price in country c and year t	0.299**	0.254**	0.271**		0.296**	0.264**
× Share of *clean* patent stock of firm i in year $t-k$	(0.126)	(0.111)	(0.120)		(0.125)	(0.112)
Fuel price in country c and year t	-0.001	-0.001	-0.001		-0.001	-0.001
× Share of *clean* patent stock of firm i in year $t-k$	(0.001)	(0.001)	(0.001)		(0.001)	(0.001)
× google trend (average) in country c and year t						
Fuel price in country c and year t	0.059	0.115	-0.003	-0.081	0.064	-0.086
× Share of *grey* patent stock of firm i in year $t-k$	(0.254)	(0.247)	(0.276)	(0.278)	(0.251)	(0.274)
Fuel price in country c and year t	0.008***	0.008***	0.008***	0.008***	0.008***	0.007***
× Share of *grey* patent stock of firm i in year $t-k$	(0.002)	(0.003)	(0.003)	(0.003)	(0.002)	(0.002)
× google trend (average) in country c and year t						
Fuel price in country c and year t	-0.086	-0.072		-0.003	-0.087	-0.009
× Share of *dirty* patent stock of firm i in year $t-k$	(0.098)	(0.107)		(0.088)	(0.099)	(0.099)
Fuel price in country c and year t	0.000	0.000		0.000	0.000	0.000
× Share of *dirty* patent stock of firm i in year $t-k$	(0.001)	(0.001)		(0.001)	(0.001)	(0.001)
× google trend (average) in country c and year t						
Fuel price in country c and year t	-0.998		-0.966	-0.665	-0.976	-1.137
× Log(stock of all patents of firm i in year $t-k$)	(0.738)		(0.728)	(0.694)	(0.765)	(0.873)
Fuel price in country c and year t	0.098	0.002	0.11	0.017		0.288
× Log(vehicles sold by firm i in country c in 2005)	(0.366)	(0.391)	(0.370)	(0.379)		(0.392)
Time trend in year t	-0.045**	-0.046**	-0.043**	-0.042**	-0.045**	
× Log(vehicles sold by firm i in country c in 2005)	(0.020)	(0.022)	(0.020)	(0.021)	(0.021)	
Constant	24.485***	22.421***	23.292***	23.396***	24.950***	8.082***
	(8.422)	(7.804)	(8.254)	(8.338)	(8.648)	(2.784)
Observations	2 067	2 067	2 067	2 067	2 067	2 067
Number of firms	123	123	123	123	123	123
F-stat	2.8	2.5	2.2	2.5	3.1	2.9

Note: All estimations include firm-country, country-year, and firm-year fixed effects. Standard errors clustered at the firm-country level. Innovation stock shares are the share of accumulated stock of patents of grey, clean, and dirty technologies over the total stock of patents of a given firm. Results from estimating Eq. (2).