# Online Appendices

# Dynamics of Expenditures on Durable Goods: the Role of New-Product Quality

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## A Data and Measurement

In this appendix, we describe our procedure for merging the Dominion dataset and the IHS dataset and explain our definitions of vehicle models.

### A.1 Merging Dominion and IHS Datasets

For each transaction in the Dominion dataset, we observe a string for make name—e.g., "TOYT" for Toyota—and a string for model name—e.g., "Camry"—as well as the corresponding model-year, which may or may not correspond with the calendar year in which the transaction takes place because new models marketed as model-year $t$ are often introduced in year $t-1$.

For each vehicle model in the IHS dataset, we observe a string for make name—e.g., "Toyota"—and a string for model name—e.g., "Toyota Camry"—as well as a variable named generation-year, which allows us to identify different generations of a same model—e.g., first generation, second generation, etc. Moreover, we also observe the total number of US transactions by calendar year.

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1. In the Dominion dataset we identify all strings corresponding to make and model names.

2. We perform the same step, identifying make and model names in the IHS dataset.

3. For all make-model names in the Dominion dataset (point 1), we find a single corresponding make-model name in the IHS dataset (point 2). Whenever we do not find a match for the make-model name (approximately 19% of cases), we assign as model name the combination of make name and the first word of the model string from the Dominion dataset.

4. For each make-model name in the Dominion dataset, we identify the corresponding set of model-years for which we observe a positive number of transactions. For example, in the case of the Toyota Camry, these model-years are 2003, 2004, ..., 2013.

5. For each make-model-generation in the IHS dataset, we identify the first model-year with a positive number of transactions in the IHS dataset. If the first year with a positive number of transactions of a make-model-generation is year $t$, we infer that the first model-year for that make-model-generation is year $t + 1$, to account for the fact that vehicles marketed as model-year $t$ are typically first introduced in the market in year $t - 1$.

6. We merge the dataset of Dominion make-model-years (point 4) with the Dominion-IHS matched list of make-model names (point 3).

7. We assign each make-model-year from the Dominion dataset (point 6) to the corresponding make-model-generation (point 5) as follows: Toyota Camry model-years 2007-2011 are assigned to the generation-year 2007 and Toyota Camry model-years 2012 through 2013 are assigned to generation-year 2012.

## A.2 Model Definitions

We define a vehicle model as a triplet of make, model, and generation obtained following the merging procedure described above—e.g., Toyota Camry generation-year 2007.

We define a new model in year $t$ as a model for which we observe the first transaction in year $t$ or in year $t-1$, to account for the fact that the first transaction on a new model tends to appear in the second half of the year. Specifically, this implies that we consider a model as new whenever its model year in the Dominion dataset corresponds with its generation year, and possibly also whenever we observe a transaction for this model that occurs in a calendar year preceding its model year. Thus, this definition includes new model names as the first generation of a model, as well as new generations of existing model names. We exclude 2004 from our analysis of new models because this is the first year in the Dominion dataset, and thus we cannot cleanly identify new models.

We should point out that because we observe transaction prices at the model level in the Dominion dataset and, thus, we merge information from the Dominion dataset and the IHS dataset at the model level, there remains some residual heterogeneity in vehicle characteristics across different trims of each model in the IHS dataset. To deal with this heterogeneity, in our analyses of car characteristics in Sections 3.3 and 3.4, we average all continuous car characteristics across different trims of each model using their respective transaction shares in the IHS dataset, whereas we treat vehicles with different values of discrete characteristics—such as diesel, or turbo injection—as different models. In Appendix B we consider an alternative approach, aggregating both continuous and discrete characteristics at the model level using their transaction shares. As Figures B12 and B13 show, our main findings are robust to this alternative approach, suggesting that the level of aggregation of car characteristics, as well as the exact number of models, do not affect our results.

# B Additional Empirical Evidence

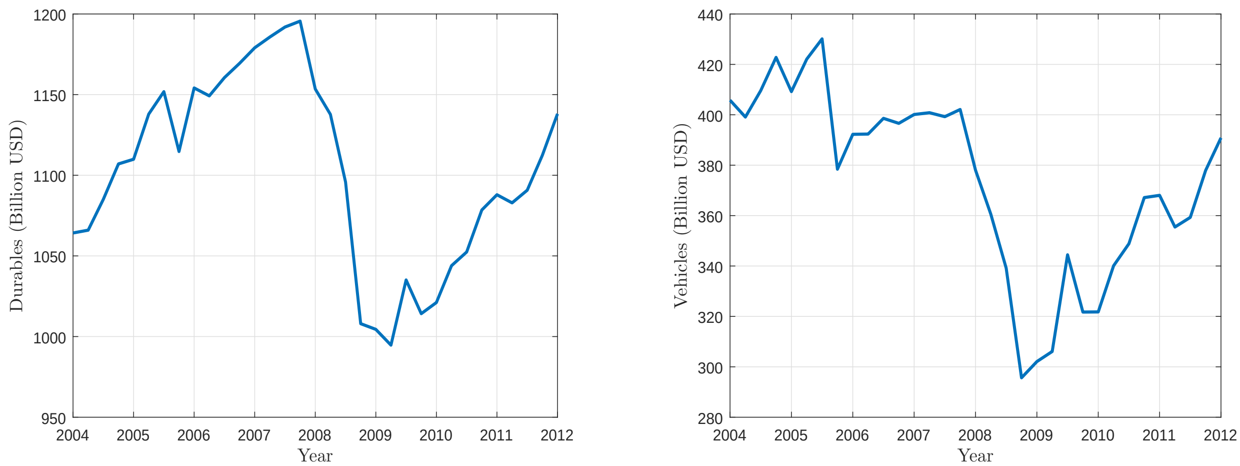
In this appendix, we provide additional empirical evidence and document several robustness checks.

## B.1 Dynamics of the Distribution of Expenditures

Figure B1 displays aggregate consumer expenditures on durable goods (left panel) and on vehicles (right panel) during 2004-2012 (US Bureau of Economic Analysis, 2022) and shows the large drop in these components of household expenditures during the Great Recession.

During July and August of 2009, the Car Allowance Rebate System, commonly known as "Cash for clunkers," subsidized the replacement of highly polluting cars with new ones, potentially affecting the pool of new-car buyers (Hoekstra, Puller, and West, 2017). Figure B2 reproduces the findings displayed in Figure 1, but excluding the months of July and August in each year to show that the patterns of the distribution of expenditures on new vehicles are not significantly affected by the Cars Allowance Rebate System. Figure B3

Figure B1: Consumer Expenditures on Durable Goods and on Motor Vehicles




(a) Durables (b) Vehicles

*Notes:* The figure displays personal consumption expenditures on durable goods (left panel) and on motor vehicles and parts (right panel), at quarterly frequency, seasonally adjusted annual rate, from the Bureau of Economic Analysis during 2004-2012.

displays the same variables, but excludes fleet sales—which account for approximately 4.4% of transactions—to show that our main findings are unchanged if we restrict attention to consumer sales only.

## B.2 Decomposing the Dispersion of Expenditures

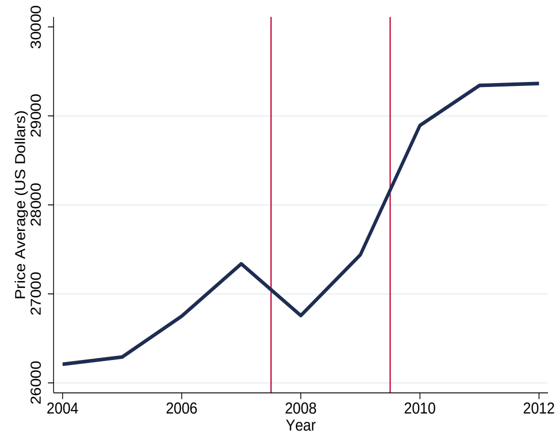
Figures B4 and B5 reproduce the findings displayed in Figure 2 under the same two robustness checks described above: namely, removing July and August to exclude the effects of "Cash for clunkers" and removing fleet sales, respectively.

Figure B6 portrays the path of the average transaction price for ten popular models. Specifically, we select the five models with the highest sales volume with price below the overall sample median, and the five models with highest sales volume with price above the median. For all of these models, the figure shows that prices did not significantly deviate from trend during the Great Recession. This confirms that reallocation between models, instead of price changes at the model level, account for changes in the distribution of expenditures during the recession. Consistent with this evidence, Gavazza and Lanteri (2021) show that price changes during the Great Recession were concentrated in used-car markets.

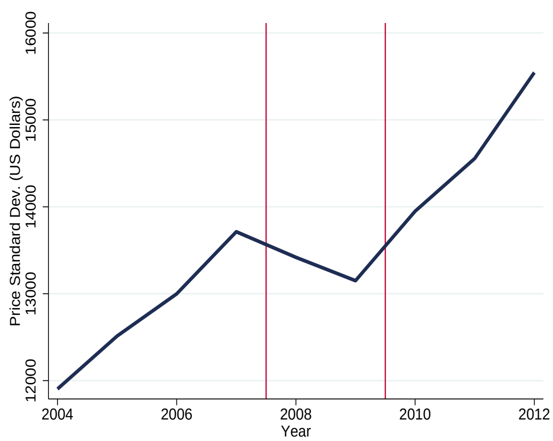
We further verify that a reallocation of market shares across different models accounts

Figure B2: Dynamics of New-Vehicle Expenditures, Excluding July and August of Each Year

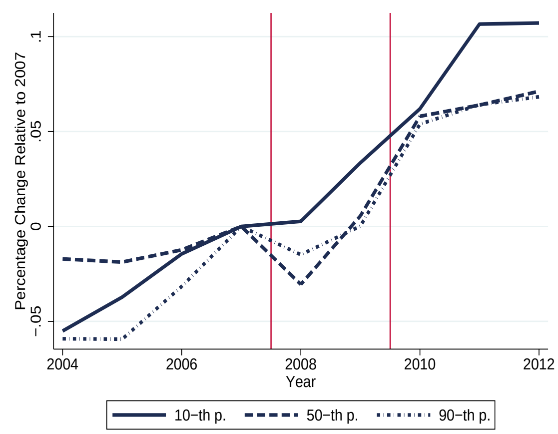

(a) Number of Transactions




(b) Average Transaction Price




(c) Standard Deviation of Prices

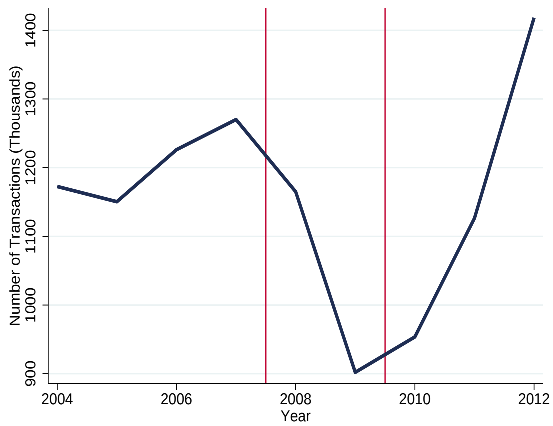



(d) Percentiles of Prices

*Notes:* The figure displays the number of new-car sales (top-left panel), the average (top-right panel), the standard deviation (bottom-left panel), and three percentiles—10th, 50th, and 90th—(bottom-right panel) of the distribution of transaction prices from the Dominion dataset, excluding the months of July and August of each year. Horizontal axes report years (2004-2012); vertical lines highlight recession years (2008 and 2009).

entirely for our findings on the dynamics of between-model price variance—as well as average price—by performing the following analysis. We decompose the difference between the between-model variance in year $t$, $V_t^B$, and the between-model variance in the whole

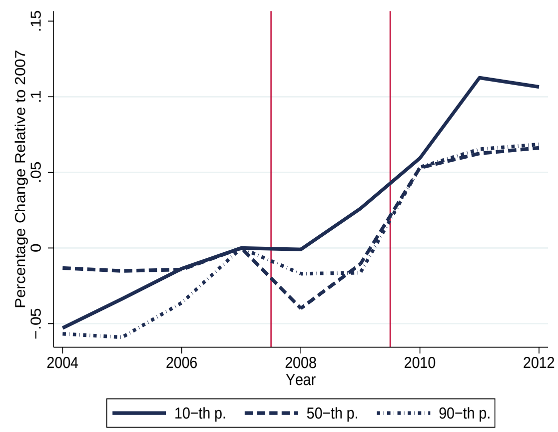
Figure B3: Dynamics of New-Vehicle Expenditures, Excluding Fleet Sales




(a) Number of Transactions


(b) Average Transaction Price


(c) Standard Deviation of Prices




(d) Percentiles of Prices

*Notes:* The figure displays the number of new-car sales (top-left panel), the average (top-right panel), the standard deviation (bottom-left panel), and three percentiles—10th, 50th, and 90th—(bottom-right panel) of the distribution of transaction prices from the Dominion dataset, excluding fleet sales. Horizontal axes report years (2004-2012); vertical lines highlight recession years (2008 and 2009).

sample, $V^B$, as follows:

$$\begin{aligned} V_t^B - V^B &= \sum_{i \in M_t} s_{it} \left(\overline{p}_{it} - \overline{p}_t\right)^2 - \sum \overline{s}_i \left(\overline{p}_i - \overline{p}\right)^2 \\ &= \sum_{i \in M_t} \left(s_{it} - \overline{s}_i\right) \left(\overline{p}_i - \overline{p}\right)^2 + \sum_{i \in M_t} \overline{s}_i \left[\left(\overline{p}_{it} - \overline{p}_t\right)^2 - \left(\overline{p}_i - \overline{p}\right)^2\right] + \\ &\quad + \sum_{i \in M_t} \left(s_{it} - \overline{s}_i\right) \left[\left(\overline{p}_{it} - \overline{p}_t\right)^2 - \left(\overline{p}_i - \overline{p}\right)^2\right], \end{aligned} \tag{B.1}$$

where the index $i$ refers to models, $t$ denotes years, and we use bars to denote averages of prices $p_{it}$ and market shares $s_{it}$.

The first term on the second line of equation (B.1) measures the role of reallocation of expenditures across models; the second term on the second line measures the role of changes in model prices; and the final term denotes the covariance term between changes in market shares and prices.

Figure B7 shows that between 2007 and 2009, the component due to reallocation (dashed line) accounts for the entire decline in between-model variance. This finding buttresses our interpretation of the variance decompositions in Section 3.2: A reallocation of expenditures toward models of lower quality accounts for the drop in dispersion of expenditures.

We also perform the same decomposition for the average price in year $t$ (equation (B.2)) and obtain again a tight match between the overall average-price dynamics around the recession and the component due to reallocation of market shares across models, as Figure B8 shows.

$$\begin{aligned} \overline{p}_t - \overline{p} &= \sum_{i \in M_t} s_{it}\overline{p}_{it} - \sum \overline{s}_i \overline{p}_i \\ &= \sum_{i \in M_t} \left(s_{it} - \overline{s}_i\right) \overline{p}_i + \sum_{i \in M_t} \overline{s}_i \left(\overline{p}_{it} - \overline{p}_i\right) + \sum_{i \in M_t} \left(s_{it} - \overline{s}_i\right)\left(\overline{p}_{it} - \overline{p}_i\right). \end{aligned} \tag{B.2}$$

Furthermore, we obtain similar results when we restrict attention to the variance of prices of new models.

Figure B9 displays the time series of the total number of sales and the number of sales of new models (left panel) and the share of models we classify as new models (right panel). These two figures show that both the share of transactions on new models and the flow of new-product introduction are procyclical, peaking in 2007 and dropping during the Great Recession.

Figure B10 displays our findings on the patterns of new-model introduction across carmakers of different geographical origin (Europe, Asia, and US). The left panel shows that the number of new models dropped for all three groups during the recession. Between 2007 and 2009, the volume of new-model introduction dropped by for European carmakers, by for Asian carmakers, and by for US carmakers. As a result, there is a missing generation of new models across all makes. After the recession, we observe some heterogeneity in the speed of recovery, with European carmakers increasing new-model introduction faster than Asian and US carmakers.

The right panel of Figure B10 focuses on new models with an average price above \$40,000, which approximately corresponds to the 90th percentile of the distribution in 2007. In this range, we observe that European carmakers account for the majority of new models. In 2007, out of 24 new models introduced by European carmakers, 17 are above the \$40,000 price threshold. In contrast, out of 26 new models introduced by US carmakers, only 5 are above the same threshold; the fraction of high-price new models introduced by Asian carmakers is even smaller. As the right panel of Figure B10 shows, high-price new-model introduction from European carmakers dropped almost by half during the recession, which largely accounts for the missing generation of high-quality new models in 2008 and 2009.

Figure B11 displays the decomposition of new-model introduction into new model names and new generations of existing model names.

## B.3 Dynamics of the Distribution of Quality

Table B1 reports the results of our hedonic-regression analysis. Specifically, column (1) in Panel A of Table B1 reports the hedonic prices of the main continuous attributes $X_{it}$ in the pre-recession subsample. Columns (2) and (3) in Panel A report the hedonic prices of the main continuous attributes $X_{it}$ in the recession and post-recession subsamples, respectively.

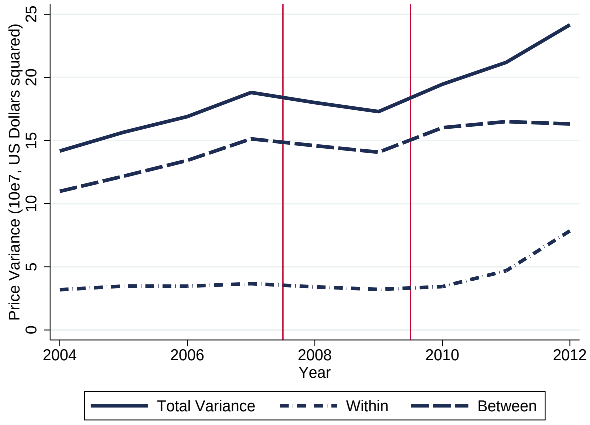
These hedonic regressions are well suited for accounting for the dispersion of expenditures. Car characteristics capture a large share of the between-model variance in prices: $R^2$ coefficients of the hedonic regressions exceed 0.93 in all subsamples.

The table shows that the coefficients of some attributes, most notably engine size, are not precisely estimated. The reason is that our regression equation (1) includes some discrete characteristics $W_{it}$, such as indicator variables for the number of cylinders, which absorb almost all variation in engine size. Hence, the residual variation in engine size is minimal and its coefficient estimate is noisy.

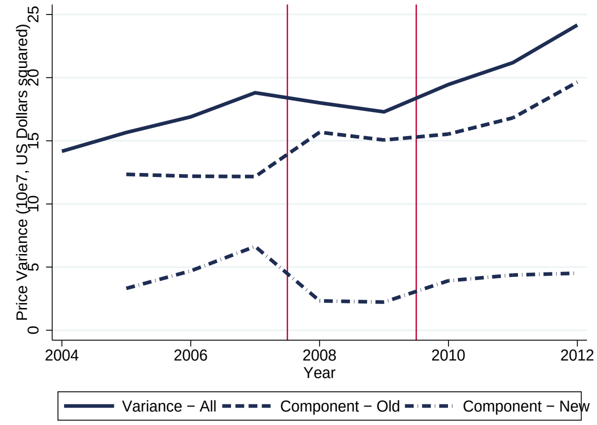
Panel B of the table reports the peak-to-trough dynamics of expenditures and quality of newly introduced models.

Figure B12 displays the results of robustness analyses of average quality dynamics measured with hedonic regressions. Specifically, whereas we produce Figure 4 in Section 3.3 by aggregating continuous characteristics of different trims at the model level, but considering trims with different discrete characteristics—such as diesel, or turbo injection—as distinct models, in these robustness analyses we aggregate both continuous and discrete characteristics of different trims of each model.

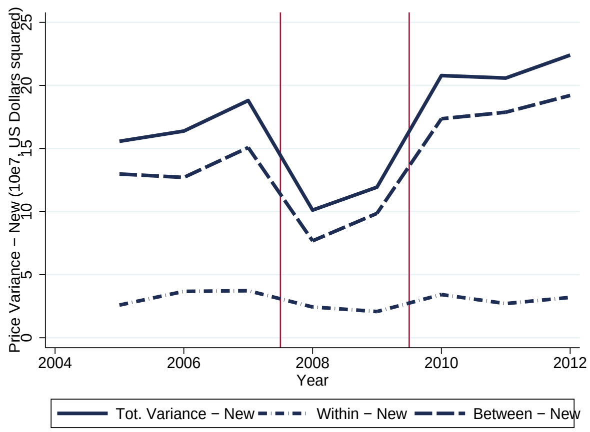
Figure B4: Variance Decomposition, Excluding July and August of Each Year



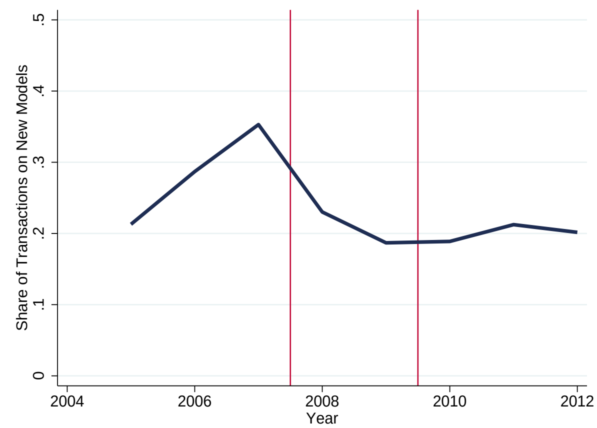

(a) Variance of New-Car Prices, Between and Within




(b) Variance of New-Car Prices, New and Continuing




(c) Variance of Newly Introduced Models

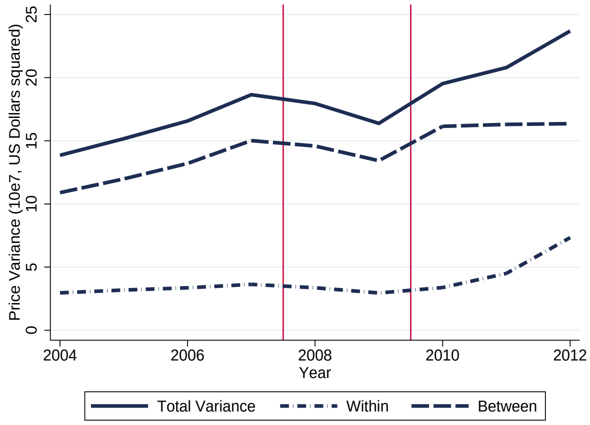



(d) Share of Newly Introduced Models

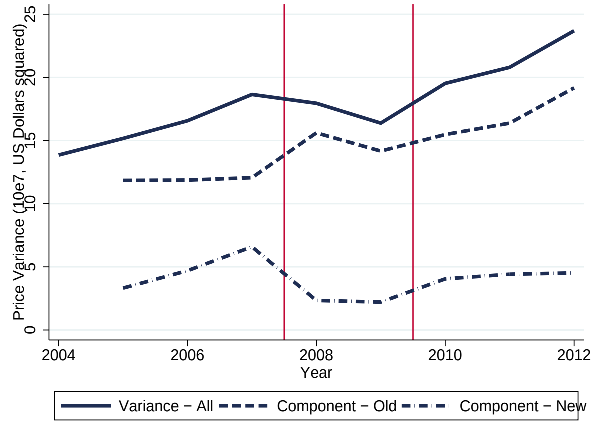
*Notes:* The figure displays several decompositions of the variance of transaction prices in the Dominion dataset, excluding the months of July and August of each year. The top-left panel displays the decomposition of the variance of new-vehicle transaction prices $V_t$ (solid line) into the following components: between models $V_t^B$ (dashed line) and within models $V_t^W$ (dashed-dotted line). The top-right panel displays the decomposition of the variance $V_t$ (solid line) into two components: new models $s_t^N V_t^N$ (dashed-dotted line) and old models $(1 - s_t^N)V_t^O$ (dashed line). The bottom-left panel displays the variance of expenditures on new models $V_t^N$ (solid line) and its decomposition into between-models component $V_t^{N,B}$ (dashed line) and within-models component $V_t^{N,W}$ (dashed-dotted line). The bottom-right panel displays the share of transactions on new models $s_t^N$. Horizontal axes report years (2004-2012); vertical lines highlight recession years (2008 and 2009).

We consider two alternative specifications of the hedonic regressions. The first specification (top panels) is more flexible and uses indicator variables for discrete characteristics,

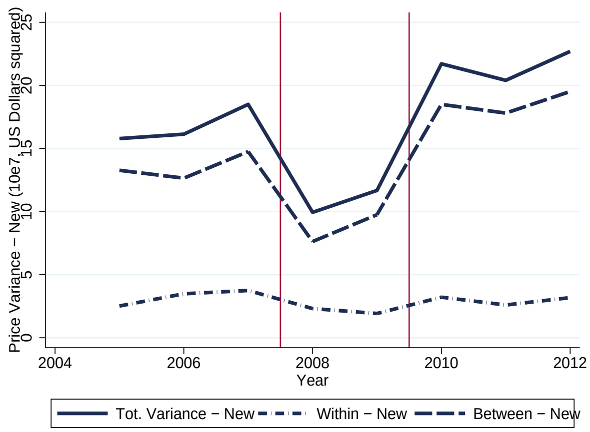
Figure B5: Variance Decomposition, Removing Fleet Sales



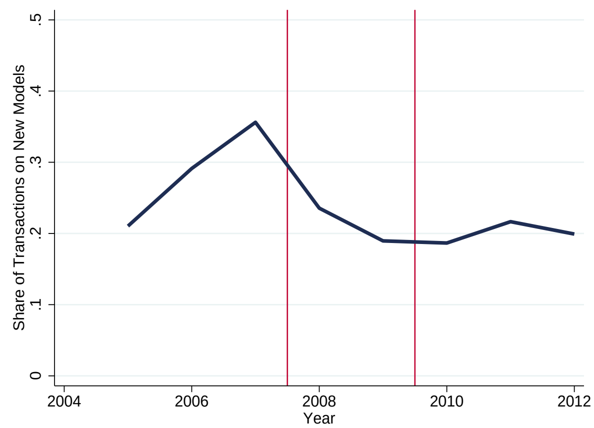

(a) Variance of New-Car Prices, Between and Within




(b) Variance of New-Car Prices, New and Continuing




(c) Variance of Newly Introduced Models

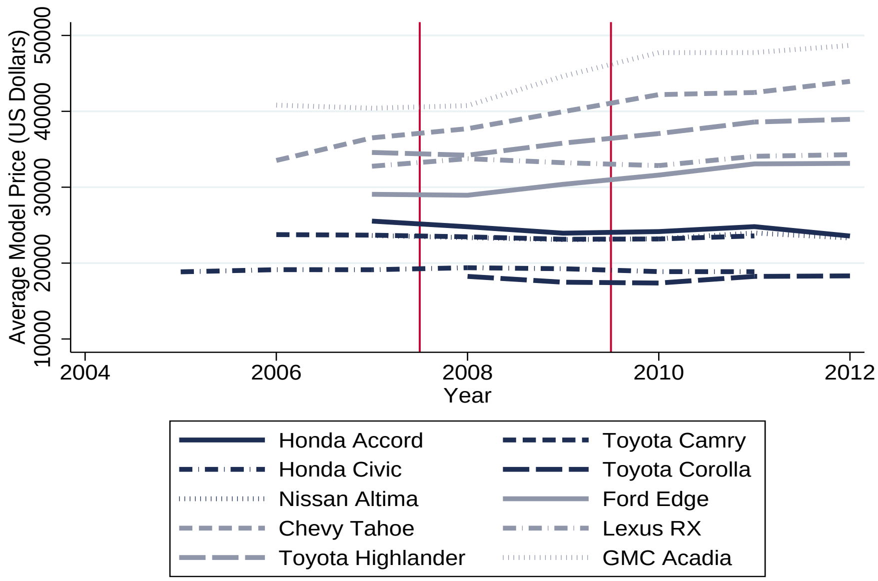



(d) Share of Newly Introduced Models

*Notes:* The figure displays several decompositions of the variance of transaction prices in the Dominion dataset, excluding fleet sales. The top-left panel displays the decomposition of the variance of new-vehicle transaction prices $V_t$ (solid line) into the following components: between models $V_t^B$ (dashed line) and within models $V_t^W$ (dashed-dotted line). The top-right panel displays the decomposition of the variance $V_t$ (solid line) into two components: new models $s_t^N V_t^N$ (dashed-dotted line) and old models $(1 - s_t^N)V_t^O$ (dashed line). The bottom-left panel displays the variance of expenditures on new models $V_t^N$ (solid line) and its decomposition into between-models component $V_t^{N,B}$ (dashed line) and within-models component $V_t^{N,W}$ (dashed-dotted line). The bottom-right panel displays the share of transactions on new models $s_t^N$. Horizontal axes report years (2004-2012); vertical lines highlight recession years (2008 and 2009).

as in equation (1). Within each model, we average the discrete characteristics weighting different trims according to their transaction shares. We then round the average to the closest discrete value, and set the corresponding indicator variable equal to one. The second

Figure B6: Average Price of Ten Popular Models



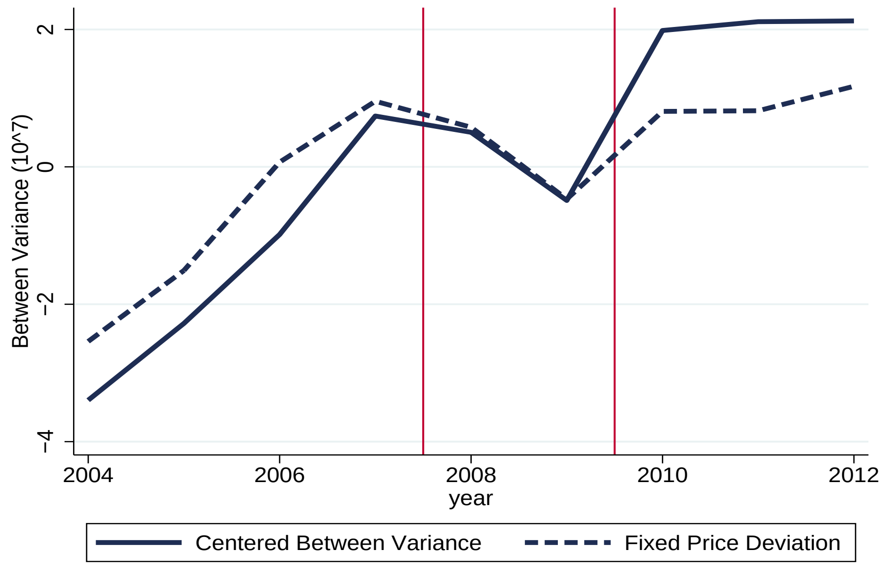

*Notes:* The figure displays the average transaction price of ten popular models in the Dominion dataset. Specifically, we select the five models with the highest levels of sales and price below the median, and the five models with the highest levels of sales and price above the median. Horizontal axes report years (2004-2012); vertical lines highlight the recession years (2008 and 2009).

specification (bottom panels) treats all characteristics that vary across trims—including discrete ones—as continuous variables and assumes a log-linear relationship between prices and all of these characteristics. Within each model, we average the discrete characteristics weighting different trims according to their transaction shares and treat the average as the value of a continuous characteristic. Because make and body type do not vary across trims within each model, we control for these two attributes with indicator variables as in equation (1).

The first specification has an overall better fit, because the indicator variables better capture the nonlinearities in the relation between discrete attributes—such as the number of cylinders—and prices, whereas the second specification features a finer measurement of discrete variables—as it does not rely on rounding—but imposes a linear relation between all attributes and prices.

Critically, in both cases we find that quality growth is stagnant after the Great Recession when we measure it with pre-recession hedonic prices (left panels), whereas average quality tracks the average price more closely when we use time-varying hedonic prices (right panels). These results suggest that the level of aggregation of car characteristics, as well as the exact number of models, do not affect our main findings.

Figure B7: Decomposition of Between-Model Variance: Role of Expenditure Reallocation




*Notes:* The figure displays the results of the decomposition of the between-model variance defined in equation (B.1). The solid line refers to the overall between-model variance, whereas the dashed line refers to the component due to reallocation of expenditures across models, for fixed deviations of prices from their average. Horizontal axes report years (2004-2012); vertical lines highlight recession years (2008 and 2009).

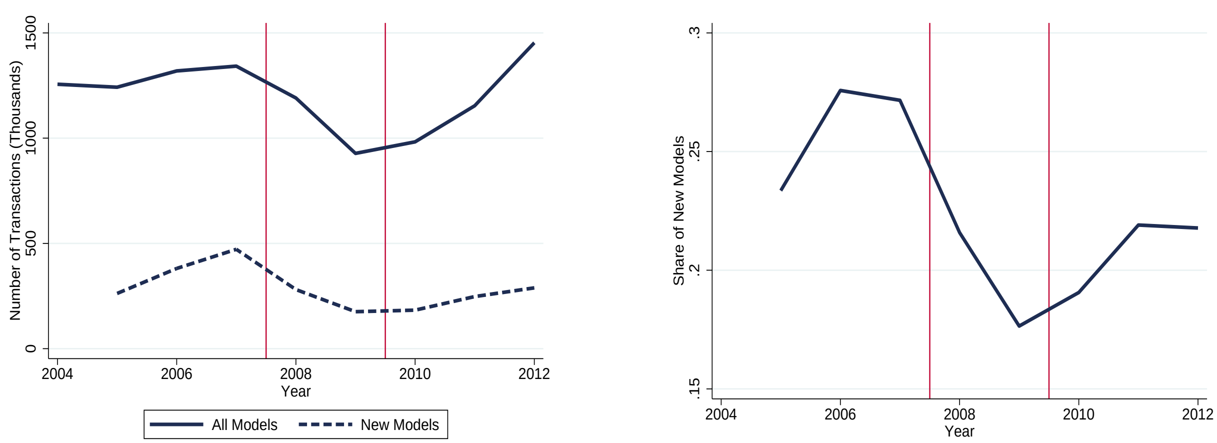
Table B2 reports selected coefficients of our hedonic regressions, with the same level of aggregation as in Section 3.3, when we focus exclusively on new models. Consistent with our baseline specification that pools all models (top panel of Table B1), we measure an increase in several hedonic prices of characteristics associated with high quality between the pre-recession and the post-recession periods.

We also explore geographical heterogeneity in the dynamics of the distribution of car quality. To this end, we reproduce the hedonic-regression analysis separately for transactions in Ohio and Texas. We first estimate the hedonic prices of car characteristics in the pre-recession period for each state. We then use these hedonic prices to measure the quality of all cars sold during and after the recession. Both states experience a decline in average prices relative to their respective trends. However, our estimates reveal that in Ohio the substitution toward lower-quality models during the recession is stronger than in Texas: The peak-to-trough decline in average quality approximately equals 2% in Ohio and 1% in Texas. Moreover, starting during the recession, Ohio features a larger gap between price and quality than Texas.

Figure B8: Decomposition of Average Price: Role of Expenditure Reallocation


*Notes:* The figure displays the results of the decomposition of the average transaction price defined in equation (B.2). The solid line refers to the overall average price, whereas the dashed line refers to the component due to reallocation of expenditures across models, for fixed average prices at the model level. Horizontal axes report years (2004-2012); vertical lines highlight recession years (2008 and 2009).

Figure B9: Transactions and Share of New Models

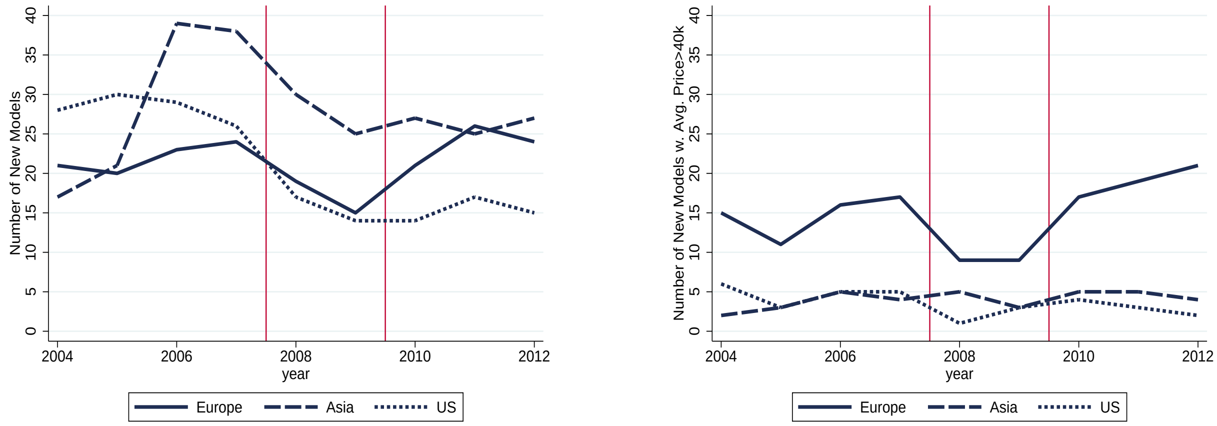



(a) Number of Transactions

(b) Share of New Models

*Notes:* The left panel displays the number and compositions of new-car sales in the Dominion dataset during 2004-2012. The solid line refers to all sales; the dashed line refers to sales of new-car models only. The right panel displays the time series of the share of models we classify as new models. Horizontal axes report years (2004-2012); vertical lines highlight the recession years (2008 and 2009).

Figure B10: Introduction of New Models by Origin of Carmakers




(a) All New Models

(b) High-Price New Models

*Notes:* The figure displays the volume of new-model introduction by origin of carmakers. The left panel refers to all new models, whereas the right panel refers to new models with a price above $40,000. Solid lines denote European carmakers; dashed lines denote US carmakers; and dotted lines denote Asian carmakers. Horizontal axes report years (2004-2012); vertical lines highlight recession years (2008 and 2009).

## B.4 New Models and Technological Progress

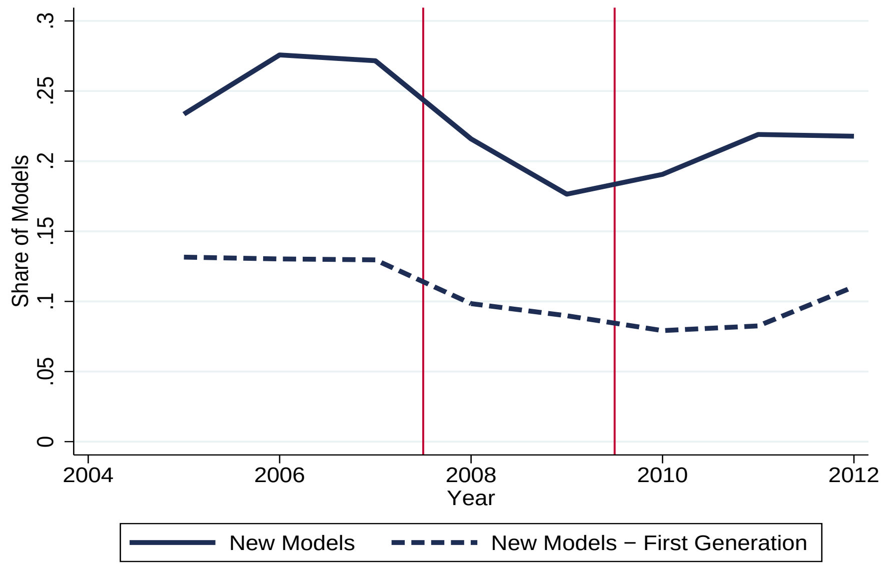
Figure B13 reports several robustness checks of our estimates of the technology level for new and old models. Specifically, the top-left panel reports the results we obtain by replacing the variable weight with three geometric dimensions—wheelbase, width, and height—in regression equation (2). Estimates of the technology level for new and old models are remarkably similar to the ones we show in Figure 2. Different from Knittel (2011), our dataset does not contain information about torque; thus, we measure engine power with horsepower across all of the specifications.

The top-right panel of Figure B13 displays our estimates of the technological level of new models and old models under the assumption of a translog cost function. Under this assumption, we recover the path of technological progress by estimating the following regression equation:

$$\begin{aligned} \log mpg_{it} \;=\; & \alpha'_{hp}\log hp_{it} + \alpha'_{w}\log w_{it} + \alpha'_{Z}Z^{1}_{it} + \alpha'_{N}\mathcal{I}^{N}_{it} + T_t + T_t \times \mathcal{I}^{N}_{it} + \\ & \alpha'_{hp^2}(\log hp_{it})^2 + \alpha'_{w^2}(\log w_{it})^2 + \alpha'_{hp,w}\log hp_{it} \times \log w_{it} + \varepsilon_{it}. \end{aligned} \tag{B.3}$$

The results are qualitatively and quantitatively similar to those we obtain in Figure 5 under the assumption of a Cobb-Douglas cost function.

Figure B11: Introduction of New Model Names



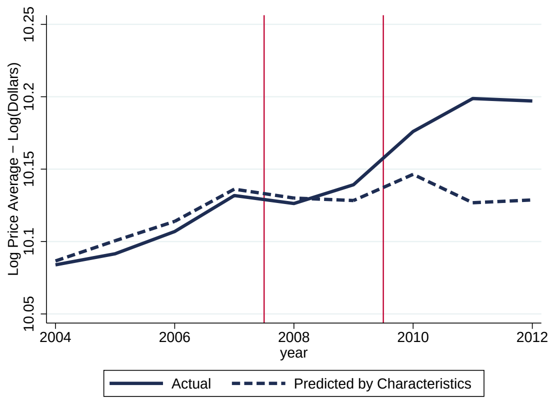

*Notes:* The figure displays a decomposition of the volume of new-model introduction between new model names and new generations of existing model names. The solid line refers to the total share of models that we classify as new and the dashed line refers to the share of models with a new model name in the Dominion dataset. Horizontal axes report years (2004-2012); vertical lines highlight recession years (2008 and 2009).

The bottom panel of Figure B13 displays our estimates of the technological level of new models and old models when we aggregate both continuous and discrete characteristics of different trims of each model, using their transaction shares in the IHS dataset, consistent with the hedonic analysis displayed in Figure B12. Our results are robust to this different level of aggregation of car characteristics, buttressing our argument that the level of aggregation of car characteristics and the exact number of models do not affect our results.

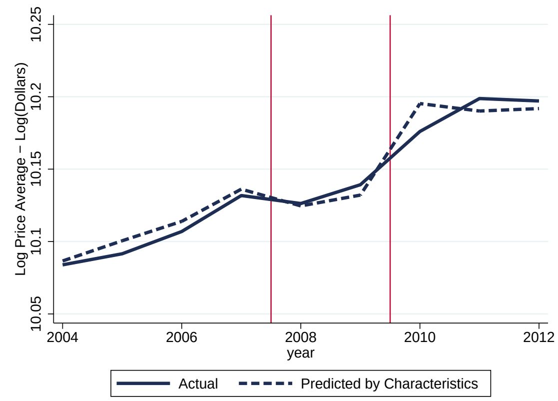
We also perform our estimation of the evolution of the technology frontier dividing carmakers by their geographical origin (Europe, Asia, and US). This strategy is useful for two main reasons. First, these groups of manufacturers are vertically differentiated in terms of average vehicle quality in the US market, as our hedonic-regression analysis confirms. Notably, European manufacturers specialize in higher-quality models. Second, these groups of manufacturers were likely differentially affected by the financial crisis. Specifically, US manufacturers were hit most directly by the crisis, which led to government bailouts.

Exploiting this heterogeneity, we find that European carmakers played a crucial role for the aggregate downward adjustment in the level of technology of new models that we discuss in Section 3.4. Notably, Figure B14 displays the estimates of the year fixed effects

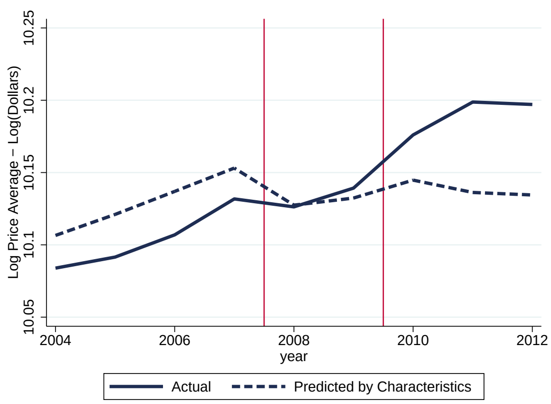
Figure B12: Hedonics and Vehicle Quality, Aggregating All Characteristics



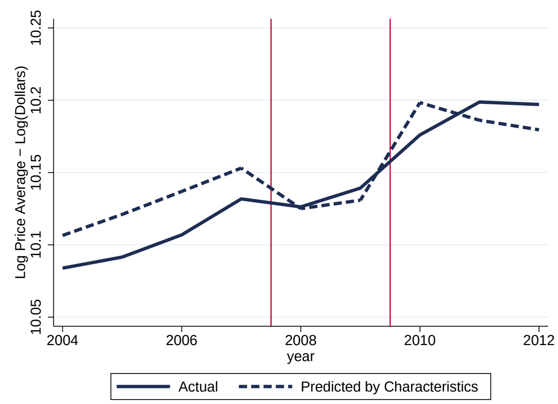

(a) Constant Hedonic Prices, Rounding




(b) Time-varying Hedonic Prices, Rounding




(c) Constant Hedonic Prices, Continuous




(d) Time-varying Hedonic Prices, Continuous

*Notes:* The figure displays the dynamics of average (log) transaction price in the merged Dominion-IHS dataset (solid lines) and the average (log) value predicted with a hedonic regression (dashed lines), when we aggregate both discrete and continuous characteristics of different trims at the model level. Top panels refer to a flexible specification with indicator variables for discrete characteristics, as in equation (1). Within each model, we average the discrete characteristics weighting different trims in proportion to their transaction shares. We then round the average to the closest discrete value, and set the corresponding indicator variable equal to one. Bottom panels refer to an alternative specification that treats all characteristics that vary across trims—including discrete ones—as continuous variables and assumes a log-linear relationship between prices and characteristics. Within each model, we average the discrete characteristics weighting different trims in proportion to their transaction shares and treat the average as the value of a continuous characteristic. Because make and body type do not vary across trims within each model, we control for these two attributes with indicator variables as in equation (1). Left panels refer to constant pre-recession hedonic prices (2004-2007); right panels to time-varying hedonic prices, estimated in three subsamples: pre-recession (2004-2007), recession (2008-2009), and post-recession (2010-2012). Horizontal axes report years (2004-2012); vertical lines highlight recession years (2008 and 2009).

Table B1: Hedonic Regressions

| Panel A: Coefficient Estimates of Continuous Attributes | (1) Pre-Recession | (2) Recession | (3) Post-Recession |
|---|---|---|---|
| Log(Wheelbase) | 1.138 | 1.273 | 1.495 |
| | (0.133) | (0.168) | (0.162) |
| Log(Horsepower) | 0.487 | 0.488 | 0.612 |
| | (0.039) | (0.051) | (0.051) |
| Log(Weight) | 0.090 | 0.153 | 0.035 |
| | (0.060) | (0.078) | (0.077) |
| Log(Fuel Efficiency) | -0.080 | -0.058 | -0.062 |
| | (0.051) | (0.044) | (0.047) |
| Log(Engine Size) | 0.095 | 0.028 | -0.038 |
| | (0.051) | (0.066) | (0.064) |
| Observations | 2,055 | 1,084 | 1,671 |
| $R^2$ | 0.939 | 0.958 | 0.950 |

| Panel B: Quality of New Models | (1) Data | (2) Constant Prices | (3) Time-Varying Prices |
|---|---|---|---|
| Average 2008 – Average 2007 | -0.044 | -0.052 | -0.059 |
| St. Dev. 2008 – St. Dev. 2007 | -0.073 | -0.072 | -0.072 |

*Notes:* Panel A reports the estimated coefficients of the log of continuous characteristics $X_{jt}$ in equation (**??**), with standard errors in parentheses, in three subsamples: column (1) refers to the pre-recession subsample (2004-2007); column (2) to the recession subsample (2008–2009); and column (3) to the post-recession subsample (2010–2012). Panel B reports the peak-to-trough dynamics of expenditures and quality of newly introduced models, weighted according to their transaction shares in the IHS dataset. Column (1) reports the difference between the average log price of new models in the 2008 and the average log price of new models in 2007 (first row) and the difference between the standard deviation of log prices of new models in 2008 and the standard deviation of log prices of new models in 2007 (second row). Column (2) reports the difference between the average (first row) and the standard deviation (second row) of predicted log prices, based on constant hedonic prices estimated in the pre-recession subsample, applied to new models introduced in 2008 and to new models introduced in 2007. Column (3) reports the difference between the average (first row) and the standard deviation (second row) of predicted log prices, based on recession hedonic prices applied to new models introduced in 2008 and pre-recession hedonic prices applied to new models introduced in 2007.

in the regression equation (2), which we estimate separately for European, Asian, and US carmakers. The level of technology of new models declined for all three groups during the recession, but European carmakers experienced the largest decline. This evidence suggests that the financial shock hitting US manufacturers is not a primary driver of the overall

Table B2: Hedonic Regressions: New Models

| | (1) Pre-Recession | (2) Recession | (3) Post-Recession |
|---|---|---|---|
| Log(Wheelbase) | 1.375 | 2.456 | 1.815 |
| | (0.272) | (0.456) | (0.511) |
| Log(Horsepower) | 0.409 | 0.324 | 0.483 |
| | (0.084) | (0.142) | (0.112) |
| Log(Weight) | 0.340 | 0.933 | 0.554 |
| | (0.143) | (0.205) | (0.216) |
| Log(Fuel Efficiency) | 0.051 | 0.307 | -0.253 |
| | (0.083) | (0.118) | (0.131) |
| Log(Engine Size) | 0.006 | -0.288 | -0.135 |
| | (0.104) | (0.166) | (0.130) |
| Observations | 457 | 215 | 306 |
| $R^2$ | 0.965 | 0.969 | 0.982 |

*Notes:* The table reports the estimated coefficients of the log of continuous characteristics $X_{jt}$ in equation (**??**), with standard errors in parentheses, using data on new models only in three subsamples: column (1) refers to the pre-recession subsample (2004-2007); column (2) to the recession subsample (2008–2009); and column (3) to the post-recession subsample (2010–2012).

downward quality adjustment that we document.

We further estimate the level of embodied technology separately for new model names and new generations of existing model names. We find that the dynamics of average quality are similar for these two groups of models in all periods, including the quality drop during the recession. These results suggest that vertical and horizontal innovations contribute similarly to aggregate quality growth. We display the results of this new analysis in Figure B15.

Figure B16 displays the results we obtain by estimating regression equation (2) without an interaction term between year fixed effects and the indicator function for new models, without sales weights (left panel) and with sales weights (right panel). In this analysis, we effectively pool all models to estimate a common level of technology, and still find a substantial decrease in quality during the Great Recession.

Finally, we perform a back-of-the-envelope calculation of the effects of low new-product quality during the recession for the quality of the overall stock of registered cars in the US. First, we leverage the estimates displayed in the right panel of Figure B16 to obtain a measure of the average annual growth rate in new-car quality, $x$, during 2004-2007, as well as the average technological level of new cars sold in year $t$, $q_t^N$. We normalize $q_{2004}^N = 1$

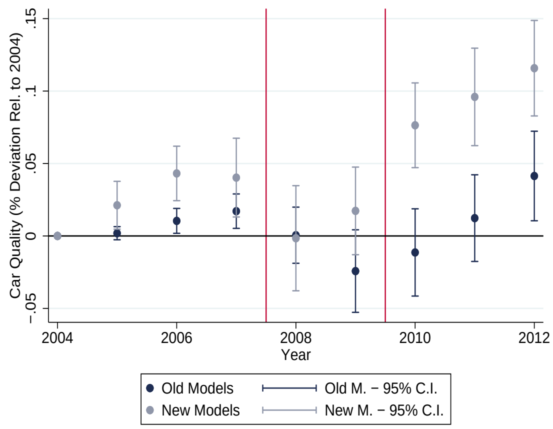
and assume that the economy in 2004 is on a balanced-growth path with constant inflow of new cars and constant growth in new-car quality equal to $x$. Thus, in 2004 the quality of cars of age $a$ is given by $q_{a,2004} = (1+x)^{-a}$. Between 2005 and 2012, we combine these assumptions with our estimates of new-car quality and update the quality of cars of age $a$ as follows: $q_{0,t} = q_t^N$ and $q_{a,t} = q_{a-1,t-1}$ for $a > 0$.

Second, we obtain data on new-vehicle registrations (automobiles and light trucks) from the Bureau of Economic Analysis during 2004-2012 (US Bureau of Economic Analysis, 2022). We assume that vehicles are scrapped at age $a = 15$ (our main findings are similar in a range of values for this parameter) and that the initial age distribution of vehicles is uniform. We update the distribution of vehicle age during 2005-2012 as follows. Let $n_{a,t}$ be the number of cars of age $a$ in year $t$. We set $n_{0,t}$ equal to the empirical flow of new registrations in year $t$ and $n_{a,t} = n_{a-1,t-1}$ for $a = 1, ..., 14$.

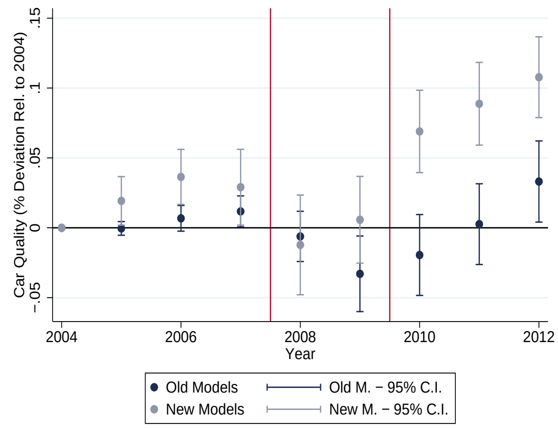
We then obtain the average quality of the stock, $q_t$, as follows: $q_t = \frac{\sum_{a=0}^{14} n_{a,t} q_{a,t}}{\sum_{a=0}^{14} n_{a,t}}$.

Figure B17 displays the time-series of $q_t$. We find that at the end of the sample the estimated quality of the stock (solid line) is 1.3% lower than if new-car quality and new-car sales had remained on their pre-recession trend (dashed-dotted line). We further decompose the difference between the estimated quality of the stock and its pre-recession trend in its two components—i.e., changes in the volume of new-car sales and changes in new-product quality. Specifically, the dashed line assumes that new-product quality $q_t^N$ remains on its pre-recession trend, whereas new-car sales follow their empirical path, dropping during the recession. As the figure shows, this counterfactual scenario accounts for approximately 0.4 percentage points of the overall decline in quality of the stock at the end of the sample, and thus almost one percentage point of the decline is due to the endogenous drop in new-product quality $q_t^N$.

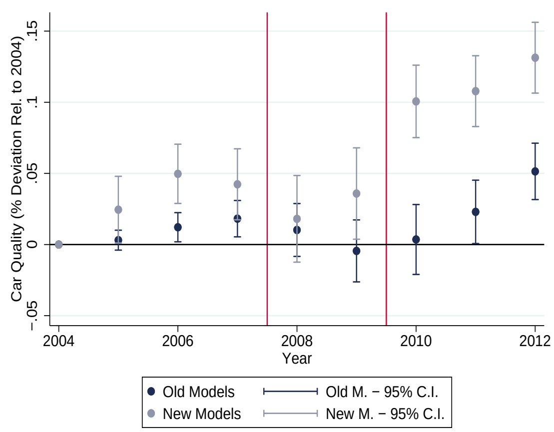
Figure B13: Technology of New and Old Models: Robustness




(a) Replacing Weight with Geometric Dimensions



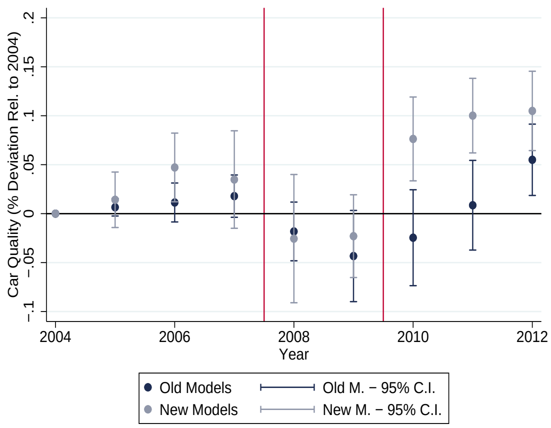

(b) Translog Cost Function



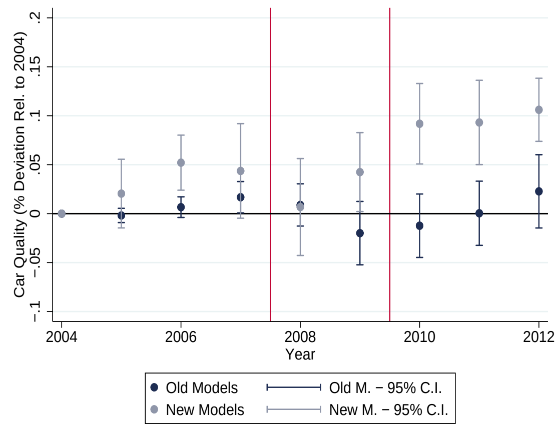

(c) Aggregating All Characteristics

*Notes:* The figure displays several robustness checks of our measure of technology level for new and old models. Specifically, the top-left panel displays the results we obtain by replacing the variable weight in equation (2) with the variables wheelbase, width, and height. The top-right panel displays the estimates we obtain for regression equation (B.3)—i.e., assuming a translog cost function. The bottom panel displays the estimates we obtain when we aggregate both continuous and discrete characteristics of different trims of each model using their transaction shares. Horizontal axes report years (2004-2012); vertical lines highlight recession years (2008 and 2009).

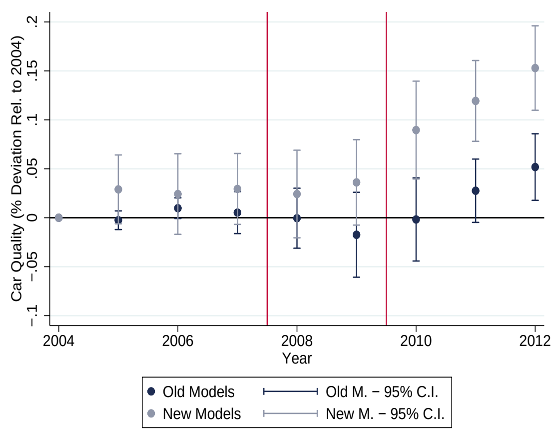
Figure B14: Technology of New and Old Models by Origin of Carmakers




(a) Europe



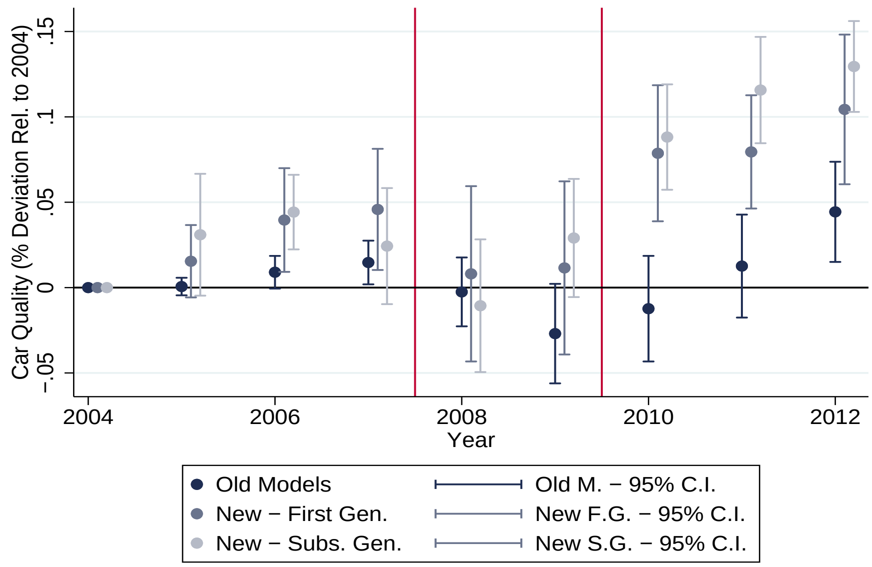

(b) Asia




(c) US

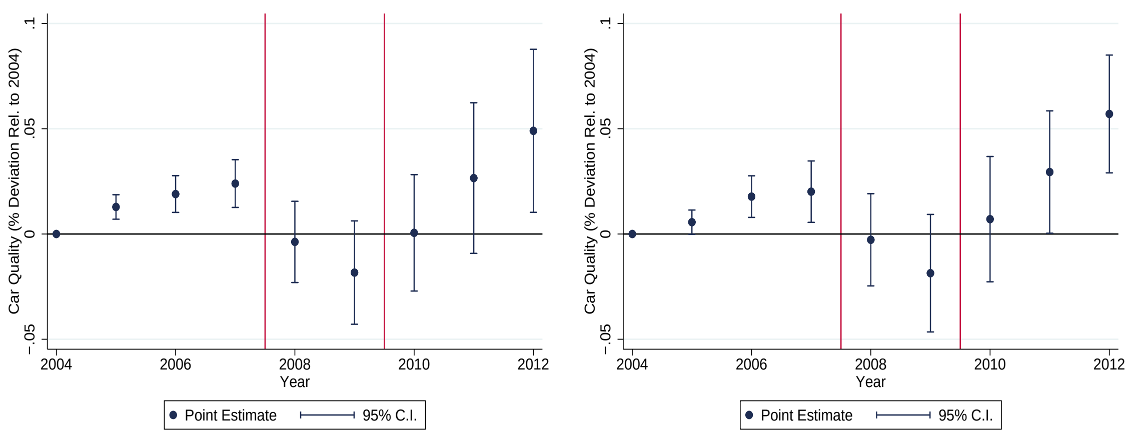
*Notes:* The figure displays the estimated average level of technological efficiency for new models (clear markers) and old models (dark markers), measured as the estimated time fixed effects in regression equation (2). The left panel refers to European carmakers; the middle panel to Asian carmakers; and the right panel to US carmakers. Horizontal axes report years (2004-2012); vertical lines highlight recession years (2008 and 2009).

Figure B15: Technology of New Model Names and New Generations




*Notes:* The figure displays the estimated average level of technological efficiency for new generations of existing model names (clear markers), new model names (intermediate-darkness markers), and continuing models (dark markers). Horizontal axes report years (2004-2012); vertical lines highlight recession years (2008 and 2009).

Figure B16: Technology of All Models

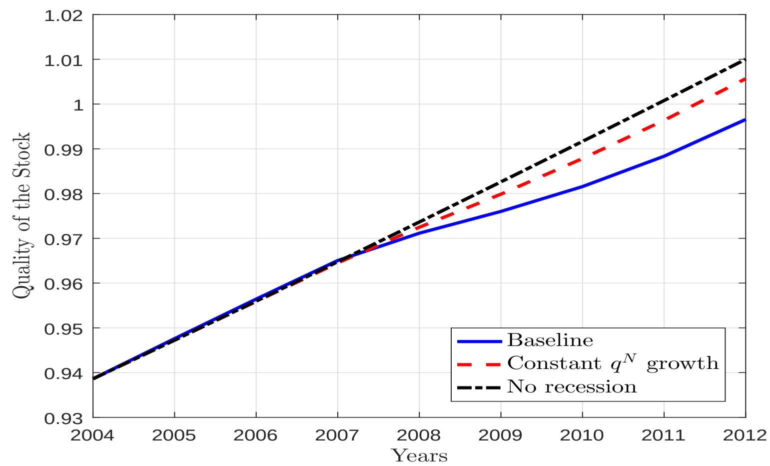



(a) Weighted by Sales

(b) Not Weighted by Sales

*Notes:* The figure displays the estimated average level of technological efficiency for all models, based on equation (2), removing the interaction term between new models and time. The left panel refers to a regression with weights based on the number of transactions in the IHS dataset, whereas the right panel refers to a regression without weights. Horizontal axes report years (2004-2012); vertical lines highlight recession years (2008 and 2009).

Figure B17: Evolution of the Quality of the Stock of Cars




*Notes:* The figure displays the results of our back-of-the-envelope calculations for the quality of the stock of registered cars, relative to the quality of new cars in 2004. The solid blue line refers to the quality of the stock $q_t$; the dashed red line refers to a counterfactual scenario with a constant growth in the quality of new cars, but the empirical inflow of new cars; the dashed-dotted black line refers to a counterfactual with a constant growth in the quality of new cars and a constant inflow of new cars. Horizontal axes report years (2004-2012); vertical lines highlight recession years (2008 and 2009).

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