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Analyzing price and efficiency dynamics of large appliances with the experience curve approach

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ABSTRACT

Large appliances are major power consumers in households of industrialized countries. Although their energy efficiency has been increasing substantially in past decades, still additional energy efficiency potentials exist. Energy policy that aims at realizing these potentials faces, however, growing concerns about possible adverse effects on commodity prices. Here, we address these concerns by applying the experience curve approach to analyze long-term price and energy efficiency trends of three wet appliances (washing machines, laundry dryers, and dishwashers) and two cold appliances (refrigerators and freezers). We identify a robust long-term decline in both specific price and specific energy consumption of large appliances. Specific prices of wet appliances decline at learning rates (LR) of $29 \pm 8\%$ and thereby much faster than those of cold appliances (LR of $9 \pm 4\%$). Our results demonstrate that technological learning leads to substantial price decline, thus indicating that the introduction of novel and initially expensive energy efficiency technologies does not necessarily imply adverse price effects in the long term. By extending the conventional experience curve approach, we find a steady decline in the specific energy consumption of wet appliances (LR of 20–35%) and cold appliances (LR of 13–17%). Our analysis suggests that energy policy might be able to bend down energy experience curves.

1. Introduction

Appliances currently consume 6% (6 EJ, exajoules) of the economy-wide final energy supply in IEA-19 countries[1] (IEA, 2008a). After space heating and cooling, appliances are the second largest energy function in households, accounting for 21% of household final energy demand. The energy consumption of appliances continues to grow rapidly, albeit with differentiation for *large* and *small* appliances. *Large appliances* such as washing machines and refrigerators account for half of the appliance-related final energy demand (IEA, 2008a). Their share is, however, falling for two reasons. Firstly, ownership of *small appliances* (e.g., juicers, cellular phones, computers, audio and video devices) shows an over-proportional increase in recent years. Secondly, the specific energy consumption of large appliances has been falling considerably in the past 30 years, partially due to effective energy efficiency policies (Bertoldi and Atanasiu, 2007; Ellis et al., 2007; IEA, 2008a–c; Dale et al., 2009).

Despite this development, still substantial and untapped potentials exist to further increase the energy efficiency of large appliances. Policy initiatives that aim at realizing these potentials face, however, growing concerns of manufacturers, consumers, and policy makers about possible adverse effects on the price of large appliances (EU, 2008). These concerns were previously fuelled by *ex-ante* engineering analysis that suggested a direct relationship between improved energy efficiency on the one hand and rising commodity prices on the other (Greening et al., 1996; Ellis et al., 2007; Dale et al., 2009). In reality, however, both prices and energy consumption of large appliances have been falling simultaneously for more than three decades (Schiellerup, 2002; Ellis et al., 2007; Bertoldi and Atanasiu, 2007; Dale et al., 2009). Hence, conventional *ex-ante* engineering analyses fail to provide reliable price and cost projections because they disregard cost reduction potentials by assuming constant additional costs of energy efficiency improvements. This assumption neglects that in reality, efficiency measures are introduced as superposition in a dynamic rather than a static product system. The entire product system (including the newly implemented energy efficiency improvements) continuously undergoes technological change and offers substantial potentials for costs reductions due to

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[1] We refer here to the 19 member countries of the International Energy Agency (IEA), i.e., Austria, Belgium, Canada, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, The Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom, and the USA.

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technological learning (i.e., growing experience of manufacturers, economies of scale, technological innovation, and market change).

In this article, we aim at supplementing *ex-ante* engineering analyses by studying long-term price and efficiency trends of large appliances. In particular, we want to obtain a better understanding of the extent to which technological learning influences both price and energy efficiency of large appliances. One tool that allows for quantifying technological learning is the *experience curve approach*.[2] Typically, the experience curve approach models production costs of a technology as a power-law function of cumulative production (BCG, 1972). Therefore, the experience curve approach allows tracing prices and, by analogy, energy efficiency closer to their actual drivers than simple time-series analysis because it eliminates volatility in yearly production volumes as explanatory variable for price and efficiency changes. The experience curve approach gained importance as management tool in manufacturing industries (Argote and Epple, 1990) and as instrument for technology forecasting in energy and CO_2 emission scenarios (e.g., IEA, 2000; Wene et al., 2000; IEA, 2008a–c; van Vuuren et al., 2006). The experience curve approach has been extensively applied to and redefined for renewable energy supply technologies (e.g., Neij, 1999; McDonald and Schrattenholzer, 2001; Junginger et al., 2004, 2005, 2006, 2008; Neij, 2008). Its application to energy demand technologies and in particular to large appliances is, however, still scarce. Bass (1980) analyzed technological learning of refrigerators (period from 1922 to 1940), dishwashers (periods from 1947 to 1960 and 1947 to 1974), and laundry dryers (periods from 1950 to 1961 and 1950 to 1974) based on price and sales data for the USA. Laitner et al. (2004) quantify technological learning of washing machines, dishwashers, laundry dryers, refrigerators, and freezers for the period between 1980 and 1998 based on production and price data for the USA. These studies cover either past time periods more than three decades ago (Bass, 1980) or only relatively short time series ([Laitner et al., 2004).

Here, we apply the experience curve approach to three *wet appliances* (i.e., washing machines, laundry dryers, dishwashers) and two *cold appliances* (i.e., refrigerators, and freezers). With our analysis, we cover very long time periods of three to four decades until most recent years. This assures as far as possible that our results correctly represent the actual price and energy efficiency dynamics of large appliances. First, we identify the rate at which prices, i.e., consumer investment costs for large appliances decline. To provide a more comprehensive picture of both price and efficiency dynamics, we extend the conventional experience curve approach by analyzing also specific energy consumption of large appliances as a function of cumulative production. Such a methodological extension is new and allows for quantifying technological learning of large appliances from a broader perspective. We justify our methodological extension by two considerations:

(i) At the system's level, energy efficiency improvements might follow autonomous technological innovation and often result from the quest of producers to decrease production costs. For example, improved wall insulation of cold appliances might allow for smaller, thus cheaper compressors; innovative rubber door gaskets might be cheaper, while having longer life-times and offering better thermal insulation. By means of such inter-linkages, energy efficiency improvements and declining production costs may go hand in hand, thereby contributing to energy efficiency improvements alongside technological learning that is directed at improved and cheaper appliances.

(ii) Over the past decade, energy efficiency became a product feature that is decisive for the market success of large appliances. Thus, producers are nowadays forced to increase the efficiency of their products as well as to decrease production costs if they want to remain competitive on the market (Ecowet, 2007a).

Following the introduction, we explain in Section 2 methodology and data sources used for constructing cost and energy experience curves. We present the results of our analysis in Section 3. In Section 4, we discuss our findings, thereby paying special attention on developing a conceptual framework for devising energy experience curves. We draw conclusions in Section 5.

2. Methodology and data sources

In this section, we first present our methodology for constructing experience curves. Afterward, we explain in detail the data sources used and data adaptations made to construct price and energy experience curves for large appliances.

2.1. The experience curve approach

With the experience curve approach, we model price and specific energy consumption of five large appliances, i.e., washing machines, laundry dryers, dishwashers, refrigerators, and freezers by as power-law function of cumulative production:

$$Ccum_i = C_{0,i}(Pcum_i)^{b_i} \quad (1)$$

where $Ccum_i$ [EUR_{2006} (real Euros deflated to the base year of 2006) per functional unit; kWh_{el} (kilowatt hour electricity) per functional unit, Energy Efficiency Index (EEI)][3],[4] represents the specific price or in analogy the specific energy consumption at $Pcum_i$, $C_{0,i}$ [EUR_{2006} per functional unit, kWh_{el} (kilowatt hour electricity) per functional unit, EEI] stands for the the specific price or the specific energy consumption of the first unit produced, $Pcum_i$ represents the cumulative experience (i.e., the cumulative production), and b_i stands for the product-specific experience index of the large household appliance i.[5] By applying the logarithmic function to Eq. (1), we plot a linear experience curve with b_i as slope parameter and $\log C_{0,i}$ as intercept with the y-axis. Based on the experience index b_i, we calculate appliance-specific learning rates (LR_i) [%] and progress ratios (PR_i) [%] and as rates, at which both, specific prices and

[2] The experience curve approach has so far mainly been used to analyze price and cost trends in manufacturing (see, e.g., Argote and Epple, 1990; Junginger et al., 2008). One exception refers to its application for analyzing the specific energy consumption of ammonia and urea production (Ramirez and Worrell, 2006). Our extension of the experience curve approach to analyze the specific energy consumption of large appliances is hence new and will be justified below.

[3] We analyze price and efficiency dynamics of wet appliances based on the following functional units: kg (kilogram) laundry capacity for washing machines and laundry dryers as well as standard place setting for dishwashers. In the case of cold appliances, we analyze price dynamics based on 100 l (liters) of volume and efficiency dynamics based on the dimensionless EEI (see Section 2.2).

[4] Dishwashers typically have a capacity of 12 standard place settings. One standard place setting consists of a dinner plate, a soup plate, a dessert plate, a glass tumbler, a tea cup and saucer, as well as a set of knife, fork, soup spoon, dessert spoon, and teaspoon.

[5] Energy experience curves should generally include a constant term to account for the thermodynamic minimum energy requirements of technologies and processes (e.g., heat effects of chemical reactions). For the five large household appliances, the thermodynamic minimum energy requirements are virtually zero. One exception from this is the first-time cooling of food products. We, however, neglect energy requirements for this service because they are in reality negligible compared to the actual energy consumption of cold appliances.

specific energy consumption decline with each doubling of cumulative production:

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

We estimate the error interval of LR_i and PR_i based on the implicit error of the regression analysis, i.e., the 95% confidence interval for the slope parameter of the experience curve. We devise experience curves based on the average specific price and the average specific energy consumption of large appliances in individual years.

2.2. Data sources and data adaptations

For constructing experience curves for large household appliances, we use price and energy consumption data that refer to the Netherlands. This choice is justified for two reasons:

(i) Data availability for this particular country allows for analyzing long and consistent time series (i.e., three to four decades).
(ii) Despite considerable price variation between countries (GfK, 2003, 2004; Ecocold, 2007b), price and efficiency trends are generally similar throughout the world (Ellis et al., 2007).

As single source for data on specific price and specific energy consumption, we use the Dutch consumer organization Consumentenbond. Typically, Consumentenbond (1964–2008) provides data on prices and energy consumption along with other supplementary product information when publishing tests of large appliances. Consumentenbond (1964–2008) tests large appliances frequently, i.e., depending on the type of appliance in intervals between twice per year to once in 2 years. The data presented by Consumentenbond (1964–2008) are not necessarily representative because individual tests often focus on either cheap or expensive appliances, on appliances, which are most successful at the Dutch market, or on appliances of a specific energy label category (Consumentenbond, 2009). Prior to our experience curve analysis, we corrected parts of the biases in the datasets as provided by Consumentenbond (1964–2008). We are now going to explain our data adaptation in more detail. We will revert to the problem of data bias and the related uncertainties in our discussion (see Section 4.1).

To assure consistency of price data, we first exclude built-in models of dishwashers, refrigerators, and freezers from our analysis. Built-in appliances have a considerably higher specific price than standard models. Without correction, differences regarding the frequency of data for these models would introduce substantial bias into our experience curve analysis.

Secondly, we deduct the sales tax from the price data and we deflate prices to the base year of 2006 by using consumer price indices for the Netherlands as obtained from CBS (2007). In third instance, we use data on absolute prices and supplementary product information to calculate specific prices expressed in EUR_{2006}/kg laundry capacity for washing machines and laundry dryers, EUR_{2006}/standard place setting for dishwashers, and EUR_{2006}/100 l for refrigerators and freezers.

In our price experience curve analysis for freezers, we differentiate between upright and chest freezers because both freezer types show considerable and systematic differences regarding their specific price (Consumentenbond, 1964–2008; Waide, 2001). Under the category of refrigerators, we uniformly include data for refrigerators without freezer compartments, refrigerators with freezer compartments, as well as two-door refrigerator–freezer combinations. We do not apply price corrections here because data obtained from Consumentenbond (1964–2008) indicate no systematic price differences between these three types of cold appliances.

Next to adaptation of price data, we also make adjustments for data on specific energy consumption as given by Consumentenbond (1964–2008) for the various types of appliances. This way, we assure consistent reproduction of the historic development in the specific energy consumption of large appliances. In the case of washing machines, we correct for temperature differences of test cycles. We consistently refer the specific energy consumption of washing machines to an average 60 °C (degrees centigrade) cotton washing cycle. We recalculate the energy consumption as given by Consumentenbond (1964–2008) for 90 °C washing cycles by making three assumptions: (i) 90% of the energy use during a 60 °C cotton washing cycle is consumed for water heating and 10% for laundry spinning and water pumping, (ii) the inlet water temperature of washing machines is 15 °C, and (iii) the energy consumption for water heating is directly proportional to the difference between inlet temperature and washing temperature (i.e., 75 °C in the case of a 90 °C washing cycle and 45 °C in the case of a 60 °C washing cycle). These assumptions yield a correction factor of 62.5% for converting the energy consumption of a 90 °C cotton washing cycle into the energy consumption of a 60 °C cotton washing cycle. Our correction factor is in line with estimates presented by GEA (1995) and Ecowet (2007a).

Accounting for the specific energy consumption of laundry dryers is complicated because data availability is limited. Consumentenbond (1964–2008) states with a few exceptions (e.g., the years 1990, 1988, 1984) only energy ratings or energy labeling categories. We therefore estimate the actual energy consumption of laundry dryers based on supplementary information provided by producers and retailers. For both washing machines and laundry dryers, we calculate the specific energy consumption (kWh_{el}/kg) by dividing absolute energy consumption (kWh_{el}) (as given by Consumentenbond, 1964–2008) by actual laundry capacity [%].

In the case of dishwashers, refrigerators, and freezers, we express energy consumption as Energy Efficiency Index (EEI). For calculating the EEI, we follow the official methodology used for determining the efficiency category of these appliances within the European energy labeling scheme (EU, 1997, 2003).[6] The energy consumption as given by Consumentenbond (1964–2008) for refrigerators and freezers refers in individual years to ambient air temperatures of 18, 20, and 25 °C (degrees centigrade). In a first step, we uniformly recalculate energy consumption for an ambient air temperature of 25 °C by assuming that energy consumption at 18 and 20 °C is 35% and 25% lower than at 25 °C.[7] Afterward, we recalculate the corrected energy consumption data into an EEI. This way, we assure consistency with the standard methodology that is used to evaluate the energy efficiency of dishwashers and cold appliances within the European energy labeling scheme (EU, 1997, 2003).

Based on the adapted data, we calculate averages of specific prices and specific energy consumption as well as the related standard deviations for individual years.

[6] For refrigerators and freezers, we base our calculation of the EEI consistently on the usable volume of cold appliances as determined through standardized product testing by Consumentenbond (1964–2008). These volumes are in general smaller than the ones stated by appliance manufacturers. The EEIs presented in our experience curve analyses are hence higher than the ones used for energy labeling.

[7] This approach is in line with the method used for temperature corrections by EU (2003). We account here only for the impact of the temperature difference between interior and ambient air on the overall energy consumption of refrigerators, thereby neglecting the effect of temperature differences on the coefficient of performance of the refrigerators heat pump.

Table 1
Average yearly change in the specific price and energy consumption of large appliances in the Netherlands. (Data source: Consumentenbond, 1964–2008.)

Appliance	Average yearly change in specific price[a] (%)		Average yearly change in specific energy consumption (%)	
	Entire period	Truncated period[b]	Entire period	Truncated period[b]
Washing machines	−2.4	−2.9	−2.5	−2.4
Laundry dryers	−2.1	−2.3	−1.5	−2.5
Dishwashers	−3.8	−3.3	−2.3	−2.3
Refrigerators	−1.2	−1.3	−2.3	−3.0
Upright freezers	−1.5	0.0	−1.9	−1.6
Chest freezers	−1.1	-0.9		

[a] Prices in real terms.
[b] Covering the years 1990 and afterward.

We estimate cumulative experience in the manufacturing of large household appliances based on global production data. This choice is justified because for more than two decades, major producers have been simultaneously operating on each of the three major global appliance markets, i.e., Europe, America, and Asia (Ecocold, 2007c; Dahlman, 2007). Although producers adjust their products for specific consumer preferences on individual markets, it is plausible to assume a global learning system for the manufacturing of large appliances and components thereof. To estimate cumulative global production of each of the five household appliances, we start out by collecting data from UN (2008), Eurostat (2008), and Ecocold (2007a). The data provided by these sources do, however, not allow for constructing complete time series that cover global yearly production of appliances, starting from the point of market commercialization) almost a century ago up until most recent years. We therefore supplement available data with information provided by various sources, including Bowden and Offer (1994), Waide (2001), Laitner et al. (2004), AM (2007), the statistical offices of Canada, China, Germany, Japan, and the USA, as well as the manufacturers association AHAM (2004a, b). We apply data interpolation and extrapolation to close remaining gaps in our datasets. The availability of production data for dishwashers and freezers is particularly limited. We estimate cumulative global freezer production based on three sources of information: (i) sales data for the USA, (ii) the fraction of refrigerator to freezer production in the EU between 1995 and 2005, and (iii) the fraction of refrigerator to freezer production and sales as provided by Ecocold (2007a) for several non-European countries. We estimate cumulative global dishwasher production based on Destatis (1995–2003), Laitner et al. (2004), and CECED (2007). We conduct a sensitivity analysis for dishwasher and freezer production to identify the uncertainties of our approach. Based on data availability, we cover the following time periods by our experience curve analysis: (i) 1965–2008 for washing machines, (ii) 1969–2003 for laundry dryers, (iii) 1968–2007 for dishwashers, (iv) 1964–2008 for refrigerators, and (v) 1970–2003 for freezers.

3. Results

We first provide an overview of average yearly changes in the specific price and energy consumption of large household appliances (Table 1). We distinguish between (i) the whole time period for which data are available to us and (ii) a shorter time period since 1990, suitable to identify more recent price and efficiency trends.

Both wet appliances (washing machines, laundry dryers, dishwashers) and cold appliances (refrigerators and freezers) show a trend towards a decline in specific price and specific energy consumption. Considering first the *long* time periods, we find specific energy consumption of wet and cold appliances to decline at similar rates of roughly 2% per year. However, specific prices of wet appliances decline at 2–4% per year and thereby considerably faster than the ones of cold appliances. Our results for *short* time periods confirm these findings (Table 1). The decline in the specific energy consumption of washing machines and dishwashers is in both time periods accompanied by an overproportional decline in water consumption of 2–6% per year (data not shown in Table 1).

Using the same data as above, we now construct two sets of experiences curves, i.e., for the specific price and for the specific energy consumption of wet and cold appliances (Figs. 1 and 2).[8]

In line with the results presented in Table 1, our experience curve analysis indicates a clear trend towards a decline in both specific prices and specific energy consumption with increasing cumulative production of large appliances. Wet appliances show relatively high price learning rates of $33 \pm 9\%$ for washing machines, $28 \pm 7\%$ for laundry dryers, and $27 \pm 7\%$ for dishwashers. By contrast, cold appliances show price learning rates, which are a factor three lower, i.e., $9 \pm 4\%$ for refrigerators as well as $10 \pm 5\%$ and $8 \pm 2\%$ for upright and chest freezers.

The learning rates identified for specific energy consumption clearly indicate a trend towards increasing energy efficiency albeit with differentiation for wet and cold appliances. For wet appliances, learning rates range from $35 \pm 3\%$ for washing machines to $20 \pm 6\%$ for laundry dryers and $18 \pm 3\%$ for dishwashers. Cold appliances show slightly lower learning rates of $17 \pm 2\%$ and $13 \pm 3\%$ for refrigerators and (upright and chest) freezers, respectively.

We now provide some explanations for the decline in specific prices. Afterward, we try to explain improvements in the energy efficiency of large household appliances. The decline in specific prices is to a large extent caused by an overall decline of production costs but also by declining markups in the wholesale and retail sector (i.e., the difference between producer prices and consumer prices). Addressing the first point, production costs for large appliances declined mainly due to the following factors (Ecocold, 2007a; Siderius, 2008; Dale et al., 2009; Kemna, 2009):

(i) technological learning and economies of scale in component manufacturing and appliance assembling in past decades, partly realized by mergers of producers;
(ii) increasing substitution of capital for labor that lowered labor requirements and increased automation and overall

[8] For washing machines and dishwashers, we also include water consumption in our experience curve analysis. This choice is justified because water consumption is (next to energy consumption) a second relevant parameter for environmental impacts and use phase costs during the life cycle of wet appliances.

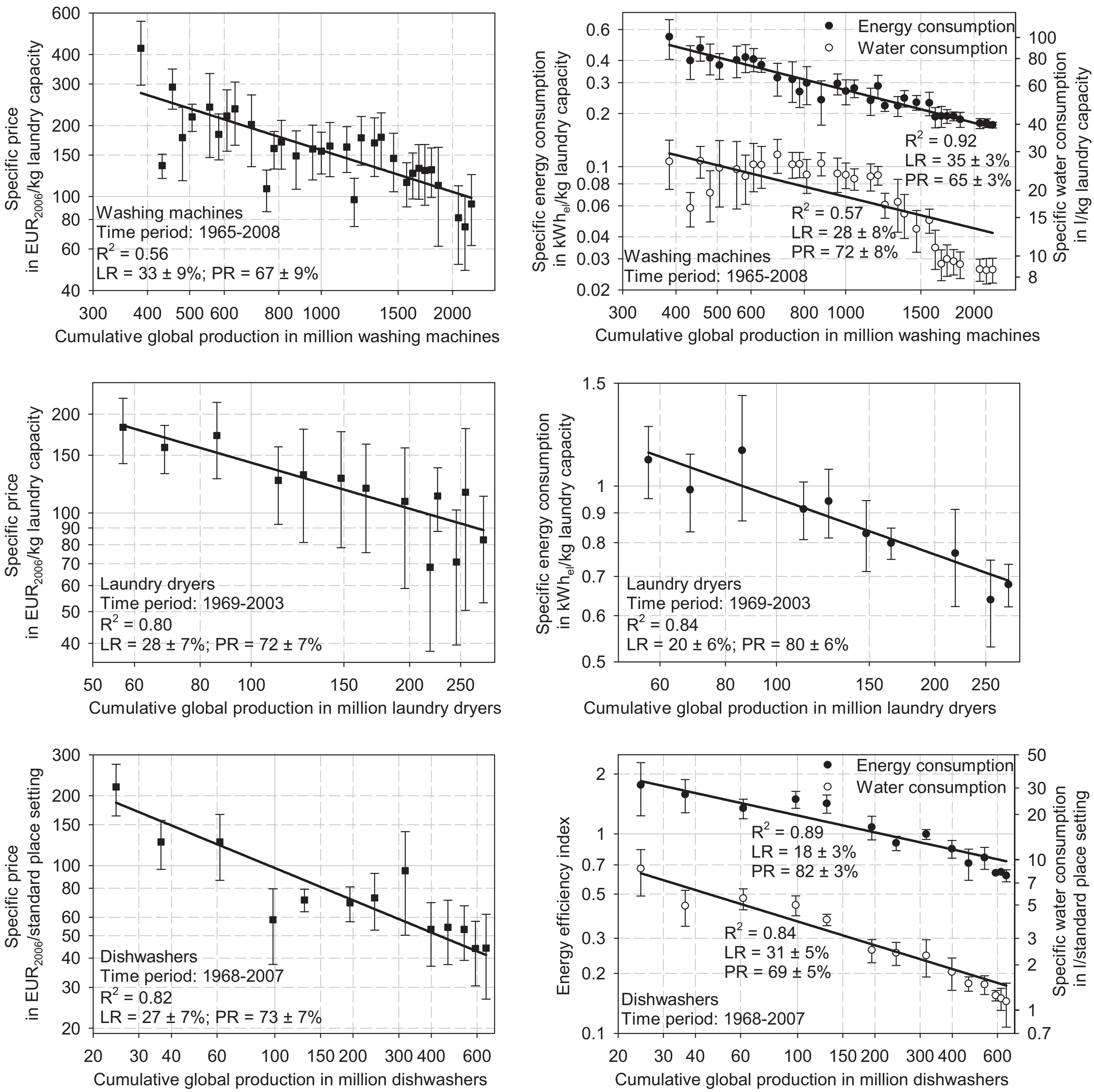

Fig. 1. Experience curves for specific prices (left column) and specific energy consumption (right column) of wet appliances (error bars indicate the standard deviation of data points; error intervals represent the 95% confidence intervals of learning rates and progress ratios based on the implicit error of the regression analysis).

productivity of appliance manufacturing in the period of 1970–1990;

(iii) standardization and competitive outsourcing of components and sub-assemblies production to specialized companies in low-wage regions like China (since the 1990s);

(iv) streamlining of assembly lines, decreasing assembly times, just-in-time manufacturing, and reduction of on-site stocks of components, semi-finished and finished products in recent years;

(v) shifting of Western European assembly lines to low-income Eastern European countries such as Hungary, Poland, or Turkey;

(vi) standardization and homogenization[9] of components as well as simplification of product design leading to a decrease in the number of materials and components;

[9] The number of cold appliance categories (i.e., spanning from simple refrigerators to multi-use cabinets) sold on the market in noticeable quantities decreased from 10 to four, with refrigerator–freezer combinations constituting to date market shares of more than 60% in Europe (Ecocold, 2007c). This development was partly facilitated by the EU energy label because producers can achieve stringent energy standards for some categories of cold appliances more easily than for others.

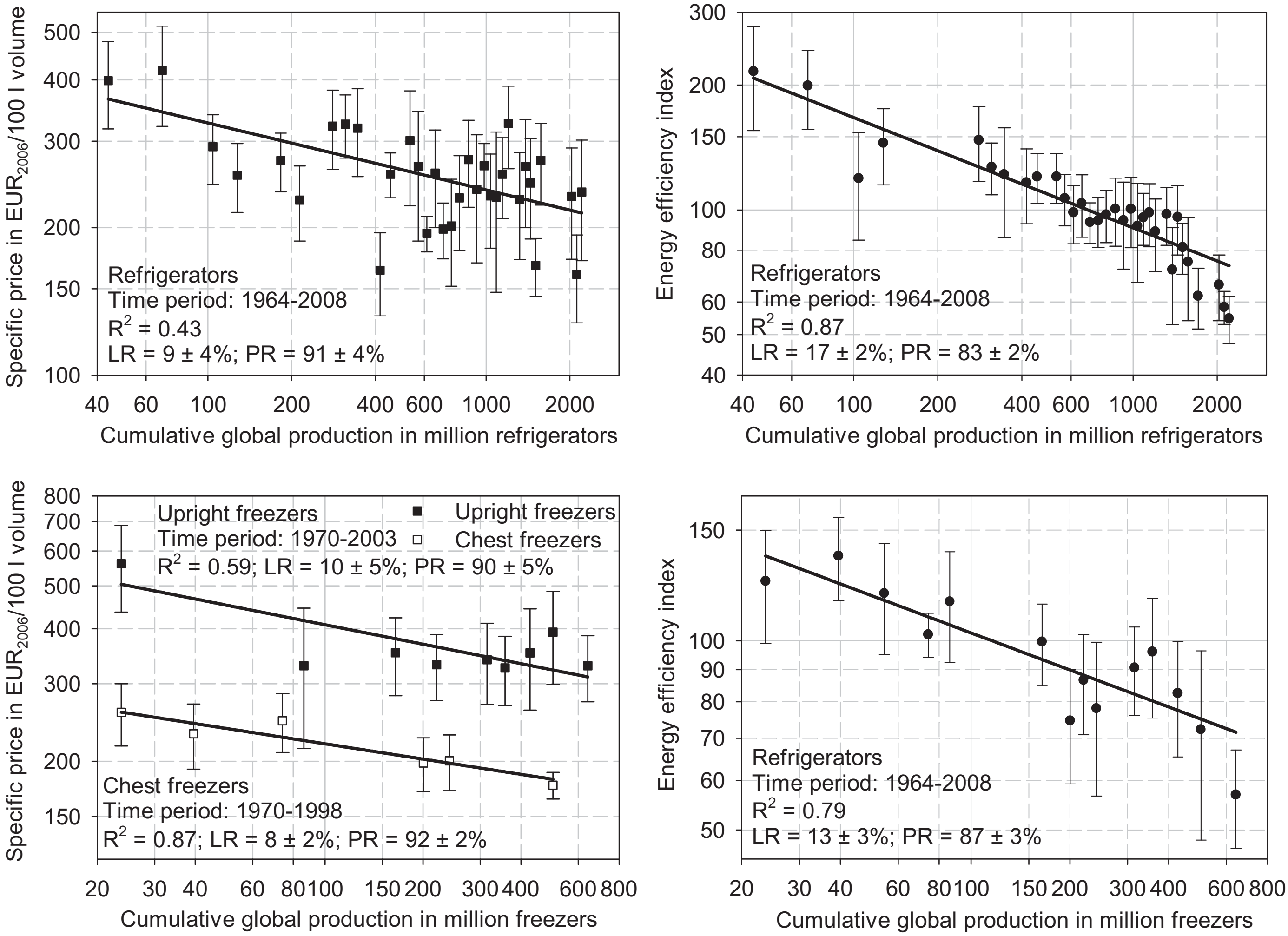

Fig. 2. Experience curves for specific prices (left column) and specific energy consumption (right column) of cold appliances; error bars indicate the standard deviation of data points; error intervals represent the 95% confidence intervals of learning rates and progress ratios based on the implicit error of the regression analysis).

(vii) technological improvements in other areas of the economy (e.g., information technology, material sciences, mechanical engineering).

During past decades, components of large appliances have been continuously improved (e.g., introduction of direct drive motors in washing machines and variable speed-drive compressors in cold appliances). Furthermore, wet appliances experienced the introduction of additional product functions (e.g., centrifuge drying, large variety of washing programs). This has been only to a minor extent the case for cold appliances (e.g., introduction of automatic defrosting function, ice cube production, or water dispensing). Such functionality improvements potentially increase production costs of large household appliances (see discussion in Section 4.2).

Our results show that the specific prices of wet appliances decline faster than the ones of cold appliances, both as a function of time and cumulative production. Changes in product functionality can therefore not explain the relatively high learning rates for wet appliances in comparison to the relatively low learning rates for cold appliances. The differences in the learning rates for wet and cold appliances might, however, be explained by three factors (Siderius, 2008; Kemna, 2009):

(i) Wet appliances are typically composed of more individual components than cold appliances. This enables higher cost reduction potentials through outsourcing of component and sub-assembly manufacturing to low-wage regions like China.
(ii) Due to the large number of components, assembling of wet appliances and their components was relatively labor intensive and time intensive in the 1960s and 1970s. Prices of wet appliances thus profited over-proportionally from increased automation.
(iii) The EU energy label was updated in 2003 for cold appliances but not for wet appliances. More stringent energy efficiency labeling might have incurred adverse short-term price effects for cold appliances thus leading to a slower price decline in most recent years (see Fig. 2).

Declining markups in the wholesale and retail sector have been realized by (Ecocold, 2007a, b; Dale et al., 2009):

(i) cost reductions due to increases in productivity, economies of scale, decreasing on-site stocks and thus storage costs;
(ii) increasing market shares of retail chains at the expense of small local retailers[10]; thus
(iii) enhanced market competition that lead to declining profit margins.

[10] In Europe, the market share of the five largest retailers rose from 12% in 1990 to 30% in 2005 (Ecocold, 2007a).

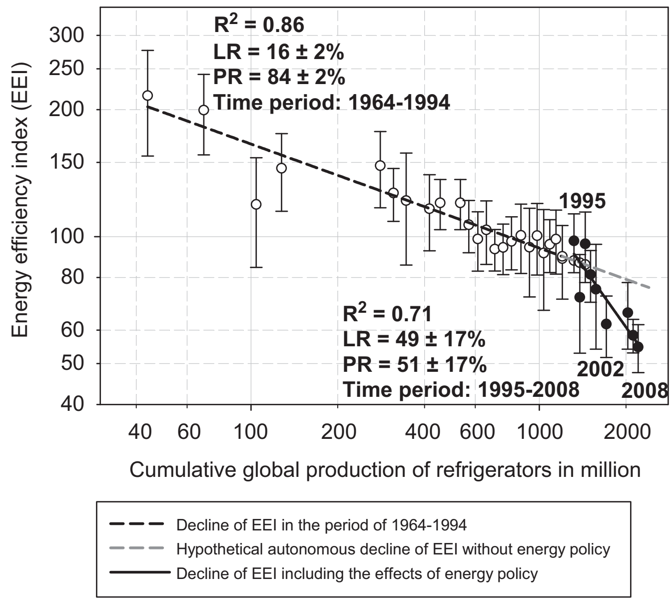

Fig. 3. Potential effect of energy policy on the decline of EEI of refrigerators; numbers attached to the error bars indicate the year of analysis.

Increasing competition in recent years supported, however, trends towards market concentration in all price segments, which might induce adverse price effects in the future (Ecowet, 2007a).

We now focus on the decline of specific energy consumption. Technological changes that lead to an increase of energy efficiency in the past include (Ecocold, 2007e; Ecowet, 2007b; Siderius, 2008; Kemna, 2009):

(i) improving insulation by increased wall thickness and introducing new insulation materials (e.g., replacing polystyrene by polyurethane foams), improving compressor technology, increasing the size of condensers, improving refrigerants, heat exchangers, control electronics as well as internal temperature distribution by fans leading to an optimization of the cooling system in the case of cold appliances;
(ii) reducing water consumption (e.g., by introducing the jet-system around 1985 for laundry spraying instead of bathing, centrifuge drying between washing cycles, and improving tub shape in washing machines), internal heat recovery (dishwashers), as well as progress in other areas of manufacturing (i.e., improvement of detergent quality) in the case of wet appliances[11];
(iii) improving heat exchangers, water vapour condensation, ventilation, and tumbling of laundry in laundry dryers.

So far, we have been focusing on the dynamics of specific energy consumption of large appliances in the past three to four decades. However, if we compare the last data points in Figs. 1 and 2 with data for earlier years, we might observe an accelerated decline of specific energy consumption for refrigerators and partly also for dishwashers and freezers in recent years. This observation might be attributed to the combined effect of in principle three energy policy measures, i.e., the implementation of the European energy labeling (EU, 1992), the European minimum energy performance standards for cold appliances (EU, 1996), and the Dutch energy premium regulation (SenterNovem, 2000). In addition, the introduction of the European eco-design directive (EU, 2005) might have facilitated to some extent energy efficiency improvements of large appliances in most recent years. To obtain a more detailed insight into energy efficiency dynamics, we devise two separate sets of energy experience curves: one covering the period before the introduction of energy policies in the Netherlands and one covering the period afterward (Fig. 3[12]; Table 2).[13] Our results indicate at first sight that learning rates for the specific energy consumption for all wet and cold appliances are higher in the period of enforced energy policy than in the period before. However, the error intervals indicate that differences are only significant in the case of dishwashers, refrigerators and freezers. Our findings nevertheless suggest that energy policy was to some extent able to accelerate energy efficiency improvements by bending down the slope of *energy* experience curves (Fig. 3).

In the case of dishwashers and refrigerators, our data point to another interesting phenomenon. Between the years 2003 and 2004 (dishwashers, see last three data points in Fig. 1) as well as between 1999 and 2000 (refrigerators, see Figs. 2 and 3), we find a relatively substantial decrease of specific energy consumption. In the years afterward, however, the decline of specific energy consumption has been far less pronounced (Figs. 1–3). This

[11] The relatively high learning rates for specific water consumption (Fig. 1) indicate an over-proportional decline in the specific consumption of non-heated rinsing water. These water savings were to some extent achieved by technological innovations as explained above but also by simply reducing the number of cold-water rinsing cycles within the entire washing cycle.

[12] The relatively low-energy efficiency index of refrigerators in the year 2002 suggests bias in the dataset presented by Consumentenbond (1964–2008) for this particular year. Both, Consumentenbond (2009) and a comparison of data from Consumentenbond (1964–2008) with results of a market analysis by Ecocold (2007d) indicate that efficient label-A refrigerators are indeed slightly over-represented in the data set of Consumentenbond (1964–2008) for this particular year.

[13] We use here the year in which energy labeling was introduced in the Netherlands to discriminate the time periods with and without energy policy. We assume that energy labels were introduced in the Netherlands in 1995 for refrigerators and freezers, in 1996 for washing machines and laundry dryers, and in 1999 for dishwashers (Luttmer, 2006). We justify this choice because it probably captures best the effect of policy measures on the energy efficiency of large appliances in the Netherlands. Other relevant policy measures were introduced around the same time or later: minimum energy performance standards for cold appliances were introduced in 1996 and the Dutch energy premium regulation was enforced in 2000.

Table 2
Energy learning rates for large household appliances before and after the introduction of energy policy; in parenthese coefficient of determination (R^2).

Appliance	Time period prior to the introduction of the energy policy	LR in % (R^2)	Time period after the introduction of energy policy	LR in % (R^2)
Washing machines	1964–1995	36 ± 5 (0.87)	1996–2008	39 ± 11 (0.79)
Laundry dryers	1969–1995	18 ± 10 (0.68)	1996–2003	36 ± 37 (0.66)
Dishwashers	1968–1998	15 ± 4 (0.85)	1997–2007	33 ± 12 (0.82)
Refrigerators	1964–1994	17 ± 2 (0.86)	1995–2008	49 ± 17 (0.71)
Freezers	1970–1994	11 ± 4 (0.72)	1995–2003	47 ± 3 (1.00)

finding might be explained by a rapid shift of the appliance market towards efficient label-A washing machines, dishwashers, and refrigerators shortly after energy policies (e.g., energy labeling, energy premium regulation) became effective (Luttmer, 2006; Ecocold, 2007b, d). As soon as manufacturers reached compliance with labeling standards, the rate at which additional efficiency improvements were realized seems to have declined again.[14] Caution is, however, necessary because the number of data points of our analysis is limited. It is therefore too early to draw firm conclusions on these issues.

4. Discussion

We start out with discussing the strengths and weaknesses of our methodology. Afterward, we discuss justification, opportunities, and limits for the applicability of the experience curve approach to specific energy consumption. In the last part of this section, we compare our findings to results from literature and we focus on implications of our results for effective energy policy.

4.1. Discussion of methodology

As for any empirical analysis, the reliability of our results depends on the applied methodology and on the quality of emperical data. We regard both as reliable, although they are subject to several uncertainties. The strength of the experience curve approach compared to simple time-series analysis refers to its ability to relate the dynamics of specific prices and specific energy consumption directly to the cumulative experience in manufacturing. With our experience curve analysis, we extend existing analyses (i) by covering long time periods until most recent years[15] and (ii) by providing uncertainty intervals of empirical data and estimated learning rates. Our analysis thus contributes to a more reliable and transparent quantification of price and efficiency dynamics of large appliances and can thus be used to improve the quality of energy and CO_2 (carbon dioxide) emission scenarios.

Uncertainties refer in first instance to the reliability of the experience curve approach for quantifying price and efficiency dynamics of technologies. Price experience curves provide reliable results, if (i) prices reliably approximate actual production costs and (ii) if the observed price dynamics are predominantly driven by growing experience in manufacturing, i.e., a decline in the *quantities* of production factors used for manufacturing.

Addressing the first point, we argue that the approximation of actual production costs by market prices is accepted practice in experience curve analyses because data on actual production costs are generally kept confidential by producers (see, e.g., Junginger et al., 2008). However, such approximation is only valid for competitive markets, where sales prices closely follow production costs (BCG, 1972). This is in general the case for large appliances, for which markets are traditionally characterized by low yet declining profit margins (Ecocold, 2007a).[16]

Addressing the second point, the experience curve phenomenon applies strictly speaking only to the cost of value added (Sallenave, 1985); more specifically to thus to changes in costs that are related to changes in the quantity of production factors used for manufacturing. Parts of the observed price dynamics are, however, not attributed to changes in the *quantity* of production factors used in manufacturing but to changes in the *price* of production factors. Examples are declining labor costs due to outsourcing of production to low-wage regions, or changes in the price of energy and materials. Changes in the price of production factors are often exogenous of the learning system and can hardly be influenced by technological learning. Variability in the price of production factors might hence lead to singular changes of production costs that might not be repeatable or could even be reversed in the future.

Uncertainties relate also to changes in the functionality of large appliances. In principle, we do not analyze with our experience curve approach a product or a technology but a service, provided by large household appliances to consumers (i.e., the cleaning of 1 kg laundry or the preserving of fresh food for a defined time period). In past decades, especially the functionality of wet appliances has been improving substantially. Adding functionality (such as the introduction of centrifuge drying and various washing programs to washing machines) potentially increases in first instance the specific price of appliances. Correcting for improved functionality would hence very likely lead to even higher learning rates for especially wet appliances than the ones found in Fig. 1. However, measuring and quantifying increasing functionality as a single parameter is rather difficult and would go beyond the scope of this research.

Uncertainties also result from the data used for our experience curve analysis. Consumentenbond (1964–2008) pre-selects large household appliances (i.e., according to price, efficiency, functionality, or other more subjective criteria). Their datasets are therefore not always representative for the whole Dutch appliance market. We nevertheless argue that using data from Consumentenbond (1964–2008) only introduces a random error into our

[14] In line with this reasoning, we find that the specific energy consumption of refrigerators continues to decline while the specific energy consumption of washing machines and dishwashers remains relatively constant after label-A products reached market saturation. This observation might be attributed to the introduction of additional and more stringent label-A+ and label-A++ categories for refrigerators in 2003 (EU, 2003).

[15] The variability of learning rates identified for different time periods (e.g., Bass, 1980; see Fig. 5 in Section 4.3) indicates that such extensions are important to improve the reliability of product-specific learning rates.

[16] Ecocold (2007c) finds price differences of up to 41% for refrigerators sold in Western and Eastern European countries. This observation indicates that pricing policy of producers might indeed present a source of uncertainty for the results of our experience curve analysis.

analysis, which is unlikely to affect the robust average price and efficiency trends identified for relatively long time periods. The situation is however different for our analysis presented in Table 2. Here, pre-selection of data with regard to appliances of specific price or efficiency categories might affect our experience curve results for the relatively short time period after the introduction of energy policies and introduces therefore uncertainty into this part of our analysis. Including additional data from other European countries could potentially ameliorate this problem; such additional data collection was, however, outside the resources for this research.

Our estimates for cumulative global appliance production are subject to uncertainties because we had to use interpolation and extrapolation to fill data gaps. This introduces an explicit error into our analysis that is excluded from the error intervals displayed in Figs. 1–3. In the case of dishwashers and freezers, for which data availability was relatively poor, we perform a sensitivity analysis. This sensitivity analysis indicates that our estimates on cumulative global dishwasher and freezer production introduce an additional uncertainty of 3–5% percent points to the error intervals quantified for dishwashers and freezers in Figs. 1 and 2.

4.2. *Justification for the applicability of the experience curve approach to specific energy consumption*

Extending the conventional experience curve approach to the specific energy consumption of large household appliances is new and was not made in this form before. We think that our methodological extension is generally valid and that it offers new insights into the dynamics of energy efficiency improvements in energy demand technologies. In this section, we want to provide a broader justification for our approach. We start out with Ramirez and Worrell (2006), who modeled the specific energy consumption for ammonia and urea production with the experience curve approach. They argue that the experience curve approach is applicable to their case because (i) energy-related costs account for a large part (i.e., more than 70%) of total production costs and (ii) production costs decline at a constant rate with each doubling of cumulative production. Reducing the specific energy consumption of chemical processes is thus a constant point of attention for chemicals manufacturers. It is however less obvious, why improving the energy efficiency of large household appliances should be a constant point of attention for manufacturers of appliances, too. One explanation might be that energy efficiency improvements follow autonomously technological innovation. In addition to these autonomous energy efficiency improvements, further energy efficiency potentials might be realized by producers in their quest for decreasing production costs (e.g., improving insulation of cold appliances, might allow for smaller compressors, improving the tub shape of washing machines might reduce water consumption and thus material demand for pipes and pumps). As a consequence, energy efficiency improvements and declining production costs may go hand in hand at the system's level. Caution is however required because autonomous energy efficiency improvements might be partially reversed, if product functionality requires so.[17]

Next to these autonomous and cost-driven energy efficiency improvements, appliance manufacturers might have experienced only little incentives in the past to improve the energy efficiency of their products. Consumers are likely to have chosen large appliances in the 1960s until the early 1990s based on information on *primary product functions* such as cleaning capacity, storage volume of cold appliances, design, formats, and price because information on these parameters were more openly available than information on energy consumption and use-phase costs. Without adequate product labeling, it is reasonable to assume that consumer awareness for energy consumption and energy-related costs was relatively low for many decades.[18]

The introduction of minimum energy performance standards for cold appliances (EU, 1996) but more importantly energy labeling of household appliances (EU, 1992) made energy efficiency a product feature. This development was successfully supported in the Netherlands by the introduction of the energy premium regulation (EPR) in the year 2000, which granted subsidies to consumers who bought efficient household appliances. Energy efficiency improvements in most recent years might have been further facilitated by the introduction of the European eco-design directive, which defines conditions and criteria for setting coherent EU-wide requirements regarding environmentally relevant product characteristics (EU, 2005). The combined effect of these policy measures increased the market elasticity with regard to the energy efficiency of large household appliances and provided incentives for producers to increase the energy efficiency of their products (Ecowet, 2007a). The accelerated decline in the specific energy consumption of cold appliances and dishwashers during the period of enforced energy policy (see, e.g., Fig. 3 and Table 2) indicates the potential policy impact on the energy efficiency of large household appliances. Today, specific energy consumption of wet and cold appliances is an important criterion for consumers when purchasing large household appliances (Ecowet, 2007a). Producers are hence forced to improve the energy efficiency of their products in a similar way that they aim at reducing production costs.

Based on these considerations, we argue that it is valid to model specific energy consumption with the experience curve approach for recent and also future years. The results of the experience curve analysis are, however, subject to greater uncertainties in the more distant past (e.g., before the enforcement of energy policy in the early 1990s). We argue that modeling energy efficiency dynamics of energy demand technologies with the experience curve approach is useful for future scenario projections because it analyzes in specific energy consumption more closely to actual production than simple time-series analyses.

4.3. *Discussion of results*

Our findings indicate a systematic decline in both specific prices and specific energy consumption of large appliances. Literature data on yearly price and efficiency changes confirm this trend for many countries and regions. Yearly rates of decline in prices and specific energy consumption show, however, relatively large variation (e.g., Dale et al., 2002; Bertoldi and Atanasiu, 2007; Ellis et al., 2007; see Table A1 in Appendix). Unlike our findings, data from literature do not indicate systematic differences between the rates of yearly price decline

[17] One example is the recent improvement of light chromaticity at the expenses of bulb efficacy in the case of compact fluorescent light bulbs (PL, 2007).

[18] Consumers buy large appliances far less frequently than other goods. They hence often lack knowledge and base their decisions upon advice provided by sales personnel or product labels. Forsa (2004) found that 70% of German consumers receive and follow advice from sales personal prior to purchasing a new appliance.

for wet and cold appliances. The data variation observed in Table A1 in Appendix might be to some extent explained by the following factors:

(i) The average yearly changes in price and energy consumption are often calculated in literature based on data for the base year and the final year of the analysis rather than based on regression analysis. Due to relatively high price variability in individual years, the former approach might especially lead to extreme results, if the analyzed time periods are short (e.g., see Table A1 in Appendix; price decline of refrigerators in Japan at yearly rates of 15% in the period of 2001–2005).
(ii) The use of absolute prices and energy consumption that disregard changes in the size and capacity of large appliances (we corrected for these changes by calculating specific prices and specific energy consumption, whereas most studies did not).

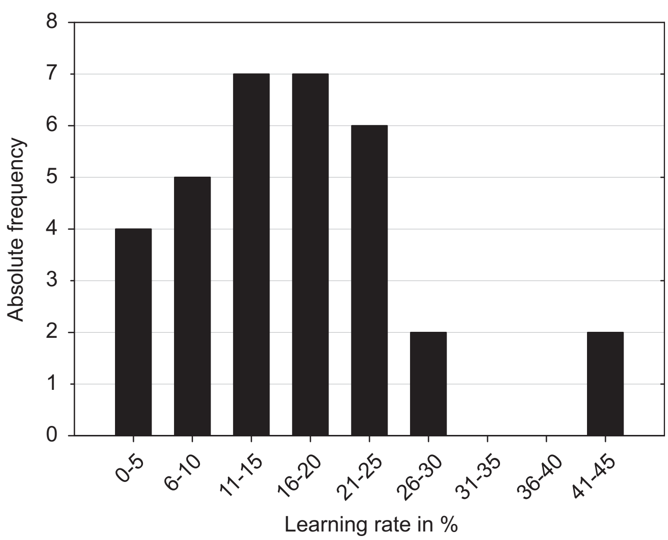

Fig. 4. Frequency histogram of learning rates for prices of various energy demand technologies; including air conditioners, building insulation, color and black-white televisions, compact fluorescent light bulbs, gas boilers, heat pumps, lamb ballasts, laser diodes, water heaters, and window coatings; n=33 (data sources: Junginger et al., 2008; Weiss et al., 2008).

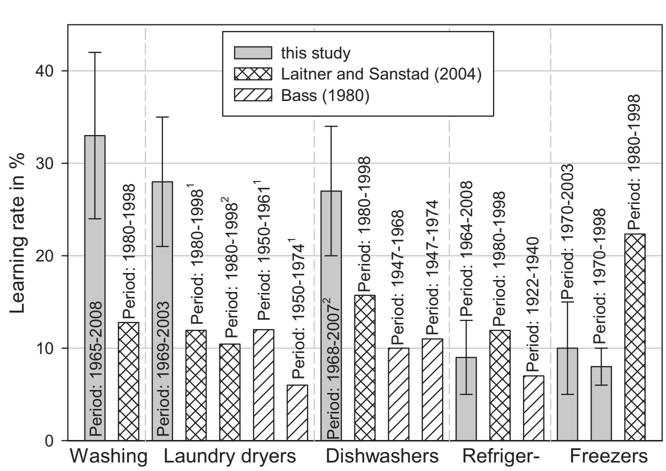

Fig. 5. Comparison of experience curve results ([1]electric laundry dryers; [2]gas laundry dryers).

(iii) International differences in market characteristics, governmental taxation policies, or product pricing of producers and retailers.

In comparison to the results of time-series analysis presented in Table A1 (see Appendix), our experience curve analysis eliminates changes in yearly market sales and production volumes as explanatory variable for price and efficiency changes. The estimated learning rates, hence, allow policy makers and energy modelers to arrive at more detailed and reliable estimates for the future price and energy dynamics of large appliances. The price trend identified by our experience curve analysis is in line with literature findings for a larger group of energy demand technologies.

We find our estimates for cold appliances near the peak and our estimates for wet appliances relatively far right of the peak in the frequency histogram of learning rates (Fig. 4). Furthermore, the experience curve analyses on household appliances as presented by Bass (1980) and Laitner et al. (2004) confirm the general trend indicated by our findings (Fig. 5). However, with the exception of freezers, our learning rates generally exceed the ones published in literature (Fig. 5).

Due to lack of detailed insight, we can only semi-quantitatively explain parts of the deviations observed in Fig. 5. The systematic differences between our estimates and the ones of Laitner et al. (2004) for wet appliances are to a large extent caused by the incomplete accounting of cumulative production in the latter publication. Laitner et al. (2004) use the year 1980 as base year of their analysis but do not account for production of appliances in earlier years. This leads firstly to a substantial underestimation of cumulative production in the base year of their analysis and thus secondly to an overestimation of doublings of cumulative production in the time period analyzed. Laitner et al. (2004) therefore substantially underestimate price learning rates. Recalculating the learning rates as identified by Laitner et al. (2004) by using our estimates for cumulative production yields substantially higher learning rates of 46% for washing machines, 31% for refrigerators, and 37% for freezers. Applying data corrections decreases the differences between the learning rates for wet appliances, whereas the differences for cold appliances become even larger. Similar methodological inconsistencies might also explain deviations between our estimates and the ones of Bass (1980).

The remaining deviations might be explained by differences regarding the time period analyzed. By recalculating our estimates for the same time period as analyzed by Laitner et al. (2004), i.e., 1980–1998, we identify learning rates, which are generally lower and which are subject to substantially higher uncertainty intervals than our previous estimates presented in Figs. 1 and 2. Further explanations for differences might include the calculation of learning rates by Laitner et al. (2004) based on price differences between base year and final year of analysis (rather than based on regression analysis) and in the case of freezers the combining of upright and chest freezers into one freezer category.[19]

Despite considerable energy efficiency improvements in the past decade, our data do not indicate adverse effects on the price of large household appliances. This finding is in line with worldwide trends for large household appliances as found

[19] Such an approach is particularly problematic because upright freezers are considerably more expensive that chest freezers. Changes in the contribution of price data for upright and chest freezers to the average freezer price can have a substantial effect on the calculated learning rate.

in literature (Ellis et al., 2007; Bertoldi and Atanasiu, 2007; Dale et al., 2009). Not only did absolute prices of large household appliances decline, Dale et al. (2009) also found evidence that the average incremental price for energy efficiency improvements in refrigerators and air conditioners declined as well. This finding indicates that, in general, still considerable and low-cost potentials for future energy efficiency improvements exist.

For utilizing these potentials, effective energy policy will be crucial. Our results demonstrate that energy policy might be able to bend down the slope of energy experience curves thereby accelerating energy efficiency improvements of large appliances. Such a finding is remarkable because literature on *price* and *cost* experience curves provides so far no indication that governmental policy can bend down the slope of cost experience curves (Junginger et al., 2008). We therefore argue that governmental policy might have larger potentials to accelerate *energy efficiency* improvements than to accelerate the decline of *production costs* or retail prices of energy demand technologies. However, caution is required because so far policies with an explicit focus on cost reduction have been rare.

The effectiveness of policy instruments like energy labels depends in particular on their ability to sufficiently differentiate products of low and high energy efficiency. To satisfy this requirement, energy labeling schemes need to be continuously monitored and updated (Ellis et al., 2007; EU, 2003). Updates of energy labels were introduced for cold appliances (EU, 2003) but not for wet appliances for which the market nowadays consists almost entirely of most efficient label-A appliances. Currently the EU is, however, updating energy labels and efficiency standards for large appliances in general. In this respect, it is important to note that in the case of washing machines and dishwashers, additional efficiency potentials at current test conditions might be relatively limited. However, substantial energy savings can be realized, e.g., due to novel enzyme detergents or ozone treatment of the wash liquor that allow for a decrease in washing temperatures (Ecowet, 2007b).

The extent to which novel and energy-efficient appliances enter the market depends often on their price. Our results show that technological learning offers substantial potentials for cost decline of large appliances. It is hence likely that novel and initially expensive components of large appliances become substantially cheaper after short time periods. Policy makers can thus expect that support of promising but initially expensive energy technologies might result in both declining consumer costs and improved energy efficiency. The case of heat pump laundry dryers illustrates these dynamics: by 2005, heat pump laundry dryers were newly introduced to the market at prices roughly 650 EUR higher than the ones for conventional condensing laundry dryers (Barthel et al., 2005). Assuming now that heat pump laundry dryers would have been forced into the market and the additional costs for the heat pump and its integration into the dryer system decline at similar learning rates than the prices of laundry dryers (i.e., $28 \pm 7\%$, see Fig. 1), the price difference between the two competing dryer technologies would have decreased to 30–130 EUR by 2009.[20] On the Dutch market, heat pump laundry dryers are currently 100–300 EUR more expensive than conventional devices (Kieskeurig, 2009). The example of heat pump laundry dryers shows that novel and efficient technologies offer substantial potentials for cost reduction because low initial market sales enable substantial growth of cumulative production within short time periods. Here, governmental policies can support the market uptake of novel and efficient appliances, thereby contributing to a rapid and substantial decline of consumer investment costs. However, policy makers need to be cautious because next to market prices other factors such as product features, consumer convenience, as well as education and awareness of consumers and sales personnel are as well critical factors for the market success of novel and efficient energy demand technologies (see, e.g., Brezet, 1994).

[20] For heat pump laundry dryers, we assume here market shares of 0.3% in 2005 and 5% in 2010 (based on European market shares and conservative estimates for future market potentials; see Bush and Nipkow, 2006). If the market for heat pump laundry dryers grows faster than assumed, the additional price will decline even more rapidly.

5. Conclusions

In this article, we construct experience curves for the specific price and the specific energy consumption of wet and cold appliances. We regard the experience curve approach as applicable and as useful for analyzing long-term price and efficiency dynamics of large appliances. For the past three to four decades, we identify a trend towards a continuous decline in specific prices, albeit with differentiation for wet and cold appliances. Our analysis suggests that technological learning is a powerful mechanism in forcing the decline of prices and production costs of large appliances. We hence argue that introducing novel and initially expensive energy efficiency technologies does not need to cause permanent and substantial adverse effects on the prices of large appliances. The example of heat pump laundry dryers shows, how experience curve analysis can supplement bottom-up *ex-ante* engineering analyses by providing more reliable forecasts on future technology costs.

Applying the experience curve analyses to the specific energy consumption of large appliances is new and reveals useful insights into the dynamics of energy efficiency improvements. Similar to the rates of price decline, we find that wet appliances show higher learning rates with respect to specific energy consumption than cold appliances. Our results suggest that energy policy might be able to bend down the slope of *energy* experience curves, thereby accelerating the decline in specific energy consumption. This finding highlights the importance of energy policy for energy efficiency improvements of large household appliances as well as of other energy demand technologies.

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Appendix

Yearly rates of decline in prices and specific energy consumption of large appliances are shown in Table A1.

Table A1
Literature overview: yearly changes in price and specific energy consumption of large appliances.

Appliance	Source	Country	Time period	Yearly change in %	
				Price	SEC[a]
Washing machines	This study	NL	1965–2008	−2.4	−2.5
	Bertoldi and Atanasiu (2007)	EU-15	1996–2004	–	−3.3
	CECED (2003)[b]	EU	1994–2002	–	−4.5
	Dale et al. (2002)	USA	1983–2001	−2.4	−0.9
	EES (2006)	AUS	1993–2005	−2.6	−1.3
	Laitner et al. (2004)	USA	1980–1998	−3.4	–
	Waide (2001)[c]	EU-15	1996–1998	–	−2.5
Laundry dryers	This study	NL	1969–2003	−2.1	−1.5
	Bass (1980)[d]	USA	1950–1961	−2.3	–
	Bass (1980)[d]	USA	1950–1974	−2.2	–
	EES (2006)	AUS	1993–2005	−1.1	−0.7
	Laitner et al. (2004)[d]	USA	1980–1998	−3.2	–
	Laitner et al. (2004)[e]	USA	1980–1998	−2.9	–
Dishwashers	This study	NL	1968–2007	−3.8	−2.3
	Bass (1980)	USA	1947–1968	−2.0	–
	Bass (1980)	USA	1947–1974	−2.0	–
	Ennen (2006)[b,f]	EU	1998–2004	–	−5.1
	Ennen (2006)[b,g]	EU	1998–2004	–	−6.0
Refrigerators	This study	NL	1964–2008	−1.2	−2.4
	Bass (1980)	USA	1922–1940	−2.6	
	Bertoldi and Atanasiu (2007)[c]	EU-15	1993–2005	–	−4.3
	Bertoldi and Atanasiu (2007)[b]	EU	1993–2004	–	−4.5
	CECED (2004)[b,h]	EU	1999–2003	–	−3.5
	Dahlman (2007)	AUS	1993–2005	–	−3.9
	Dale et al. (2002)	USA	1980–2001	−2.5	−4.6
	EES (2006)	AUS	1993–2005	−1.7	−4.6
	ECCJ (2006)	JPN	2001–2005	−15.1	−5.1
	Laitner et al. (2004)	USA	1980–1998	−3.2	–
	Schiellerup (2002)	UK	1992–1999	−6.3	−3.9
	Schiellerup (2002)[i]	UK	1992–2000	–	−3.4
	Waide (2001)[c,j]	EU-15	1994–1998	–	−2.3
Freezers	This study[k]	NL	1970–2003	−1.5	−1.9
	This study[l]	NL	1970–2003	−1.1	
	EES (2006)	AUS	1993–2005	−2.5	−3.3
	Laitner et al. (2004)	USA	1980–1998	−5.3	–
	Schiellerup (2002)[k]	UK	1992–1999	−5.1	−3.1
	Schiellerup (2002)[l]	UK	1992–1999	−5.0	−5.6

Abbreviations: AUS—Australia; EU—Europe; EU-15—15 member countries of the European Union; JPN—Japan; NL—The Netherlands; UK—United Kingdom; USA—United States of America.

[a] SEC—specific energy consumption.
[b] Including member countries of CECED (European Committee for Domestic Equipment Manufacturers).
[c] Sales weighted averages.
[d] Electric laundry dryers.
[e] Gas laundry dryers.
[f] Referring to dishwashers with a capacity of 12 standard place settings.
[g] Referring to dishwashers with a capacity of 9 standard place settings.
[h] Total of cold appliances.
[i] Refrigerator–freezer combinations.
[j] Covering the total of cold appliances.
[k] Upright freezers.
[l] Chest freezers.

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