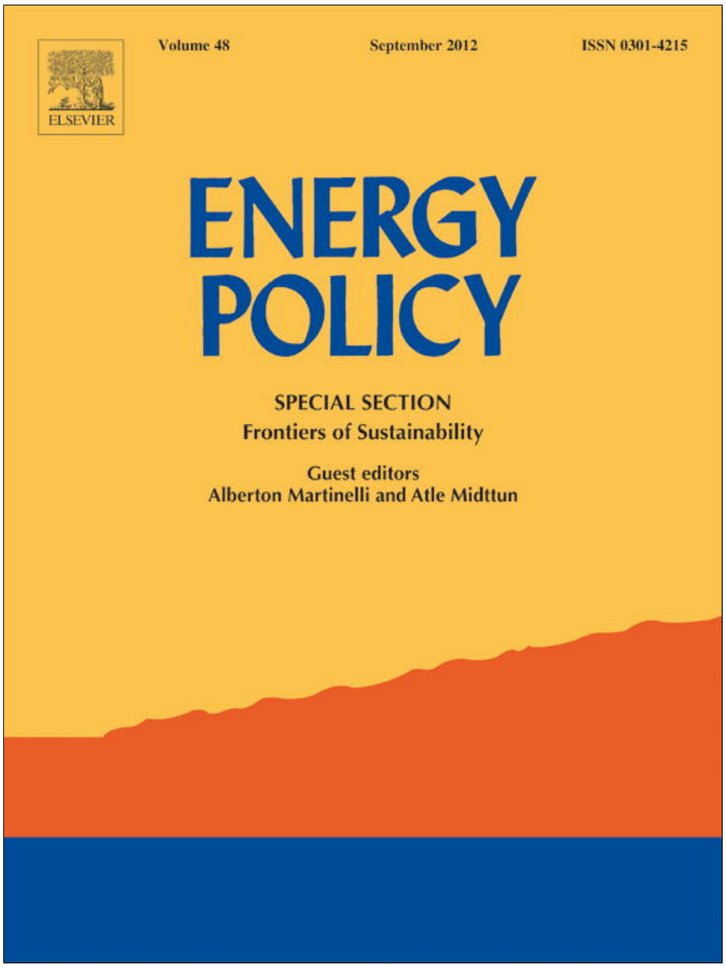

Volume 48 September 2012 ISSN 0301-4215

ELSEVIER

ENERGY
POLICY

SPECIAL SECTION
Frontiers of Sustainability

Guest editors
Alberton Martinelli and Atle Midttun

Energy Policy 48 (2012) 374–393

Contents lists available at SciVerse ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

On the electrification of road transport - Learning rates and price forecasts for hybrid-electric and battery-electric vehicles

Martin Weiss [a],*, Martin K. Patel [b], Martin Junginger [b], Adolfo Perujo [a], Pierre Bonnel [a], Geert van Grootveld [a]

[a] European Commission – Directorate General Joint Research Centre, Institute for Energy and Transport, Sustainable Transport Unit, via Enrico Fermi 2749 TP 230, Ispra 21010, Italy
[b] Utrecht University, Copernicus Institute for Sustainable Development and Innovation, Budapestlaan 6, 3584 CD Utrecht, The Netherlands

HIGHLIGHTS

- Learning rates for hybrid-electric and battery-electric vehicles.
- Prices and price differentials of hybrid-electric vehicles show a robust decline.
- Battery-electric vehicles may require policy support for decades.

ARTICLE INFO

Article history:
Received 11 January 2012
Accepted 17 May 2012
Available online 15 June 2012

Keywords::
Technological learning
Hybrid-electric vehicles
Battery-electric vehicles

ABSTRACT

Hybrid-electric vehicles (HEVs) and battery-electric vehicles (BEVs) are currently more expensive than conventional passenger cars but may become cheaper due to technological learning. Here, we obtain insight into the prospects of future price decline by establishing *ex-post* learning rates for HEVs and *ex-ante* price forecasts for HEVs and BEVs. Since 1997, HEVs have shown a robust decline in their price and price differential at learning rates of 7 ± 2% and 23 ± 5%, respectively. By 2010, HEVs were only 31 ± 22 €$_{2010}$ kW^{-1} more expensive than conventional cars. Mass-produced BEVs are currently introduced into the market at prices of 479 ± 171 €$_{2010}$ kW^{-1}, which is 285 ± 213 €$_{2010}$ kW^{-1} and 316 ± 209 €$_{2010}$ kW^{-1} more expensive than HEVs and conventional cars. Our forecast suggests that price breakeven with these vehicles may only be achieved by 2026 and 2032, when 50 and 80 million BEVs, respectively, would have been produced worldwide. We estimate that BEVs may require until then global learning investments of 100–150 billion € which is less than the global subsidies for fossil fuel consumption paid in 2009. These findings suggest that HEVs, including plug-in HEVs, could become the dominant vehicle technology in the next two decades, while BEVs may require long-term policy support.

1. Introduction

The continuous growth of global passenger road transport raises concerns about urban air pollution, anthropogenic greenhouse gas emissions, and the depletion of fossil energy resources (EEA, 2009, 2010; EPA, 2006; WB, 2007). By 2010, passenger road transport consumed 54 exajoules of fuels, emitted 4.6 gigatonnes of carbon dioxide (CO_2), and accounted for 11% of both global primary energy use and energy-related CO_2 emissions (IEA, 2009; ITF, 2010). These shares are likely to increase in the future if the worldwide fleet of light-duty vehicles triples to the projected 2 billion cars and light-commercial vehicles by 2050 (de Jong et al., 2009; IEA, 2009).

In response to this projection, vehicle manufacturers and policy makers support the gradual electrification of road transport via the introduction of innovative hybrid-electric vehicles (HEVs), plug-in HEVs, battery-electric vehicles (BEVs), and fuel-cell-electric vehicles (FCEVs; EC, 2009a, 2011a,c; EGCI, 2010; IEA, 2010). FCEVs have been considered as a viable technology option in the past decade; their high production costs, however, have shifted the focus to HEVs and BEVs (see, e.g., Eberle and von Helmolt, 2010; Bakker, 2011). HEVs were introduced into the market in 1997; by 2010, they accounted for 2% of the global passenger car sales (estimates based on Honda, 2009; OICA, 2010; Toyota, 2011a). The first generation of plug-in HEVs and mass-produced BEVs are currently being introduced into the market. For the latter two vehicle types, industry and governments have defined

---

* Corresponding author. Tel.: +39 0332 78 6649.
E-mail address: martin.weiss@jrc.ec.europa.eu (M. Weiss).

0301-4215/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.enpol.2012.05.038

ambitious targets: As frontrunners of electrification, the car manufacturers Nissan and Renault plan to reach a joint yearly production capacity of half a million BEVs by 2015 (Wüst, 2012). China aims at reaching half a million cumulative BEV sales by 2015 (Fulton, 2011). The USA aspires to achieve one million cumulative sales of plug-in HEVs and BEVs by 2015 (Hardy, 2010; Lee and Lovellette, 2011). The cumulative sales of plug-in HEVs and BEVs in the European Union (EU) are expected to reach five million by 2020 (EGCI, 2010), potentially accounting then for 8% of the yearly sales of passenger cars (RBSC, 2011).

The current prospects of HEVs, plug-in HEVs, and BEVs are hampered, however, by high vehicle prices paired with a comparatively low use value, including limited payload, uncertainty regarding durability and safety, short driving range. To achieve substantial market shares under the current economic conditions, HEVs, plug-in HEVs, and BEVs have to become cheaper and more functional (de Jong et al., 2009; IEA, 2009; EGCI, 2010).

Several attempts have been made to forecast production costs, prices, and the costs of ownership for HEVs, plug-in HEVs, and BEVs (e.g., Thiel et al., 2010; Burke et al., 2011; Lee and Lovellette, 2011). These forecasts typically combine detailed vehicle component models with average vehicle use data and fuel price scenarios (e.g., based on Lipman and Delucchi, 2003; Edwards et al., 2008). A particular source of uncertainty arises from the relatively crude assumptions used to project the rate at which production costs of vehicles and their powertrain components decline. This article provides rationale for the established forecasts by analyzing the price development of HEVs and BEVs using the experience curve approach.

Experience curves typically model the production costs of technologies as a power-law function of cumulative production; they have been frequently applied for strategic planning in industry (Dutton and Thomas, 1984) and, more recently, to forecast the costs of renewable energy-supply technologies (Kahouli-Brahmi, 2008; Neij, 2008; Junginger et al., 2010) and efficient energy-demand technologies (Weiss et al., 2010).

Here, we establish experience curves in a step-wise approach: First, we quantify for the period from 1997 to 2010 *ex post* the rate of price decline for HEVs and comparable conventional vehicles equipped with spark-ignition combustion engines (ICEs). Second, we use the insight gained from this analysis to derive *ex-ante* forecasts of the future price development of BEVs for which time-series data are not yet available. The results of these analyses provide valuable input for:

(i) deriving more reliable market projections for HEVs, plug-in HEVs, and BEVs,
(ii) developing more robust scenarios for the future energy use as well as CO_2 and pollutant emissions of passenger road transport,
(iii) supporting the establishment of efficient research, development, and innovation support, subsidy programs, and tax allowances that facilitate the electrification of passenger road transport.

Our analysis excludes detailed forecasts of component costs as well as projections on the costs of vehicle ownership, e.g., costs per kilometer driven. The former limitation presents ample opportunities for additional in-depth research (see Section 4.2). The latter limitation is justified because projections are available (e.g., Thiel et al., 2010; Lee and Lovellette, 2011), to which we add here insight into one critical parameter.

The article continues with background information and a description of our research methodology in Section 2. We present results in Section 3 and discuss the strength, limitations, and implications of our research in Section 4.

2. Background information and methodology

2.1. Background information

We define HEVs as passenger cars that draw energy for mechanical propulsion from both consumable fuels and an electric power storage device, i.e., a battery (EC, 2007). Several categories of HEVs can be differentiated:

(i) mild and full HEVs depending on the degree of hybridization[1], and
(ii) parallel and series HEVs depending on the mode of power supply[2] (for detailed explanations, see, e.g., Lipman and Delucchi, 2003; Emadi et al., 2005; HC, 2011).

The battery of HEVs is recharged by regenerative braking and through the work of the internal combustion engine. Plug-in HEVs share the principal features of HEVs but allow recharging the battery by an external power source. BEVs are passenger cars that draw energy for mechanical propulsion solely from a rechargeable electric power storage device such as a battery (EC, 2007).

The first mass-produced HEVs were introduced to the market in 1997 by Toyota in Japan (Toyota Prius), in 1999 by Honda in the USA (Honda Insight), and in 2000 by Toyota in Europe (Toyota Prius). Since then, annual global HEV sales have been growing on average by 47%, reaching about one million in 2010 (Fig. 1). The USA currently represents the largest HEV market with more than two million vehicles cumulatively sold by January 2012, followed by Japan and the EU with cumulative sales of more than 1.5 million and approximately 450 thousand HEVs, respectively. In 2009, the USA and Japan accounted together for 84% of the worldwide registration of new HEVs (Wikipedia, 2012).[3] The USA is expected to remain the largest HEV market through 2015, while the largest market growth will likely occur in China (PR, 2010).

Most major vehicle manufacturers currently offer HEVs, while beginning to introduce plug-in HEVs into the market (GCC, 2010b). BEVs have a long history dating back to the mid-19th century (Cowan and Hultén, 1996; Bellis, 2010). However, it was only in the 1980s that BEVs experienced a *renaissance* owing to concerns about the security of fossil fuel supply and transport-related air pollution. In the past three decades, numerous BEVs have been presented for experimental purposes (Bakker, 2011). Several small-batch producers have offered BEVs for several years now, while most major vehicle manufacturers are only starting to commercialize compact BEVs, designed predominantly for short-range city driving (e.g., Mitsubishi, 2010; Chambers, 2011; Citroën, 2011; Nissan, 2011a).

The markets for HEVs, plug-in HEVs, and BEVs in Japan, Europe, and the USA are highly dynamic; new vehicles are introduced almost on a monthly basis. The market penetration of novel hybrid-electric and electric powertrains exhibits distinct differences from other novel technologies in the automotive sector. Typically,

---

[1] We exclude from this definition and from our research micro HEVs that comprise vehicles equipped with conventional internal combustion engines (ICE) and an electric motor or generator that allows switching the ICE off during coasting, braking, or stopping but which cannot propel the vehicle. Mild HEVs have a relatively small battery and electric motor (with a capacity typically lower than 20 kW) and do not possess a hybrid powertrain. Full HEVs operate one or more electric motors in combination with a relatively large battery. Full HEVs can be propelled solely by the work of the electric motor.

[2] Parallel HEVs are propelled jointly or individually by an electric motor and an internal combustion engine. Series HEVs are solely propelled by an electric motor, while the ICE powers a generator that supplies electric energy to the battery.

[3] The data presented here are compiled by Wikipedia (2012) based on multiple primary data sources. Space limitations precluded us from listing all sources here. We refer the reader to the link in the reference list for more detailed information.

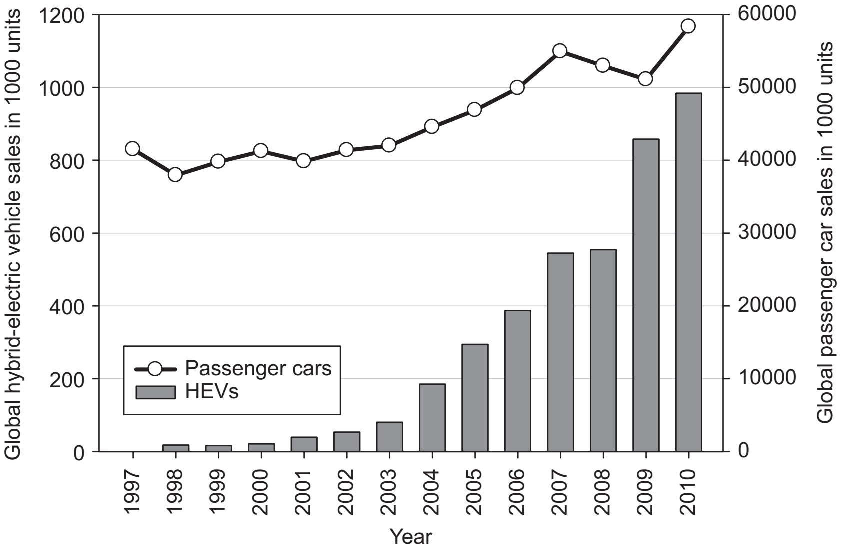

Fig. 1. Global sales of HEVs (left vertical axis) and total global passenger car sales (right vertical axis; estimates based on Honda, 2009; OICA, 2010; Toyota, 2011a).

novel technologies such as airbags, anti-lock breaking systems, and electronic stability controls offer additional value to consumers but are expensive at the point of their market introduction. These technologies are therefore first introduced into high-price vehicles for which consumers are willing to accept a price premium in exchange for superior product functionality. Eventually, technological learning reduces production costs and enables the diffusion of novel technologies into mid-price and low-price vehicles. Hybrid-electric powertrains, however, were first introduced to compact cars (i.e., the Toyota Prius and the Honda Insight) because this strategy arguably enabled manufacturers best to demonstrate and capitalize the potentials of this technology for reducing fuel consumption and carbon dioxide emissions. Since 2006, hybrid-electric powertrains have been diffusing into both full-size luxury and small passenger cars. A similar pattern of technology deployment may be observed in the future for plug-in HEVs and BEVs, for which limited electric driving ranges favor applications in small and compact cars.

The deployment of HEVs, plug-in HEVs, and BEVs points to a particular problem: While offering superior powertrain efficiency and potentially low operating costs, these vehicles are substantially more expensive and provide lower functionality than vehicles equipped with conventional internal combustion engines. Many countries have been establishing subsidy schemes or tax allowance programs to increase the attractiveness of HEVs, plug-in HEVs, and BEVs for consumers (see, e.g., ACEA, 2010; Chandra et al., 2010; McConnell and Turrentine, 2010; Xiang, 2010; DOE, 2011)[4]. In parallel, research and development in vehicle components receives substantial funding with the objective of accelerating technological learning and improving the performance of innovative powertrain concepts (Hardy, 2010; EC, 2011b). This background provides the context of our empirical analysis, which we explain next.

2.2. Methodology

The production costs of technologies typically decline through the interaction of various mechanisms such as learning-by-doing, economies of scale, technological innovation, and factor substitution. Together, these mechanisms are typically referred to as technological learning that can be quantified by experience curves. The experience curve approach is, strictly speaking, only applicable to production costs (BCG, 1972; Dutton and Thomas, 1984). Here, we approximate production costs of HEVs and BEVs by retail prices because cost data are kept confidential by manufacturers. This simplification is common practice in experience curve analyses (Kahouli-Brahmi, 2008; Weiss et al., 2010) but introduces uncertainty if price margins vary in the period of analysis, e.g., due to cross-subsidies or demand-driven changes in profit margins (see Section 4.1).

We quantify technological learning for HEVs and BEVs with the experience curve approach (BCG, 1972) by modeling the price of vehicles as a power-law function of cumulative production:

$$C(x_{t,i}) = C(x_{0,i})\left(\frac{x_{t,i}}{x_{0,i}}\right)^{b_i} \quad (1)$$

where $x_{0,i}$ is the cumulative production of technology i at an arbitrary starting point 0, $x_{t,i}$ is the cumulative production at time point t, $C(x_{t,i})$ is the specific price or price differential at $x_{t,i}$, $C(x_{0,i})$ is the specific price or price differential at $x_{0,i}$, and b_i is the technology-specific experience index.

By applying the logarithmic function, Eq. (1) yields a linear equation with b_i as the slope parameter and log $C(x_{0,i})$ as the intercept with the price axis. We calculate progress ratios (PR_i) [%] and learning rates (LR_i) [%] as rates of price decline with each doubling of cumulative production as:

$$PR_i = 2^{b_i} \quad (2)$$

$$LR_i = 1 - PR_i = 1 - 2^{b_i} \quad (3)$$

We estimate the error interval of PR_i and LR_i as the implicit error of experience curves, i.e., the 95% confidence interval of the slope parameters.

Our experience curve analysis consists of two parts: First, we establish *ex-post* experience curves and learning rates for HEVs. Second, we use the established learning rates to derive *ex-ante* price forecasts for BEVs. In the first part of our analysis, we establish learning rates for the price of HEVs and the price differential between HEVs and conventional spark-ignition ICE vehicles in the period between 1997 and 2010. For

---

[4] Beresteanu and Li (2011) estimate that in 2006, 20% of the HEV sales in the USA can be attributed to governmental tax incentives. Similar effects have been identified by Chandra et al. (2010) for Canada, where 26% of the HEV sales during rebate programs may be attributable to rebates.

each of the two parameters, we construct two sets of experience curves:

(i) for the Toyota Prius (i.e., the first mass-produced HEV) sold in Japan, Germany, and the USA,
(ii) for all HEVs sold in Germany and the USA.

Before continuing, it is important to note that modeling the price differentials of HEVs with the experience curve approach entails the caveat that the established values cannot become negative due to the mathematical properties of the applied power-law function. This caveat is acceptable because the costs of electric components in hybrid powertrains add to the costs of conventional ICE powertrains. However, this may not necessarily be so in the future if economies of scale and technological innovation in battery technology allow a substantial downscaling of ICE components.

In the second part of our analysis, we use the learning rates established for the price differentials of HEVs and for the price of conventional ICE vehicles to derive *ex-ante* estimates for the price development of BEVs in the period between 2010 and 2035. This analysis consists of four steps:

(i) We divide the price of BEVs into two components, i.e., the costs of electrification (e.g., including the costs of battery, electric motor, and auxiliary components) and the ancillary costs (e.g., including the costs of the vehicle chassis, the suspension, the interior, and the markup of retailers). We begin our calculations by assuming that the ancillary costs in the case of conventional ICE vehicles accounts for 82 ± 4% of the total vehicle price (Lipman and Delucchi, 2003). To estimate the ancillary costs for BEVs in the year 2010, we first multiply the share of 82 ± 4% by the price of conventional ICE vehicles that are included in our analysis (see below). This calculation yields average ancillary costs of 129 ± 6 €$_{2010}$ kW^{-1} that are not related to the powertrain in conventional ICE vehicles. We now assume that the ancillary costs of 129 ± 6 €$_{2010}$ kW^{-1} also apply to BEVs and that the difference between this number and the average price of BEVs represents the costs of electrification.
(ii) We establish experience curves and estimate learning rates for conventional ICE vehicles.
(iii) We forecast the ancillary costs for BEVs until 2035 by assuming a similar learning rate as for conventional ICE vehicles. We forecast the cumulative production of components constituting the ancillary costs based on the combined sales projections for BEVs, HEVs, and conventional ICE vehicles (see below).
(iv) We forecast the decline in the costs of electrification by assuming a learning rate similar to that found for the price differential of HEVs. This assumption is justified because the price differential between HEVs and conventional ICE vehicles essentially represents the costs of the additional battery capacity, the electric motor, the inverter and controller, and the integration of the electric components into the powertrain. We assume that the cumulative production of BEVs increases from 2010 onwards at rates similar to the ones observed for HEVs since 1997.
(v) We forecast the price of BEVs in each year by calculating the sum of the costs of electrification and the ancillary costs.

We present the price forecasts of BEVs together with our price forecasts for HEVs and conventional ICE vehicles. We estimate the cumulative production ($x_{b,i}$) of BEVs at which price breakeven is reached as:

$$x_{b,i} = x_{0,i} \cdot \left(\frac{C(x_{b,i})}{C(x_{0,i})}\right)^{1/b_i} \tag{4}$$

where $C(x_{b,i})$ is the specific price at $x_{b,i}$

We estimate the learning investments (I_i) required until BEVs reach price breakeven as:

$$I_i = C(x_{0,i})x_{0,i}\left\{\frac{1}{1+b}\left[-b\left(\frac{C(x_{b,i})}{C(x_{0,i})}\right)^{(-b_i-1)/-b_i} - 1\right] + \frac{C(x_{b,i})}{C(x_{0,i})}\right\} \tag{5}$$

In the forecast above, we assume that the cost components and the factors driving down the costs of electrification in HEVs are similar to the ones in BEVs. This assumption, however, disregards that battery costs may account for a substantially larger share in the price of BEVs than in the price of HEVs. We therefore conduct a sensitivity analysis by assuming that the costs of electrification decline at a learning rate of 17% as identified for lithium-ion batteries by Nagelhout and Ros (2009).

Having clarified our research approach, we next define the system boundary of our analysis and we provide the sources of input data. Our experience curve analysis covers HEVs, BEVs, and conventional ICE vehicles of category M_1, i.e., we include passenger cars with no more than eight seats in addition to the driver's seat (EC, 2001). We include both mild and full HEVs; however, we refrain from presenting individual experience curves for these two vehicle types because both essentially represent the same learning system (see section 4.1). We differentiate the three vehicle markets of Japan, Germany, and the USA to identify, to the extent possible, the effect of pricing policies and costs of shipment on the established learning rates.

We estimate the cumulative global production of HEVs, BEVs, and conventional ICE vehicles based on the following sources (see Appendix A):

(i) HEVs: Honda (2009), USDE (2011a), Brambach (2009), Daimler (2010), Chambers (2011), Toyota (2011a,b),
(ii) BEVs: Blanco (2010), Tesla (2010), GCC (2010a, 2011), Chambers (2011), KFZ (2011),
(iii) Conventional ICE vehicles: OICA (2010), BC (1998).

We forecast the price of HEVs, BEVs, and conventional ICE vehicles until 2035 by using the sales projections published by IEA (2010).

The price data for HEVs, BEVs, and conventional ICE vehicles cover the time period from December 1997 until February 2011; data are obtained from AP (2011), CGA (2011), GNE (2011), and the webpages of the various vehicle manufacturers (see Appendix A). Although we aim at obtaining a comprehensive data set, our price data may not cover all HEVs and BEVs currently offered on the highly dynamic vehicle market.

We express prices in terms of real specific retail prices, excluding sales tax, in Euro per kilowatt of engine power, deflated to the base year 2010 [€$_{2010}$ kW^{-1}]. We uniformly report engine power as the maximum power available from a vehicle's powertrain. Normalizing the absolute vehicle prices by engine power allows us to account for differences between the various HEVs, BEVs, and conventional ICE vehicles. This approach may be generally acceptable for HEVs and conventional ICE vehicles, where vehicle prices closely follow engine power; the approach may be, however, subject to uncertainty in the case of BEVs for which vehicle prices may be linked closely to battery capacity. Data characterization revealed that battery capacity and engine power each explain 87% and 94%, respectively in the price variability of BEVs. This finding confirms that battery capacity

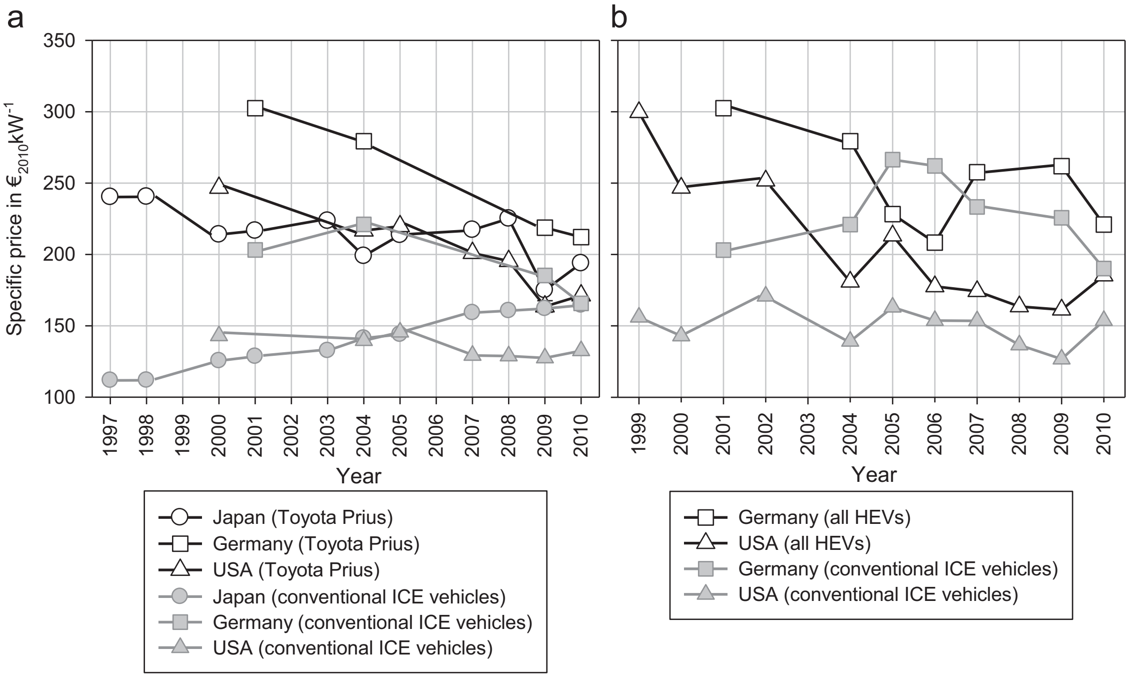

Fig. 2. Specific prices of the Toyota Prius (a) and of all HEVs offered on the market (b); data points represent price averages, which are un-weighed for vehicle sales.

closely follows engine power[5] and that our approach to normalize absolute BEV prices with engine power is valid.

We convert currencies based on average market exchange rates for the year 2010, i.e., 116 Yen per € and 1.32 US Dollar per € (X-Rates, 2011). We deflate nominal vehicle prices by using gross domestic product deflators as provided by WB (2011). The most recent year of our experience curve analysis is 2010. To establish vehicle prices for this year, we also include price data published by manufacturers in early 2011. To correct for inflation effects, we uniformly deflate 2011 price data by assuming a GDP deflator of 1.02 between the years 2011 and 2010 (WB, 2011).

We determine the price differentials of HEVs by subtracting the prices of conventional spark-ignition ICE vehicles from the prices of HEVs. We ensure comparability of HEVs with their conventional counterparts by matching, to the extent possible, chassis size, engine power, and technical features (e.g., automatic transmission and air conditioning). For cases, in which no conventional ICE vehicle with a chassis identical to the one of HEVs exist (e.g., Toyota Prius, Honda Insight, Lexus CT and, Lexus HS), we chose vehicles that match the respective HEVs as closely as possible (see Appendix A).

3. Results

First, we present a data overview in a simple time-series analysis (Section 3.1). Second, we establish *ex-post* experience curves and learning rates for HEVs and conventional ICE vehicles (Section 3.2). In the third part, we forecast *ex ante* the price development of HEVs, BEVs, and conventional ICE vehicles until 2035 (Section 3.3).

3.1. Time series analysis

We find a robust decline in the price of HEVs since their market introduction in 1997 (Fig. 2). The specific price of the Toyota Prius in Japan declined by 19% between 1997 and 2010, i.e., from 240 $€_{2010}$ kW^{-1} to 194 $€_{2010}$ kW^{-1} (Fig. 2a). Higher price declines can be observed for the Toyota Prius in Germany (30% between 2001 and 2010) and in the USA (31% between 2000 and 2010). This observation indicates that the Prius may have been subsidized by Toyota during the first years after its market introduction in Japan. Although Toyota does not provide information, BW (1997) suggests that the production costs of a Toyota Prius in 1997 may have reached 450 $€_{2010}$ kW^{-1}, i.e., approximately 28,600 $€_{2010}$ per vehicle, excluding sales tax. The absolute price of the Toyota Prius differs between Japan, Germany, and the USA (Fig. 2a). This finding may be attributed, in part, to the differences in the costs of shipment, the pricing strategy of Toyota, and the applied price deflation.

Expanding the analysis to all HEVs shows that average prices have declined by 27% in Germany between 2001 and 2010 and by 38% in the USA between 1999 and 2010 (Fig. 2b). The relatively low prices in Germany in the years 2005 and 2006 solely stem from one vehicle, i.e., the Lexus RX; it is likely that these two data points reflect the pricing strategy rather than the technological learning of the manufacturer.

The price of HEVs declines, on average, at a higher rate than the price of conventional ICE vehicles (Fig. 3). Thus, the price differential of the Toyota Prius sold in Japan declined by 77% between 1997 (128 $€_{2010}$ kW^{-1}) and 2010 (29 $€_{2010}$ kW^{-1}). We observe a similar decline of price differentials in Germany and the USA.

The price differential of all HEVs declines in Germany by 69% between 2001 and 2010 (14% per year) and in the USA by 78% between 1999 and 2010 (15% per year; Fig. 3b). The price differentials for Germany and the USA differ from each other to a smaller extent than the absolute prices of HEVs do (compare Figs. 2b and 3b). This finding indicates that the absolute prices of HEVs and conventional ICE vehicles reflect the specifics of the vehicle markets in Japan, Germany, and the USA thereby suggesting that absolute prices are probably a poor proxy of actual production costs. In line with the data of Fig. 2, we find negative price differentials for all HEVs in Germany in the years 2005 and 2006. Again, price differentials in these years solely stem from the Lexus RX. We neither identify similarly low price differentials for

---

[5] We identify a coefficient of determination of 0.90 between the battery capacity and engine power of BEVs.

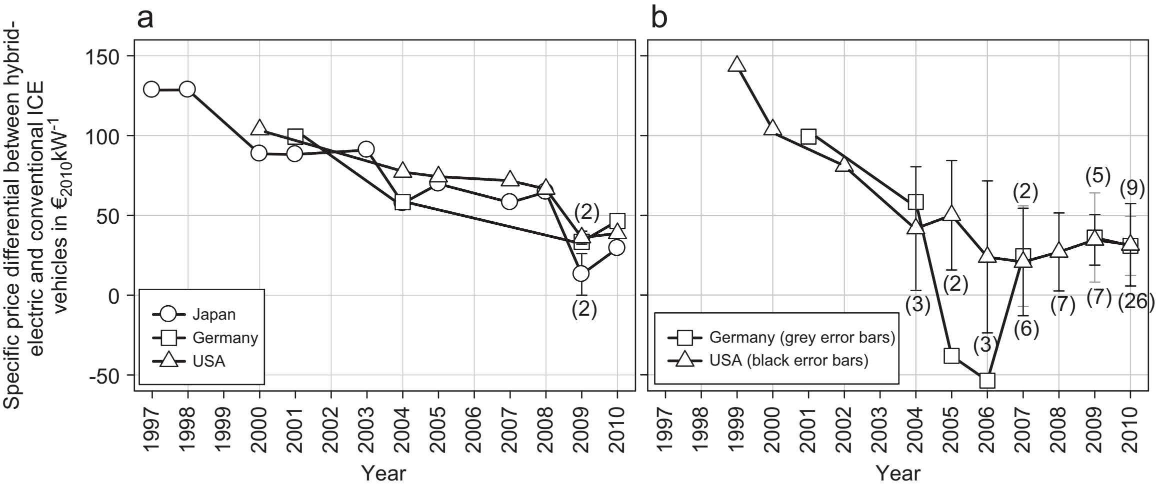

Fig. 3. Specific price differential of the Toyota Prius (a) and of all HEVs offered on the market (b) as compared to conventional ICE vehicles; the higher (lower) numbers in parentheses indicate the sample size for Germany (USA); data points represent price averages, which are un-weighed for vehicle sales; error bars indicate the standard deviation of price data.

any other HEV nor for any other year. It is thus likely that these two data points present outliers resulting from the pricing strategy of the manufacturer.

The average prices and price differentials of all HEVs vary substantially between individual years and show a lower decline in the period after 2006 (Figs. 2b and 3b). This observation may stem from a bias in our data that include after 2006 an increasing share of powerful and expensive HEVs that often come with additional safety and comfort features. The expansion of hybrid-electric powertrains to high-price vehicles may thus result in a lower decline of specific HEV prices. Linear regression analysis (see Appendix B) reveals that indeed the specific price of HEVs and conventional ICE vehicles is correlated with the absolute vehicle price. By contrast, the specific price differential of HEVs hardly depends on the absolute price (see Appendix B).

We account for this effect by normalizing the specific prices of all HEVs and conventional ICE vehicles to a price level of 20,000 $€_{2010}$ based on the linear relationships established for the year 2010 in Appendix B. We assume that this relationship holds for all years of the analysis. We find that normalizing the specific prices of HEVs and conventional ICE vehicles slightly decreases the average vehicle prices in the later years of our analysis (Fig. 4).

The average specific price of the ten BEVs included in our analysis (814 ± 478 $€_{2010}$ kW^{-1}) exceeds the specific price of HEVs and conventional ICE vehicles by 626 ± 502 $€_{2010}$ kW^{-1} and 657 ± 492 $€_{2010}$ kW^{-1}, respectively (Fig. 4). The specific price of the three mass-produced BEVs (i.e., the Nissan Leaf, the Mitsubishi i-MiEV, and its derivative the Citroën C-Zero) is substantially lower (479 ± 171 $€_{2010}$ kW^{-1}) than the average price of all BEVs. For these three mass-produced vehicles, the average price differential as compared with HEVs and conventional ICE vehicles amounts to 291 ± 195 $€_{2010}$ kW^{-1} and 322 ± 185 $€_{2010}$ kW^{-1}, respectively. The price data presented so far provide the empirical basis of the experience curves analyses, which we present next.

3.2. Experience curves for HEVs and conventional ICE vehicles

We find that the specific price of the Toyota Prius declines at learning rates of 1 ± 1% in Japan and 6 ± 2% in Germany and the USA (Fig. 5a). The relatively low learning rate in Japan supports our earlier argument that Toyota may have subsidized Prius sales after market introduction. By excluding the data point for the year 1997, the learning rate for Japan doubles to 2 ± 1%. The experience curve analysis for all HEVs yields learning rates of 5 ± 4% for Germany and 8 ± 2% for the USA (Fig. 5b).

We obtain slightly higher learning rates of 6 ± 5% for Germany and 10 ± 2% for the USA when plotting the normalized specific prices of all HEVs. The exceptionally low prices for Germany in 2005 and 2006 may be the result of pricing strategy. Excluding these data points yields a higher coefficient of determination ($R^2 = 0.89$), a smaller uncertainty interval, and a slightly lower learning rate of 5 ± 2% for HEVs in Germany (Fig. 6). If we assume that the experience curves of all HEVs best represent the technological learning of HEVs, we can average the learning rates for Germany (excluding the data points for the years 2005 and 2006) and the USA (Fig. 6) to estimate an overall average learning rate for HEVs of 7 ± 2%.

The observed price decline can be explained in part by declining battery costs, accompanied by substantial improvements in battery performance. Since 1997, Toyota decreased the production costs of the nickel–metal-hydride batteries used in the Prius by 75%, reduced the battery size by 33%, and increased the battery capacity by 50% (Pander, 2009). In support of this information, Nagelhout and Ros (2009) identified a learning rate of 17% for lithium-ion batteries, indicating a decline in the costs of this battery type by roughly a factor of ten in the period between 1993 and 2003.

Our results suggest substantially lower learning rates for HEVs than for the average of energy-demand technologies, i.e., 18 ± 9% (Weiss et al., 2010). This finding may be explained by the relatively low share of the costs of hybridization (i.e., the costs for the battery, electric motor, inverter, controller, and the integration of the electric components into the powertrain) on the total vehicle price. Although the hybrid-electric powertrain supposedly offers large potentials for technological learning, it only accounts for 69 ± 12% and 33 ± 5% of the manufacturing costs and the retail price of HEVs, respectively (Lipman and Delucchi, 2003). Around two-third of the HEV price is thus unrelated to the powertrain.

Additional analyses reveal that conventional ICE vehicles show substantially higher learning rates than HEVs (i.e., 30 ± 37% in Germany, 54 ± 18% in the USA, resulting in an average of 42 ± 27%). This finding can be explained by the comparatively low amounts of doublings in the cumulative production of ICE vehicles between 1997 and 2010.[6] The cumulative production of

---

[6] The large uncertainty intervals suggest being cautious when interpreting these learning rates. Typically, price data should span several doublings of cumulative production before they may allow calculating reliable and accurate learning rates. Our price data for ICE vehicles do not fulfill this criterion.

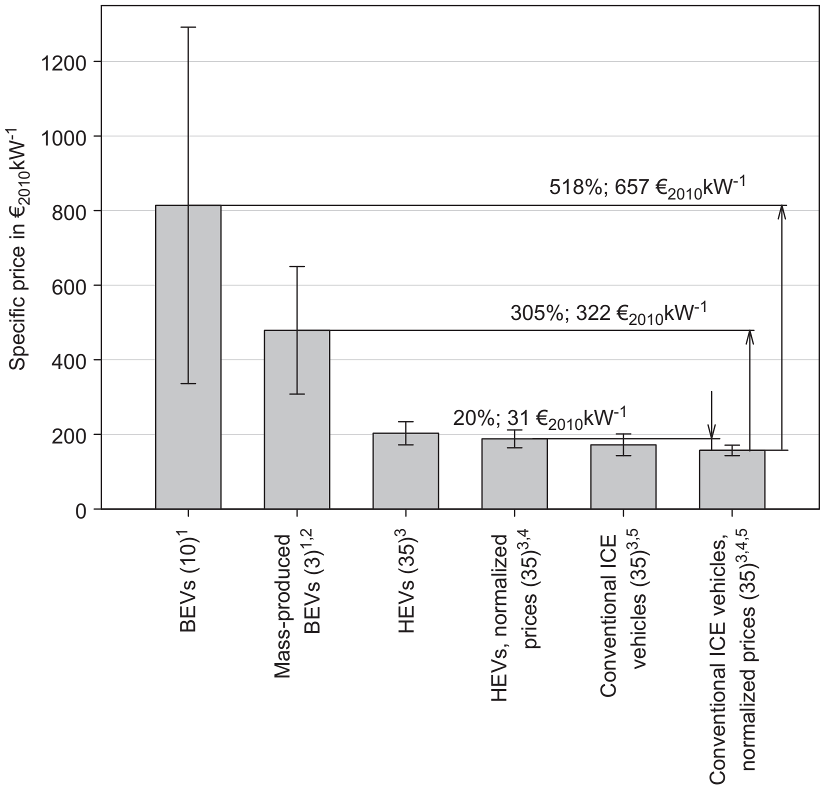

Fig. 4. The average specific price of BEVs, HEVs, and conventional ICE vehicles in 2010; numbers in parentheses indicate the sample size; [1] including price data for vehicles offered in Germany and the USA; [2] including price data for the Nissan Leaf, the Mitsubishi i-MiEV, and the Citroën C-Zero; [3]representing the un-weighed price average of data for Germany and the USA; [4]price data normalized to an absolute vehicle price of 20,000 $€_{2010}$; [5]including conventional spark-ignition ICE vehicles that are used to calculate the price differential of HEVs.

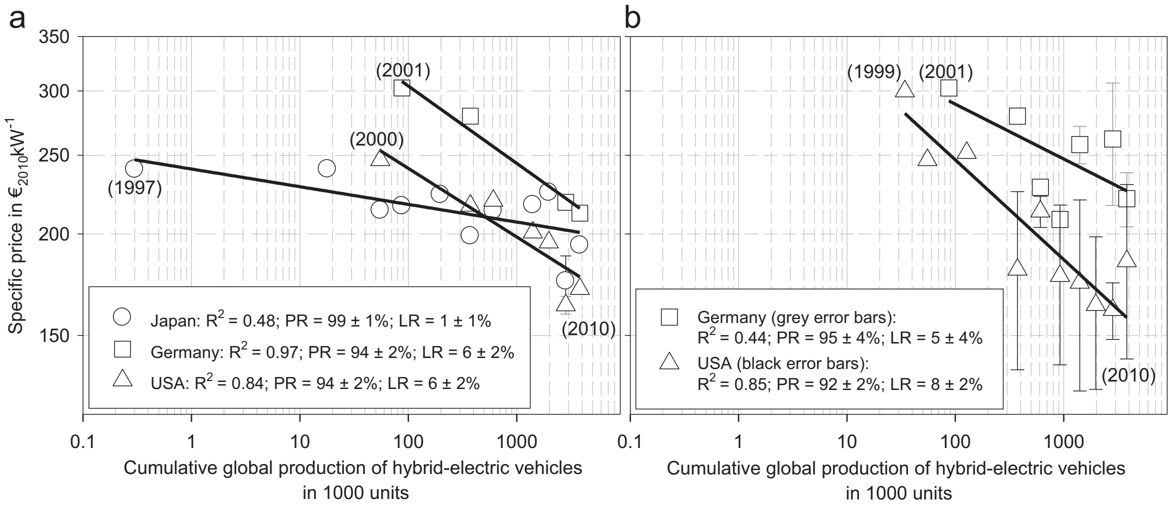

Fig. 5. Experience curves for the Toyota Prius (a) and all HEVs (b); numbers in parentheses indicate the year of analysis; error bars indicate the standard deviation of price data.

conventional ICE vehicles only increased by 40%, while the cumulative production of HEVs doubled nearly 14 times in the period of the analysis.

So far, our analysis addressed the specific price of vehicles. More insight into the competitiveness of HEVs can be obtained, however, by analyzing the price differentials between HEVs and conventional ICE vehicles. We find that the learning rates for the price differential of HEVs are higher than those for the prices, ranging for the Toyota Prius between 7 ± 3% (Japan) and 17 ± 7% (Germany; Fig. 7a). Again, the learning rates for all HEVs are higher than those for the Toyota Prius and span a range between 24 ± 4% (USA) and 60 ± 104% (Germany; Fig. 7b). By excluding the data for the years 2005 and 2006[7], we obtain a learning rate 22 ± 6% for HEVs sold in Germany.

We estimate an average learning rate of 23 ± 5% for the price differential of HEVs by averaging the learning rates for Germany

---

[7] The negative price differentials in the years 2005 and 2006 stem from one vehicle only. These data points likely represent outliers because we do not identify similarly low price differentials for other HEVs in any other year of our analysis.

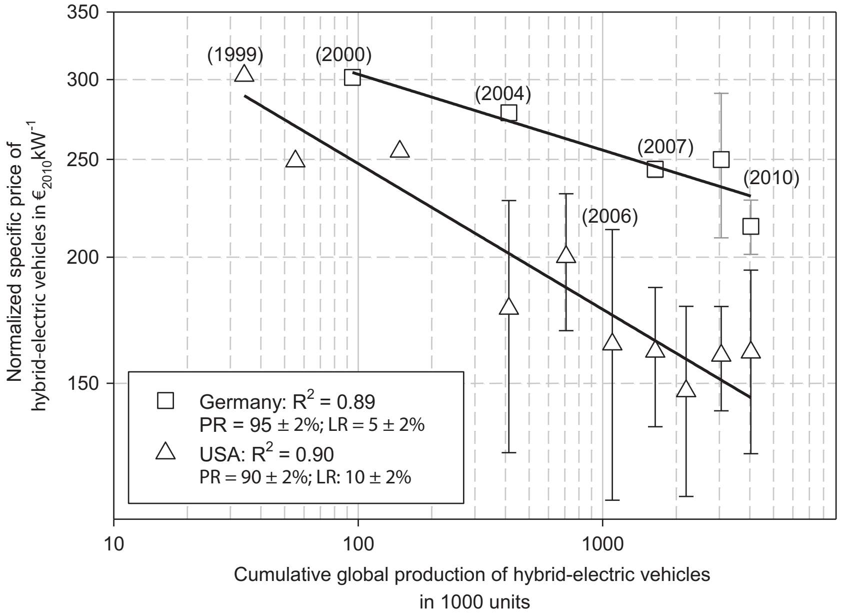

Fig. 6. Experience curves based on the normalized specific price of all HEVs sold in Germany and the USA (see also Appendix B); numbers in parentheses indicate the year of analysis; error bars indicate the standard deviation of price data; German price data for the years 2005 and 2006 are excluded.

(excluding the data for 2005 and 2006) and the USA (see Fig. 7b). This estimate is higher than the conservative value of 10% as applied by Thiel et al. (2010) to battery, electric motor, and other miscellaneous costs for electrification. Our analysis hence suggests that the production costs of hybrid-electric powertrains may decline at higher rates than previously assumed.

3.3. *Price forecasts for BEVs, HEVs, and conventional ICE vehicles*

Approximately 145 million BEVs will have been produced worldwide by 2035, if the production of BEVs shows growth rates similar to those observed for HEVs since 1997. Likewise, the market for HEVs and conventional ICE vehicles may continue to grow. Until 2035, these vehicles may reach a cumulative production of 270 and 4,500 million vehicles, respectively (IEA, 2010b; see Table A10 in Appendix A). In this section, we combine these scenarios with our estimates of learning rates to forecast the prices of BEVs, HEVs, and conventional ICE vehicles. The price differential of HEVs can be regarded as a proxy for the costs of electrification, i.e., the costs of an additional battery, the electric motor, inverter, controller, and the integration of the electric components into the powertrain. If these cost components together show a learning rate of 23 ± 5% in HEVs, it is reasonable to assume a similar learning rate for electric powertrains in BEVs. To forecast the ancillary costs for BEVs, we assume (i) a learning rate similar to the one found for ICE vehicles (i.e., 42 ± 27%) and (ii) an increase in cumulative production of vehicles as forecasted by IEA (2010; see Section 2.2)[8].

Under these assumptions, the average vehicle prices may decline until 2035 to 100 ± 46 €$_{2010}$ kW^{-1} for BEVs, 120 ± 28 €$_{2010}$ kW^{-1} for HEVs, and 103 ± 33 €$_{2010}$kW^{-1} for conventional ICE vehicles (Fig. 8a). Thus, BEVs may reach price breakeven with HEVs on average around the year 2026 and with conventional ICE vehicles around 2032 (Fig. 8b).[9] However, the large uncertainty margins in our forecast together with the considerable difference in the price levels between Germany and the USA suggest that these estimates are subject to substantial uncertainty.

The price differential between BEVs and HEVs as well as conventional ICE vehicles can be regarded as indicative of the learning investments of BEVs. Our forecasts suggest that BEVs may require learning investments of around 100 billion € and 150 billion € before reaching price breakeven with HEVs and conventional ICE vehicles. Although appearing impressive, these numbers still fall short of the 226 billion € fossil fuel consumption subsidies granted worldwide in 2009 (IEA, 2010). Our estimates are subject to substantial uncertainty given the range of plausible assumptions on future production volumes and vehicle prices. It is beyond the scope of this research to address the resulting uncertainty in a comprehensive manner. Still, a sensitivity analysis of our forecasts indicates that price breakeven of BEVs may also be achieved later than suggested by Fig. 8, if powertrain components show similar learning rates than lithium-ion batteries, i.e., 17%.[10] In this scenario, price breakeven with HEVs and conventional ICE vehicles may be reached only after the year 2035 (Fig. 9).

The learning investments increase in this scenario to 300 billion € and 500 billion € before reaching price breakeven with HEVs and conventional ICE vehicles, respectively. The discrepancy between our previous finding and the result of this sensitivity analysis suggests caution when drawing conclusions on the future dynamics of prices and production costs of BEVs, HEVs, and conventional ICE vehicles.

4. Discussion

4.1. *Strengths and limitations of the research*

This article develops experience curves and quantifies learning rates for HEVs and conventional ICE vehicles. The insight gained is

---

[8] These assumptions result in an overall learning rate of 14.7 ± 0.3% for BEVs in the period between 2010 and 2035.

[9] We refer here and in the sensitivity analysis below to the average price of BEVs compared to the average price of HEVs and conventional ICE vehicles in Germany and the USA.

[10] These assumptions result in an overall learning rate of 11.5 ± 0.1% for BEVs in the period between 2010 and 2035.

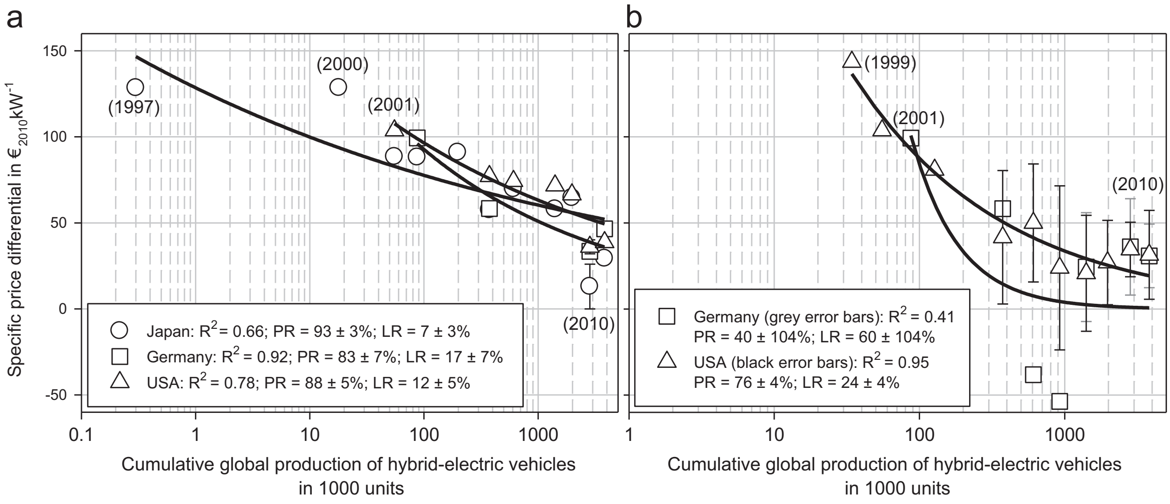

Fig. 7. Experience curves for the specific price differential of the Toyota Prius (a) and all HEVs (b); numbers in parentheses indicate the year of analysis; error bars indicate the standard deviation of price differentials.

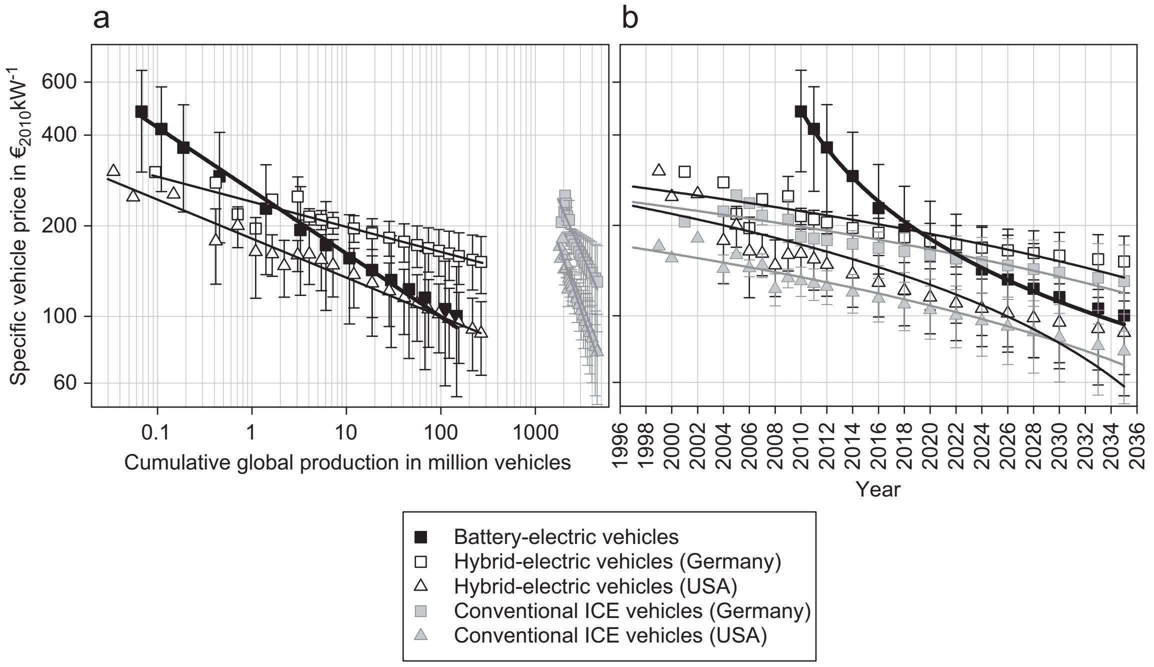

Fig. 8. Forecasting the specific price of BEVs, HEVs, and conventional ICE vehicles for the period between 2010 and 2035: (a) experience curves, (b) time series analysis; error bars represent the price variability resulting from the error interval associated with the applied learning rates.

used to forecast the prices of BEVs, HEVs, and conventional ICE vehicles until 2035. Our analysis provides an empirically-based first-order estimate of the future price dynamics for passenger cars equipped with innovative powertrain technologies. The findings provide rationale to the forecasting of vehicle costs in transport and emission models.

The accuracy of our results depends on the reliability of the experience curve approach and the collected input data. Addressing the first point, the phenomenon of a constant rate of cost decline is an empirical observation but not a natural law (Dutton and Thomas, 1984). Technology costs neither have to decline with increasing production nor does the rate of cost decline need to remain constant *per se* (Argote and Epple, 1990; Hultman and Koomey, 2007). In fact, economics of scale and process innovation tend to decrease labor and capital costs in manufacturing but may be offset by increasing prices for, e.g., raw materials, energy, and product components. Such dynamics have been observed by Yu et al. (2011) for photovoltaics and may occur for HEVs and BEVs, if the demand for, e.g., batteries substantially increases. Changes in the price of production factors thus limit the reliability of forecasts based on experience curves.

Next to methodological issues, our input data introduce uncertainty into the present analysis. First, we use experience curves to forecast vehicle prices although this approach is strictly valid only for modeling production costs. Similar shortcomings are widespread in many experience curve studies because actual cost data are typically kept confidential by producers (see, e.g., Junginger et al., 2010). The IEA (2000) argues that prices and production costs of emerging technologies are likely to differ in their dynamics: at the point of market introduction, prices are typically lower than production costs because manufacturers try to open markets for their innovative products. With increasing

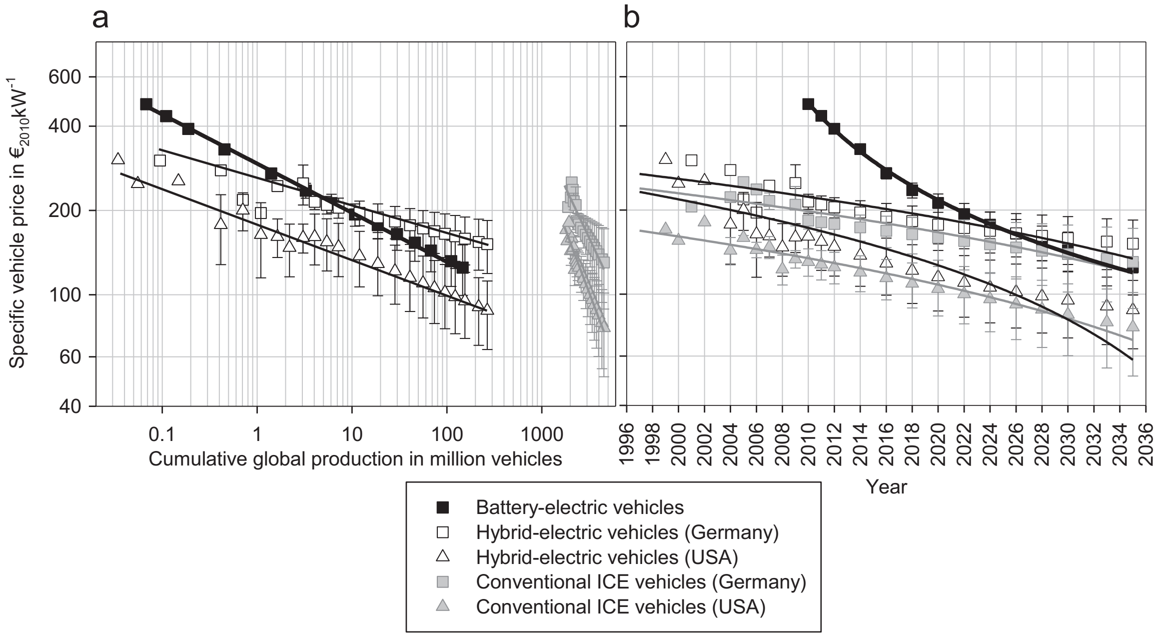

Fig. 9. Sensitivity analysis – Forecasting the specific price of BEVs, HEVs, and conventional ICE vehicles for the period between 2010 and 2035: (a) experience curves, (b) time series analysis; error bars represent the price variability resulting from the error interval associated with the applied learning rates.

technological learning, production costs may eventually decline below the actual market price. Only later in a phase of enhanced market competition, prices tend to parallel costs. Our price data suggest that such price-cost dynamics may also be found for HEVs. We find strong indication that the Toyota Prius sold in the late 1990s in Japan has been subsidized by Toyota (see Section 3.1). Similar effects are likely to prevail on the level of individual vehicle components (e.g., batteries), where prices may reflect strategic business decisions of component suppliers and vehicle manufacturers in a potentially growing market. Manufacturing costs, on average, account for only 48% and 43% of the manufacturers-suggested retail price of HEVs and conventional ICE vehicles (Lipman and Delucchi, 2003), providing manufacturers scope for pricing strategies. Since the potential sources of cost and price volatility may compensate each other in the long term, the use of longer time series in the future may enable more robust forecasts of production costs.

Second, deriving accurate learning rates requires that the analyzed product system remains homogenous throughout the period of analysis. HEVs do not fulfill this criterion in a strict sense because novel HEVs contain advanced safety and comfort features that were absent in older ones (e.g., electronic stability control). Likewise, it is reasonable to assume that the characteristics and features of BEVs, HEVs, and conventional ICE vehicles will change considerably in the future. Although we partially account for heterogeneities among vehicles by normalizing our price data, it is difficult to quantify to what extent new features have been adding to the price of HEVs in the period of our analysis. Overall, the effect of heterogeneity in the product systems may lead to an underestimation of actual learning rates for the specific price of HEVs and conventional ICE vehicles. The effect can be expected to cancel out in the learning rates established based on price differentials.

Third, we include mild and full HEVs into our analysis. The costs for hybridization are, however, lower for mild than for full HEVs, i.e., the manufacturing costs of mild and full hybrid-electric powertrains account for around $30 \pm 3\%$ and $38 \pm 4\%$ in the retail price of HEVs, respectively (Lipman and Delucchi, 2003). We may thus argue that our estimated learning rates overestimate to some extent the potentials for a price decline of mild HEVs and underestimate the potentials for a price decline of full HEVs.

Finally, we limit our analysis to Japan, Germany, and the USA because these countries together account for roughly 85% of the worldwide HEV registrations in 2009 (HC, 2008, 2009). The magnitude in the variability of both price levels and price trends suggests that including additional countries in the experience curve analysis may not change the conclusions of this research. Caution is nevertheless required when interpreting the results because small deviations in the actual learning rates can cause substantial differences in the estimated break-even production and learning investments.

4.2. *Implications for energy and transport policy*

Technological learning has substantially reduced the price of HEVs since 1997 and will very likely also reduce the price of HEVs and BEVs in the future. The competitiveness of these vehicles depends on a variety of factors including purchase and operating costs, reliability, design, safety,[11] driving characteristics, accessibility of refueling or re-charging infrastructure, as well as social perception (see, e.g., Lee and Lovellette, 2011). These factors are relevant for consumers and thus for strategic decision making by manufacturers, policy makers, and utility companies that can provide incentives for HEVs, plug-in HEVs and BEVs, recharging infrastructure, and options for advanced vehicle-to-grid integration. Although not addressed by this research, the above mentioned factors need to be addressed by stakeholders before a wide-spread electrification of passenger road transport can be achieved.

Lipman and Delucchi (2003) found that HEVs in the USA reach cost breakeven with conventional ICE vehicles at a gasoline price of \$1.49-\$2.65 per gallon (i.e., \$0.39-\$0.69 per liter). Such price levels have been observed in most regions of the USA since 2004

---

[11] The Electromagnetic compatibility of vehicle components along the entire chain of production, use and recycling of HEVs, and BEVs is particularly critical. The incidence of the Chevrolet Volt catching fire long after a side-impact crash test (NHTSA, 2011) presents only one example for persisting challenges.

(USDE, 2011b). Likewise, the IEA (2010) estimates pay-back times for HEVs of 4–8 years in 2009, indicating that HEV are cost-competitive on a life cycle basis at current fuel prices. The situation is, however, different for BEVs, which reach cost break-even only at gasoline prices of \$4.50–\$5.50 per gallon (i.e., \$1.19–\$1.45 per liter) in the USA (Lee and Lovellette, 2011).[12]

The high prices and customer costs of BEVs principally stem from the battery pack that presents the most critical factor in the development of these vehicles (e.g., Nemry and Brons, 2010; Bakker, 2011). Battery capacities in BEVs typically range between 15 and 35 kWh (McConnell and Turrentine, 2010) at production costs of 200 € $kW\,h^{-1}$ for nickel-metal hydride batteries and 500–1,200 € $kW\,h^{-1}$ for lithium-ion batteries (IEA, 2008; McConnell and Turrentine, 2010; Ernst et al., 2011; Lee and Lovellette, 2011; Dinger et al., 2010; RBSC, 2011). Around 75% of the battery costs may be volume dependent (Dinger et al., 2010) and could thus be substantially reduced by up-scaling battery production. This way, the production costs of lithium-ion batteries may decline by 6–9% per year, potentially reaching levels of around 200–440 € $kW\,h^{-1}$ by 2020 (Dinger et al., 2010; DB, 2011) and eventually 100 € $kW\,h^{-1}$ by 2030 (IEA, 2011). At the same time, energy densities may double within a decade to 200 $W\,h\,kg^{-1}$ (IEA, 2011). The currently high battery demand also triggers research on alternative battery chemistries such as lithium–air and lithium–sulfur batteries that may offer substantially higher energy densities than current lithium-ion batteries (Bruce et al., 2012). Still, such novel battery chemistries may only be available for production on a significant scale after the year 2020 (Dinger et al., 2010). Although the demand for BEVs will likely accelerate technological learning in battery manufacturing, adverse price effects can occur if the supply of resources (e.g., neodymium) and battery manufacturing capacities lag behind demand (Lowe et al., 2010) or if relatively high market entry barriers enable a business concentration of battery manufacturers (RBSC, 2011).

Our analysis shows that closing the price gap between BEVs and conventional ICE vehicles may require several decades if the current price dynamics persist. Dedicated governmental support policies may thus be necessary if policy makers regard it desirable to close persisting price gaps earlier or in case boundary conditions inhibit the market penetration of BEVs (see discussions below). In parallel, manufacturers could curb high production costs in the short term by installing small batteries, thus limiting the driving range of BEVs to applications in urban areas (McConnell and Turrentine, 2010). Ernst et al. (2011) found that plug-in HEVs equipped with batteries of 4 kW h show payback times of less than five years, whereas larger batteries of, e.g., 12 kW h incur longer payback times of 8–9 years. Together with our findings, these estimates have two implications for the electrification of road transport:

(i) Hybrid-electric power trains may not present a short-term *bridge* technology. Instead, HEVs and plug-in HEVs could become the dominant light-duty vehicle technology in the coming decades (see, e.g., Nemry and Brons, 2010; Burke et al., 2011; Sams, 2011). An exception may be present in large urban areas, where short driving ranges, accessible recharging infrastructure, and concerns over local air pollution may facilitate the market penetration of small, and thus comparatively cheap, BEVs (Book et al., 2009).
(ii) Two-wheelers such as mopeds, scooters, and motorbikes that could run on comparatively small batteries may present large potentials for the cost effective electrification of road transport in urban areas around the world; additional research is highly warranted.

The market prospects for both HEVs and BEVs rest upon the rate of technological learning but also on progress in competing spark ignition and compression ignition ICE vehicles. Conventional ICEs are expected to achieve at least another 30% increase in fuel efficiency over the next decade (Smokers et al., 2006; EARPA, 2003; Kobayashi et al., 2009; Hardy, 2010; Ernst et al., 2011; Burke et al., 2011). These improvements may support HEVs to some extent but will mainly benefit conventional ICE vehicles running on fossil and renewable fuels.

In addition to these aspects, several economic and political factors are critical for the market penetration of BEVs:

(i) future fossil fuel and gasoline prices – increasing sales of HEVs after the year 2007 are likely to have occurred in response to high oil prices[13], and suggest that price differentials can be acceptable if customers achieve in return adequate savings in fuel costs,
(ii) the stringency of future emission limits for ICE vehicles, which may partially compensate gains in fuel efficiency while incuring costs for the installation of additional after-treatment systems (see, e.g., Weiss et al., 2011),
(iii) potential penalties faced by manufacturers for exceeding fleet-average CO_2 emission targets, e.g., 95 g/km in the EU from 2020 onwards (EC, 2009b),
(iv) the willingness of governments to provide incentives such as tax allowances or purchasing subsidies,
(v) the existence of local policies addressing urban air pollution and traffic congestion such as the introduction of environmental zones, emissions-free driving zones, or city taxes for selected vehicle categories.

From an environmental perspective, the large-scale market penetration of HEVs and BEVs may substantially reduce the distance-specific CO_2 emissions (Fontaras et al., 2008; Samaras and Meisterling, 2008; de Jong et al., 2009; Thiel et al., 2010) as well as the emissions of gaseous and particulate air pollutants of passenger cars (de Jong et al., 2009; Weiss et al., 2011). Such a development shifts the environmental impacts of road transport to the location of electricity generation. Policy makers should also be aware that any consumer savings in distance-specific fuel costs and the associated CO_2 emissions may cause unintended rebound effects elsewhere in the economy. From the perspective of infrastructure, the electrification of passenger transport will require adaptations of electricity grids, including intelligent load management that makes optimal use of BEVs as a large-scale energy buffer and storage facility (Perujo and Ciuffo, 2010).

To summarize, we draw the following conclusions:

(i) Since 1997, hybrid-electric vehicles (HEVs) have shown a robust trend towards declining prices and price differentials.
(ii) Battery-electric vehicles (BEVs) are currently substantially more expensive than HEVs and conventional ICE vehicles. If BEVs demonstrate technological learning at rates similar to HEVs in the past, they still may require several decades to reach price breakeven with HEVs and conventional ICE

---

[12] Dinger et al. (2010) conclude based on market surveys that customers in the USA would accept pay-back times of three years for BEVs.

[13] One may argue that HEVs have reached higher market shares in the USA than in the EU because US citizens were affected more directly by increasing oil prices than EU citizens who were already offered relatively efficient conventional diesel and gasoline cars in response to relatively expensive and heavily taxed fuel. The low efficiency of conventional passenger cars in combination with a high relative increase in fuel prices in the USA may have provided thus the critical leverage for the market success of HEVs.

vehicles. This conclusion rests on the analysis of relatively short time-series of price data and the assumption that BEV sales increase at similar rates than HEV sales did in the past. Our conclusions may change if longer time series as well as actual production costs are used for analysis.

(iii) Before achieving a substantial market share under current economic conditions, BEVs may require a consistent and long-term policy support.

(iv) Critical for the production costs of both HEVs and BEVs is the cost performance of batteries. If current developments persist, vehicles with smaller, and thus less costly, batteries such as plug-in HEVs and short-range BEVs for city driving could present the economically most viable options for the electrification of passenger road transport until 2020.

Disclaimer and acknowledgments

The views expressed in this article are those of the authors and may not be regarded as an official position of the European Commission. We thank Hugo Carrão, Toshinari Nagai, and Berthold Weiss for providing valuable background information. We are grateful to Alexandra Newman, Marc Steen, Juliana Stropp, and two anonymous reviewers for commenting on earlier drafts of this article.

Appendix A. Data used for experience curve analyses

See Tables A1–A10.

Table A1
Japanese price data for the Toyota Prius.

Vehicle	Year	Total system power [kW]	Nominal sales price [10^6 YEN]	Real sales price [€$_{2010}$][a,b]	Real specific price [€$_{2010}$ kW^{-1}][a,b]	Principal reference
Toyota Prius (NHW10)	1997	*63*[c]	2.15	15,132	240	GNE (2011)
Toyota Prius (NHW10)	1998	*63*[c]	2.15	15,141	240	GNE (2011)
Toyota Prius (NHW11)	2000	74	2.18	15,828	214	GNE (2011)
Toyota Prius (NHW11)	2001	74	2.18	16,026	217	GNE (2011)
Toyota Prius (NHW11)	2003	74	2.18	16,540	224	GNE (2011)
Toyota Prius (NHW20)	2004	83	2.15	16,503	199	GNE (2011)
Toyota Prius (NHW20)	2005	83	2.27	17,730	214	GNE (2011)
Toyota Prius (NHW20)	2007	83	2.27	18,026	217	GNE (2011)
Toyota Prius (NHW20)	2008	83	2.33	18,678	225	GNE (2011)
Toyota Prius (NHW20)	2009	83	1.89	15,287	184	GNE (2011)
Toyota Prius (ZVW30)	2009	100	2.05	16,581	166	GNE (2011)
Toyota Prius (ZVW30)	2010	100	2.36	19,376	194	GNE (2011)

[a] Excluding sales taxes.
[b] Assuming an average exchange rate for the year 2010 of 116 YEN per €.
[c] Estimates based secondary literature.

Table A2
Japanese price data for conventional gasoline reference vehicles and price differentials between the Toyota Prius and conventional gasoline reference vehicles.

Vehicle	Year	Power [kW]	Nominal sales price [10^6 YEN]	Real sales price [€$_{2010}$][a,b]	Real specific price [€$_{2010}$ kW^{-1}][a,b]	Real price difference [€$_{2010}$][a,b]	Real specific price difference [€$_{2010}$ kW^{-1}][a,b]	Principal reference
Toyota Corolla DX 1.3	1997	63	1.00	7,038	112	8,094	128	GNE (2011)
Toyota Corolla DX 1.3	1998	63	1.00	7,042	112	8,099	129	GNE (2011)
Toyota Corolla X	2000	65	1.12	8,154	125	7,674	88	GNE (2011)
Toyota Alex XS 150	2001	80	1.40	10,277	128	5,749	88	GNE (2011)
Toyota Alex XS 150	2003	80	1.40	10,607	133	5,933	91	GNE (2011)
Toyota Alex XS 150	2004	81	1.49	11,444	141	5,058	58	GNE (2011)
Toyota Alex XS 150	2005	81	1.49	11,656	144	6,074	70	GNE (2011)
Toyota Auris 150x	2007	81	1.62	12,894	159	5,132	58	GNE (2011)
Toyota Auris 150x	2008	81	1.62	12,999	160	5,679	65	GNE (2011)
Toyota Auris 150x	2009	81	1.62	13,121	162	2,166	22	GNE (2011)
Toyota Auris 150x	2009	81	1.62	13,121	162	3,460	4	GNE (2011)
Toyota Auris 150x	2010	81	1.62	13,317	164	6,059	29	GNE (2011)

[a] Excluding sales taxes.
[b] Assuming an average exchange rate for the year 2010 of 116 YEN per €.

Table A3
German price data for hybrid-electric vehicles.

Vehicle	Year	Total system power [kW]	Nominal sales price [€]	Real sales price [$€_{2010}$][a]	Real specific price [$€_{2010}$ kW^{-1}][a]	Principal reference
Toyota Prius (NHW11)	2001	74	23,500	22,377	302	AP (2011)
Toyota Prius (NHW20)	2004	83	25,150	23,183	279	AP (2011)
Lexus RX 400h	2005	200	49,750	45,646	228	AP (2011)
Lexus GS 450h	2006	253	57,600	52,713	208	AP (2011)
Honda Civic Hybrid	2007	84	23,800	20,832	248	AP (2011)
BMW 7 Hybrid	2009	342	10,5900	88,047	257	AP (2011)
Honda Insight	2009	74	19,550	19,760	267	AP (2011)
Lexus LS 600h	2007	327	99,850	87,399	267	AP (2011)
Lexus RX 450h	2009	220	59,950	50,918	231	AP (2011)
Mercedes S Hybrid	2009	220	85,323	73,572	334	AP (2011)
Toyota Prius (ZVW30)	2009	100	24,950	21,871	219	AP (2011)
BMW X6 Hybrid	2010	357	102,900	86,471	242	BMW (2011b)
Honda Insight	2010	74	19,990	16,798	227	Honda (2011b)
Honda CR-Z	2010	91.5	21,990	18,479	202	Honda (2011b)
Porsche Cayenne Hybrid	2010	279	78,636	66,081	237	Porsche (2011b)
Toyota Auris Hybrid	2010	100	22,950	19,286	193	Toyota (2011c)
VW Touareg Hybrid	2010	279	73,500	61,765	221	VW (2011b)
Honda Jazz Hybrid	2011	72	18,900	15,571	216	Honda (2011b)
Lexus CT 200h	2011	100	28,900	23,810	238	Lexus (2011b)
Toyota Prius (ZVW30)	2011	100	25,750	21,214	212	Toyota (2011c)

[a] Excluding sales taxes.

Table A4
German price data for conventional gasoline reference vehicles and price differentials between hybrid-electric vehicles and conventional gasoline reference vehicles.

Vehicle	Year	Power [kW]	Nominal sales price [€]	Real sales price [$€_{2010}$][a]	Real specific price [$€_{2010}$ kW^{-1}][a]	Real price difference [$€_{2010}$][a]	Real specific price difference [$€_{2010}$ kW^{-1}][a]	Principal reference
Toyota Corolla 1.6	2001	81	*17,275*[b]	16,450	203	5,928	99	AP (2011)
Toyota Corolla 1.6 VVT-i	2004	81	19,419	17,901	221	5,283	58	AP (2011)
Lexus RX 300	2005	150	43,550	39,957	266	5,689	−38	AP (2011)
Lexus GS 430	2006	208	*59,550*	54,498	262	−1,785	−54	AP (2011)
Lexus LS 460	2007	280	*84,850*[b]	74,269	265	13,129	2	AP (2011)
Honda Civic 1.4 i-VTEC	2007	73	16,790	14,696	201	6,136	47	AP (2011)
BMW 750i	2009	299	*91,900*[c]	78,055	261	9,993	−4	AP (2011)
Honda Civic (Base model)	2009	74	16,700	14,184	192	5,576	75	AP (2011)
Lexus RX 350	2009	203	46,250	39,282	194	11,636	38	AP (2011)
Mercedes S 350 Blue Efficiency	2009	225	*78,719*[b]	66,859	297	6,712	37	AP (2011)
Toyota Auris 1.6 VVT-i	2009	91	*19,850*[c]	16,860	185	5,011	33	AP (2011)
BMW X6 50i	2010	300	*76,800*[b]	64,538	215	21,933	27	BMW (2011b)
Honda Civic 1.4 (Base model)	2010	73	*16,790*[c]	14,109	193	2,689	34	Honda (2011b)
Honda Civic 1.8 Sport	2010	103	*22,850*[c]	19,202	186	−723	16	Honda (2011b)
Porsche Cayenne S	2010	294	*74,043*[b]	62,221	212	3,860	25	Porsche (2011b)
Toyota Auris 1.6 VVT-i	2010	97	19,500[c]	16,387	169	2,899	24	Toyota (2011c)
VW Touareg V6 FSI Blue Motion	2010	206	50,500	42,437	206	19,328	15	VW (2011b)
Honda Jazz 1.4 Comfort	2011	73	17,590	14,492	199	1,079	18	Honda (2011b)
Toyota Auris 1.6 Life	2011	97	19,500	16,065	166	7,744	72	Toyota (2011c)
Toyota Auris 1.6 Life	2011	97	19,500	16,065	166	5,149	47	Toyota (2011c)

[a] Excluding sales taxes.
[b] Estimate based on secondary literature.
[c] Prices as of February 2011.

Table A5
US American price data for hybrid-electric vehicles.

Vehicle	Year	Total system power [kW]	Nominal sales price [USD]	Real sales price [$€_{2010}$][a]	Real specific price [$€_{2010}$ kW^{-1}][a]	Principal reference
Honda Insight	1999	59	18,880	17,676	300	CGA (2011)
Toyota Prius (NHW11)	2000	74	19,995	18,251	247	Robinson (2001), CGA (2011)
Honda Civic Hybrid	2002	*71*[2]	*20,000*[b]	17,867	252	Csere (2002), CGA (2011)
Ford Escape Hybrid	2004	116	26,380	22,618	195	CGA (2011)
Honda Accord Hybrid	2004	200	30,505	26,154	131	CGA (2011)
Toyota Prius (NHW20)	2004	83	20,975	17,983	217	CGA (2011)
Lexus RX 400h	2005	200	49,185	41,292	206	CGA (2011)
Toyota Prius (NHW20)	2005	83	21,725	18,239	220	CGA (2011)
Honda Civic	2006	84	22,400	18,281	218	CGA (2011)
Lexus GS 450h	2006	254	54,900	44,804	176	CGA (2011)
Toyota Highlander Hybrid	2006	200	33,033	27,732	139	CGA (2011)
Lexus LS 600h	2007	322	104,000	82,189	255	CGA (2011)
Mazda Tribute Hybrid	2007	114	25,310	20,002	156	CGA (2011)
Nissan Altima	2007	148	24,400	19,283	130	CGA (2011)
Saturn Vue	2007	*128*[a]	24,795	19,595	153	CGA (2011)
Toyota Camry Hybrid	2007	140	26,480	20,927	149	CGA (2011)
Toyota Prius (NHW20)	2007	83	21,100	16,675	201	CGA (2011)
Cadillac Escalade Hybrid	2008	244	71,685	55,467	227	CGA (2011)
Chevrolet Tahoe Hybrid	2008	244	50,540	39,106	160	CGA (2011)
Chrysler Aspen	2008	254	45,570	35,260	141	CGA (2011)
Dodge Durango Hybrid	2008	254	45,340	35,082	140	CGA (2011)
Saturn Aura Hybrid	2008	*122*[b]	*23,000*[b]	17,796	146	CGA (2011)
Toyota Highlander Hybrid	2008	199	34,700	26,849	135	CGA (2011)
Toyota Prius (NHW20)	2008	83	20,950	16,210	195	CGA (2011)
Chevrolet Malibu Hybrid	2009	*121*[b]	24,695	18,884	155	CGA (2011)
Chevrolet Tahoe Hybrid	2009	244	51,405	39,308	161	CGA (2011)
Honda Insight	2009	81	19,800	15,141	187	CGA (2011)
Ford Fusion Hybrid	2009	140	27,270	20,853	149	CGA (2011)
Mercury Milan Hybrid	2009	140	27,500	21,029	150	CGA (2011)
Mercury Milan Hybrid	2009	140	27,500	21,029	150	CGA (2011)
Toyota Prius (ZVW30)	2009	100	21,750	16,632	166	CGA (2011)
Toyota Prius (ZVW30)	2009	100	21,000	16,058	161	CGA (2011)
Honda Insight	2010	81	18,200	13,788	170	Honda (2011a)
Honda CR-Z	2010	91	19,950	15,114	166	Honda (2011a)
BMW 7 Hybrid	2011	339	102,300	75,980	224	BMW (2011a)
BMW 7 Hybrid Li	2011	339	106,200	78,877	233	BMW (2011a)
BMW X6 Hybrid	2011	357	88,900	66,028	185	BMW (2011a)
Cadillac Escalade Hybrid	2011	244	73,840	54,843	225	BMW (2011a)
Chevrolet Silverado Hybrid	2011	244	38,340	28,476	117	Chevrolet (2011)
Chevrolet Tahoe Hybrid	2011	244	50,735	37,682	154	Chevrolet (2011)
Ford Escape Hybrid	2011	*132*[1]	29,860	22,178	168	Ford (2011)
Ford Fusion Hybrid	2011	140	28,340	21,049	150	Ford (2011)
Honda Civic Hybrid	2011	81	23,950	17,788	220	Honda (2011a)
Honda Insight	2011	81	18,200	13,518	167	Honda (2011a)
Lexus CT 200 h	2011	100	29,120	21,628	216	Lexus (2011a)
Lexus GS 450h	2011	254	58,050	43,115	170	Lexus (2011a)
Lexus HS Hybrid	2011	140	34,650	25,735	184	Lexus (2011a)
Lexus LS 600h	2011	322	111,350	82,702	257	Lexus (2011a)
Lexus RX Hybrid	2011	220	43,935	32,631	148	Lexus (2011a)
Lincoln MKZ Hybrid	2011	*142*[a]	34,605	25,702	181	Lincoln (2011)
Mercedes S Hybrid	2011	217	91,000	67,588	311	Daimler (2011)
Nissan Altima Hybrid	2011	148	26,800	19,905	134	Nissan (2011b)
Porsche Cayenne Hybrid	2011	283	67,700	50,282	178	Porsche (2011a)
Porsche Panamera S Hybrid	2011	283	95,000	70,559	249	Porsche (2011a)
Toyota Camry Hybrid	2011	140	26,675	19,812	142	Toyota (2011b)
Toyota Highlander Hybrid	2011	206	37,490	27,845	135	Toyota (2011b)
Toyota Prius (ZVW30)	2011	100	23,050	17,120	171	Toyota (2011b)
VW Touareg Hybrid	2011	283	60,565	44,983	159	VW (2011a)

[a] Assuming an average exchange rate for the year 2010 of 1.32 USD per €.
[b] Estimate based on secondary literature.

Table A6
US American price data for conventional gasoline reference vehicles and price differentials between hybrid-electric vehicles and conventional gasoline reference vehicles.

Vehicle	Year	Power [kW]	Nominal sales price [USD]	Real sales price [€$_{2010}$][a]	Real specific price [€$_{2010}$ kW^{-1}][a]	Real price difference [€$_{2010}$][a]	Real specific price difference [€$_{2010}$ kW^{-1}][a]	Principal references
Honda Civic DX Automatic Hatchback	1999	78	*13,000*[b]	12,171	156	5,505	144	CGA (2011)
Toyota Corolla LE Automatic	2000	92	*14,198*[c]	13,147	143	5,104	104	CGA (2011)
Honda Civic LX Automatic Sedan	2002	85	16,250	14,517	171	3,350	81	CGA (2011)
Ford Escape 2.3 XLS	2004	113	19,425	16,655	147	5,963	48	CGA (2011)
Honda Accord V6 EX-L Automatic Coupe	2004	177	26,950	23,106	131	3,048	0	CGA (2011)
Toyota Corolla SE	2004	96	15,625	13,397	140	4,587	77	CGA (2011)
Lexus RX 350	2005	169	36,370	30,533	181	10,758	26	CGA (2011)
Toyota Corolla SE	2005	93	16,115	13,529	145	4,710	74	CGA (2011)
Lexus GS 430	2006	213	48,348	39,457	185	5,347	−9	CGA (2011)
Toyota Highlander 3.5 V6	2006	159	26,625	21,729	137	6,003	2	CGA (2011)
Mazda Tribute 2.4 I4 Touring	2007	113	21,325	16,853	149	3,149	7	CGA (2011)
Nissan Altima 2.5 I4 CVT S	2007	129	20,970	16,572	128	2,711	2	CGA (2011)
Lexus LS 460 L	2007	279	72,900	57,612	206	24,578	49	CGA (2011)
Saturn Vue FWD I4 XE	2007	124	21,525	17,011	137	2,584	16	CGA (2011)
Toyota Camry 2.4 XLE	2007	116	*25,000*[d]	19,757	170	1,170	−21	CGA (2011)
Toyota Corolla SE Automatic	2007	93	15,205	12,016	129	4,659	72	CGA (2011)
Cadillac Escalade	2008	296	66,685	51,598	174	3,869	53	CGA (2011)
Chevrolet Tahoe LS	2008	217	36,965	28,602	132	10,504	28	CGA (2011)
Chrysler Aspen	2008	223	37,115	28,718	129	6,542	12	CGA (2011)
Dodge Durango	2008	223	39,785	30,784	138	4,298	2	CGA (2011)
Saturn Aura XE	2008	124	22,655	17,529	141	267	5	CGA (2011)
Toyota Corolla SE	2008	97	16,150	12,496	129	3,714	66	CGA (2011)
Toyota Highlander 3.5 V6	2008	199	29,050	22,478	113	4,372	22	CGA (2011)
Chevrolet Malibu	2009	124	20,745	15,863	128	3,020	27	CGA (2011)
Chevrolet Tahoe LS	2009	217	*36,965*[d]	28,266	130	11,042	31	CGA (2011)
Ford Fusion 2.5	2009	129	19,995	15,290	119	5,563	30	CGA (2011)
Ford Fusion 2.5	2009	129	19,995	15,290	119	5,563	30	CGA (2011)
Honda Civic Sedan	2009	103	16,215	12,399	120	2,741	67	CGA (2011)
Mercury Milan	2009	129	22,750	17,396	135	3,632	15	CGA (2011)
Toyota Corolla	2009	97	16,160	12,357	127	4,275	39	CGA (2011)
Toyota Corolla	2009	97	16,160	12,357	127	3,701	33	CGA (2011)
Honda Civic Sedan DX	2010	103	15,805	11,739	114	2,049	56	Honda (2011a)
Honda Civic Coupe LX	2010	103	17,555	13,038	127	2,075	39	Honda (2011a)
BMW 750 Sedan	2011	294	82,500	61,275	208	14,706	16	BMW (2011a)
BMW 750 Li Sedan	2011	294	86,400	64,171	218	14,706	14	BMW (2011a)
BMW X6 xdrive50i	2011	294	67,700	50,282	171	15,746	14	BMW (2011a)
Cadillac Escalade 6.2L V8	2011	296	63,160	46,910	158	7,932	66	Cadillac (2011)
Chevrolet Silverado XFE 5.3	2011	235	33,225	24,677	105	3,799	12	Chevrolet (2011)
Chevrolet Tahoe LT two wheel drive	2011	235	42,830	31,811	135	5,871	19	Chevrolet (2011)
Ford Escape 2.5L Duratec I-4 XLT	2011	128	24,335	18,074	141	4,104	27	Ford (2011)
Ford Fusion I4S 2.5L	2011	129	19,820	14,721	114	6,328	36	Ford (2011)
Honda Civic Sedan DX	2011	103	15,805	11,739	114	1,779	53	Honda (2011a)
Honda Civic Sedan DX	2011	103	15,805	11,739	114	6,049	106	Honda (2011a)
Lexus GS 460 RWD	2011	252	54,570	40,530	161	2,585	9	Lexus (2011a)
Lexus IS 250	2011	150	32,645	24,246	162	−2,618	55	Lexus (2011a)
Lexus IS 250	2011	150	32,645	24,246	162	1,489	22	Lexus (2011a)
Lexus LS 460 L AWD	2011	279	74,080	55,021	197	27,681	60	Lexus (2011a)
Lexus RX 3.5	2011	202	38,875	28,873	143	3,758	5	Lexus (2011a)
Lincoln MKZ FWD	2011	193	34,605	25,702	133	0	48	Lincoln (2011)
Mercedes S 550 Sedan	2011	281	93,000	69,073	246	−1,485	66	Daimler (2011)
Nissan Altima 2.5 S	2011	129	22,070	16,392	127	3,513	7	Nissan (2011b)
Porsche Cayenne S	2011	294	64,400	47,831	163	2,451	15	Porsche (2011a)
Porsche Panamera S	2011	294	89,800	66,696	227	3,862	22	Porsche (2011a)
Toyota Camry 2.5 LE 6-speed Automatic	2011	124	22,325	16,581	134	3,231	8	Toyota (2011b)
Toyota Highlander 4WD 3.5L V6	2011	199	34,750	25,810	130	2,035	5	Toyota (2011b)
Toyota Corolla LE	2011	97	17,300	12,849	132	4,271	39	Toyota (2011b)
VW Touareg VR6 FSI Sport	2011	206	44,450	33,014	160	11,969	−1	VW (2011a)

[a] Assuming an average exchange rate for the year 2010 of 1.32 USD per €.
[b] Estimate based on price data for the year 2000.
[c] Estimate based on price data for the year 2001.
[d] Estimate based information from secondary sources and averaging of price data.

Table A7
Price data for electric vehicles.

Vehicle	Year	Power [kW]	Nominal sales price [€]	Real sales price [$€_{2010}$][a]	Real specific price [$€_{2010}$ kW^{-1}][a]	Reference
Tesla Roadster	2008	185	*101*,500[c]	92,605	501	Grünweg (2008), Kohlenberg (2008)
Think City	2008	30	20,000[b]	17,059	569	Blessing (2008)
Mitsubishi i-MiEV	2010	49	34,990[d]	29,403	600	Mitsubishi (2010)
Nissan Leaf	2010	80	33,239[e]	28,634	358	own estimate[g]
Citroën C-Zero	2011	49	35,165[d,f]	28,971	591	Citroën (2011)
Luis4U	2011	54	39,900[d]	32,872	609	Luis4U (2011)
Smiles REVA	2011	13	14,499[d]	11,945	919	Smiles (2011)
Smiles City EL	2011	4,5	9,999[d]	8,238	1,831	Smiles (2011)
Smiles Tazzari ZERO	2011	15	24,499[d]	20,184	1,346	Smiles (2011)

[a] Excluding sales taxes.
[b] Indicated prices for Europe.
[c] Estimate based on the average of sales price in Europe (117,800 €) and the USA (109,000 USD) assuming an exchange rate of 1 to 1.28 between € and USD.
[d] Price in Germany.
[e] Average of sales prices in Ireland, Japan, Portugal, the Netherlands, United Kingdom, and the USA.
[f] Vehicle is identical with the Mitsubishi i-MiEV.
[g] Based on an overview compiled by Wikipedia (2011).

Table A8
Data for estimating the cumulative global production of hybrid-electric vehicles.

Year	Yearly sales by manufacturer in 1000 units										Global yearly sales of hybrid-electric cars in 1000 units	Cumulative global production of hybrid-electric cars in 1000 units
	BMW[a,b]	Chrysler[a,b]	Ford[a,b]	General motors[a,b]	Honda[d]	Mazda[a,b]	Mercedes[a]	Nissan[a,b]	Toyota[c]	Volkswagen[a,b]		
1997	–	–	–	–	–	–	–	–	0.3	–	300	0.3
1998	–	–	–	–	–	–	–	–	17.7	–	17700	18
1999	–	–	–	–	*1.0*	–	–	–	15.2	–	16200	34
2000	–	–	–	–	*2.0*	–	–	–	19.1	–	21100	55
2001	–	–	–	–	*2.5*	–	–	–	36.9	–	39400	95
2002	–	–	–	–	*12.0*	–	–	–	41.3	–	53300	148
2003	–	–	–	–	*27.2*	–	–	–	53.3	–	80500	229
2004	–	–	*17.0*[a]	–	*33.3*	–	–	–	134.7	–	185000	414
2005	–	–	*19.8*[a]	–	*39.7*	–	–	–	235.0	–	294495	708
2006	–	–	*23.3*[a]	–	*51.5*	–	–	–	312.5	–	387323	1,095
2007	–	–	*25.1*[a]	*5.2*[a]	*55.0*	–	–	*30.0*[a]	429.4	–	544683	1,640
2008	*0*	*0.05*[a]	*17.2*[a]	*11.4*[a]	*61.0*	–	–	*35.0*[a]	429.7	*0*[a]	554375	2,194
2009	*0*	*0.04*[a]	*33.5*[a]	*17.1*[a]	*187.4*[e]	–	*12.5*[f]	*40.0*[a]	*567.2*[a,c]	*0*[a]	857823	3,052
2010	0.3	*0*[a]	*35.5*[a]	*6.8*[a]	*193.9*[a]	0.7[a]	*13.5*[f]	*40.0*[a]	*692.9*[a,c]	*0.3*[a]	983927	4,036

–: No sales.
[a] *Primary data source*: USDE (2011a).
[b] Only including US sales.
[c] Primary data source: Toyota (2011a).
[d] Primary data source: Honda (2009).
[e] Estimates based on Honda (2009).
[f] Estimates based on Brambach (2009) and Daimler (2010).

Table A9
Data for estimating the cumulative production of electric vehicles until early 2011.

Vehicle	Estimate of cumulative production until early 2011	Comment	Reference
Global Electric Motorcars	45,000[a]	Subsidiary of the Chrysler Group, manufacturing low-speed electric vehicles since 1998	GCC (2011)
Nissan Leaf	10,000	Rough estimate	Chambers (2011)
Mitsubishi i-MiEV[b]	5,000		GCC (2010a)
Tesla Roadster	1,400		Tesla (2010)
Think City	2,500		Blanco (2010)
Smiles vehicles[c]	4,000		KFZ (2011)
Total	67,900		

[a] Representing cumulative sales.
[b] Including the Citroën C-Zero.
[c] Including all Smiles vehicles listed in Table A7.

Table A10
Forecasting the cumulative global production of passenger cars until the year 2035 (own estimates based on IEA, 2010).

Year	Cumulative global production in million units		
	Conventional ICE vehicles	Hybrid-electric vehicles	Battery-electric vehicles
2010	2338	4.0	0.1
2011	2400	5.4	0.1
2012	2465	7.2	0.2
2013	2532	9.4	0.3
2014	2603	12.0	0.5
2015	2677	15.0	0.8
2016	2752	18.7	1.4
2017	2829	23.2	2.2
2018	2907	28.3	3.3
2019	2987	34.2	4.4
2020	3068	40.8	6.1
2021	3150	48.1	8.0
2022	3234	56.0	10.8
2023	3319	64.7	14.3
2024	3406	74.0	18.7
2025	3494	84.0	23.8
2026	3585	95.4	29.8
2027	3679	108.2	37.2
2028	3776	122.4	46.0
2029	3876	138.0	56.2
2030	3979	155.0	67.9
2031	4084	173.8	81.0
2032	4190	194.4	95.5
2033	4299	216.8	111.3
2034	4409	241.0	128.4
2035	4521	267.0	146.9

Appendix B. Linear regression analysis for absolute and specific vehicle prices

Figs. 2b and 3b suggest that the decline in the specific price and price differential of HEVs flattens after the year 2006. This observation could, however, be an artifact of our data samples that include in the years after 2006 an increasing share of relatively powerful and over-proportionally expensive HEVs. To estimate the magnitude of the artifact, we conduct a linear regression analysis for the year 2010 by plotting the specific vehicle price [$€_{2010}\,kW^{-1}$] as a function of the absolute vehicle price [$€_{2010}$]. Figs. B1–B3 indicate a linear relationship between both parameters, albeit to a varying extent for HEVs, BEVs, and conventional spark-ignition ICE vehicles. The specific price of HEVs is weakly correlated with the absolute vehicle price (Fig. B1), while the specific price of conventional ICE vehicles is strongly correlated with the absolute vehicle prices (Fig. B2). The detailed cost analysis presented by Lipman and Delucchi (2003) indicates that powertrains account for only 33 ± 5% and 69 ± 12% of the retail price and manufacturing costs of HEVs, respectively. These shares are substantially higher for HEVs than for conventional ICE vehicles (i.e., 18 ± 4% and 33 ± 5%, respectively). The specific vehicle price [$€_{2010}\,kW^{-1}$] may thus not sufficiently account for large parts in the variability of absolute vehicle prices that may results from, e.g., more complex chassis suspension, additional safety and comfort features, and higher sales margins of luxury vehicles. In conclusion, the analyses in Figs. B1 and B2 support our hypothesis that high-price vehicles are disproportionally more expensive per unit of engine power than medium and low-price vehicles.

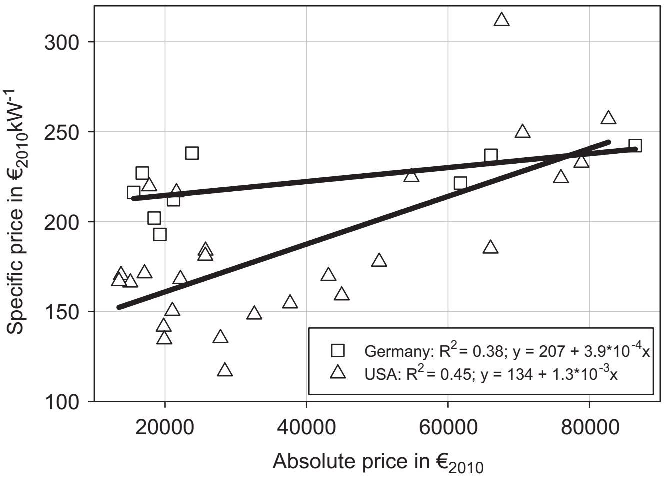

Fig. B1. The specific price of HEVs as a function of the absolute vehicle price in the year 2010.

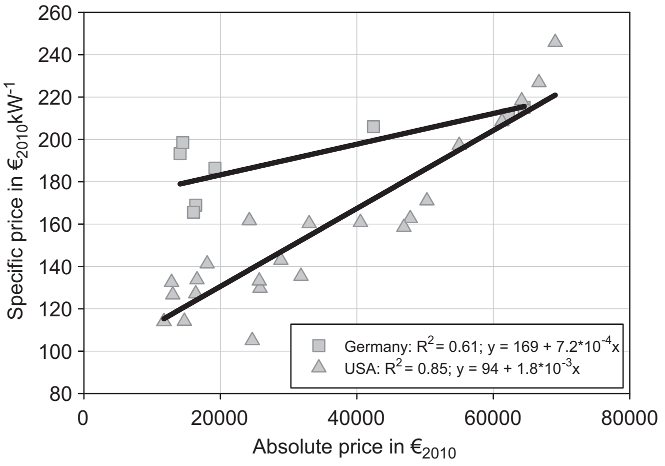

Fig. B2. The specific price of conventional spark-ignition ICE vehicles as a function of the absolute vehicle price in the year 2010.

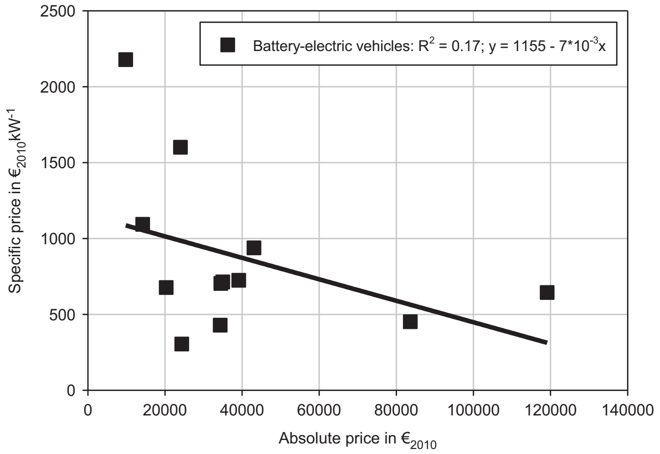

Fig. B3. The specific price of BEVs sold in Europe as a function of absolute vehicle price in the year 2010.

We find for BEVs, however, a different trend: the specific vehicle price tends to show a weak negative correlation with the absolute vehicle prices (Fig. B3). The data set shown in Fig. B3 contains price data for both small-batch and mass-produced BEVs. The negative linear relationship can be explained by the data points for mass-produced vehicles (i.e., Citroën C-Zero, Mitsubishi i-MiEV, and Nissan Leaf) that have a substantially

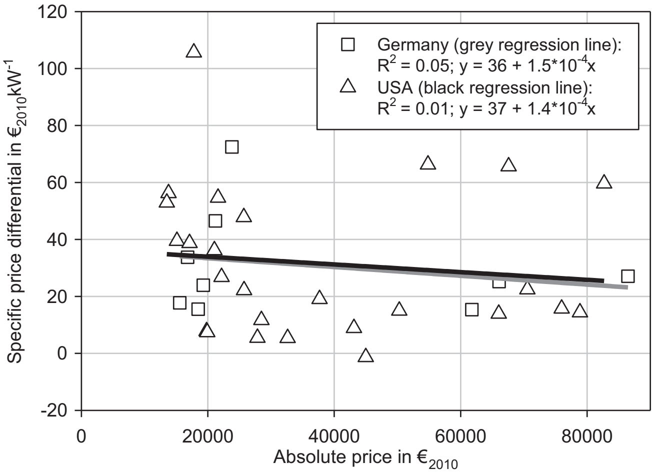

Fig. B4. The specific price differential of HEVs as a function of the absolute vehicle price in the year 2010.

higher absolute price but a lower specific price then the small-batch BEVs included in our analysis.

Additional linear regression analysis indicates that the specific price differential for HEVs is uncorrelated with the absolute vehicle price. Only 5% of the variability in the price differentials is explained by changes in the absolute vehicle price (Fig. B4). We therefore abstain from normalizing the specific price differentials to a predefined absolute price level.

References

ACEA, 2010. Overview of tax incentives for electric vehicles in the EU. ACEA—European Automobile Manufacturers' Association. *Source*: 〈http://www.acea.be/images/uploads/files/20100420_EV_tax_overview.pdf〉 (retrieved 5.08.11.).

AP, 2011. Autos. AP—Autoplenum. *Source*: 〈http://www.autoplenum.de/Automarken〉 (retrieved 8.08.11.).

Argote, L., Epple, D., 1990. Learning curves in manufacturing. Science 247, 920–924.

Bakker, S., 2011. Competing expectations: The case of the hydrogen car. Dissertation Utrecht University. Utrecht, the Netherlands.

BC, 1998. The history of American technology—Fall 1998. The Automobile industry. BC—Bryant College. *Source*: 〈http://web.bryant.edu/∼ehu/h364/materials/cars/〉 (retrieved 8.12.11.).

BCG, 1972. Perspectives on experience, third edition BCG—Boston Consulting Group Inc., Boston, USA.

Bellis, M., 2010. History of electric vehicles. About.com. *Source*: 〈http://inventors.about.com/od/estartinventions/a/History-Of-Electric-Vehicles.htm〉 (retrieved 22.11.2011.).

Beresteanu, A., Li, S., 2011. Gasoline prices, government support, and the demand for hybrid cars in the U.S. International Economic Review 52, 161–182.

Blanco, S., 2010. Think builds 2,500th Think City in Europe; US operations are ahead of schedule. *Source*: 〈http://green.autoblog.com/2010/10/11/think-builds-2-500th-think-city-in-€ope-u-s-operations-are-a/〉 (retrieved 08.08.11.).

Blessing, U., 2008. Th!ink City 2008. *Source*: 〈http://www.hybrid-autos.info/Elektro-Fahrzeuge/THNK/thnk-city-2008.html〉 (retrieved 08.08.11.).

BMW, 2011a. All BMWs. BMW of North America, LLC. *Source*: 〈http://www.bmwusa.com/standard/content/allbmws/default.aspx〉 (retrieved 08.08.11.).

BMW, 2011b. BMW. BMW AG. *Source*: 〈http://www.bmw.de/de/de/index.html〉 (retrieved 08.08.11.).

Book, M., Groll, M., Mosquet, X., Rizoulis, D., Sticher, G. 2009. The comeback of the electric car? Boston Consulting Group. *Source*: 〈http://www.bcg.com/documents/ file15404.pdf〉 (retrieved 24.05.11.).

Brambach, H., 2009. Redemanuskript Shell-Energie-Dialog Stuttgart: Auto-Mobilität im Wandel—Alternative Antriebe vor dem Durchbruch? Verband des Kraftfahrzeuggewerbes Baden-Württemberg e.V. *Source*: 〈http://www-static.shell.com/static/deu/downloads/aboutshell/our_commitment/energy_dialogue/2009/stuttgart_041109/speech_brambach_041109.pdf〉 (retrieved 16.05.11.).

Bruce, P.G., Freunberger, S.A., Hardwick, L.J., Tarascon, J.-M., 2012. Li–O_2 and Li–S batteries with high energy storage. Nature Materials 11, 19–29.

Burke, A., Zhao, H., Miller, M., 2011. Comparing fuel economies and costs of advanced vs. conventional vehicles. In: Ogden, J., Anderson, A. (Eds.), Sustainable Transportation Energy Pathways - A Research Summary for Decision Makers. University of California, Davis. USA.

BW, 1997. Japan's hybrid cars (int'l edition). BW—Bloomberg Businessweek. *Source*: 〈http://www.businessweek.com/archives/1997/b3557013.arc.htm〉 (retrieved 16.05.11.).

Cadillac, 2011. Cadillac vehicles. General Motors Company. *Source*: 〈http://www.cadillac.com/vehicles/〉 (retrieved 08.08.11.).

CGA, 2011. CGA—Consumer Guide Automotive. *Source*: 〈http://consumerguideauto.howstuffworks.com/〉 (retrieved 08.08.11.).

Chambers, N., 2011. Nissan clarifies: 10,000 LEAFs built by end of March, faster charging upgrade being "Studied". Plugincars. *Source*: 〈http://www.plugincars.com/nissan-clarifies-10000-leafs-built-end-march-faster-charging-upgrade-being-studied-106922.html〉 (retrieved 08.08.11.).

Chandra, A., Gulati, S., Kandlikar, M., 2010. Green drivers or free riders? An analysis of tax rebates for hybrid vehicles. Journal of Environmental Economics and Management 60, 78–93.

Chevrolet, 2011. Chevrolet vehicles. General Motors Company. *Source*: 〈http://www.chevrolet.com/vehicles/〉 (retrieved 08.08.11.).

Citroën, 2011. Citroën C-zero. *Source*: 〈http://www.Citroën.de/Citroën-c-zero/#/Citroën-c-zero/〉. Citroën Deutschland GmbH (retrieved 08.08.11.).

Cowan, R., Hultén, S., 1996. Escaping lock-In: The case of the electric vehicle. Technological Forecasting and Social Change 53, 61–79.

Csere, C., 2002. 2003 Honda Civic Hybrid—road test. Car and Driver. *Source*: 〈http://www.caranddriver.com/reviews/car/02q2/2003_honda_civic_hybrid-road_test〉 (retrieved 08.08.11.).

Daimler, 2010. Mercedes-Benz im Dezember und vierten Quartal Premiummarke mit stärkstem Zuwachs. Daimler AG. *Source*: 〈http://www.daimler.com/dccom/0-5-7153-49-1264482-1-0-0-0-0-0-9293-7145-0-0-0-0-0-0-0.html〉 (retrieved 16.05.11.).

Daimler, 2011. The S-Class. Mercedes-Benz USA LLC. *Source*: 〈http://www.mbusa.com/mercedes/vehicles/class/class-S〉 (retrieved 08.08.11.).

DB, 2011. Deutsche Bank revises li-ion battery cost forecasts downward to $250/kWh by 2020. DB – Deutsche Bank. Green Auto Blog. *Source*: 〈http://green.autoblog.com/2011/01/06/deutsche-bank-li-ion-battery-cost-forecast-per-kwh/〉 (accessed 02.09.11.).

de Jong, R., Åhman, M., Jacobs, R., Dumitrescu, E., 2009. Hybrid-electric vehicles: An overview of current technology and its application in developing and transitional countries. UNEP - United Nations Environment Programme (UNEP), Nairobi, Kenya.

Dinger, A., Martin, R., Mosquet, X., Rabl, M., Rizoulis, D., Russo, M., Sticher, G., 2010. Batteries for electric cars – Challenges, opportunities, and the outlook to 2020. The Boston Consulting Group. *Source*: 〈http://www.bcg.com/documents/file36615.pdf〉 (accessed 11.04.11.).

DOE, 2011. Federal tax credits for electric vehicles. DOE—US Department of Energy. *Source*: 〈http://www.fueleconomy.gov/feg/taxevb.shtml〉 (retrieved 08.12.11.).

Dutton, J.M., Thomas, A., 1984. Treating progress functions as a managerial opportunity. The Academy of Management Review 9, 235–247.

EARPA, 2003. R&D Technology roadmap - A contribution to the identification of key technologies for a sustainable development of European road transport. EARPA – European Automotive Research Partners Association. *Source*: 〈http://www.furore-network.com/documents/furore_rod_map_final.pdf〉 (retrieved 23.08.11.).

Eberle, U., von Helmolt, R., 2010. Sustainable transportation based on electric vehicle concepts: a brief overview. Energy and Environmental Science 3, 689–699.

EC, 2001. Commission Directive 2001/116/EC of 20 December 2001 adapting to technical progress Council Directive 70/156/EEC on the approximation of the laws of the Member States relating to the type-approval of motor vehicles and their trailers. EC – European Commission. Official Journal of the European Communities L 18, 1–115.

EC, 2007. Commission Directive 2007/46/EC of the European Parliament and of the Council of 5 September 2007 establishing a framework for the approval of motor cars and their trailers, and of systems, components and separate technical units intended for such cars. EC – European Commission. Official Journal of the European Union L263, 1–160.

EC, 2009a. A sustainable future for transport. EC – European Commission. *Source*: 〈http://ec.Europa.eu/transport/publications/doc/2009_future_of_transport_en.pdf〉 (retrieved 14.02.11.).

EC, 2009b. Regulation (EC) No. 443/2009 of the European Parliament and of the Council of 23 April 2009 setting emission performance standards for new passenger cars as part of the Community's integrated approach to reduce CO_2 emissions from light-duty vehicles. EC – European Commission. Official Journal of the European Union L 140, 1–15.

EC, 2011a. White paper - Roadmap to a single European transport area - Towards a competitive and resource efficient transport system. COM(2011) 144 final. EC – European Commission, Brussels, Belgium.

EC, 2011b. Green cars initiative. EC – European Commission. *Source*: 〈http://ec.pa.eu/research/transport/info/green_cars_initiative_en.html〉 (retrieved 14.02.11.).

EC, 2011c. Electrification of road transport at the JRC. EC – European Commission.

Edwards, R., Larivé J.-F., Mahieu V., Rouveirolles P., 2008. Well-to-wheels analysis of future automotive fuels and powertrains in the European context—tank-to-wheels report, Version3. JRC, EUCAR, CONCAWE. *Source*: 〈http://ies.jrc.ec.europa.eu/uploads/media/V3.1%20TTW%20Report%2007102008.pdf〉 (retrieved 22.11.11.).

EEA, 2009. Exceedance of air quality limit values in urban areas (CSI 004)—Assessment published December 2009. EEA – European Environmental Agency. *Source*: 〈http://www.eea.€opa.eu/data-and-maps/indicators/exceedance-of-airquality-limit1/exceedance-of-air-quality-limit-1〉 (accessed 11.10.11.).

EEA, 2010. European Union emission inventory report 1990–2008 under the UNECE convention on Long-Range Transboundary Air Pollution (LRTAP). EEA – European Environmental Agency. EEA Technical Report No 7/2010. Copenhagen, Denmark.

EGCI, 2010. European roadmap electrification of road transport. Version 2, November 2010. EGCI – European Green Car Initiative. *Source*: ⟨http://www.green-cars-initiative.eu/public/documents/Roadmap%20Electrification.pdf/view⟩ (retrieved 22.11.11.).

Emadi, A., Rajashekara, K., Williamson, S.S., Lukic, S.M., 2005. Topological overview of hybrid electric and fuel cell vehicular power system architectures and configurations. IEEE Transactions on Vehicular Technology 54, 763–770.

EPA, 2006. Latest findings on national air quality—status and trends through 2006. EPA – Environmental Protection Agency. *Source*: ⟨http://www.epa.gov/air/airtrends/2007/ report/highlights.pdf⟩ (retrieved 14.02.11.).

Ernst, C.-S., Hackbarth, A., Madlener, R., Lunz, B., Sauer, D.U., Eckstein, L., 2011. Battery sizing for serial plug-in hybrid electric vehicles: a model-based economic analysis for Germany. FCN Working Paper No. 14/2010. RWTH Aachen, Germany.

Fontaras, G., Pistikopoulos, P., Samaras, Z., 2008. Experimental evaluation of hybrid vehicle fuel economy and pollutant emissions over real-world simulation driving cycles. Atmospheric Environment 42, 4023–4035.

Ford, 2011. Ford vehicles. Ford Motor Company. *Source*: ⟨http://www.ford.com/vehicles/⟩ (retrieved 08.08.11.).

Fulton, M., 2011. 12th Five year plan – Chinese leadership towards a low carbon economy. Deutsche Bank Group. *Source*: ⟨http://www.dbcca.com/dbcca/EN/_media/China_12th_Five_Year_Plan.pdf⟩ (retrieved 04.08.11.).

GCC, 2010a. Mitsubishi Motors has produced 5,000 i-MiEVs to date. GCC – Green Car Congress. *Source*: ⟨http://www.greencarcongress.com/2010/11/mmc-20101124.html?utm_source=feedburner&utm_medium=feed&utm_campaign=Feed:+greencarcongress/TrBK+%28Green+Car+Congress%29⟩ (retrieved 08.08.11.).

GCC, 2010b. BYD Auto to begin sales of F3DM plug-in to individuals. GCC – Green Car Congress. *Source*: ⟨http://www.greencarcongress.com/2010/03/byd-20100323.html#more⟩ (retrieved 02.09.11.).

GCC, 2011. Chrysler launches the 2011 GEM line. GCC – Green Car Congress. *Source*: ⟨http://www.greencarcongress.com/2011/01/gem-20110107.html⟩ (retrieved 08.08.11.).

GNE, 2011. Specification - Toyota. GNE - Goo-Net Exchange: *Source*: ⟨http://exchange.goo-net.com/⟩ (retrieved 08.08.11.).

Grünweg, T., 2008. Stromschlag für Europa. Spiegel Online. *Source*: ⟨http://www.spiegel.de/auto/aktuell/0,1518,568814,00.html⟩ (retrieved 08.08.11.).

Hardy, K., 2010. Vehicle technologies program. Presentation given at the IEEE-SA SCC40 P1809 Meeting. Argonne National Laboratory, US Department of Energy, Argonne, USA.

HC, 2008. February 2008 Hybrid Market Dashboard. HC – HybridCars.com. *Source*: ⟨http://www.hybridcars.com/files/feb08-hybrid-market-dashboard.pdf⟩ (retrieved 12.12.11.).

HC, 2009. February 2009 Hybrid Market Dashboard. HC - HybridCars.com. *Source*: ⟨http://www.hybridcars.com/files/feb09-hybrid-market-dashboard-v2.pdf⟩ (retrieved 12.12.11.).

HC, 2011. Auto alternatives for the 21th century. HC—HybridCars.com. *Source*: ⟨http://www.hybridcars.com/hybrid-technology⟩ (retrieved 22.11.11.).

Honda, 2009. Honda reaches 300,000 units in cumulative global sales of hybrid vehicles. Honda Motor Co., Ltd. *Source*: ⟨http://www.hondaeu-news.com/en/news/ index.pmode/modul,detail,7,1076-DEFAULT,21,text,1/index.pmode⟩ (retrieved 16.05.11.).

Honda, 2011a. Honda automobiles. American Honda Motor Co., Inc. *Source*: ⟨http://automobiles.honda.com/⟩ (retrieved 08.08.11.).

Honda, 2011b. Honda Automobile. Honda Deutschland GmbH. *Source*: ⟨http://www.honda.de/automobile/index.php⟩ (retrieved 08.08.11.).

Hultman, N.E., Koomey, J.G., 2007. The risk of surprise in energy technology costs. Environmental Research Letters 2, 1–6.

IEA, 2000. Experience curves for energy technology policy. IEA - International Energy Agency, Paris, France.

IEA, 2008. Energy technology perspectives - Scenario's and Strategies to 2050. IEA – International Energy Agency, Paris, France.

IEA, 2009. Transport, energy and CO_2 – Moving toward sustainability. IEA – International Energy Agency, Paris, France.

IEA, 2010. World energy outlook 2010. IEA – International Energy Agency, Paris, France.

IEA, 2011. Technology roadmap - electric and plug-in hybrid electric vehicles. IEA – International Energy Agency. *Source*: ⟨http://www.iea.org/papers/2011/EV_PHEV_Roadmap.pdf⟩ (retrieved 25.01.11.).

ITF, 2010. Reducing transport greenhouse gas emissions – trends and data 2010. ITF – International Transport Forum, Paris, France.

Junginger, H.M., van Sark, W., Faaij, A., 2010. Technological learning in the energy sector. Edward Elgar Publishing, Cheltenham, UK.

Kahouli-Brahmi, S., 2008. Technological learning in energy-environment-economy modeling: a survey. Energy Policy 36, 138–162.

KFZ, 2011. KfZ-Betrieb online. *Source*: ⟨http://www.kfz-betrieb.vogel.de/wirtschaft/articles/312443/⟩ (retrieved 08.08.11.).

Kobayashi, S., Plotkin, S., Kahn Ribeiro, S., 2009. Energy efficiency technologies for road vehicles. Energy Efficiency 2, 125–137.

Kohlenberg, K., 2008. Der Herausforderer. Zeit Online. *Source*: ⟨http://www.zeit.de/2007/13/Elektroauto/komplettansicht⟩ (retrieved 08.08.11.).

Lee, H., Lovellette, G., 2011. Will electric cars transform the U.S. vehicle market? An analysis of the key determinants. Discussion Paper 2011-08. Harvard University, Cambridge, USA. *Source*: ⟨http://belfercenter.ksg.harvard.edu/files/Lee%20Lovellette%20Electric%20Vehicles%20DP%202011%20web.pdf⟩ (retrieved 05.08.11.).

Lexus, 2011a. Lexus vehicles. Toyota Motor Sales, U.S.A., Inc. *Source*: ⟨http://www.lexus.com/models/allVehicles/index.html⟩ (retrieved 08.08.11.).

Lexus, 2011b. Lexus Deutschland GmbH. *Source*: ⟨http://www.lexus.de⟩ (retrieved 09.08.11.).

Lincoln, 2011. Lincoln MKZ. Ford Motor Company. *Source*: ⟨http://www.lincoln.com/cars/mkz/⟩ (retrieved 08.08.11.).

Lipman, T.E., Delucchi, M.A., 2003. Hybrid-electric vehicle design - Retail and life cycle cost analysis. Report UCD-ITS-RR-03-01 prepared for The Energy Foundation. San Francisco, USA.

Lowe, M., Tokuoka, S., Trigg, T., Gereffi, G., 2010. Lithium-ion batteries for electric vehicles: The U.S. value chain. Center on Globalization, Governance & Competitiveness, Duke University, Durham, USA.

Luis4U, 2011. Luis4U. Luis Motors GmbH. *Source*: ⟨http://4u.luis.de/⟩ (retrieved 08.08.11.).

McConnell, V., Turrentine T., 2010. Should hybrid cars be subsidized? Resources for the Future. Washington D.C., USA.

Mitsubishi. 2010. Mitsubishi i-MiEV. Mitsubishi Motors Deutschland GmbH. *Source*: ⟨http://www.imiev.de/impressum.html⟩ (retrieved 08.08.11.).

Nagelhout, D., Ros, J.P.M., 2009. Elektrisch autorijden – Evaluatie van transities op basis van systeemopties. Report 500083010. PBL - Planbureau voor de Leefomgeving, Bilthoven, The Netherlands.

Neij, L., 2008. Cost development of future technologies for power generation—a study based on experience curves and complementary bottom-up assessments. Energy Policy 36, 2200–2211.

Nemry, F., Brons, M., 2010. Plug-in hybrid and battery-electric vehicles - Market penetration scenarios of electric drive vehicles. Report JRC 58748. JRC – Joint Research Centre, Seville, Spain.

NHTSA, 2011. Statement of the national highway traffic safety administration on formal safety defect investigation of post-crash fire risk in Chevy Volts. NHTSA - National Highway Traffic Safety Administration. *Source*: ⟨http://www.nhtsa.gov/PR/Volt⟩ (retrieved 25.01.12.).

Nissan, 2011a. Nissan Leaf. Nissan Nederland. *Source*: ⟨http://www.nissan.nl/#vehicles/electricvehicles/leaf⟩ (retrieved 22.11.11.).

Nissan, 2011b. Nissan Altima. Nissan North America Inc. *Source*: ⟨http://www.nissanusa.com/altima/?next=header.vlp.postcard.picture.thumbnail⟩ (retrieved 08.08.11.).

OICA, 2010. Production statistics. OICA - International Organization of Motor Vehicle Manufacturers. *Source*: ⟨http://oica.net/category/production-statistics/⟩ (retrieved 15.05.11.).

Pander, J., 2009. Batterieentwicklung bei Toyota—Im Herzen der Hybridwelt. Spiegel Online. *Source*: ⟨http://www.spiegel.de/auto/aktuell/0,1518,629496,00.html⟩ (retrieved 11.08.11.).

Perujo, A., Ciuffo, B., 2010. The introduction of electric vehicles in the private fleet: Potential impact on the electric supply system and on the environment. A case study for the Province of Milan, Italy. Energy Policy 38, 4549–4561.

Porsche, 2011a. Porsche vehicles. Porsche Cars North America *Source*: ⟨http://www.porsche.com/usa/⟩ (retrieved 08.08.11.).

Porsche, 2011b. Porsche. Dr. Ing. h.c. F. Porsche AG. *Source*: ⟨http://www.porsche.com/germany/⟩ (retrieved 08.08.11.).

PR, 2010. Hybrid-electric vehicles for fleet markets. PR – Pike Research. Cited from: ⟨http://www.greencarcongress.com/2010/09/pike-20100917.html⟩ (retrieved 19.04.12.).

RBSC, 2011: Powertrain 2020 - The Li-ion battery value chain - trends and implications. RBSC – Roland Berger Strategic Consultants. *Source*: ⟨http://www.rolandberger.com/media/pdf/Roland_Berger_The_Li_Ion_Battery_Value_Chain_20110801.pdf⟩ (retrieved 25.01.12.).

Robinson, A., 2001. 2001 Toyota Prius—road test. Car and Driver. *Source*: ⟨http://www.caranddriver.com/reviews/car/00q1/2001_toyota_prius-road_test⟩ (retrieved 08.08.11.).

Samaras, C., Meisterling, K., 2008. Life cycle assessment of greenhouse gas emissions from plug-in hybrid vehicles: implications for policy. Environmental Science and Technology 42, 3170–3176.

Sams, T., 2011. The cost efficient electrified powertrain. AVL List GmbH. Presentation at the Ulysses workshop, 21 May 2011. Brussels, Belgium.

Smiles, 2011. Produkte aus der Smiles-World. Smiles AG. *Source*: ⟨http://www.smiles-world.de/produkte⟩ (retrieved 08.08.11.).

Smokers, R., Vermeulen, R., van Mieghem, R., Gense, R., Skinner, I., Fergusson, M., MacKay, E., ten Brink, P., Fontaras, G., Samaras, Z., 2006. Review and analysis of the reduction potential and costs of technological and other measures to reduce CO_2 emissions from passenger cars. TNO Report 06.OR.PT.040.2/RSM. Delft, the Netherlands.

Tesla, 2010. Tesla delivers 100th German car during race of champions. Tesla Motors Ltd. *Source*: ⟨http://www.teslamotors.com/about/press/releases/tesla-delivers-100th-german-car-during-race-champions⟩ (retrieved 08.08.11.).

Thiel, C., Perujo, A., Mercier, A., 2010. Cost and CO_2 aspects of future vehicle options in Europe under new energy policy scenarios. Energy Policy 38, 7142–7151.

Toyota, 2011a. World sales of TMC hybrids top 2 million units. Toyota Motor Corporation. *Source*: ⟨http://www.toyota-global.com/terms_of_use/index.html⟩ (retrieved 16.05.10.).

Toyota, 2011b. Toyota vehicles. Toyota Motor Sales, U.S.A, Inc. *Source*: ⟨http://www.toyota.com/⟩ (retrieved 08.08.11.).

Toyota, 2011c. Toyota Modelle. Toyota Deutschland GmbH. *Source*: ⟨http://www.toyota.de/cars/new_cars/index.aspx⟩ (retrieved 08.08.11.).

USDE, 2011a. Alternative fuels and advanced vehicles data center. USDE – United States Department of Energy. *Source*: ⟨http://www.afdc.energy.gov/afdc/data/vehicles.html#afv_hev⟩ (retrieved 16.05.11.).

USDE, 2011b. US gasoline and diesel retail prices. USDE – United States Department of Energy. *Source*: 〈http://wikiposit.org/w?filter=Energy/US%20Department%20of%20Energy/Petroleum/U.S.%20Gasoline%20and%20Diesel%20Retail%20Prices/〉 (retrieved 26.07.11.).

VW, 2011a. Touareg. VW—Volkswagen of America Inc. *Source*: 〈http://www.vw.com/en/models/touareg/gallery.html〉 (retrieved 08.08.11.).

VW, 2011b. Touareg. VW-Volkswagen AG. *Source*: 〈http://www.volkswagen.de/de/models/touareg.html〉 (retrieved 08.08.11.).

WB, 2007. World development indicators – air pollution. WB – World Bank. *Source*: 〈http://siteresources.worldbank.org/DATASTATISTICS/Resources/table3_13.pdf〉 (retrieved 14.02.11.).

WB, 2011. Data – inflation, GDP deflator. WB – World Bank. *Source*: 〈http://data.worldbank.org/indicator/NY.GDP.DEFL.KD.ZG〉 (retrieved 10.05.11.).

Weiss, M., Junginger, M.H., Patel, M.K., Blok, K., 2010. A review of experience curve analyses for energy demand technologies. Technological Forecasting and Social Change 77, 411–428.

Weiss, M., Bonnel, P., Hummel, R., Provenza, A., Manfredi, U., 2011. On-road emissions of light-duty vehicles in Europe. Environmental Science and Technology 45, 8575–8581.

Wikipedia, 2011. Nissan Leaf. Wikimedia Foundation, Inc. *Source*: 〈http://en.wikipedia.org/wiki/Nissan_Leaf〉 (retrieved 08.08.11.).

Wikipedia, 2012. Hybrid electric vehicle. Wikimedia Foundation, Inc. Source: 〈http://en.wikipedia.org/wiki/Hybrid_electric_vehicle#Sales_and_rankings〉 (retrieved 18.04.12.).

Wüst, C., 2012. Zwitter des Zeitgeists. Der Spiegel, No. 15., 7 April 2012. Spiegel Verlag, Hamburg, Germany.

Xiang, Z., 2010. China to subsidize electric, hybrid car purchases in five cities. *Source*: 〈http://news.xinhuanet.com/english2010/china/2010-06/01/c_13327814.htm〉 (retrieved 05.08.11.).

X-Rates, 2011. X-Rates – currency exchange rates. *Source*: 〈www.x-rates.com〉 (retrieved 10.05.11.).

Yu, C.F., van Sark, W.G.J.H.M., Alsema, E.A., 2011. Unraveling the photovoltaic technology learning curve by incorporation of input price changes and scale effects. Renewable and Sustainable Energy Reviews 15, 324–337.