Environmental performance and firm strategies in the dutch automotive sector

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ABSTRACT

This paper explores how automotive firms positioned their portfolio since the introduction of energy labels for cars. Using data on product characteristics of automobiles offered on the Dutch market over the period 2001–2010, we analyse how car manufacturers' product portfolios have changed. Portfolio changes by the top 15 car manufacturers in the Netherlands are analysed. Though the analysis shows that manufacturers move in a similar direction towards a portfolio with cleaner vehicles, the different manufacturers have chosen very different portfolio management strategies. In particular the manufacturers that followed a portfolio strategy of relatively large propulsion efficiency improvements without large weight changes increased their sales numbers compared to other car manufacturers. Manufacturers lagging behind with CO_2 emission reduction performed weak in terms of sales.

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1. Introduction

Both in the EU and in the US energy-labelling or eco-labelling schemes are an increasingly popular instrument to stimulate the demand for and supply of more environmentally friendly goods (EPA, 2011; EU Directive, 1992/75/EC; EU Directive, 1999/94/EC). The main idea of energy-labelling schemes is that these labels will increase consumer demand for eco-friendly goods and, as a consequence, stimulate firms to produce and supply more of those goods. Firms can achieve a cleaner product portfolio by reducing the environmental impact of existing products, through adding products with low environmental impact to their portfolio, and/or by discontinuing the supply of their most polluting products. It has, however, been difficult to assess whether energy-labelling schemes realise their intended outcomes and in several studies no clear environmental effect of energy-labelling was found (AEA, 2011; OECD, 1997; Teisl et al., 2002).

Most studies focus on the demand side rather than on the supply side effects of emission reduction incentives such as energy labels and carbon taxes, as ultimately the behaviour of consumers determines the effectiveness of such incentives, e.g. (Noblet et al., 2006; Rogan et al., 2011; Small, 2012; Beck et al., 2013; Van der Vooren and Alkemade, 2012). An exception is Jamalpuria (2012), who demonstrates that from a social welfare perspective it is desirable that governments provide tax incentives to firms to encourage the use of energy labels. Thus by attaching financial incentives to the labels, policymakers have an additional influence on firm and consumer behaviour. For policymakers it is also important to understand the effects of these incentives as it is an intermediate step in realising the intended benefits of energy-labelling schemes. The extent to which firms adapt their product portfolios should be taken into account when assessing the effects of energy labels and other emission reduction incentives. Firms decide on product portfolio decisions not only in relation to consumers, but also with

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respect to the (expected) strategies of other firms, and other incentives provided by EU and national regulations. These product portfolio decisions of firms are the topic of the current paper.

Energy labels provide consumers with information about the environmental performance of a product (Gallastegui, 2002). Energy labels thereby introduce an additional product characteristic that consumers can take into account in their purchase decision (Truffer et al., 2001). Consumers differ in their preferences for environmentally friendly products, but environmental characteristics have generally gained importance in recent years (Banerjee and Solomon, 2003). For firms, environmental performance thus provide an additional source of consumer heterogeneity. Firms can exploit this heterogeneity through strategic product positioning (Anderson et al., 1992). For firms, the introduction of energy labels thus creates opportunities for repositioning. The results of a firm's positioning strategy therefor strongly depend on whether competitors choose similar or different strategies. The aim of this paper is to investigate firms' behaviour since the introduction of energy-labelling schemes. Our application domain is the automotive sector. The car market is one of the largest for durable goods and is a large contributor to the emissions of greenhouse gasses (IPCC, 2011). In 2001 the EU implemented a labelling scheme for cars (EU Directive, 1999/94/EC), and more recently the US adopted this policy instrument (EPA, 2011). The main research question of the paper is therefore:

How have the portfolios of car manufacturers changed with the introduction of energy labels?

To study how the introduction of a new characteristic affects changes in product portfolios we make use of evolutionary theories of economic change (Nelson and Winter, 1982). Evolutionary theories describe that firms need to adapt to changes in the selection environment in order to survive (Metcalfe, 1994; Nelson and Winter, 1982; Silverberg et al., 1988). The introduction of a new characteristic such as energy labels is a typical situation of a change in the selection environment. In particular theoretical extensions of Lancaster's characteristics approach (Lancaster, 2002) by Saviotti and Pyka (1995, 2008a,b) and Saviotti and Metcalfe (1984) on products clouds and characteristics contribute to insights into portfolio change. Portfolio dynamics can be observed empirically when the cloud of products change position and shape, showing differentiation or specialisation strategies of firms and changes in the intensity of competition.

The empirical base for the analysis is a unique database consisting of all 41,000 car models (versions) that were offered on the Dutch car market between 2001 and 2010. The database contains information on performance characteristics of the car models, including energy labels and CO_2 emissions but also characteristics describing fuel type, weight and type of car (for example, hatchback or sedan). Using this database we determine the product portfolio strategies regarding three strongly related characteristics: the CO_2 emissions, the weight and the list price of the cars. Changes in car manufacturers' portfolios regarding these characteristics provide us with insight into firm strategies and competition in the automotive sector. The results of the analysis show that manufacturers move in a similar direction towards cleaner vehicles, however the different manufacturers have chosen very different portfolio management strategies. Manufacturers with relatively large reductions in CO_2 emissions tend to perform better than manufacturers with relatively small reductions.

The remainder of this paper is structured as follows: Section 2 provides a background on evolutionary theories of economic change and product portfolios, Section 3 describes the Dutch car market and the introduction of energy labels. Section 4 provides the data and methods. Section 5 presents the empirical analysis and Section 6 concludes.

2. Theory

In evolutionary theories of economic change, the firm is usually the unit of selection. A firm with a high fitness, i.e. a high degree of adaptation to its selection environment, will increase its sales numbers, profits or other performance measures compared to other firms with lower fitness (Metcalfe, 1994; Nelson and Winter, 1982; Silverberg et al., 1988). Cantner et al. (2012) argue that in reality it is not the firm but its multiple products that are subject to direct market selection. The fitness of the firm is determined by the aggregated fitness of its individual products. However, for multi-product firms this aggregation might be complex as they are influenced by different, possibly interrelated, selection processes in parallel (Cantner et al., 2012). This paper is therefore focused on the product portfolio of a firm.

This paper describes the products in a firm's portfolio by using the characteristics approach, in which consumers select one of the products based on their preferences for a number of characteristics that the product possesses (Hotelling, 1929; Lancaster, 2002; Saviotti and Metcalfe, 1984). According to Anderson et al. (2006) the characteristics approach provides an adequate representation of product competition. Consumers thus have preferences for the characteristics of the product and not for the product as such. As long as a homogenous product population is analysed a rather similar set of characteristics can be expected. The products of various firms and the different products within a single firm's portfolio differ in their values or performance levels of the same characteristics (Saviotti and Pyka, 1995).

Saviotti and Metcalfe (1984) extended the characteristics approach by representing a technological model by its performance on two sets of characteristics: the internal structure of the product's technology and the services provided by the product technology to consumers, which are labelled the technological characteristics and the service characteristics, respectively. The services performed for its consumers follow from the technological characteristics of the product technology. So, innovation in technological characteristics determines changes in the environmental impact of the product, i.e. the service characteristic. Because consumers select on service characteristics and not so much on changes in technological characteristics, in this paper we focus mainly on changes in service characteristics. Graphically, each product can be represented by one point in an *n*-dimensional space of characteristics. Since firms produce multiple products with different performance on the service characteristics, the technological population is represented by a cloud of points. Fig. 1 illustrates different

situations of the product portfolio of two competing firms in an industry. A firm's competitive position is determined by the part of the total product cloud produced by all firms in the industry that is covered by a firm's product portfolio. The more overlap between the firms' portfolio, the more intensive their competition is. A more elaborate discussion of the different portfolio changes illustrated in Fig. 1 will be presented towards the end of this section.

Evolutionary technological change means that product portfolios and competition are dynamic. Product portfolios can change position and shape, or completely new product populations can emerge (Saviotti and Mani, 1995). In this paper product portfolio dynamics are analysed as a response to the introduction of a new service characteristic. Such technological change can be induced by changes in the selection environment of the firm or through product positioning strategies enabled by innovation. In practice it may be difficult to distinguish these two motives as they may occur simultaneously.

The notion of selection environment comprises factors that affect the competition process such as consumer demand, governmental policy and availability of resources (Lambooy, 2002; Nelson and Winter, 1982). If changes occur in the selection environment, due to changing consumer preferences, government intervention or depletion of resources, the firm has to adapt its strategies in order to survive. For example, the EU introduced energy labels for cars to stimulate the supply of and demand for more environmentally friendly cars, which is desirable from a societal point of view. While the underlying technical characteristic already existed, energy labels provide a new service characteristic to consumers, i.e. environmental performance. The introduction of environmental performance as new service characteristic changes the selection environment since it is expected that consumers take environmental performance of a car into account more when energy labels are provided. This effect is the main policy rationale for the introduction of energy-labelling schemes. In addition, labels enable the use of financial policy instruments to influence the purchase behaviour of consumers. However, consumers will evaluate this additional service characteristic differently. Firms can exploit this additional source of consumer heterogeneity through differentiation within their own product portfolio and by setting their own portfolio apart from the portfolio of competitors.

The introduction of a new characteristic might be supply driven as well, when firms innovate and change their portfolio strategy in order to escape competition (Swann, 2009). When firms position themselves in unoccupied regions of the characteristics space they might temporarily escape the competition and benefit from monopoly power (Saviotti and Pyka, 1995). Such a first-mover advantage holds until other firms take that position as well. The motivation to innovate, i.e. to escape from the competition, is higher when the competition is more intense (Saviotti and Pyka, 2008a). Whether or not a firm is actively involved in a neck-and-neck race to have the best product with regard to the new characteristic, the strategy and search process to reposition its portfolio of products might vary significantly from other firms. Search activities have an incremental nature when changes occur within the existing product population and a more radical nature when a new product population emerges (Saviotti and Pyka, 2008a). Search activities are constrained by a firm's current position and routines (Nelson and Winter, 1982; Teece et al., 1997).

In reality, the co-evolution of the selection environment on the one hand and changing portfolio strategies on the other hand, will cause the dynamics in product portfolios. These dynamics can be observed when the clouds of products change
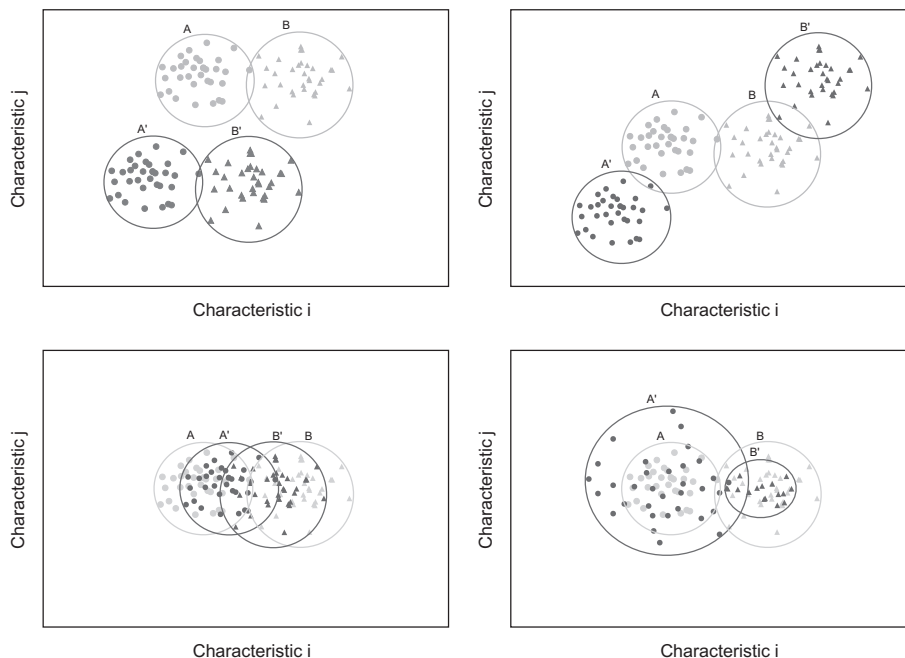

Fig. 1. Firm A and firm B are competing and change their portfolio of multiple products towards A′ and B′. Four typical changes in product clouds may occur: a change in industry product cloud (top left); increase in range and decrease in density (top right); an increase in density and competition intensity (bottom left); a generalisation strategy by firm A and a specialisation strategy by firm B (bottom right).

position and shape or when completely new clouds emerge (Saviotti and Mani, 1995). Fig. 1 illustrates four typical changes in product clouds with two competing firms, A and B. The position of the industry product cloud, A + B, will change position when the product portfolios of both firms move in a similar direction. Fig. 1 (top left) shows the shift from firm A to A′ and firm B to B′. Fig. 1 (top right) illustrates that if firm A and B move in opposite directions the range increases and the density of the cloud decreases. Fig. 1(bottom left) shows that the more similar the product portfolio of firm A and firm B become, the higher the density of the industry product cloud, and the more intense is the competition amongst the firms (Saviotti and Pyka, 2008a). A higher degree of differentiation therefore decreases the intensity of the competition. Fig. 1(bottom right) illustrates that when a firm (firm A) exploits the additional consumer heterogeneity through differentiation, this decreases the density of its product portfolio, at least when the number of products remains the same. In this case firm A becomes a generalist while firm B in this figure tends towards specialisation.

With the introduction of a new service characteristic it is not necessarily the case that firms exploit consumer heterogeneity by differentiation, as illustrated by the seminal paper by Hotelling (1929). Hotelling shows that two competing firms tend to agglomerate on a particular product dimension in an effort to catch as many consumers as possible that are served by the other firm. Anderson et al. (1992) refine these results and argue that firms agglomerate on pre-existing dimensions while they become more dispersed on a new and additional dimension when consumers attach more importance to this new dimension. The introduction of a new dimension thus creates different opportunities for repositioning (Anderson et al., 1992). The results of a firm's positioning strategy thereby strongly depend on whether competitors choose similar or different strategies.

In this paper we also study empirically how the introduction of a new service characteristic changes the product cloud in general and how firms have different strategies to reposition their portfolio of products in particular. In order to answer this question we study changes in the portfolio position of car manufacturers since the introduction of graded energy labels. We thereby focus on the search and strategy process of car manufacturers that have an incremental nature, leaving out entirely new types of vehicles such as hydrogen or battery electric vehicles. The technological population exists of cars that have a fossil fuel powered internal-combustion engine as their principal propulsion. Hence, changes in the position and shape of the cloud of products will be studied, while the emergence of new clouds is not taken into account.

3. The 'Dutch' car market

The 'Dutch' passenger car market provides an interesting case to study how the introduction of a new service characteristic changes the product cloud and the portfolio position of firms. With the introduction of energy labels in 2001 environmental performance emerged as a new service characteristic which consumers and firms may take into account. The 'Dutch' car market is put in between quotes as no significant automobile production takes place in the Netherlands (48,025 passenger cars in 2010 (OICA, 2012)). In addition, none of the major passenger car manufacturers have the Netherlands as their home country. Despite the fact that most cars are imported, with more than 7 million passenger cars on its roads (2010) (European Union - Eurostat, 2012), the Netherlands is the sixth largest automotive market in Europe. The car density, i.e. the number of passenger cars per one thousand inhabitants was 467 in 2010 (European Union - Eurostat, 2012). About half a million cars were sold in the Netherlands in 2010 (BOVAG-RAI, 2006b).

In this paper we will analyse the portfolio changes from 2001 to 2010 by the fifteen car manufacturers with the highest market shares on the Dutch market in 2010. Fig. 2 below shows the sales figures of the fifteen manufacturers on the Dutch market for the years 2001 and 2010. The fifteen selected companies represent 82.5% (77.7%) of the total Dutch car market in 2010 (2001).
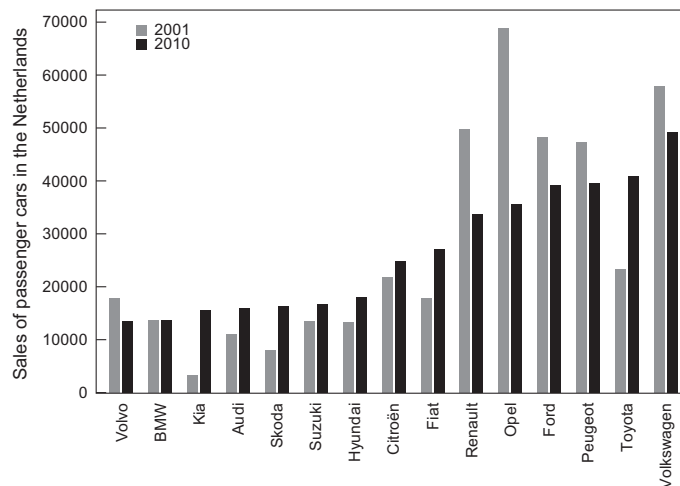

Fig. 2. Sales of passenger cars in the Netherlands in 2001 and 2010. Source: (BOVAG-RAI, 2006a; BOVAG-RAI, 2006b).
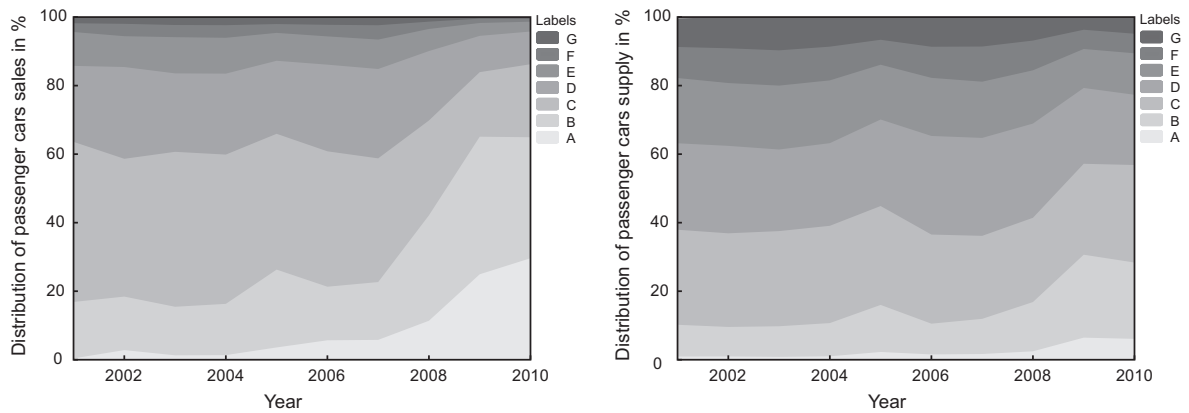
Fig. 3. Distribution of passenger car sales (left) and supply (right) over energy labels. Source: (CBS, PBL and Wageningen UR, 2012) based on data from RDW.

3.1. The Dutch energy-labelling scheme

In order to create a more sustainable and environmentally friendly car market the EU agreed upon a graded energy-labelling scheme for cars (EU Directive, 1999/94/EC). The energy label is a new service characteristic. It enables consumers to weigh their preferences for the environmental impact of a product against the price and other important service characteristics of the product (Sammer and Wüstenhagen, 2006).

The graded labelling scheme was implemented in the Netherlands in 2001. The mandatory energy labels show the relative performance of a car regarding CO_2 emissions in its own class (determined by length and width of the car). On a scale of A to G an A-label indicates that a car belongs to the cleanest vehicles in its class, while a G-label indicates the most polluting cars in terms of carbon emissions. The labels are dynamic in the sense that the standards may become stricter from year to year when cleaner vehicles become available. For example, a car that is labelled A one year, can be labelled B in following year (AMvB BWBR0011761, 2012).

The Netherlands had a slow reduction of CO_2 emissions of new passenger cars for years, compared to other EU countries. However, thanks to progressive tax policies regarding greening of the Dutch car market, the CO_2 emissions of new passengers in the Netherlands were below the European average again in 2009 (Geilenkirchen et al., 2012). Fig. 3 shows the share of each label in the total sales of the Netherlands. Both the demand for (Fig. 3 left) and supply of (Fig. 3 right) A and B labelled cars tripled from 2001 to 2010. The increase in the presence of A and B labelled cars took off by 2006 and increased rapidly by 2008. This increase is explained by tax policies and the fact that standards were not adjusted between 2007 and 2009, even though technological progress took place (CBS, PBL and Wageningen UR, 2012).

With the introduction of tax policies in 2006 the Dutch government attempted to add momentum to the energy labels. A feebate system[1] based on these labels was introduced in 2006.[2] The amounts shown in Table 1 are in addition to other private vehicle taxes consumers had to pay. Consumers buying cars with a relatively green label receive a rebate, while those buying cars with a dirty label pay a fee. In 2008 the Dutch government started with a CO_2 tax as well. In 2010 this tax, based on the absolute CO_2 emission of cars, completely replaced the feebate system as well as other private vehicle taxes. After 2010, also the monthly taxes that consumers pay for the private use of company cars (leasing) have been directly related to absolute CO_2 emissions. Kieboom and Geurs (2009) found that the rebates for A and B labelled cars were effective, but the limited number of cars with an A or a B label hampered the success. However, the low fees compared to the purchase price of the vehicle were not at all effective.

The second explanation for the rapid increase of A and B labelled cars is the labelling procedure applied by the Dutch government. In 2008 and 2009 the government kept the standards for adjudging the labels fixed to the 2007 level. As cars became cleaner in these years a significant share of them received an A or B label. The standards for the labels were revised again in 2010 (CBS, PBL and Wageningen UR, 2012).

Since car prices are directly linked to energy labels and CO_2 emissions these service characteristics of environmental impact guide consumers in their purchase decision. In this paper CO_2 emission as the key determinant of energy labels will be used as the new service characteristic. The reason for using absolute CO_2 emissions instead of labels is threefold. First, more and more financial policy incentives are based on absolute CO_2 emissions. Secondly, energy labels are established based on parameters provided by the government. As we explained above the Dutch government does not consistently measure and

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[1] A feebate system is intended as a self-financing system of fees and rebates that are used to provide carrot-and-stick incentives to change the behaviour of consumers. For more information on the effectiveness of feebate systems see Brand et al. (2013).

[2] A different scheme was put in place for hybrid cars.

Table 1
The Dutch feebate system for petrol-based passenger cars: 1-7-2006 to 31-1-2008 (Top), 1-2-2008 to 31-12-2009 (Bottom).

Label A >20% lower consumption	Label B 10–20% lower consumption	Label C 0–10% lower consumption	Label D 0–10% higher consumption	Label E 10–20% higher consumption	Label F 20–30% higher consumption	Label G >30% higher consumption
−€1000	−€500	0	+€135	+€270	+€405	+€540
−€1400	−€700	0	+€400	+€800	+€1200	+€1600

update these parameters, and therefore using the labels might give a disturbed picture of technological progress and positioning of manufacturers. Thirdly, absolute CO_2 emissions are used because they are measured for all vehicles sizes in a similar manner.

4. Data and methods

4.1. Data description and sample selection

We use a unique supply-side panel database of cars offered on the Dutch market to study how the portfolio of car manufacturers has changed with the introduction of energy labels. The 'carbase' database available at http://www.autoweek.nl encompasses more than 3400 different car models and 60,000 different car versions offered on the Dutch market from 1980 onwards.[3] The dataset presents the performance on more than 150 characteristics of each of these car versions. Among others the characteristics provide insights into the engine technology, car size, list price and standard accessories.

The characteristic we are most interested in this paper, the CO_2 emissions of cars, has been structurally recorded in the dataset since the introduction of energy labels for cars in 2001. Besides CO_2 emissions we also take into account the list price and the weight of the car versions. List prices include private vehicle taxes, but might differ from the actual transaction prices. However, corrected for inflation, the list price is often used as indicator to study firm strategies and price changes (Uri, 1988; Wells et al., 2013). Price and CO_2 emissions are linked due to policy instruments, as noted in the final paragraph of the previous section. The CO_2 emissions and the purchase price are therefore important factors that guide the purchase decisions of consumers. The weight of cars is taken into account to distinguish between the different search strategies that manufacturers may have adopted to change their portfolio position. For example, reducing CO_2 emissions of a portfolio, while keeping weight fixed, reflect propulsion efficiency improvements. And reducing CO_2 emissions of the portfolio by reducing the weight of the portfolio reflects either of two strategies. Manufacturers may innovate regarding the technological design of a vehicle or they may put an end to their heavy vehicles and embrace lighter vehicles.

Moreover, the three characteristics, CO_2 emissions, price and weight of car versions are highly correlated.[4] Together they provide a picture of how manufacturers have adapted their portfolio of car versions. Table 2 provides the descriptive statistics of the three characteristics. It shows that the average CO_2 emissions decreased from 2001 to 2010, while the average weight and price increased.

4.1.1. Car models and versions

Consumers can choose between many different versions of a single car model. These versions may differ on the product characteristics that are the focus of the analysis such as CO_2 emissions, price and weight and different versions of the same car model may even be assigned different energy labels. The version is therefore the appropriate level of analysis. For example, the Ford Focus is available in the Netherlands as a four-door sedan, a five-door hatchback and a five-door station wagon. Each of these model variants has a range of versions, from a low-priced simple car to a more expensive luxury car, with a petrol or diesel engine. Cantner et al. (2012) aggregate over different versions using the model variant as data point. Since we focus on CO_2 emissions, which can vary substantially among versions of a single model variant, this would be problematic in our case. So, we include each unique car version in our analysis. Note, however, that a 'new' car version introduced by a manufacturer might actually be a version that is not substantially different from existing car versions. Car manufacturers that use this strategy change the position of their portfolio without technologically introducing something new to the market.

4.1.2. Sample selection

A comparison between the portfolio changes of the 15 selected manufacturers is possible only for rather homogeneous portfolios of car versions. Therefore we choose to take into account only those versions that qualify as a family car, which we define as four or five-door cars with a petrol engine as their principal drivetrain.[5] So, versions with diesel engines that are

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[3] The data in the database is submitted by the car manufacturers to Autoweek.
[4] Correlation between key variables in 2010: Weight CO_2 emissions (.860); weight price (.859); CO_2 emissions price (.832).
[5] This is in line with the criteria for the family car of the year contest of the ANWB, the Dutch Automobile Association.

Table 2
Descriptive statistics of characteristics incorporated in the analysis (1716 car versions in 2001 and 3077 car versions in 2010).

	Characteristics	Mean	(SD)	Median	Min	Max
2001	CO_2 emissions in g/km	208	(40)	202	118	396
	Weight in kg	1297	(228)	1280	730	2235
	Price in 2001 Euros	29,092	(16,393)	24,797	7576	173,072
2010	CO_2 emissions in g/km	177	(41)	169	89	375
	Weight in kg	1399	(269)	1402	775	2485
	Price in 2001 Euros	33,306	(22,599)	27,136	5856	179,797

mainly used in the professional market, sports cars, pick-ups and jeeps for example, are excluded from the analysis. While diesels capture increasingly large shares of the new vehicle market in Europe (Schipper and Fulton, 2013), this trend is not observed in the Netherlands. In 2010, petrol cars represented 75.4% of the new vehicle market in the Netherlands, while diesel cars accounted for 20.4% (BOVAG-RAI, 2006b).[6] In the period between 2001 and 2010 12,961 different family car versions have been offered by the fifteen selected companies, of those car versions 4793 are in our sample, as we focus on the years 2001 (1716 versions) and 2010 (3077 versions).

4.2. Steps for analysing portfolio strategies

The portfolio strategies of manufacturers are analysed in three steps that are introduced here. A more detailed and formal description of each step will be integrated in the empirical analysis. First, changes in the product portfolio of manufacturers are analysed regarding CO_2 emissions and the purchase price, because these are important factors that guide the purchase decisions of consumers. We measure changes in the position, the range and the density of car manufacturers portfolios. Secondly, an analysis is performed towards the search strategies that manufacturer performed in order to realise the reduction in CO_2 emissions. Hereby the relative portfolio changes regarding weight and CO_2 emissions compared to industry changes are used to determine the search strategy of manufacturers. A cluster analysis is performed to group manufacturers with similar portfolio strategies. Thirdly, an evaluation of the portfolio change and search strategies is performed. Strategies are evaluated based on the relative increases in car manufacturers' sales.

5. Empirical analysis

5.1. Measuring portfolio change

A plot of the family car versions offered by a manufacturer on two product characteristics is sufficient to create a static picture of the product cloud as in Saviotti (1985). Changes in such a product cloud become visible when the car versions offered in two different years are presented in one graph. For example, Fig. 4 (left) plots the CO_2 emission (grams per kilometre) and the price of all BMW versions in our sample for 2001 and 2010. To analyse how the portfolio changed shape and position we measure, where the core of the portfolio moved, how the range of the portfolio changed and whether the density of the portfolio increased or decreased from 2001 to 2010. Three indicators are used to determine portfolio change: the median[7] representing the core of the portfolio at time t, boxplots to provide insight into the range in which products are offered, and the average distance of the versions in the portfolio to measure the density.

The large black dots in Fig. 4 indicate the median values, i.e. the core of the portfolio. Changes in the core (median) of the portfolio provide a quantified measure of shifts in the product cloud of a manufacturer. A non-parametric Mann–Whitney test (Mann and Whitney, 1947) is used to analyse whether the portfolio of versions in 2001 is similar to the portfolio of versions in 2010, regarding a characteristic. For example, a significant Mann–Whitney test indicates that the CO_2 emissions of the 2001 portfolio are larger than the CO_2 emissions of the 2010 portfolio. The figure illustrates that the core position (median of car versions) of BMW in 2010 is cleaner but slightly more expensive than in 2001.

The boxplot for CO_2 emissions on the right of Fig. 4 shows that BMW offered versions in a range from 140 to 361 g CO_2/km in 2010. BMW expanded its range of versions in terms of CO_2 emissions; on the one hand it shifted its focus towards cleaner vehicles, but on the other hand also increased the emissions of its most polluting models. In terms of prices, changes are small: BMW only slightly increased its price range.

The average distance between car versions in BMW's portfolio increased from .16 in 2001 to .19 in 2010.[8] Despite an increase in the number of car versions, from 164 in 2001 to 393 in 2010, the portfolio of BMW is less dense and therefore more diversified.

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[6] The share of the new vehicle market in the Netherlands captured by diesels fluctuates between 20% and 28% in the period between 2001 and 2010.

[7] The median is preferred over the average as it is less sensitive for outliers.

[8] The average distance is based on the Euclidean distance. Both CO_2 emissions and price are normalised with respect to all versions in the selected sample of the 15 manufacturers.
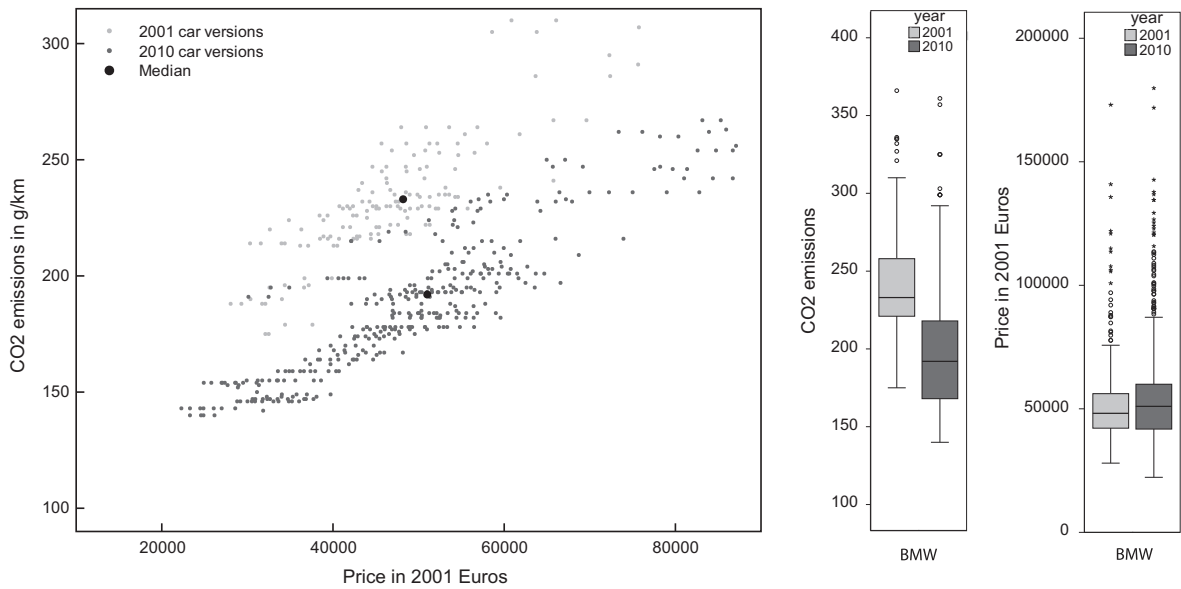
Fig. 4. Left: overview of the BMW's portfolio of "family" car versions up to 90,000 euro in 2001 and 2010. Right: boxplots provide an overview of range of BMW's portfolio of "family" car versions in terms of CO_2 emissions and price in 2001 and 2010.

5.2. Portfolio change

Table 3 provides an overview of the portfolio positions of the manufacturers in 2001 and 2010. For each manufacturer a comparison between the 2001 and 2010 portfolio is conducted with a Mann–Whitney test. Besides the median values, the table indicates the Mann–Whitney's U statistic, the effect size r and its significance.[9] The table shows that the CO_2 emissions of each manufacturer decreased significantly from 2001 to 2010. Effect sizes range from $-.15$ (Volvo) to $-.63$ (Fiat). The cloud of car versions of 'All' car manufacturers together moved from 202 g/km in 2001 to 169 g/km in 2010. With respect to price changes are small (Wells et al., 2013), only the portfolio position of Fiat, Skoda, Toyota, Volkswagen and Volvo changed significantly. Of these five manufacturers Fiat ($r = -.30$) and Toyota ($r = -.15$) reduced their prices, while Skoda ($r = .14$), Volkswagen ($r = .15$) and Volvo ($r = .39$) became more expensive. The cloud of 'All' car versions moved from 24,797 Euro in 2001 to a price of 27,136 Euros in 2010.

Fig. 5 shows the portfolio position of the manufacturers with respect to price and CO_2 emissions. The arrows illustrate the direction and size of the change from 2001 to 2010. The figure shows that all manufacturers lowered the CO_2 emissions of their portfolio and that there is a correlation between price and CO_2 emissions. This correlation is mainly caused by engine size an weight, although registration taxes are increasingly dependent on CO_2 emissions. Car versions with low CO_2 emissions become relatively less expensive, while polluting cars become more expensive. The figure shows that the portfolios of Fiat and Suzuki are the most affordable and least polluting. However, Toyota is a close third with respect to CO_2 emissions. The high-end of the market is covered by Volvo, BMW, and Audi, of which Audi and BMW made substantial improvements in reducing the CO_2 emissions. Volvo became much more expensive.

The last two columns of Table 3 show the number of cars versions in the portfolio. Except for Opel, all manufacturers increased the variety of car versions on offer. This number almost doubled in ten years' time. This does not necessarily mean that all manufacturers increased the range in which versions are offered. The boxplots in the Figs. 6 and 7 below show the product range per manufacturer on the price characteristic (Fig. 6) and on the CO_2 emissions characteristic (Fig. 7).[10]

In Fig. 6 the price range of the car manufacturers up to 100,000 Euro is presented in ascending order with respect to the median price in 2010. The figure shows that the price range in which manufacturers offer versions is larger for manufacturers that focus on the high end of the market. Most firms increased their range from 2001 to 2010, except for Toyota, which discontinued most of its more expensive car versions. Quite some manufacturers started to sell more exclusive versions (or premiums cars) such as Volkswagen and Volvo, and to a lesser extent Hyundai and Skoda.

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[9] The test statistic U is based on the sum of ranks for the portfolio in a year. The smaller the U (taking into account the number of car versions in each year), the less likely it is that the difference has occurred by chance. The significance illustrates the two-tailed probability that the test statistic is a chance result. If significant this indicates that the 2001 portfolio had significantly higher CO_2 emissions than the 2010 portfolio. And, a larger effect size indicates a larger difference between the 2001 and 2010 portfolio (Field, 2009).

[10] The circles represent outliers between 1.5 and 3 interquartile ranges from the edge of the box. Stars represent outliers farther than 3 interquartile ranges from the edge of the box.

Table 3
Comparison of the portfolio of car versions in 2001 and 2010. Median values represent the portfolio position in 2001 and 2010. Mann–Whitney test with U is Mann–Whitney's U statistic, r is the effect size estimate.

	CO_2 emissions in g/km				Price in 2001 Euros ($\times 1000$)				No. of car versions	
	2001	2010	U	r	2001	2010	U	r	2001	2010
Audi	230	175	11,106	−.51***	42	42	29,596	.02	171	340
BMW	233	192	12,426	−.49***	48	51	34,379	.05	164	393
Citroën	191	167	1177	−.45***	23	24	3056	.04	44	132
Fiat	201	146	318	−.63***	18	15	931	−.30***	37	80
Ford	190	179	6980	−.37***	22	25	15,389	.21	127	195
Hyundai	190	152	1390	−.32***	17	18	2941	.12	38	133
Kia	220	165	359	−.55***	18	18	1522	−.04	30	108
Opel	200	167	15,988	−.43***	23	23	30,341	−.05	296	217
Peugeot	188	155	3649	−.57***	19	21	11,249	.03	132	165
Renault	177	174	11,739	−.20***	20	22	15,806	.03	164	186
Skoda	185	155	3599	−.42***	17	18	11,296	.14*	67	281
Suzuki	173	143	685	−.48***	15	13	1254	−.14	40	75
Toyota	196	155	1541	−.60***	25	23	4492	−.15*	80	136
Volkswagen	204	159	21,495	−.39***	26	28	46,136	.15***	245	322
Volvo	215	198	9971	−.15***	27	39	19,883	.39***	81	314
All	202	169			25	27			1716	3077

** Significance $p < .025$.
* Significance $p < 0.05$.
*** Significance $p < .01$.

In Fig. 7 the CO_2 emission range of the car manufacturers is presented in ascending order with respect to the median CO_2 emission in 2010. The figure shows that most manufacturers added versions with lower CO_2 emissions to their portfolio. In the case of Citroën en Peugeot this has even resulted in outliers at the bottom of the boxplot, because these versions are much cleaner than the rest of their portfolio.[11] From a theoretical perspective these firms may be said to attempt to temporarily escape the competition by positioning themselves in unoccupied regions of the characteristics space. Besides adding cleaner car versions, most manufacturers discontinued their most polluting versions. As described above, some manufacturers started to sell more exclusive versions. In particular for Volkswagen it is visible that these more exclusive versions come with high CO_2 emissions.

Since most manufacturers increased the number of versions as well as the range in which they offer cars, it is not obvious how the density of the product portfolios changed. The change in density of the individual manufacturers is presented in Fig. 8. In addition, the figure presents the change in density for the population of 'All' car versions in the sample. The x-axis presents the number of versions offered by the manufacturers (mean number of versions for 'All') and the y-axis presents the normalised average distance.[12] Both the average distance and the average number of versions of 'All' car versions increased from 2001 to 2010. It should be noted here that the manufacturers with a larger portfolio have a higher weight in the calculation of the average, as they offer more versions. The figure illustrates that larger firms tend to increase the average distance between the versions they offer. This is in line with Fig. 6, which shows that the manufacturers active in the high end of the market increased their range. These firms are also the manufacturers with the larger portfolios. The manufacturers that increased the density of their portfolio, i.e. lower average distance, are those firms with a smaller portfolio of car versions. Toyota and Volkswagen are the extremes with respect to changing their density. Toyota increased the density of its portfolio substantially, which corresponds to the fact that Toyota pulled their most polluting versions from the Dutch market (Figs. 6 and 7). Volkswagen decreased the density of its portfolio by offering more exclusive versions as well in 2010 (see Fig. 6). So, Volkswagen adopted a twin-track strategy by offering cars to consumers that prefer cars with low energy consumption as well as consumers that do not prefer these. However, Toyota adopted a strategy, where reduction of energy consumption is its guiding principle.

To summarise, since the introduction of energy labels each car manufacturer reduced the CO_2 emissions of its portfolio. However, the extent to which they reduced their CO_2 emissions differs substantially: it ranges between 3 g/km (Renault) and 55 g/km (Audi and Kia). Portfolio changes in terms of price are limited and go in both directions. The manufacturers with large reductions in CO_2 emissions added versions with lower CO_2 emissions to their portfolio, while discontinuing their most polluting versions. The manufacturers with lower reductions in CO_2 emissions also added versions with lower CO_2 emissions, but these firms tend to keep the more polluting versions in their portfolio as well. Many manufacturers increased the range in which they offer versions by adding more expensive versions to their portfolio. A more expensive version tends to have higher CO_2 emissions and therefore increases the range of their portfolio. However, the range of the product portfolio can increase in one direction while the core of the portfolio shifts into another direction. An increase in range tends to increase

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[11] It is not a coincidence that these car versions have similar CO_2 emissions, because they are practically the same cars sold by "different" manufacturers under the same holding company (PSA): Citroën's C1 and Peugeot's 107. This car is also sold by Toyota as the Aygo.

[12] The average distance is based on the Euclidean distance. Both CO_2 emissions and price are normalised with all car versions in the selected sample of the 15 manufacturers.
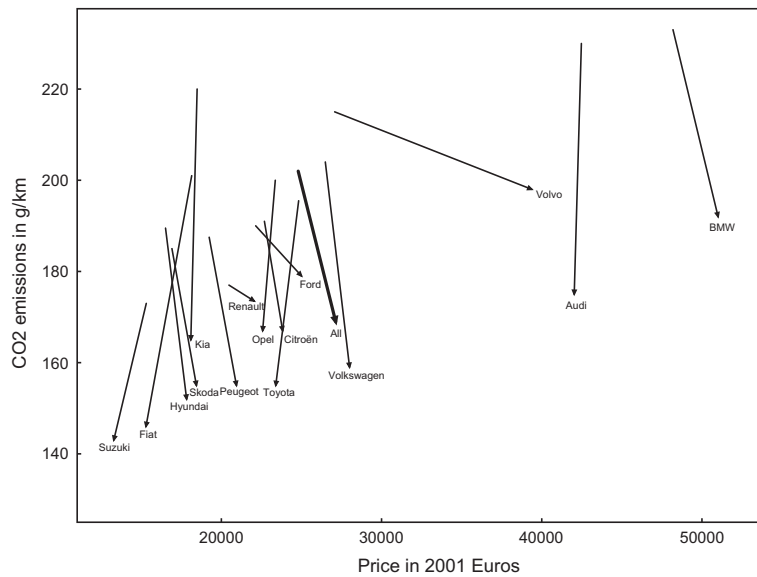
Fig. 5. Portfolio change of car manufacturers in median price and CO_2 emissions between 2001 and 2010.
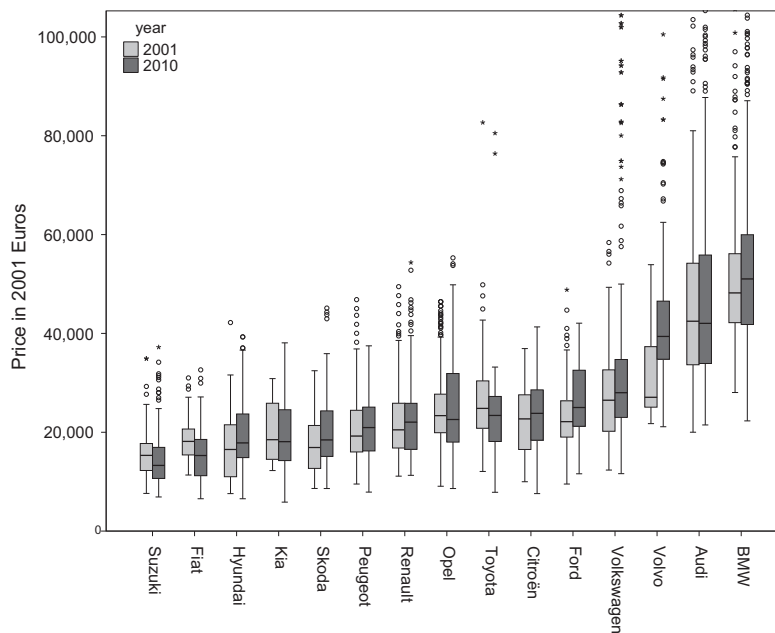

Fig. 6. Boxplots of manufacturers' portfolio of car versions in terms of price in 2001 and 2010.

the average distance between versions as long as the number of car versions is constant, which is not the case. The number of versions increased substantially. The manufacturers with large portfolios mostly decreased the density of their portfolio, while those with smaller portfolio mostly increased the density of the portfolio. So, manufacturers with a large portfolio became more generalised, while manufacturers with small portfolios became more specialised.

5.3. Search strategies of car manufacturers

The introduction of energy labels as a new service characteristic in combination with tax policies requires that car manufacturers reposition their portfolio and reduce their CO_2 emissions. The previous section showed that most manufacturers substantially shifted their portfolio towards lower CO_2 emissions, but only minor attention was paid to how manufacturers reduced the CO_2 emissions of their portfolio. This section therefore discusses the search strategies of car manufacturers towards lower CO_2 emissions.
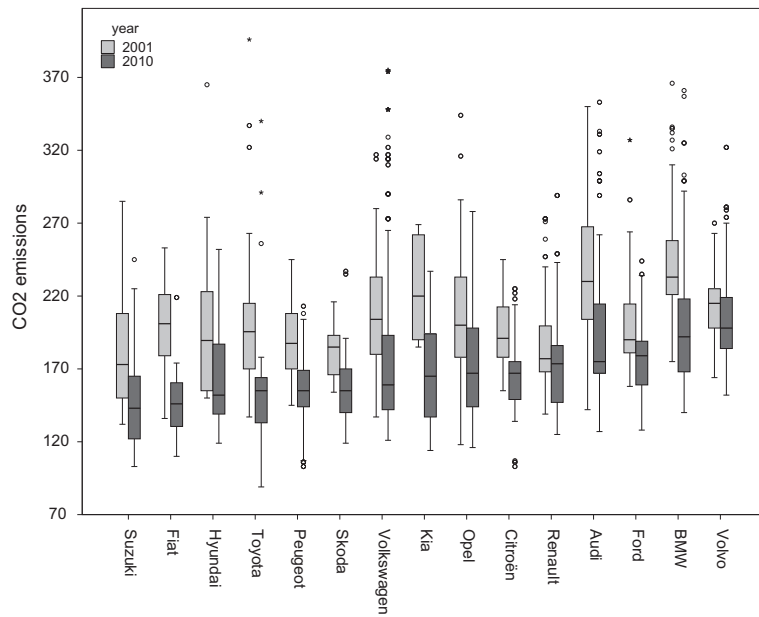
Fig. 7. Boxplots of manufacturers' portfolio of car versions in terms of CO_2 emissions in 2001 and 2010.
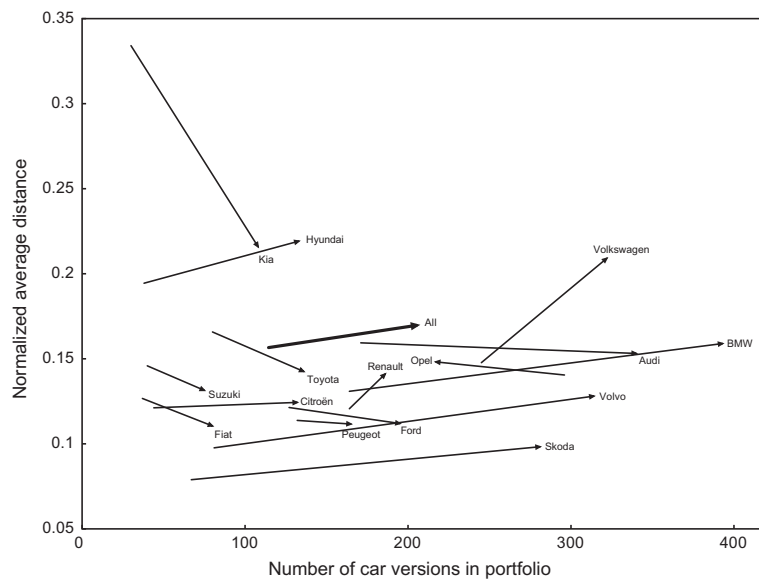

Fig. 8. Manufacturers' portfolio change in average distance and number of car versions and between 2001 and 2010. The average distance is based on the Euclidean distance. Both CO_2 emissions and price are normalised with all car versions in the selected sample of the 15 manufacturers.

There are basically two search strategies for car manufacturers to reduce the CO_2 emissions of their product portfolio. When firms use the first, incremental search strategy, firms innovate to reduce vehicle emissions while maintaining their performance levels on the other product characteristics. This innovation strategy is labelled an *efficiency improvement*: the per kilogram CO_2 emissions of the car decrease. A second search strategy for firms is a portfolio shift, where firms introduce lighter car models in their portfolio to meet the demand for vehicles with lower emissions. This *weight positioning* strategy

can be effective as about one-third of a passenger car's fuel consumption is directly dependent on its weight (European Commission, 2009). The data shows that weight reduction of existing car models appears not to be a manufacturer strategy.[13]

Another strategy for car manufacturers to reduce the CO_2 emissions of their product portfolio, which is not considered in this paper, is to increase the share of diesels in the portfolio. Diesel models may have up to 25% lower CO_2 emissions than their petrol equivalents, although in practice new diesels bought in 2009 had only 2% lower average CO_2 emissions than new petrol cars, because diesel buyers choose large and more powerful cars (Schipper and Fulton, 2013; Zachariadis, 2013).

Table 4 provides an overview of the portfolio positions of the manufacturers with respect to *weight* in kg and *propulsion efficiency* in CO_2/kg. Similar to Table 3 a comparison between the 2001 and 2010 portfolio is conducted for each manufacturer with a Mann–Whitney test. The table shows that reducing the weight of the portfolio was clearly not the key strategy to reduce CO_2 emissions. The portfolio position of 12 out of the 15 manufacturers increased significantly in terms of weight. Fiat and Kia are the only manufacturers that reduced the weight of their median car version, however, no significant reduction in the weight of the portfolio is observed. All car manufactures did significantly improve their portfolio with respect to propulsion efficiency.

In addition to insights into how these positions of car manufacturers changed over time, the relative changes in portfolio position are measured relative to the other manufacturers. The relative change in the portfolio position ΔRp_i^X on characteristic X of manufacturer i compares the absolute median (Mdn) portfolio position change $Mdn_{i,t-1}^X - Mdn_{i,t}^X$ of manufacturer i to the absolute median portfolio change of the car versions of all 15 manufacturers together $Mdn_{t-1}^X - Mdn_t^X$:

$$\Delta Rp_{i,t}^X = \left(Mdn_{i,t-1}^X - Mdn_{i,t}^X \right) \Big/ \left(Mdn_{t-1}^X - Mdn_t^X \right) \tag{1}$$

The relative portfolio changes of the car manufacturers are discussed by using a cluster analysis. A cluster analysis illustrates which firms had similar strategies. The relative change in weight and the relative change in propulsion efficiency are used as input variables for this cluster analysis. The relative portfolio change on *weight* and *propulsion efficiency* are presented for each manufacturer in Fig. 9. Both for the relative change in weight and the relative change in propulsion efficiency, a positive position refers to a favourable change from the perspective of a reduction in CO_2 emissions compared to the median of all manufacturers. On both variables manufacturers can perform above or below the median of all 15 manufacturers together, which means that there are four combinations of the two variables possible. Therefore we first ran a two-step cluster analysis in SPSS with four clusters to group the manufacturers into the different strategies. Fig. 9 shows the four clusters generated by SPSS. Although the *cluster quality* is good (.6), we also analysed this test with other numbers of clusters. We found that a cluster analysis with five groups not only has a higher *cluster quality* (.7), also it separates Volvo from Ford and Renault, which have a more favourable relative change in weight. The dashed eclipses in Fig. 9 show the two smaller clusters. Below we discuss the five clusters represented in Fig. 9.

5.3.1. Cluster 1

The first cluster represents Volvo in the bottom left corner of Fig. 9. Volvo changed its portfolio position from 2001 to 2010 such that they became relatively less efficient and heavier than the other manufacturers. Volvo is alone in the cluster because it acted differently from all other manufacturers. In terms of innovation to reduce CO_2 emission, this is the least effective strategy.

5.3.2. Cluster 2

The second cluster in the bottom right corner of Fig. 9 consists of Ford and Renault. Similar to Volvo the improvement of the *propulsion efficiency* (CO_2/kg) by Ford and Renault lags far behind that of the other manufacturers. With respect to the relative *weight* change, through the introduction of lighter models, they do relatively well, which means in this case that they increased less in weight than most other manufacturers. Although Ford and Renault perform relatively well on weight change, this is not enough to offset their weak improvement in propulsion efficiency, such that the relative CO_2 emission reduction is above the median.

5.3.3. Cluster 3

The third cluster, with Citroën, Peugeot, Opel, BMW and Skoda, is in the centre of Fig. 9. Particularly in terms of propulsion efficiency, these manufacturers have about a median rate of change: they have no clear performance above or below the median. Their performance on relative weight change is more diverse, but close to the median as well. This cluster is labelled the 'median cluster'.

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[13] We followed the evolution of popular car models (in the Netherlands) of each car manufacturer that was available from 2001 to 2010. We explicitly focused on the weight development of the car version with the lowest CO_2 emissions. The weight of these car models remained stable or increased over time (Zachariadis, 2008). Exceptions are the Skoda Fabia and Volvo V70, which that became 24 and 30 kg lighter, respectively. Other car models we followed are: Audi A4 4-doors sedan, BMW 3 4-doors sedan, Citroën C5 5-doors hatchback, Fiat Punto 5-doors hatchback, Ford Fiesta 5-doors hatchback, Opel Corsa 5-doors hatchback, Peugeot 206 5-doors hatchback, Renault Clio 5-doors hatchback, Suzuki Alto 5-doors hatchback, Toyota Yaris 5-doors hatchback, Volkswagen Golf 5-doors hatchback.

Table 4

Comparison of the portfolio of car versions in 2001 and 2010. Median values represent the portfolio position in 2001 and 2010. Mann–Whitney test with U is Mann–Whitney's U statistic, r is the effect size estimate.

	Weight in kg				Propulsion efficiency in CO_2/kg			
	2001	2010	U	r	2001	2010	U	r
Audi	1450	1550	1205	.25***	.17	.12	1205	−.78***
BMW	1515	1600	37,479	.13**	.16	.12	1657	−.75***
Citroën	1290	1461	3842	.24***	.15	.12	44	−.74***
Fiat	1175	1155	1225	−.14	.16	.13	50	−.78***
Ford	1274	1337	15,390	.21***	.16	.14	3002	−.64***
Hyundai	1199	1211	2936	.12	.17	.13	232	−.65***
Kia	1261	1217	1660	.02	.18	.13	43	−.69***
Opel	1260	1390	41,626	.25***	.16	.13	843	−.83***
Peugeot	1194	1371	14,391	.28***	.16	.12	259	−.84***
Renault	1225	1295	19,191	.22***	.15	.13	2488	−.72***
Skoda	1105	1190	11,728	.17**	.16	.13	1419	−.58***
Suzuki	965	995	1846	.19*	.18	.14	32	−.80***
Toyota	1225	1375	6394	.15*	.16	.12	165	−.81***
Volkswagen	1268	1403	53,301	.30***	.16	.12	2603	−.80***
Volvo	1,295	1468	18,007	.29***	.16	.14	4042	−.48***
All	1280	1402			.16	.13		

* Significance $p < 0.05$.
** Significance $p < .025$.
*** Significance $p < .01$.

5.3.4. Cluster 4

The fourth cluster representing Toyota, Volkswagen and Audi is at the top of Fig. 9. These manufacturers are ahead of the others mainly in terms of propulsion efficiency improvement. Kia alone could have been placed in the same cluster if propulsion efficiency had been the only variable. The weight change of Toyota, Volkswagen and Audi is just below or above the median.

5.3.5. Cluster 5

The fifth cluster at the right side of Fig. 9 represents Fiat, Hyundai, Suzuki and Kia. This cluster performs relatively well on weight change as well as propulsion efficiency. However, it is mainly Kia that has an outstanding position. Suzuki, Hyundai and Fiat mainly perform well on weight change, through their focus on introduction of lighter models. But in terms of propulsion efficiency these manufacturers have a mixed performance.

In summary, the search strategies of manufacturers to reduce their CO_2 emissions seems rather similar in absolute terms. However, a cluster analysis of the relative portfolio changes illustrates that there are differences in their strategies. Although 12 out of the 15 car manufacturers increased rather than reduced the weight of their portfolio, it still appears to be a valuable indicator to cluster the manufacturers by relative change in weight. In the next section we will present a rough evaluation of whether the search strategies and relative CO_2 reduction contributed to the car sales.
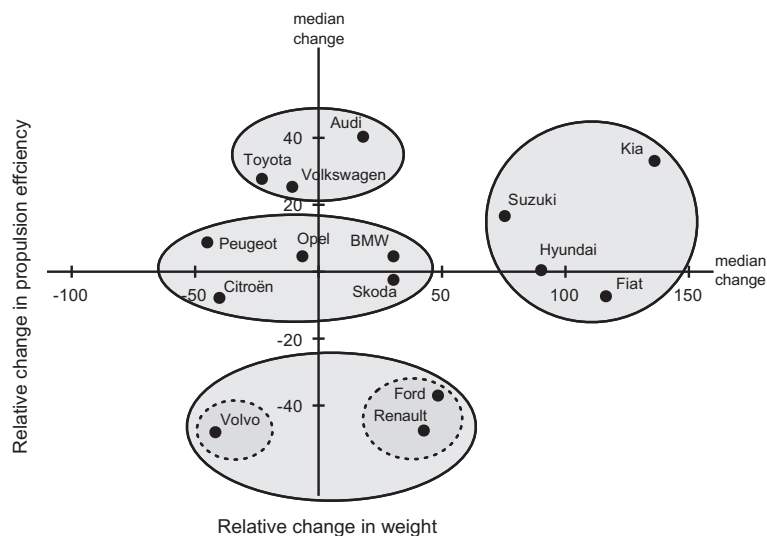

Fig. 9. Relative change in propulsion efficiency and weight of the 15 selected manufacturers. A positive position refers to a favourable change from the perspective of a reduction in CO_2 emissions. The eclipses show the clusters as a result of a two-step cluster analysis in SPSS (dashed lines with five clusters).
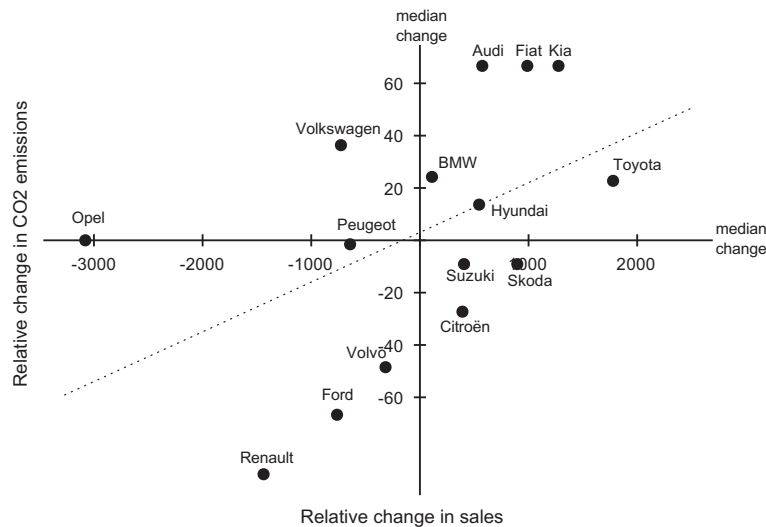
Fig. 10. Relative change in CO_2 emissions and sales of the 15 selected manufacturers. A positive position refers to a favourable change in terms of CO_2 emissions and sales.

5.4. Evaluation of search strategies

Fig. 9 shows the relative change in weight and the relative change in propulsion efficiency of the 15 car manufacturers. The next step is to evaluate how the relative performance of the manufacturers on change in CO_2 emissions affects their relative change in sales. We use the aggregate passenger car sales of each manufacturer as an indicator for the performance of its positioning strategy. Because both petrol cars and family cars are the majority of the car sales in the Netherlands this is a relevant performance indicator (exact numbers of the combination of petrol cars and family cars are not publicly available). Only Volvo and Skoda have a minority of petrol car sales in 2010, 39% and 48% respectively.

The sales figures are used as a performance indicator in the following way: The relative change in sales $\Delta S_{i,t}$ of manufacturer i at time t is calculated as the absolute change in sales $Q_{i,t-1} - Q_{i,t}$ relative to the mean change in sales of the 15 manufacturers $\mu_{t-1}^Q - \mu_t^Q$:

$$\Delta S_{i,t} = (Q_{i,t-1} - Q_{i,t})/(\mu_{t-1}^Q - \mu_t^Q) \tag{2}$$

Fig. 10 shows the relative performance change of the car manufacturers on CO_2 emission and sales between 2001 and 2010. A positive position refers to a favourable change in terms of CO_2 emissions and sales compared to the median of all manufacturers. The figure shows that the manufacturers from clusters 1 and 2 (Volvo, Renault and Ford) performed relatively poorly both in terms of sales and in terms of CO_2 reduction. In contrast, most manufacturers in clusters 4 and 5 performed relatively well in terms of sales and in terms of CO_2 reduction. This holds for Audi, Fiat, Kia, Hyundai and Toyota. Volkswagen's (cluster 4) relative sales improvement is below the median, but they perform well on the relative change in CO_2 emissions. Suzuki's (cluster 5) relative change in sales is above the median, but they perform just below the median on change in CO_2 emissions. The manufacturers in the 'median cluster (3) are also close to the median with respect to relative change in sales and relative change in CO_2 emissions. Of this cluster only Opel is an outlier. Opels sales dropped dramatically, while its relative change in CO_2 emission is at the median. While we present mainly aggregated outcomes of manufacturers, there are specific explanations for each manufacturer's performance. Box 1 provides some insights by zooming in on the portfolio performance of some car manufacturers.

The trend line in Fig. 10 shows a positive correlation between the relative change in CO_2 emissions and relative change in sales.[14] The least innovative car manufacturers experienced a relative decrease in sales in the Netherlands from 2001 to 2010, while the most innovative manufacturers saw an increase in sales from 2001 to 2010. So, CO_2 emission reduction seems to be rewarding for car manufacturers, but in the absence of a joint analysis of other car attributes (e.g. engine power, car size, etc.) this conclusion has to be treated with caution.

The results presented in Fig. 10 are robust with respect to our choices to use only 2001 and 2010 data and our focus on cars with a petrol engine as principal drivetrain (including non-family cars). When using 3 year average sales numbers for both 2001 (2000–2002) and 2010 (2009–2011) some manufacturers perform slightly better (Volvo and Skoda) or worse (Suzuki), but overall results are robust and a similar trend is observed. Results are also robust when we include only petrol cars. In this case we observe that BMW, Suzuki, Volvo and Skoda perform worse and Citroën and Peugeot better. For Volvo and Skoda this might be related to their (increased) focus on diesel cars.

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[14] Correlation .479 (.071).

6. Conclusions

Policy makers and consumers increasingly express the need for a more sustainable transport system. This paper studies car manufacturers' behaviour in this changing socio-economic environment. More specifically we have investigated how firms' product portfolios changed with the introduction of energy labels for cars by analysing the CO_2 emissions of the top 15 manufacturers in the Netherlands. Increased understanding of car manufacturers' behaviour provides policy makers with insights into the consequences of emission reduction incentives such as energy-labelling schemes.

The Dutch case showed that car manufacturers reduced their CO_2 emissions substantially. The range in which car manufacturers offered versions increased and the cloud representing the product portfolio of versions of all car manufacturers increased in size. In addition to an increase in the number of versions, we also observed an increase in the average distance between versions when considering the price and CO_2 emissions of cars. The manufacturers with large portfolios are mainly responsible for this increase in average distance. These large portfolio firms became more generalised and adopted a twin-track strategy by offering cars to both consumers who prefer cars with low energy consumption and consumers who do not prefer such cars, while most manufacturers with small portfolios became more specialised and adopted a one-track strategy with reduction of energy consumption as their guiding principle.

Although all manufacturers moved in a similar direction by reducing their CO_2 emissions, the Dutch car market did not follow the pattern predicted by Hotelling's theory that firms tend to agglomerate. We found that the Dutch car market became less dense, i.e. more differentiated. Neither did the Dutch car market follow the pattern predicted by the theory of Anderson et al. who claim that firms agglomerate on pre-existing dimensions while they become more dispersed on a new and additional dimension when consumers put more weight on this new dimension. The product range increased both in terms of price, the pre-existing dimension, and CO_2 emissions, the new dimension. The Dutch car market did follow a pattern predicted by Saviotti and Pyka, however, who argue that firms position themselves in unoccupied regions of the characteristics space as they attempt to escape the competition, resulting in a more dispersed product cloud. In the car market a more dispersed product cloud is supported by technological innovations that have led to a decrease in costs of offering additional versions (Autocar, 2007).

Finally, we show that innovation to reduce CO_2 emissions seems rewarding in a country with tight environmental regulation such as the Netherlands, but in the absence of a joint analysis of other car attributes (e.g. engine power, car size, etc.) this conclusion has to be treated with caution. The paper shows that the frontrunners in CO_2 emission reduction experienced the highest relative increase in sales. In particular the manufacturers that followed an innovation strategy of propulsion efficiency improvements and relatively stable weight increased their sales numbers compared to other car manufacturers. Manufacturers lagging behind with CO_2 emission reduction performed weak in terms of sales.

Box 1. Zooming in on car manufacturers' performance

Kia: Kia was a relative newcomer with minor activities on the Dutch car market. In 2001 its offer was limited to a small range of quite polluting car versions. However, the number of 'family' car versions offered on the Dutch market almost quadrupled between 2001 and 2010. Towards 2010 Kia expanded the price range by adding mainly cheaper and also lighter cars to its portfolio that produce less CO_2 emissions. In addition, Kia substantially reduced its CO_2 emissions over the whole range of versions. Kia's activities in more diverse segments appear to be successful as its sales quintupled between 2001 and 2010.

Peugeot and Citroën (PSA): Similar portfolio changes are observed for Peugeot and Citroën, which is not completely surprising as together they constitute PSA automotive group. Peugeot and Citroën are among the firms that increased the weight of their portfolio the most, with a median and below median change in CO_2 emissions. Most remarkable is the shared introduction of the cheap, light and low CO_2 emitting Citroën C1 and Peugeot 107. These car models account for almost half of their sales in 2010.[*]

Toyota: The data shows that Toyota's strategy was to specialise in relatively low emission vehicles and to discontinue most of its exclusive and polluting versions. This decreased range of versions, which includes the Toyota Prius, made them the second largest car manufacturer for the Netherlands in 2010. The hybridization of Toyota is an example of a technological innovation strategy to reduce CO_2 emissions. Since hybrids are quite heavy this explains Toyota's poor performance in relative weight change.

Audi: Audi is another firm that reduced the CO_2 emissions of its portfolio through technological innovations. Audi showed an outstanding performance in the improvement of propulsion efficiency of its internal combustion engine. Audi doubled its portfolio of versions over the whole range and is among the best performing European car manufacturers in terms of relative sales.

[*]11,766 sales of the Citroën C1 in 2010 (source RDW), 24,908 total sales of Citroën in 2010. 18,247 sales of the Peugeot 107 in 2010 (source RDW), 39,659 total sales of Peugeot in 2010.

Acknowledgements

References

AEA, 2011. Report on the Implementation of Directive 1999/94/EC Relating to the Availability of Consumer Information on Fuel Economy and CO_2 Emissions in Respect of the Marketing of New Passenger Cars. Tech. Rep.

AMvB BWBR0011761, 2012. Besluit etikettering energiegebruik personenauto+s.

Anderson, S., De Palma, A., Thisse, J.-F., 1992. Discrete Choice Theory of Product Differentiation. MIT Press.

Anderson, S.P., De Palma, A., Thisse, J.-F., 2006. Discrete Choice Theory of Product Differentiation. Edward Elgar, Cheltenham, UK, Northampton, MA.

Autocar, 2007, November 27. VW+s four-platform future uncovered. Haymarket Media Group.

Banerjee, A., Solomon, B., 2003. Eco-labeling for energy efficiency and sustainability? A meta-evaluation of US programs. Energy Policy 31, 109–123.

Beck, M., Rose, J., Hensher, D., 2013. Environmental attitudes and emissions charging: an example of policy implications for vehicle choice. Transportation Research Part A: Policy and Practice 50 (0), 171–182.

BOVAG-RAI, 2006a. Mobility in Figs. 2006. Tech. Rep., Amsterdam.

BOVAG-RAI, 2006b. Mobility in Figs. 2011/2012. Tech. Rep., Amsterdam.

Brand, C., Anable, J., Martino, T., 2013. Accelerating the transformation to a low carbon passenger transport system: the role of car purchase taxes, feebates, road taxes and scrappage incentives in the UK. Transportation Research Part A: Policy and Practice 49, 132–148.

Cantner, U., Krüger, J., Söllner, R., 2012. Product quality, product price, and share dynamics in the German compact car market. Industrial and Corporate Change 21 (5), 1085–1115.

CBS, PBL and Wageningen UR, 2012. Energielabels voor personenauto+s, 2001–2011.

EPA, 2011. New Fuel Economy and Environment Labels for a New Generation of Vehicles. United States Environmental Protection Agency.

EU Directive, 1992/75/EC. On the Indication by Labelling and Standard Product Information of the Consumption of Energy and Other Resources by Household Appliances. Tech. Rep.

EU Directive, 1999/94/EC. On the Availability of Consumer Information on Fuel Economy and CO_2 Emissions in Respect of the Marketing of New Passenger Cars. Tech. Rep.

European Commission, 2009. Reducing Car Weight and Cutting Down Greenhouse Gas Emissions. Tech. Rep.

European Union - Eurostat, 2012. Energy, Transport and Environment Indicators.

Field, A., 2009. Discovering Statistics Using SPSS, third ed. Sage.

Gallastegui, I.G., 2002. The use of eco-labels: a review of the literature. European Environment 12, 316–331.

Geilenkirchen, G., Meerkerk, J., Hoen, A., 2012. Doet het kabinet de zuinige auto in de ban? Milieu Dossier 1, 56–59.

Hotelling, H., 1929. Stability in competition. The Economic Journal 39 (153), 41–57.

IPCC, 2011. IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation. Tech. Rep.

Jamalpuria, A., 2012. On voluntary eco-labeling and fiscal incentives. Economics Letters 117, 110–114.

Kieboom, S.F., Geurs, K.T., 2009. Energielabels en autotypekeuze – Effect van het energielabel op de aanschaf van nieuwe personenauto+s door consumenten. Tech. Rep., PBL, Bilthoven.

Lambooy, J., 2002. Knowledge and urban economic development: an evolutionary perspective. Urban Studies 39 (4), 1019–1035.

Lancaster, K., 2002. A new approach to consumer theory. The Journal of Political Economy 74 (2), 132–157.

Mann, H., Whitney, D., 1947. Con a test of whether one of two random variables is stochastically larger than the other. Annals of Mathematical Statistics 18, 50–60.

Metcalfe, J., 1994. Competition, Fisher's principle and increasing returns to selection. Journal of Evolutionary Economics 4, 327–346.

Nelson, R., Winter, S., 1982. An Evolutionary Theory of Economic Change. Harvard University Press, Cambridge, MA.

Noblet, C., Teisl, M., Rubin, J., 2006. Factors affecting consumer assessment of eco-labeled vehicles. Transportation Research Part D 11, 422–431.

OECD, 1997. Eco-labelling: Actual Effects of Selected Programme.

OICA, 2012. World Motor Vehicle Production by Country and Type.

Rogan, F., Dennehy, E., Daly, H., Howley, M., Ó Gallachóir, B., 2011. Impacts of an emission based private car taxation policy first year ex-post analysis. Transportation Research Part A: Policy and Practice 45 (7), 583–597.

Sammer, K., Wüstenhagen, R., 2006. The influence of eco-labelling on consumer behaviour – results of a discrete choice analysis for washing machines. Business Strategy and the Environment 15 (3), 185–199.

Saviotti, P., 1985. An approach to the measurement of technology based on the hedonic price method and related methods. Technological Forecasting and Social Change 27 (2-3), 309–334.

Saviotti, P., Mani, G., 1995. Competition, variety and technological evolution: a replicator dynamics model. Journal of Evolutionary Economics 5 (4), 369–392.

Saviotti, P., Metcalfe, J., 1984. A theoretical approach to the construction of technological output indicators. Research Policy 13, 141–151.

Saviotti, P., Pyka, A., 1995. Economic development by the creation of new sectors. Journal of Evolutionary Economics 14 (1), 1–35.

Saviotti, P., Pyka, A., 2008a. Micro and macro dynamics: industry life cycles, inter-sector coordination and aggregate growth. Journal of Evolutionary Economics 18 (2), 167–182.

Saviotti, P., Pyka, A., 2008b. Product variety, competition and economic growth. Journal of Evolutionary Economics 18 (3-4), 323–347.

Schipper, L., Fulton, L., 2013. Dazzled by diesel? The impact on carbon dioxide emissions of the shift to diesels in Europe through 2009. Energy Policy 54, 3–10.

Silverberg, G., Dosi, G., Orsenigo, L., 1988. Innovation, diversity and diffusion: a self-organisation model. The Economic Journal 98 (393), 1032–1054.

Small, K., 2012. Energy policies for passenger motor vehicles. Transportation Research Part A: Policy and Practice 46 (6), 874–889.

Swann, G., 2009. The Economics of Innovation: An Introduction. Edward Elgar, Cheltenham.

Teece, D., Pisano, G., Shuen, A., 1997. Dynamic capabilities and strategic management. Strategic Management Journal 18 (7), 509–533.

Teisl, M., Roe, B., Hicks, R., 2002. Can eco-labels tune a market? Evidence from dolphin-safe labeling. Journal of Environmental Economics and Management 43, 339–359.

Truffer, B., Markard, J., Wüstenhagen, R., 2001. Eco-labeling of electricity – strategies and tradeoffs in the de definition of environmental standards. Science and Technology 29, 885–897.

Uri, N., 1988. The market valuation of new car quality. Transportation Research Part A: General 22 (5), 361–373.

Van der Vooren, A., Alkemade, F., 2012. Managing the diffusion of low emission vehicles. IEEE Transactions on Engineering Management 59 (4), 728–740.

Wells, P., Varma, A., Newman, D., Kay, D., Gibson, G., Beevor, J., Skinner, I., 2013. Governmental regulation impact on producers and consumers: a longitudinal analysis of the european automotive market. Transportation Research Part A: Policy and Practice 47, 28–41.

Zachariadis, T., 2008. The effect of improved safety on fuel economy of european cars. Transportation Research Part D: Transport and Environment 13 (2), 133–139.

Zachariadis, T., 2013. Gasoline, diesel and climate policy implications – insights from the recent evolution of new car sales in Germany. Energy Policy 54, 3–10.