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Assessing the rebound effect using a natural experiment setting: Evidence from the private transportation sector in Israel

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HIGHLIGHTS

- Subsidizing energy-efficient cars has become a popular policy in many countries.
- We are unaware of studies identifying rebound via cars' subsidization policy.
- We explored a rebound in light of such a policy in Israel.
- Household expenditure survey data, fuel prices and car characteristics were employed.
- We found an average rebound effect of 40%.

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ABSTRACT

Subsidizing energy-efficient technologies is considered by energy and environmental organizations to be one of the most effective policies for decreasing energy consumption. In the transportation sector such policies are becoming ever more popular, and have been implemented in a considerable number of countries in recent years. Because these policies promote energy-efficient cars with lower usage costs, they may rebound and increase the distances traveled by households that have switched to energy-efficient cars. From an econometric perspective, a subsidization policy can be used as a valid instrument to identify the households' choice of energy efficiency levels of the cars they own. This identification, in turn, can be utilized to account for endogeneity in the estimation of a rebound effect. The present study uses a natural experiment setting of such a policy implemented in Israel in 2009. The empirical results indicate a fairly large average rebound effect of 40%. The results also indicate that while the policy indeed encouraged the purchase of energy-efficient cars, households that bought a new or used car during the surveyed period did not generate a rebound effect of a different magnitude compared with other households that did not. We discuss the implications of our findings.

1. Introduction

Energy-consuming products have long been a key component in human progress, and are indeed one of the factors best characterizing life in the developed world. Energy supply has thus become a major concern for policy makers, as has the need for policies that moderate the different types of damage resulting from extensive energy consumption, such as greenhouse gas (GHG) emission, air pollution and its associated health problems, resource depletion, etc. (International Energy Agency (IEA), 2008a). In 2008, the IEA published a set of 25 policy recommendations in priority areas (e.g., transportation, industry, and buildings) to aid IEA member countries to address energy, environmental, and economic challenges driven by extensive energy consumption (International Energy Agency (IEA), 2008b). A major policy recommendation for all the priority areas was to subsidize energy-efficient products, and thereby to incentivize consumers to purchase these products. It was subsequently shown

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that energy-efficiency policies do indeed play a crucial role in curbing energy usage (Gillingham et al., 2013). However, as an energy-consuming product becomes more efficient using it becomes cheaper, which provides an incentive to increase the usage of this product. Consequently, the potential energy savings from the switch to energy-efficient products are offset, and actual savings in energy are lower than expected (e.g., Berkhout et al., 2000; de Haan et al., 2006; de Haan et al., 2009). In light of these findings, there is an ongoing debate as to whether this rebound effect should be a key consideration in policies that promote energy efficiency (Frondel and Vance, 2013; Khazzoom et al., 1990) or whether this effect is minor (Gillingham et al., 2013).

The rebound effect varies among different products, technologies, and users, and its occurrence and magnitude are thus difficult to predict. Consequently, when designing policies that encourage consumers to adopt energy-efficient products (e.g., cars, light bulbs, refrigerators, and air-conditioners), policy makers generally fail to account for the potential increase in energy consumption (Geller et al., 2006). The present study (1) examines the potential effects of policy measures designed to incentivize energy efficiency through subsidizing energy-efficient products, and (2) uses the policy to identify households' decision regarding the energy efficiency of their car. This identification, in turn, enables the estimation of a potential rebound effect in transportation while accounting for endogeneity in choice of car. Specifically, we aim to estimate a rebound effect in light of a policy that effectively decreases, through subsidization, the prices of energy-efficient cars. The importance of this study lies in its contribution to assessing the rebound effect in transportation, with the attendant far-reaching health, environmental, and economic implications, as discussed next.

1.1. Energy efficiency in transportation

Transportation accounts for about one quarter of energy-related global GHG emissions and about one fifth of global energy use. Transportation-related emissions are associated with increased risks of lung cancer, heart disease, and adverse pregnancy outcomes (World Health Organization, 2010). Recent reports reveal that OECD countries spent about 1 trillion US$ in 2010 on addressing health damages resulting from transportation emissions (Organization for Economic Co-operation and Development (OECD), 2014). Moreover, transportation-related energy use and GHG emissions are expected to rise by nearly 26% by 2030, and by more than 60% by 2050 (International Energy Agency (IEA), 2015; see also Kahn Ribeiro et al., 2007).

Between 2008 and 2014, the IEA's World Energy Outlook consistently advocated that improving the energy efficiency of new cars should be the dominant policy for reducing GHG emissions and saving energy (International Energy Agency (IEA), 2008–2014). A 2010 IEA brief reported that the subsidization of energy-efficient cars had indeed become a widely-used energy-efficiency policy, and that such incentives had been implemented by some IEA member states, including Japan, the Netherlands, the UK, Ireland, Korea, and the USA (International Energy Agency (IEA), 2010). Yet, despite its widespread implementation, such a subsidization policy has not been sufficiently scrutinized to determine its potential consequences.

Whereas energy-efficient cars are expected to increase distance traveled because of lower usage costs, such a prediction should be made with caution, because a reverse causality is possible – namely, that consumers who drive long distances may choose to purchase an energy-efficient car, and such a choice cannot represent a rebound effect. Accordingly, some scholars treat consumers' choice regarding their car's energy efficiency as an additional decision variable (i.e., as an endogenous variable) (Greene et al., 1999; Puller and Greening, 1999; Small and Van Dender, 2007). An additional factor that is central to consumer decisions regarding whether to purchase an energy-efficient car is the price of fuel. Specifically, the history of fuel prices affects the choice of purchasing energy-efficient cars (Puller and Greening, 1999).

A fairly recent meta-analysis review of previous studies reported a range from −0.4 to −0.8 of fuel consumption elasticity with respect to price and a range from −0.2 to −0.3 of distances traveled with respect to price (Litman, 2013). Nonetheless, Frondel et al. (2008) reported an elasticity of −0.6 for both fuel consumption and distances traveled with respect to price. One of the implications of a high price elasticity is that fuel pricing policies (i.e., increasing the tax) are relatively effective in decreasing consumers' demand for fuel and in reducing distances traveled; particularly, when the price elasticity is high, policies that increase energy efficiency and effectively reduce the cost of travel are likely to generate a substantial rebound effect (Litman, 2013). However, we are unaware of studies assessing the consequences of policies that subsidize the purchase of energy-efficient cars. Thus, further investigation is needed to determine whether the effect on distance traveled of a policy that subsidizes energy-efficient cars differs from that resulting from a policy of increasing the price of fuel.

1.2. The direct rebound effect

Studies have identified three main types of rebound effects (e.g., Berkhout et al., 2000; Greening et al., 2000; Sorrell and Dimitropoulos, 2008): (1) direct rebound effect – an increase in the use of the focal product, caused by the decrease in its usage costs, (2) indirect rebound effect – an increase in demand for other products or for the use of other products, due to an increase in disposable income caused by the decrease in the focal product's usage costs, and (3) macro-level rebound effect – a structural effect on the economy caused by changing demand, production, and distribution patterns resulting from the decrease in usage costs of an energy efficient product. For reviews on the various possible consequences of rebound effects, see Greening et al. (2000) and Sorrell and Dimitropoulos (2008). The present study focuses on the direct rebound effect in private transportation, namely, the potential increase in distance traveled due to the usage of more energy-efficient cars.

It is customary to measure the magnitude of the direct rebound effect as a percentage of the potential energy savings, namely,

$$Rebound effect(\%)=\frac{100(CalculatedSavings - ActualSavings)}{CalculatedSavings}.$$

For example, a rebound effect of 30% means that only 70% of engineers' predictions of energy savings following an improvement in energy efficiency were actually achieved. In other words, increased consumption offsets 30% of the expected energy savings. Scholars estimating the rebound effect for private transportation have reported a wide range of magnitudes. For example, Small and Van Dender (2007) found a short-run rebound of 4.5% and a long-run rebound of 22%, whereas Frondel et al. (2008) reported an average rebound of 56–66%. Based on a meta-analysis of 36 studies, Sorrell et al. (2009) suggested a long-run rebound effect for private transportation of 10–30% in OECD countries.

However, some of these estimates do not consider the likelihood of endogeneity in the consumers' decision to own an energy-efficient car. While it is expected that individuals who drive more would purchase an energy-efficient car, instrumental variables for solving this measurement problem are scarce. To the best of our knowledge, no studies to date have examined the rebound effect using a policy that subsidizes energy-efficient cars as a strategy to endogenize the consumers' decision to own an energy-efficient car.

2. Data

A subsidization policy that was implemented in Israel in August 2009 replaced the traditional fixed sales tax of new private cars in two ways. First, the tax rate was updated from a fixed 75% to a maximum of 92%. Second, a differential subsidy that accounts for the car's environmental externalities (pollution-generation potential) was set. Specifically, the government established a “Green Meter”, which rates each car according to its pollutant emissions, and groups cars into 15 categories according to their pollution levels, where category 1 is the least pollutant and category 15 is the most pollutant. A subsidy off the baseline of 92% tax is determined according to the pollution level of each category. The subsidized sales tax is paid as a lump sum upon purchasing a new car from its importer (Israel Ministry of the Treasury, 2009). For example, energy-efficient cars in category 3 enjoy a sales tax reduction of 13,750 NIS (New Israeli Shekel), whereas the least energy-efficient cars in catogory 15 levy the maximal 92% tax. Appendix A provides a detailed description of the policy, and its pollution categories and tax and subsidy rates.

Effectively, the policy decreased the price of – and increased demand for – cars with higher energy-efficiency levels. Fig. 1 shows a report of the Israel Tax Authority that demonstrates the increase in the market share of less-polluting cars in the years following the implementation of the policy.

The policy introduced an exogenous price shock to the car market. As a result, prices of new cars directly and immediately decreased. In addition, since new and used cars are close substitutes, the prices of used cars adjusted accordingly. Moreover, the prices of energy-efficient used cars dropped as soon as their newer models were subsidized. This effect was indirect, but still immediate.

2.1. Overview of the private car market in Israel

During the past 10 years, the private car market in Israel has experienced an average growth of 4.4% per year, with 2,457,200 privately-owned cars on the road at the end of 2014. The average number of new private cars sold during 2007–2008 was 83,724, and this number increased to 96,403 during 2010–2011 (Israel Central Bureau of Statistics, 2014). Israel Tax Authority (2012) data indicate that the deduction in the price of new cars that followed the implementation of the new policy was accompanied by an erosion in the prices of used cars. Another trend observed in the Israeli car market was a growing demand for cars with manual gears, which are usually more energy efficient (Israel Tax Authority, 2010).

Importantly, two unique features characterize the Israeli car market and make it a particularly suitable context in which to examine the occurrence of a rebound. First, no private cars are manufactured in Israel – all cars are imported. This fact eliminates a potential differential impact of the policy on imported vs. domestic cars through adjustments in local markets, thus eliminating potential local effects. Second, because the entire stock of fuel in Israel is imported, and the government determines a fixed markup, fuel prices in Israel are uniform and can be treated as exogenous. Hence, the economic environment of the Israeli private car market makes the identification of the rebound effect more precise.

2.2. Data sources

We used household survey data provided by the Israel Central Bureau of Statistics (CBS), to which we added supplementary data from other sources. The subsidization policy described above was implemented in August 2009. To use it as an effective instrument, we examined household behavior with respect to private transportation patterns two years before (2007, 2008) and two years after (2010, 2011) the implementation of the policy. Our sample comprised 8299 observations (about 2000 for each year). Each observation represented a single household, with each household being surveyed only once. A household was included in the sample only if it owned at least one car. Households that used company cars were excluded, because their traveling habits differ from those of other households, namely, their monthly distances traveled tend to be twice as high as the distances traveled by households with privately-owned cars (Israel Central Bureau of

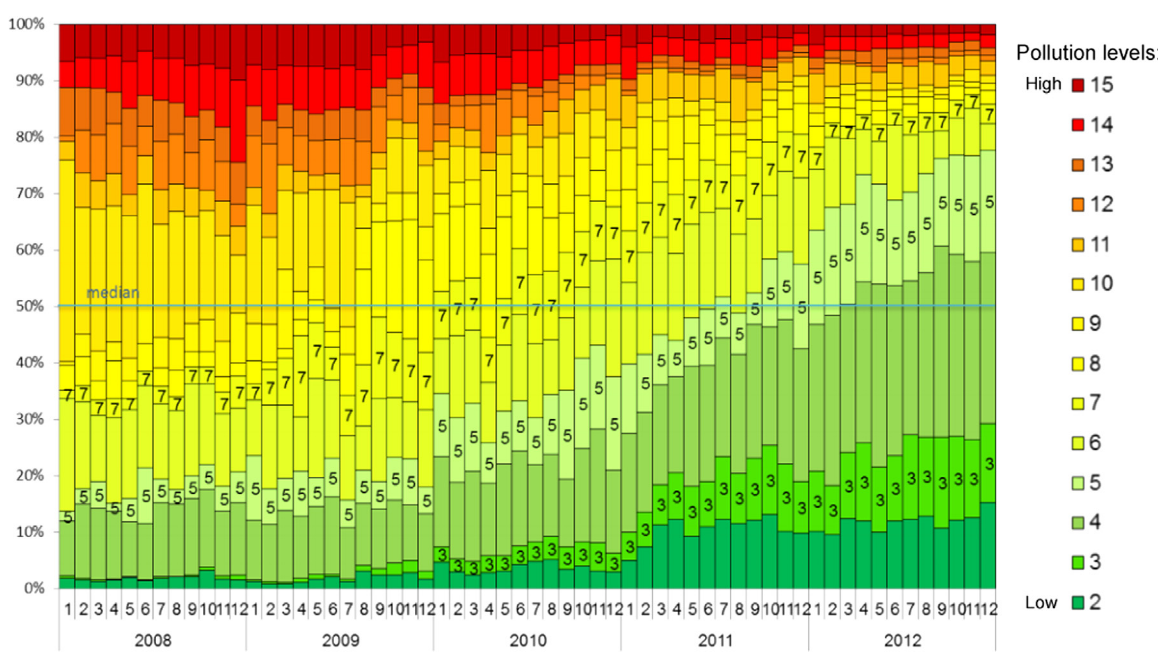

Fig. 1. Distribution of new cars marketed in 2008–2012 by pollution levels.

Statistics, 2012; Shiftan et al., 2012). Our data set covered a variety of car characteristics, including brand, type, model year, engine size, and monetary value. Additionally, the data set included the household's fuel consumption and whether the household had purchased a new or a used car during the surveyed year. The data set also contained socio-economic and demographic data, including education and income levels, number of persons up to and over 18 years old in the household, residential area, employment status, and other variables that may affect distances traveled and choice of car in terms of its energy-efficiency level. We retrieved energy-efficiency data from two different sources. First, for each car model we collected information regarding energy efficiency as stated by the car manufacturers. However, since such data are likely to be biased because car manufacturers tend to report exaggerated energy-efficiency levels (Dings, 2013), we also retrieved data on the car's energy efficiency from a large consumer-generated database that is publically available.[1] We used the average energy efficiency reported by consumers and cross-checked the consistency of these data by matching them with the information stated by car manufacturers, establishing the reliability of the consumer-generated energy efficiency reports. We ran our model with both manufacturers' and consumers' energy-efficiency reports, and found no significant differences between the results.

Because fuel prices in Israel are uniform, we were in the comfortable situation of being able to use a single time series of fuel prices. We used data from the Israel Ministry of National Infrastructures, Energy and Water Resources, and matched each household with the price of fuel during the month it was surveyed. Similarly, to account for historical fuel prices (that may have affected households' preference for an energy-efficient car), we calculated for each household the average fuel prices in the 6 and 12 months preceding the month it was surveyed. Using the Consumer Price Index, we adjusted the nominal local currency (NIS) to 2014 real values (i.e., income, fuel prices, and car value).

Following Puller and Greening (1999), we coded the households' kilometers traveled as missing for households that reported a fuel consumption of less than 5 l per month.

2.3. Descriptive statistics

The main focus of our analysis was households' distance traveled and the average energy efficiency of the households' cars. Fig. 2 shows the distribution of kilometers traveled per month in our sample. The distribution is single-peaked, with a mean of 321.83 km per month. Fig. 3 shows that the cars' energy efficiency has a single-peak distribution, with a mean of 12.98 km per liter.

Because both kilometers traveled and energy efficiency may be affected by changes in fuel prices, it was important to examine fuel price dynamics and government control over local fuel prices. Fig. 4 illustrates the dynamics of real fuel prices in Israel and real world oil prices (Israel Ministry of National Infrastructures, Energy and Water Resources, 2015; U.S. Energy Information Administration, 2015). The strong correlation between the two price series indicates the consistency by which the Government of Israel keeps the prices in close correspondence with those on world markets. This situation constitutes an advantage for our analysis: in the absence of government-controlled fuel prices, the adoption of energy-efficient cars that decrease the demand for fuel may generate a price response, such that the net effect of a potential rebound becomes complex to estimate. Because fuel prices in our setting closely correspond with those on world markets, they can be treated as independent of any trend in energy efficiency of the national car fleet.

[1] www.kml.co.il

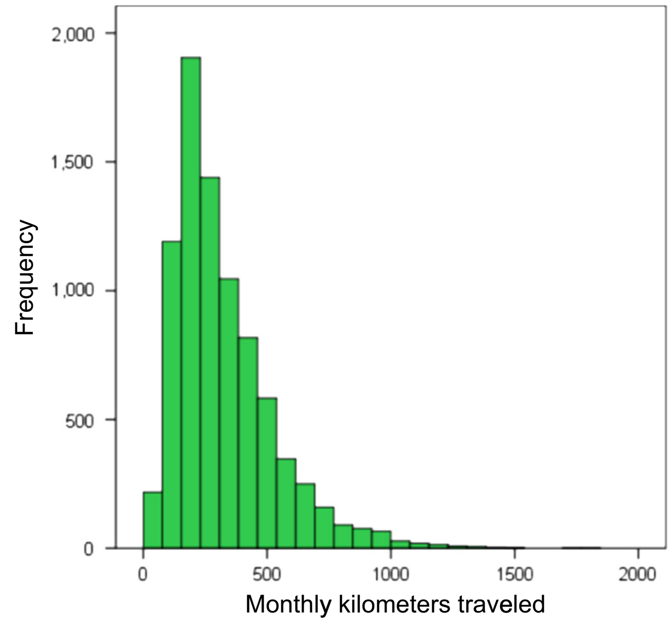

Fig. 2. Distribution of households' kilometers traveled per month.

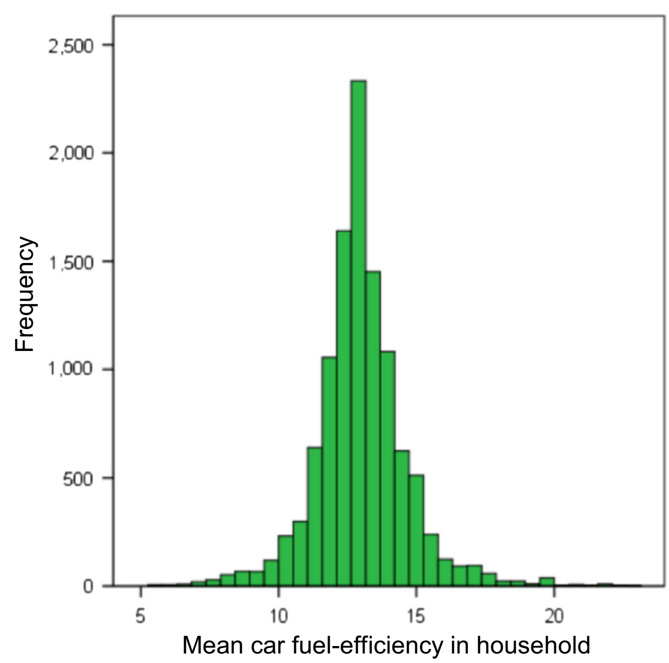

Fig. 3. Distribution of households' cars' energy efficiency.

Table 1 presents the summary statistics of the variables in our study, including kilometers traveled per month, the average energy efficiency of all cars in a household, and fuel prices. The average monthly income for a household was 15,926 NIS, and the average price per liter of fuel was 7.14 NIS. The average number of cars per household was 1.24, and households that purchased a new car during the surveyed years constituted about 5% of the sample. 43% of households were situated in periphery areas. The average age of the head of the household was 46. Among the household heads, 31% were women, 32% were holders of an academic degree, 26% did not have a spouse, and 16% were self-employed. Table 2 presents summary statistics of some key variables before and after the implementation of the policy, demonstrating that the sample characteristics were largely consistent across the two examined periods. Importantly, whereas the average energy

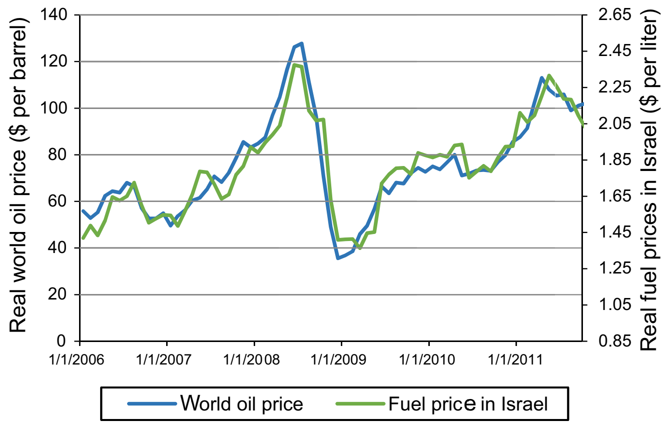

Fig. 4. Real price of fuel in Israel compared with real world oil prices (Israel Ministry of National Infrastructures, Energy, and Water Resources, 2015; U.S. Energy Information Administration, 2015).

efficiency increased by 3%, the variance in the energy efficiency of cars increased by about 30% – from 2.66 before the implementation of the policy to 3.46 post implementation.

3. Methodology

Energy efficiency (μ) may be defined as the input energy (e) required for an energy-consuming product to perform a single unit of work (s), i.e., $\mu = s/e$. Our study used kilometers per liter as a measure of energy efficiency. The cost of energy per kilometer (p_s) is given by $p_s = p/\mu$, where p is the price of fuel at the pump. In the absence of a rebound effect, an improvement in energy efficiency ($\Delta\mu > 0$) will keep kilometers traveled fixed ($\Delta s = 0$), and the demand for energy will decrease proportionally to the improvement in energy efficiency. But because energy improvements reduce usage cost per kilometer (p_s), as long as fuel price elasticity is within the normal range the number of kilometers traveled is likely to increase (Sorrell and Dimitropoulos, 2008).

We define this potential increase in kilometers traveled as a direct rebound effect. More precisely, it is the percentage change in kilometers traveled due to a 1% change in the cars' energy efficiency. This is also described as the elasticity of demand for kilometers traveled with respect to energy efficiency (e.g., kilometers per liter), depicted as: $\eta_\mu(s) = \frac{ds/s}{d\mu/\mu} = \frac{ds}{d\mu}\frac{\mu}{s}$. This is a convenient description of the rebound as it can also be expressed as $\frac{dlns}{dln\mu}$, which in turn facilitates a straightforward econometric modeling (e.g., Berkhout et al., 2000; Frondel et al., 2008).[2]

Following Greene et al. (1999) and Small and Van Dender (2007), we address the endogeneity of consumers who choose cars with a particular energy efficiency level based on the number of kilometers they expected to travel, by simultaneously estimating kilometers traveled and energy efficiency. We assume that consumers decide how many kilometers to travel (s) by taking into consideration the fuel efficiency of their cars (μ), fuel prices (p), household income (m), the number of cars they own (c), and other exogenous variables that may affect kilometers traveled (X). Similarly, consumers choose to own a car characterized by a certain level of energy efficiency, taking into consideration the kilometers they plan to travel, history of fuel prices (lp), household income, car age (a), car value (v), and other exogenous variables that may affect cars' energy efficiency choice (Z). Finally, we utilize the policy implemented in Israel in 2009 for identification purposes (τ), as the policy is expected to have had an effect on energy efficiency but not directly alter kilometers traveled.

We wish to emphasize that when considering the new prices resulting from the policy, households could have made one of the following three decisions: (1) buy a new car, (2) buy a used car, or (3) stick with the car they owned. Because we examine the rebound effect for the entire car pool, it is crucial that we account for all three decisions. This is important because, for example, if a household chooses not to purchase a new car and thereby remain with its current choice of energy efficiency, there may be unobservable reasons for doing so, and omitting these households from the sample would result in biased estimates. In other words, if we omit one or more of these household groups, we may create a selection bias with respect to the rebound effect that we seek to measure.

These assumptions create the following structural model:

$$s = s(\mu, p, m, c, X)\mu = \mu(s, lp, m, a, v, \tau, Z) \tag{1}$$

The rebound effect is estimated by a reduced form of the structural model, by integrating the second equation into the first and solving for s (and vice versa), where $\hat{s}$ denotes the solution:

$$\hat{s} = s[\mu(\hat{s}, lp, m, a, v, \tau, Z)p, m, c, X] \equiv \hat{s}(lp, m, a, v, \tau, p, c, Z, X) \tag{2}$$

The solution of the reduced-form equation involves the prediction of the endogenous variable by using the exogenous variables of the first equation with instrumental variables. For this purpose, we used a two-stage least squares (2SLS) model, which predicts the endogenous variable using instrumental variables in the first stage, and then uses the predicted value to estimate its effect on the dependent variable in the second stage. This same procedure was used for both the energy efficiency equation (in which the endogenous variable is kilometers traveled) and for the kilometers traveled equation (in which the endogenous variable is energy efficiency) (Wooldridge, 2002). To examine whether the lower usage costs rebound and increase kilometers traveled, the coefficients in the following set of equations were estimated:

$$\begin{aligned} \ln(s_i) &= \beta_0 + \beta_1 \ln(\mu_i) + \beta_2 \ln(p_i) + \beta_3 \ln(m_i) + \beta_4 c_i + \beta_5 n_i + \beta_6 u_i \\ &\quad + \sum_{k=7}^{K} \beta_k X_{ik-6} + \varepsilon_i \\ \ln(\mu_i) &= \gamma_0 + \gamma_1 \ln(s_i) + \gamma_2 \ln(lp6_i) + \gamma_3 \ln(lp12_i) + \gamma_4 \ln(m_i) + \gamma_5 \\ &\quad \ln(a_i) + \gamma_6 \ln(v_i) + \gamma_7 \tau + \sum_{j=8}^{J} \gamma_j Z_{ij-7} + \varphi_i, \end{aligned} \tag{3}$$

where n_i and u_i indicate the purchase of new or used cars, respectively, and $lp6_i$ and $lp12_i$ are the lagged fuel prices calculated as the average fuel price in the 6 (12) months preceding the survey, respectively, namely, variables that likely affect consumers' decisions regarding the energy efficiency of the cars they own. Variables included in X are: age and square age of the head of the household, number of individuals under the age of 18, and number of individuals above the age of 18; and the following dummy variables: head of household is self-employed, no spouse, head of household has an academic degree, head of household has a matriculation certificate, head of household is a woman, both head of household and spouse are unemployed, and residency in a periphery area. Variables included in Z are: age and square age of the head of household, number of individuals under the age of 18, number of individuals above the age of 18; and the following dummy variables: head of household has an academic degree, head of household has a matriculation certificate, head of household is a woman, both the head of the household and spouse are unemployed, and residency in a periphery area.

[2] Note that $d(lns) = \frac{1}{s}ds$, and similarly: $d(ln\mu) = \frac{1}{\mu}d\mu$, and therefore: $\frac{d(lns)}{d(ln\mu)} = \frac{\frac{ds}{s}}{\frac{d\mu}{\mu}} = \eta_\mu(s)$.

Table 1
Summary statistics, full sample.

Variable	Minimum	Maximum	Mean	Std. deviation
Kilometers traveled (km/month)	50	1784.88	321.83	205.06
Average energy efficiency of all cars in household (km/liter)	5.89	25.60	12.98	1.83
Real fuel prices (NIS[*]/liter)	5.62	7.89	7.14	.45
Real lagged fuel prices (6-month average)	6.25	7.65	7.14	.30
Real lagged fuel prices (12-month average)	6.51	7.55	7.08	.22
Real net monthly income (NIS[*])[a]	−49,218	457,032	15,926	12,378
Cars in the household (#)	1	4	1.24	.47
Average age of cars in household (# of years)	.00	46	7.99	5.04
Real value of all cars in household (NIS[*])	1065	855,867	55,045	46,615
Residency in a periphery area (yes/no)	.00	1	.43	.49
Age of the head of household	17	93	46.16	14.88
Household head has an academic degree (yes/no)	.00	1	.32	.47
Household head has a matriculation certificate (yes/no)	.00	1	.33	.47
No spouse (yes/no)	.00	1	.26	.44
Head of household is a woman (yes/no)	.00	1	.31	.46
Head of household is self-employed (yes/no)	.00	1	.16	.37
Head and spouse do not work (yes/no)	.00	1	.09	.28
Individuals under 18 in household (#)	.00	12	1.16	1.48
Individuals aged 18 and up in household (#)	1	11	2.38	1.04
Bought a new car (yes/no)	.00	1	.05	.21
Bought a used car (yes/no)	.00	1	.13	.34

[*] $1 ≈ 4 NIS.
[a] A negative income is possible for households holding a business bank account. The average net real monthly income in Israel during the four examined years was 12,525 NIS; our sample includes households owning at least one car and therefore the average net real monthly income is higher.

Table 2
Selected summary statistics before and after the implementation of the policy.

	2007–2008				2010–2011			
Variable	Minimum	Maximum	Mean	Std. deviation	Minimum	Maximum	Mean	Std. deviation
Kilometers traveled (km/month)	50	1739.87	318.08	198.15	50.06	1784.88	324.46	201.77
Average energy efficiency of all cars in household (km/liter)	6.12	24.20	12.79	1.63	5.89	25.60	13.18	1.86
Real fuel prices (NIS[*]/liter)	5.62	7.89	7.04	.52	6.73	7.86	7.25	.32
Real lagged fuel prices (6-month average)	6.25	7.54	7.07	.29	6.86	7.65	7.21	.29
Real lagged fuel prices (12-month average)	6.80	7.37	7.04	.18	6.51	7.55	7.10	.25
Real net monthly income (NIS[*])[a]	−49,218	191,100	15,804	10,251	−40,111	457,032	16,540	13,999
Cars in the household (#)	1	4	1.23	.46	1	4	1.29	.51
Bought a new car (yes/no)	.00	1	.06	.23	.00	1	.04	.20
Bought a used car (yes/no)	.00	1	.13	.33	.00	1	.15	.36
Bought an energy-efficient car[b]	.00	1	.01	.11	.00	1	.02	.13

[*] $1 ≈ 4 NIS.
[a] A negative income is possible for households holding a business bank account. The average net real monthly income in Israel during the four examined years was 12,525 NIS; our sample includes households owning at least one car and therefore the average net real monthly income is higher.
[b] Refers to new and used cars with an energy efficiency level of 15.58 km per liter or higher, which reflects the average level of energy efficiency in the fourth pollution category.

Importantly, using this method allows us to examine the existence and assess the magnitude of the rebound effect by estimating the coefficient β_1, as it stands for the elasticity $\eta_\mu(s)$. Moreover, we wish to emphasize that the rebound we seek to measure is not confined to the implemented policy. Rather, it is a general phenomenon characterizing the “taking back” of potential energy savings in the use of improved energy-efficiency technology. As there were energy efficient cars before as well as after the implementation of the policy, we base our analysis on a representative sample of all households with at least one car.

4. Results and discussion

This section will present and discuss the results of this study. We begin by describing the main findings of our simultaneous equations model. We then explain the meaning of loss of energy savings in light of the estimated rebound effect, and focus on the impact of fuel prices on fuel consumption in the Israeli private transportation market. Finally, we report and discuss some additional findings of our analyses.

4.1. Main results

Tables 3 and 4 present the simultaneous estimations of kilometers traveled and energy efficiency. The kilometers traveled model (Table 3) suggests that energy efficiency positively affects kilometers traveled, indicating the occurrence of a rebound. The energy efficiency model (Table 4) suggests that (1) kilometers traveled are positively and significantly associated with consumers' choice of their cars' energy efficiency, emphasizing the importance of accounting for endogeneity in this estimation; and (2) the implementation of the policy positively and significantly affects consumers' choice of cars' energy efficiency, emphasizing the effectiveness of using the policy as an instrument.

4.2. Rebound effect and energy savings

The kilometers traveled model demonstrates that the estimated average rebound was fairly high, suggesting that about 40% of the potential energy savings due to an improvement in energy efficiency are lost to increased driving.

Recall that the average household in our sample has a driving

Table 3
km traveled model.

Variable	Coefficient (SE)
ln(average energy efficiency of all cars in household) (km/liter)	**.400 (.190)****
ln(real fuel prices) (NIS*/liter)	**−.661 (.123)*****
ln(real net monthly income) (NIS*)	.148 (.016)***
Cars in the household (#)	.094 (.019)***
Residency in a periphery area (yes/no)	.049 (.017)***
Age of the head of household	.003 (.004)
Squared age of the head of household	−.000 (.000)**
Household head has an academic degree (yes/no)	.105 (.022)***
Household head has a matriculation certificate (yes/no)	.034 (.020)*
No spouse (yes/no)	−.029 (.022)
Head of household is a woman (yes/no)	−.021 (.018)
Head of household is self-employed (yes/no)	−.394 (.024)***
Head and spouse do not work (yes/no)	.050 (.036)
Individuals under 18 in household (#)	.024 (.007)***
Individuals aged 18 and up in household (#)	.026 (.009)***
Bought a new car (yes/no)	.752 (1.99)
Bought a used car (yes/no)	−.332 (1.01)
Bought a new car X ln(average energy efficiency of all cars in household)	−.271 (.396)
Bought a used car (yes/no) X ln(average energy efficiency of all cars in household)	.135 (.396)
Intercept	4.183 (.593)***
Number of observations	8299

*$1 ≈ 4NIS
* $p < .1$
** $p < .05$
*** $p < .01$

Table 4
Energy-efficiency model.

Variable	Coefficient (SE)
ln(kilometers traveled) (km/month)	**.062 (.010)*****
Implementation of the policy (yes/no)	**.020 (.003)*****
ln(real net monthly income) (NIS*)	−.036 (.003)***
Real lagged fuel prices (6-month average)	.002 (.008)
Real lagged fuel prices (12-month average)	.002 (.011)
ln(real value of all cars in household) (NIS*)	−.047 (.003)***
ln(average age of cars in household) (#)	−.087 (.003)***
Residency in a periphery area (yes/no)	.018 (.003)***
Age of the head of household	−.003 (.001)***
Square age of the head of household	.000 (6.92e-06)***
Household head has an academic degree (yes/no)	.012 (.004)***
Household head has a matriculation certificate (yes/no)	.008 (.004)**
Head of household is a woman (yes/no)	.007 (.003)**
Head and spouse do not work (yes/no)	−.020 (.007)***
Individuals under 18 in household (#)	−.010 (.001)***
Individuals aged 18 and up in household (#)	−.005 (.002)***
Intercept	3.268 (.074)***
Number of observations	8299

*$ 1 ≈ 4 NIS.
* $p < .1$
** $p < .05$
*** $p < .01$

record of 321.83 km per month, in a car with an energy-efficiency level of 12.98 km per liter and consumes 24.79 l of fuel per month. A 40% rebound effect means that households for which the energy efficiency of their car improved by 1% increased their kilometers traveled by 0.40%. Thus, if for the average household the energy efficiency of the car was increased by 10% (i.e., to 14.28 km per liter), the household's kilometers traveled were expected to increase by 12.87 km per month. Whereas the potential decrease in fuel consumption was 2.25 l per month, the actual savings were only 1.35 l per month, which constitute 60% (100%–40%) of the potential energy savings.

4.3. *The impact of fuel prices*

Our findings regarding the elasticity of kilometers traveled with respect to fuel prices may provide relevant insight for a fuel pricing policy (e.g., Pigovian tax). We found the elasticity of kilometers traveled with respect to fuel prices to be −0.66, indicating that an increase of 1% in fuel prices leads to an average decrease of 0.66% in kilometers traveled. Importantly, the energy efficiency equation suggests that Israeli drivers are insensitive to historical prices of fuel when deciding on the extent of energy efficiency of the car they own (Table 4). We further discuss this point below. Coupling these two observations may generate a concrete policy implication. A Pigovian tax of 10% that increases fuel prices from 7.14 to 7.85 NIS per liter would decrease the average household's kilometers traveled by 6.6%, i.e., from 321.83 to 300.59 km per month. Therefore, under a pricing policy that increases fuel prices by 10%, the energy efficiency levels of cars are not expected to change, and the predicted impact of this policy is that the average household will reduce its fuel consumption by 1.74 l per month.

4.4. *Additional findings*

We found a plausible elasticity of kilometers traveled with respect to income (0.15), and that a high income decreased the likelihood for a household to own an energy-efficient car. A possible reason for the negative relationship between income and energy-efficiency level is that expensive cars (e.g., luxury cars and SUVs with a high engine capacity) are typically less energy efficient. We also found a positive and significant association between head of household's education and both kilometers traveled and energy efficiency (above and beyond income), indicating that households with an educated household head tend to drive more, but they do so in relatively energy-efficient cars. Similarly, we found that households in which the head of the household is a woman tend to own cars with a higher energy efficiency. For the categories of both education and women heading the household, owning an energy-efficient car is consistent with these characteristics being positively associated with high environmental awareness (Diamantopoulos et al., 2003).

Another important finding of our empirical estimation was that households in peripheral areas owned cars with higher energy efficiency than households in central areas, and they used them more. The more intense driving of households in the periphery reflects their need to travel more. However, further investigation is needed to determine whether this intense driving habit, due to higher accessibility to relatively energy-efficient cars, reflects an opportunity to improve the welfare of periphery households compared with households in central areas.

We found that the number of children in the household, like the number of adults, was positively associated with kilometers traveled but negatively associated with the energy efficiency of cars, perhaps because having a higher number of individuals encourages the household to own a larger, hence less energy-efficient, car.

We also found that, as expected, the number of cars positively affected kilometers traveled, and that a household travelled about 39% less when the head of the household was self-employed, which could be because some of these households' heads do not commute to their workplace every day. Regarding car value and car age, we found that both were negatively associated with the cars' energy efficiency; the former is consistent with the fact that expensive cars usually have a high engine capacity that is less energy efficient, and the latter is consistent with the fact that older cars tend to be less energy efficient.

Importantly, households that bought a new or a used car during the surveyed period did not generate a rebound effect of a different magnitude (captured by the dummy variables and their interactions with energy efficiency, as can be seen in Table 3). Given that a rebound is observed ($\beta = 0.40$; $p < 0.05$) but the coefficients of the interactions are insignificant, there is no evidence that the behavior of households that bought a new or a used car is different from the behavior of other households in terms of the contribution to the rebound effect. Namely, households with a higher-efficiency car (whether switching due to the policy or any other reason), generate, on average, a rebound effect of the same magnitude as the rest of the population (i.e., 40%). This result is plausible because there is no reason for there to be a fundamental difference in the behavior of these households compared with other households that might generate a rebound of a different magnitude. Namely, the rebound occurs not directly because of the policy or because of the purchase of a car, but due to the energy efficiency level of the car.

Finally, the observation that historical fuel prices had no significant effect on energy efficiency is not trivial, because one expects that high prices will encourage the purchasing of cars with low usage-costs (see Archibald and Gillingham, 1980; Puller and Greening, 1999). One possible explanation is that up to two years following the implementation of the policy, consumers were still unaware of the potential savings associated with switching to energy-efficient cars. Another plausible reason is that individuals in Israel do not expect fuel prices to be consistent over time, therefore, they do not consider historical fuel prices to be good indicators of the expected savings associated with switching to an energy-efficient car.

5. Conclusion and policy implications

The main objective of this study was to measure a rebound effect while controlling for the endogeneity of the households' choice of energy efficiency level of the car they own. To do so, we used a policy that subsidizes energy-efficient cars as an instrumental variable. We used a simultaneous equations model to measure the occurrence and magnitude of the rebound effect. Our empirical results indicate an average rebound effect of 40%, and a relatively high kilometers-traveled elasticity with respect to fuel prices of approximately -0.66. This elasticity may be useful in evaluating the effectiveness of a fuel pricing policy in decreasing kilometers traveled, as it represents consumers' short-term response to changes in fuel prices. Next, we discuss the implications of our findings with respect to the advantages and disadvantages of a technology-subsidization policy versus a fuel-pricing policy.

First, a major potential benefit of a policy that subsidizes energy-efficient cars is that the increased demand for these cars will incentivize manufacturers and importers to introduce a larger variety of energy-efficient cars, thereby expanding the range of energy-efficient cars available on the market. A larger range of energy-efficient cars increases consumer choice, and decreases car prices due to increased competition. Thus, by taking measures directed towards consumers, the government increases consumer welfare, but also incentivizes technology improvements through promoting energy-efficient technologies. Recall that the variance of cars' energy efficiency in our sample increased by about 30%. Similarly, Fig. 1 indicates that the share of energy-efficient cars increased after the implementation of the policy. These increases signify an increase in the range and share of energy-efficient cars owned by Israeli households, indicating the positive effect of the policy on consumers' preference for energy-efficient technology.

Second, unlike a fuel pricing policy that decreases demand for kilometers traveled, subsidizing energy efficiency does not decrease kilometers traveled, thereby contributing to economic activity. Moreover, given that periphery households travel more, increasing subsidization will result in increased traveling of periphery residents, promoting progressiveness toward periphery residents compared with households located in central areas.

However, one drawback of a subsidization policy may be that lower prices of energy-efficient new cars will immediately affect respective used car prices. Subsidizing a specific car model immediately and proportionally affects the price of used cars of the same model (otherwise consumers would prefer the new model over the old one). By affecting the prices of used cars, the policy is likely to indirectly increase energy consumption. First, used cars tend to be less energy-efficient, because of both technological progress in the automobile industry and engine depreciation. Second, the decrease in the price of used cars makes them more accessible to consumers that, due to financial reasons, had used public transportation in the past. Moreover, a price decrease eventually diffuses to other car models on the used car market. Overall, consumers purchasing a new car, consumers purchasing a used car, and consumers shifting from public to private transportation and thereby increasing kilometers traveled, all reflect a growth in the consumption of private transportation and contribute to the underlying reason for the 40% rebound effect we found. The increase in disposable income resulting from lower usage costs enables consumers to purchase other goods, some of which may be energy-consuming. The literature refers to this latter consumer behavior as an indirect rebound effect.

The high price elasticity that we found indicates that a fuel pricing policy may considerably decrease energy consumption. Given that the decision of the Israeli consumer to purchase an energy-efficient car does not seem to be affected by historical fuel prices, the energy-efficiency levels of cars are not expected to change under a pricing policy that increases fuel prices, and on average, households will directly decrease their demand for energy. A second major benefit of such a policy is that higher fuel prices resulting from the additional tax may have a progressive effect, because low-income households tend to own fewer cars and to drive them less than high-income households (Buchs et al., 2011). However, our regression results should be treated with caution, as the estimated coefficient of the price elasticity represents responses to marginal changes in prices. The literature suggests that if the tax increase is substantial, in the long run some households will decrease the use of their car, thereby negatively affecting economic activity, and other households may purchase a more energy-efficient car to cut expenses – but this may generate a rebound.

Considering the advantages and disadvantages of both policy strategies, we advocate using subsidization of energy-efficient cars and fuel taxes as complimentary components in a policy aimed at decreasing energy consumption. In particular, while the subsidizing of energy-efficient cars increases the share of these cars on the market, it also encourages households to increase their kilometers traveled. The latter may be moderated using a corresponding fuel tax. Therefore, we suggest applying a policy that subsidizes the purchase of the car on one hand and levies tax on the marginal use that generates the externality on the other hand.

This study has several limitations that serve as opportunities for future research. First, in terms of data availability, time series data would have enabled us to estimate whether consumers who chose to increase their cars' energy efficiency following the introduction of the policy (i.e., to buy a new, energy-efficient car) did indeed subsequently change their kilometers traveled. Furthermore, the data do not allow us to identify households that switched from public transportation to a private car, or from a less efficient to a more energy-efficient car. Time series data would have enabled us to measure the sources of the direct rebound effect mechanism more precisely. Unfortunately, time series data of household expenditures are not collected by the Israel Central

Table A1
A detailed structure of car categories and corresponding tax rates.

Pollution level	The green meter	Tax rate	Sales-tax reduction (NIS)
1[a]	0–50	10–30%	
2[b]	51–130	30–92%	
	51–130	92%[c]	15,000
3	131–150		13,750
4	151–170		12,000
5	171–175		10,500
6	176–180		9250
7	181–185		8250
8	186–190		7250
9	191–195		6500
10	196–200		5500
11	201–205		5000
12	206–210		4000
13	211–220		3250
14	221–250		2000
15	251–400		–

[a] The first pollution category includes emissions-free cars (e.g., electric). The purchase tax rate in this group is set at 10% in 2009–2014 and 30% in 2015–2019.

[b] The second pollution category is divided into two groups according to the type of the car's engine. For cars with an alternative engine (e.g., hybrid) the purchase tax rate is set at 30% in 2009–2012, 45% in 2013, and 60% in 2014. For cars with a regular engine, the purchase tax is set at 92% with a reduction of 15,000 NIS. Starting in 2015, the two categories are merged, and the sales tax rate in the merged group is set at 92% with a reduction of 15,000 NIS.

[c] For all the other categories, the baseline sales tax is 92%, and upon purchase consumers enjoy a one-time tax reduction in accordance with the car's pollution category.

Bureau of Statistics. Second, data that include additional years would have enabled us to examine the consistency of the rebound over time. From a policy perspective, it would be useful to know whether a rebound in the presence of a subsidization policy is persistent, increases, or declines over time. Third, in terms of methodology, we use the implementation of the policy as an instrumental variable. It is possible that other relevant factors took place at the point that the policy was launched, of which we are unaware. If this were the case, although by statistical criteria the instrumental variable is adequate, it may capture more than just the policy. However, to the best of our knowledge such factors did not take place during the examined period in Israel. Finally, in terms of the generalization of our results, as described in Section 2.1, the Israeli car market is characterized by controlled fuel prices and only imported cars. These conditions, which provide a unique environment for measuring the rebound effect, may be dramatically different in other countries, leading to differences in the magnitude of the estimated rebound.

Appendix A

The "Green Taxation" policy uses the following components: (1) the "green meter" – a formula for calculating pollution levels of cars:

$$\frac{500*CO+900*HC+10{,}000*NO_X+20{,}000*PM+30*CO_2}{30}$$

and (2) a table that categorizes cars' pollution level, as calculated in the formula, into 15 pollution levels and determines the corresponding incentive for each category (Israel Ministry of the Treasury, 2009) (Table A1).

References

Archibald, R., Gillingham, R., 1980. An analysis of the short-run consumer demand for gasoline using household survey data. Rev. Econ. Stat. 62 (4), 622–628.

Berkhout, P.H., Muskens, J.C., Velthuijsen, J.W., 2000. Defining the rebound effect. Energy Policy 28, 425–432.

Buchs, M., Bardsley, N., Duwe, S., 2011. Who bears the brunt? Distributional effects of climate change mitigation polisiec. Crit. Soc. Policy 31, 285–302.

de Haan, P., Mueller, M.G., Peters, A., 2006. Does the hybrid Toyota Prius lead to rebound effect? Analysis of size and number of cars previously owned by Swiss Prius buyers. Ecol. Econ. 58, 592–605.

de Haan, P., Mueller, M.G., Scholz, R.W., 2009. How much do incentives affect car purchase? Agent-based microsimulation of consumer choice of new cars – part II: forcasting effects of feebates based on energy-efficiency. Energy Policy 37, 1083–1094.

Diamantopoulos, A., Schlegelmilch, B.B., Sinkovics, R.R., Bohlen, G.M., 2003. Can socio-demographics still play a role in profiling green consumers? J. Bus. Res. 56, 465–480.

Dings, J., 2013. Mind the Gap! Why official car fuel economy figures don't match up to reality. Transp. Environ.

Frondel, M., Vance, C., 2013. Energy efficiency: Don't belittle the rebound effect. Nature 494 (7438) 430–430.

Frondel, M., Peters, J., Vance, C., 2008. Identifying the rebound: evidence from a German household panel. Energy J. 29 (4), 145–163.

Geller, H., Harrington, P., Rosenfeld, A.H., Tanishima, S., Unander, F., 2006. Policies for increasing energy efficiency: Thirty years of experience in OECD countries. Energy Policy 34, 556–573.

Gillingham, K., Kotchen, M.J., Raspon, D.S., Wagner, G., 2013. Energy policy: the rebound effect is overplayed. Nature 493, 475–476.

Greene, D.L., Kahn, J.R., Gibson, R.C., 1999. Fuel economy rebound effect for U.S. household vehicles. Energy J. 20 (3), 1–31.

Greening, L.A., Greene, D.L., Difiglio, C., 2000. Energy efficiency and consumption – the rebound effect – a survey. Energy Policy 28, 389–401.

International Energy Agency (IEA), 2008a. Worldwide Trends in Energy Use and Efficiency. International Energy Agency, Paris.

International Energy Agency (IEA), 2008b. Energy Efficiency Policy: Recommendations. The International Energy Agency, Paris.

International Energy Agency (IEA), 2010. Transport Energy Efficiency: Implementation of IEA Recommendations. The International Energy Agency, Paris.

International Energy Agency (IEA), 2008. World Energy Outlook 2008–2014. International Energy Agency, Paris.

International Energy Agency (IEA), 2015. Energy Technology Perspectives 2015 – Mobilising Innovation to Accelerate Climate Action. International Energy Agency, Paris.

Israel Central Bureau of Statistics, 2012. Kilometers Traveled Survey. Central Bureau of Statistics, Jerusalem, In Hebrew.

Israel Central Bureau of Statistics, 2014. Motor Vehicles. Central Bureau of Statistics, Jerusalem, In Hebrew.

Israel Ministry of the Treasury, 2009. Press Release: Green Tax Revolution is Underway – Leveraging Economy to Benefit the Environment. Israel Ministry of the Treasury, Jerusalem, In Hebrew.

Israel Ministry of National Infrastractures, Energy and Water Resources, 2015. Fuel Prices on Gas Stations – historical prices. Available at: 〈http://energy.gov.il/Subjects/Fuel/Pages/GxmsMniPricesatStation.aspx〉 (In Hebrew).

Israel Tax Authority, 2010. Taxation and Selected Data on the Automotive Industry for 2010. Israel Tax Authority, Jerusalem, In Hebrew.

Israel Tax Authority, 2012. Taxation and Selected Data on the Automotive Industry for 2012. Israel Tax Authority, Jerusalem, In Hebrew.

Kahn Ribeiro, S., Kobayashi, S., Beuthe, M., Gasca, J., Greene, D., Lee, D.S., Muromachi, Y., Newton, P.J., Plotkin, S., Sperling, D., Wit, R., Zhou, P.J., 2007. Transport and its infrastructure, in: Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York.

Khazzoom, J.D., Shelby, M., Wolcott, R., 1990. The conflict between energy conservation and environmental policy in the US transportation sector. Energy Policy 18 (5), 456–458.

Litman, T., 2013. Changing North America vehicle-travel price sensitivities: implications for transport and energy policy. Transp. Policy 28, 2–10.

Organization for Economic Co-operation and Development (OECD), 2014. The Cost of Air Pollution: Health Impacts of Road Transport. Available at: 〈http://www.oecd-ilibrary.org/environment/the-cost-of-air-pollution_9789264210448-en〉.

Puller, S.L., Greening, L.A., 1999. Household adjustment to gasoline price change: an analysis using 9 years of US survey data. Energy Econ. 21, 37–52.

Shiftan, Y., Albert, G., Keinan, T., 2012. The impact of company-car taxation policy on travel behavior. Transp. Policy 19, 139–146.

Small, K.A., Van Dender, K., 2007. Fuel efficiency and motor vehicle travel: the declining rebound effect. Energy J. 28 (1), 25–52.

Sorrell, S., Dimitropoulos, J., 2008. The rebound effect: microeconomic definitions, limitations and extentions. Ecol. Econ. 65, 636–649.

Sorrell, S., Dimitropoulos, J., Sommerville, M., 2009. Empirical estimates of the direct rebound effect: a review. Energy Policy 37, 1356–1371.

U.S. Energy Information Administration, 2015. Short-Term Energy Outlook. Available at: 〈http://www.eia.gov/forecasts/steo/realprices/〉.

Wooldridge, J.M., 2002. Introductory Econometrics: A Modern Approach, second ed South Western Educational Publishing, US.

World Health Organization, 2010. Exposure to Air Pollution: A Major Public Health Concern. World Health Organization, Geneva.