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DYNAMICS OF EXPENDITURES ON DURABLE GOODS: THE ROLE OF NEW-PRODUCT QUALITY*

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We study the role of new-product quality for the dynamics of durable-good expenditures around the Great Recession. We assemble a rich dataset on US new-car markets during 2004–12, combining data on transaction prices with detailed information about vehicles' technical characteristics. During the recession, a reallocation of expenditures away from high-quality new models accounts for a significant decline in the dispersion of expenditures. In turn, car manufacturers introduced new models of lower quality. The drop in new-model quality persistently depressed the technology embodied in vehicles, and likely contributed to the slow recovery of expenditures.

Households adopt new technologies by purchasing new durable goods, such as vehicles. During the Great Recession of 2008–9, consumer expenditures on durable goods dropped by approximately 17%. Expenditures on motor vehicles—which constitute approximately 35% of durable-good expenditures—accounted for more than half of this decrease and remained low during the recovery.

The goal of this paper is to empirically investigate the role of new-product quality for these dynamics. Our descriptive analysis suggests that complementary demand and supply factors contributed to a downward quality adjustment in durable-good purchases during the recession. Specifically, households reallocated their purchases of new cars toward cheaper models—which tend to be continuing models, of lower quality than new models—or delayed their purchases. Amid this decline in demand, manufacturers introduced new models of low quality, persistently depressing the path of technology.

Cars represent an ideal object for our analysis for two reasons. First, they are a large and procyclical component of durable-good expenditures. Second, detailed information on car markets allows us to measure quality dynamics, providing evidence on the importance of new products. To this end, we assemble a rich dataset on US new-car markets, combining two data sources. The first dataset contains the universe of new-car transactions in several US states between 2004 and 2012, and reports transaction prices as well as car features, such as make and model. The second

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The data and codes for this paper are available on the Journal repository. They were checked for their ability to reproduce the results presented in the paper. The authors were granted an exemption to publish parts of their data because access to these data is restricted. However, the authors provided the Journal with temporary access to the data, which enabled the Journal to run their codes. The codes for the parts subject to exemption are also available on the Journal repository. The restricted access data and these codes were also checked for their ability to reproduce the results presented in the paper. The replication package for this paper is available at the following address: https://doi.org/10.5281/zenodo.7492191.

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dataset contains detailed information on the technical characteristics of each vehicle model sold in the United States during the same period.

We exploit these data to provide new evidence about the distribution of vehicle expenditures and quality around the Great Recession. Our analysis proceeds in four steps, each yielding a main finding.

First, we document a drop in the dispersion of new-car expenditures during the Great Recession—and a smaller decline in the average price—due to a decline in the volume of high-price transactions.

Second, we show that the drop in dispersion is due to expenditure reallocation across models—specifically, a decline in expenditures on expensive newly introduced models. Furthermore, exploiting geographical variation, we relate this drop in demand for high-quality models with the severity of the recession. Because the supply of vehicles does not vary across locations, this finding shows that shocks to household demand play a primary role in the downward quality adjustment.

Third, we connect car prices and characteristics. We use hedonic regressions to construct a measure of vertical quality that summarises vehicle technical characteristics (Griliches, 1961). We show that compositional changes in the characteristics of cars sold account for the drop in expenditures. Furthermore, vehicle quality, based on pre-recession hedonic prices, displays no growth during the recovery.

Fourth, we estimate the level of technology embodied in vehicles using only data on car characteristics. We document that new models introduced during the Great Recession featured a significantly worse trade-off between their main attributes than models introduced in other years. This finding is consistent with an endogenous response of manufacturers that contributed to the drop in durable-good quality. Moreover, this technological slowdown had persistent effects throughout the recovery, reducing the quality of the stock of registered vehicles.

Overall, our analysis highlights the complementary role of demand and supply forces for quality dynamics. The narrative that emerges from our findings is that a drop in household demand for quality led to an endogenous response on the supply side, with a decrease in both volume and quality of new products, which further reduced technology adoption.

Our findings have several implications. Most directly, the motor vehicle industry experienced a deep crisis in 2008–9, which led to a drop in employment and government bailouts. Moreover, because of the centrality of this industry in the US production structure, the effects of this crisis spread across different sectors.[1] Thus, understanding the micro-dynamics of expenditures on vehicles is an important step toward understanding the Great Recession and the subsequent slow recovery.

Furthermore, our findings have broader implications, contributing to several strands of the literature. First, we provide evidence for the complementary roles of demand and supply factors for innovation and technology adoption. Several papers show that downward adjustment in consumer demand for quality is an important margin in the Great Recession (Jaimovich *et al.*, 2019; Argente and Lee, 2021).[2] A related literature emphasises the entry and exit of retail products as an important margin for the evolution of technology around the same period (Argente *et al.*,

[1] Atalay (2017) and vom Lehn and Winberry (2022) documented that the auto industry plays a central role in the US production network.

[2] Fisher *et al.* (2013) and Meyer and Sullivan (2013) found that consumption inequality declined during the Great Recession.

2018; Jaravel, 2019; Granja and Moreira, 2023).[3] Whereas these studies mainly focus on services and non-durable goods, we analyse one of the most important household durable goods, building on the insights of Bils and Klenow (2001) and Bils (2009). The evidence on complementarity between demand and supply is also consistent with the mechanism in Shleifer (1986).[4]

Second, a large literature studies the role of durable goods for business cycles (for seminal contributions, see Mankiw, 1982; Bernanke, 1985 and Caballero, 1993). An important force in models of demand for durable goods (Barsky *et al.*, 2007; Berger and Vavra, 2015; Dupor *et al.*, 2018; Gavazza and Lanteri, 2021; McKay and Wieland, 2021; Attanasio *et al.*, 2022; Beraja and Wolf, 2022) is intertemporal substitution, which implies that pent-up demand may induce strong recoveries after drops in expenditures on durables.[5] However, expenditures on durables recovered sluggishly after the Great Recession. Our finding that new-car quality was persistently depressed during the recovery may partially account for the slow recovery in expenditures.

Relatedly, our findings on the persistent implications of the downward quality adjustment during the Great Recession are consistent with the literature on medium-run business cycles (e.g., Comin and Gertler, 2006; Benigno and Fornaro, 2018; Anzoategui *et al.*, 2019; Bianchi *et al.*, 2019; Vinci and Licandro, 2020). Our contribution is to measure the medium-run effects of new-product introduction around the Great Recession.

1. Data

Our empirical analysis exploits two datasets on new-car transactions and model characteristics, respectively. We introduce them in this section.

New-car prices (Dominion Dealer Solutions, 2019). This dataset (henceforth the Dominion dataset) reports the universe of new-car sales in five states—Colorado, Idaho, North Dakota, Ohio and Texas—for the period 2004–12. For each sale, the dataset reports the transaction price, the month of the transaction, and the make, model, body type and trim of the vehicle. The dataset contains approximately 16.5 million vehicle transactions.[6]

New-car model characteristics (IHS Markit, 2020). This dataset (henceforth the IHS dataset) reports detailed characteristics of all new passenger-car models sold during 2003–12, including make, model, trim, body type, generation year, dimensions as well as engine attributes, such as size and horsepower, fuel type, fuel consumption, transmission and turbo injection.[7]

The dataset also reports the aggregate number of US sales for each model at annual frequency during 2003–12. We exclude pick-up trucks from our analysis, because the dataset does not have comprehensive information about them.

The product life cycle of cars typically features the replacement of a ‘generation’ of a car model with a new generation on average every 5.8 years. For example, all 2007–11 Toyota

[3] Broda and Weinstein (2010) documented that product creation is pro-cyclical during the period 1999–2003.

[4] Acemoglu and Linn (2004) provided related evidence from the pharmaceutical industry and Einav (2007) from the motion picture industry.

[5] Several papers build on Eberly (1994) and Attanasio (2000), which abstract from business cycles. Adda and Cooper (2000; 2006) and Gavazza *et al.* (2014) developed quantitative models of car replacement.

[6] For North Dakota, prices are reported for 2008–12 only. Transaction prices in Colorado exhibit some unusually low values compared to those in other states; all our empirical findings are robust to excluding transactions in Colorado.

[7] Information about weight is missing in approximately 40% of models. Thus, we use all models for which we observe their weight to estimate a log-linear relationship between weight and other physical dimensions: wheelbase, width, height and the number of seats. This regression has an R^2 of 0.93. We use its predicted values to impute the weight whenever we do not observe it.

Camry models belong to the 2007 generation. Whereas small changes in characteristics happen at annual frequency within a generation, a new generation features a larger redesign. Hence, we define a vehicle model in the IHS data as a triplet of make, model and generation. We further define a new model in year t as a model for which we observe the first transaction in year t or $t-1$, to account for the fact that the first transaction on a new model tends to appear in the second half of the year. This definition of a new model encompasses entirely new model names.

Based on this definition, we merge the Dominion and IHS datasets by matching vehicle models across the two datasets, and allocating each transaction in the Dominion dataset to a model generation in the IHS dataset. Online Appendix A provides more details on our model definition and procedure to merge the datasets.

We thus obtain a rich dataset on car sales that combines information on prices and technical characteristics. Throughout the paper, we refer to a car model as a make-model-generation triplet. According to this industry-wide definition, our dataset contains over 500 models.

2. Empirical Patterns

In this section, we describe several empirical patterns: (*i*) we document the dynamics of the distribution of expenditures on new cars around the Great Recession; (*ii*) we decompose the dispersion into expenditures highlighting the role of new models; (*iii*) we relate expenditures to car characteristics and (*iv*) we analyse the level of technology embodied in cars. Online Appendix B reports additional details and robustness checks.

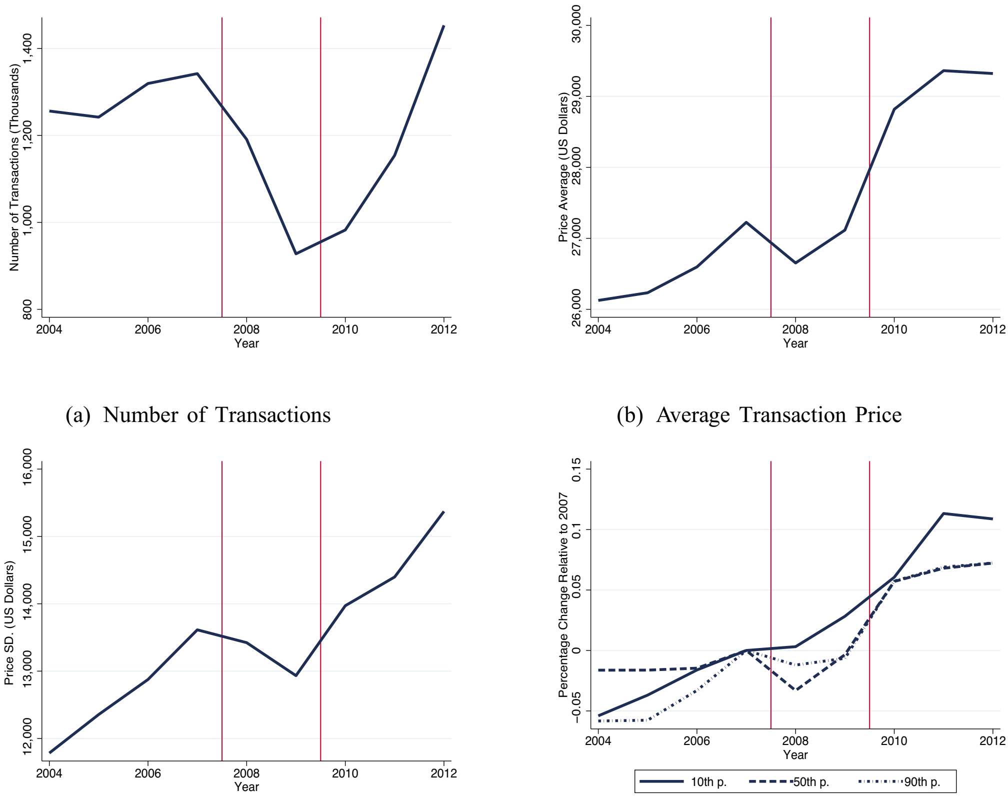
2.1. *Dynamics of the Distribution of Expenditures on New Vehicles*

We begin by describing the distribution of expenditures on new cars in the Dominion dataset. Figure 1 displays the main features of this distribution during 2004–12. The transactions in this dataset provide a representative account of the dramatic effects of the Great Recession on US car markets: panel (a) shows that the total number of new-car sales drops by approximately 30% during the recession and only returns to pre-recession levels in 2012, similar to the US aggregate dynamics.

We thus exploit the dataset to analyse the micro-dynamics of the expenditure distribution. Panel (b) of Figure 1 plots the average transaction price, panel (c) the SD and panel (d) the 10th, 50th and 90th percentiles of the distribution, all normalised to zero in 2007.

Both first and second moments of the expenditure distribution display an increasing trend. On average, transaction prices increase by 1.6% annually between 2004 and 2012. However, during the Great Recession, we observe a decline in the average price and a larger decline in the dispersion of prices. Notably, the average price, which equals $27,226 in 2007, displays a peak-to-trough decline of approximately 2%. The SD, which equals $13,614 in 2007, declines by approximately 5%. Relative to their respective trends, the average price drops by approximately 3% and the SD by approximately 6% during the recession. In summary, our first main finding is that the decrease in dispersion during the recession is about twice as large as the decrease in average expenditures.

The evidence on the first two moments of the distribution suggests that households reallocated their expenditures away from expensive vehicles during the recession. Different percentiles of the



(a) Number of Transactions

(b) Average Transaction Price

(c) SD of Prices

(d) Percentiles of Prices

Fig. 1. *Dynamics of New-Vehicle Expenditures.*
Notes: The figure displays (a) the number of new-car sales, (b) the average, (c) the SD and (d) three percentiles—10th, 50th and 90th—of the distribution of transaction prices from the Dominion dataset. Horizontal axes report years 2004–12; vertical lines highlight recession years (2008 and 2009).

distribution confirm this pattern. Consistent with the low-frequency dynamics of average prices, all percentiles increase over time between 2004 and 2012. However, the median and the 90th percentile decline significantly during the recession, both in absolute terms and relative to their trends. In contrast, the 10th percentile remains on its trend. This analysis suggests that a drop in expenditures on intermediate- and high-quality cars accounts for the declines in the average and the dispersion of expenditures.

These findings are consistent with the evidence on household expenditures based on the Consumer Expenditure Survey. Meyer and Sullivan (2013) documented a low-frequency increase in consumption inequality and a decrease in dispersion during the Great Recession, with lower percentiles of expenditures displaying smaller declines than higher percentiles. However, our dataset allows us to take further steps to connect the distribution of expenditures with features of the goods purchased.

2.2. *Decomposing the Dispersion of Expenditures*

We perform several decompositions of the variance of prices to investigate the drivers of the cyclical dynamics of the distribution of expenditures. Our second main finding is that reallocation of expenditures *between* car models—specifically a drop in expenditures on newly introduced models with high price—accounts for the compression in the distribution in the recession. In contrast, average prices conditional on the vehicle model do not display significant changes relative to their trend.

2.2.1. *Between versus within models*

We decompose the total variance of expenditures on new vehicles in year t, V_t, as

$$V_t = V_t^B + V_t^W,$$

where V_t^B denotes the between-model component of the total variance and V_t^W denotes the within-model component.[8] Formally, we have

$$V_t \equiv \frac{1}{N_t} \sum_{i \in M_t} \sum_{j \in X_{it}} (p_{ijt} - \overline{p}_t)^2,$$

$$V_t^B \equiv \sum_{i \in M_t} s_{it} (\overline{p}_{it} - \overline{p}_t)^2,$$

$$V_t^W \equiv \frac{1}{N_t} \sum_{i \in M_t} \sum_{j \in X_{it}} (p_{ijt} - \overline{p}_{it})^2,$$

where $i \in M_t$ denotes a model sold in year t; $j \in X_{it}$ denotes a transaction on model i in year t, with market share s_{it}; N_t is the total number of transactions in year t; the p_{ijt} are individual prices; $\overline{p}_{it}$ is the average price of model i in year t and $\overline{p}_t$ is the average price in year t.

Figure 2(a) displays the total variance V_t (solid line) and its components: between models V_t^B (dashed line) and within models V_t^W (dash–dot line). The between-model component accounts for almost 80% of total variation in prices before the recession, whereas within-model dispersion in transaction prices accounts for approximately 20% of total variation.[9] Notably, the between-model component accounts for the entire reduction in total dispersion during the recession. In contrast, during the same period there are no significant changes in the dispersion of prices within models. This evidence establishes that households reallocated their expenditures toward models with a price close to the average.

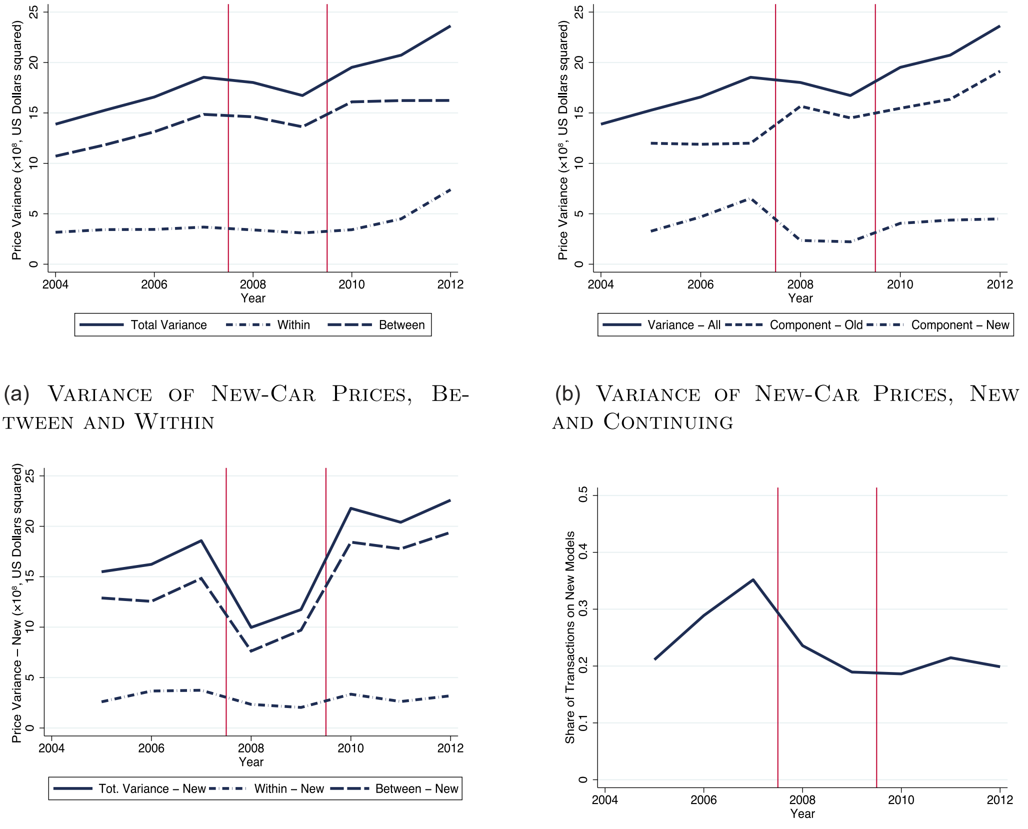
2.2.2. *New versus old models*

The reallocation of expenditures away from expensive models prompts us to analyse the role of newly introduced models. New models tend to be more expensive than continuing models, fuelling the long-run growth in the average price.

Based on our definition of a new model (Section 1), we find that new models play a prominent role in the dynamics of the expenditure distribution. Strikingly, between 2005 and 2007, the

[8] The covariance term equals zero.

[9] Variation in prices within models is mostly due to different trims within each model. This variation does not appear to be relevant for the cyclical dynamics, which confirms that our approach of merging the Dominion and IHS datasets at the model level is sound.



(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

Fig. 2. *Variance Decomposition.*

Notes: The figure displays several decompositions of the variance of transaction prices in the Dominion dataset. Panel (a) 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 (dash–dot line). Panel (b) displays the decomposition of the variance V_t (solid line) into two components: new models $s_t^N V_t^N$ (dash–dot line) and old models $(1 - s_t^N)V_t^O$ (dashed line). Panel (c) displays the variance of expenditures on new models V_t^N (solid line) and its decomposition into a between-model component $V_t^{N,B}$ (dashed line) and within-model component $V_t^{N,W}$ (dash–dot line). Panel (d) displays the share of transactions on new models s_t^N. Horizontal axes report years 2004–12; vertical lines highlight recession years (2008 and 2009).

average transaction price for new models is \$28,080, which is higher than the average for old models, \$26,144. However, in 2008, the average price of new models drops to \$25,764, which is lower than the average for old models, \$26,927.

We analyse the contribution of new models to the variance of expenditures, using the variance decomposition

$$V_t = s_t^N V_t^N + (1 - s_t^N)V_t^O,$$

where s_t^N is the share of transactions on new models in year t and V_t^N (V_t^O) is the variance of expenditures on new (old) models. In turn, these variances equal

$$V_t^N \equiv \frac{1}{N_t^N} \sum_{i \in M_t^N} \sum_{j \in X_{it}} (p_{ijt} - \overline{p}_t)^2,$$

$$V_t^O \equiv \frac{1}{N_t^O} \sum_{i \in M_t^O} \sum_{j \in X_{it}} (p_{ijt} - \overline{p}_t)^2,$$

where M_t^N and M_t^O are the sets of new and continuing models in year t, and N_t^N and $N_t^O = N_t - N_t^N$ are the respective numbers of transactions.

Figure 2(b) displays the decomposition of the total variance of expenditures V_t into expenditures on new models, $s_t^N V_t^N$, and on old models, $(1 - s_t^N) V_t^O$. The component due to new models displays a sharp drop during the recession, fully accounting for the drop in total variance. This pattern arises for two concurring reasons. First, the dispersion of prices of new models drops by nearly one-half during the recession. Figure 2(c) portrays the dynamics of the variance of expenditures on new models V_t^N, showing that its between-model component accounts for its drop, consistent with the same decomposition for all models.

Second, the share of transactions on new models s_t^N decreases sharply, from a peak in 2007 of approximately 35% to less than 20% in 2009, as Figure 2(d) shows, despite the fact that new models were cheaper during the recession.[10] This pattern suggests a drop in the quality of new models during the recession, which is thus the focus of the following subsections. Nonetheless, we do not observe large changes in the variance of expenditures on old models, V_t^O, relative to its trend, suggesting that households did not substitute the 'missing' new models of high quality with old models of high quality—most likely delaying their purchases.

In the aftermath of the recession, the dispersion of expenditures on new models V_t^N returns to its trend. However, Figure 2, as well as Figure B9 in Online Appendix B, show that neither the share of transactions on new models s_t^N nor the fraction of new models on sale overshoots during the recovery. This evidence suggests that car manufacturers did not simply respond to the recession by delaying the introduction of high-quality new models; rather, there was a missing generation of new products, likely contributing to the slow recovery of expenditures.

In Online Appendix B, we analyse cross-sectional heterogeneity in new-model introduction across carmakers. We divide carmakers into three groups, depending on their geographical origin (Europe, Asia and the United States). This analysis reveals two patterns. First, all groups of carmakers decreased the volume of new-model introduction during the recession. Second, European carmakers specialise in the introduction of high-quality models. As a result, they largely account for the drop in high-quality new models during the recession.

We also decompose the margin of new-model introduction between new model names, which may expand the set of models available to consumers (*horizontal* innovation), and new generations of existing model names, which improve on past generations of existing products (*vertical* innovation). Before the recession, both margins account for approximately half of new-model introduction. During the recession, both margins decline, but the bulk of the overall drop in new models is due to missing new generations of existing models. This evidence (tentatively)

[10] The 2007 peak in the market share of new models is due to the simultaneous introduction of new generations of three popular models: Toyota Camry, Nissan Altima and Chevrolet Tahoe. Figure B9 in Online Appendix B displays the time series of the number of transactions on new models N_t^N, as well as the share of models we classify as new.

suggests that the vertical margin of product introduction is more responsive to the drop in demand. However, we acknowledge that it is challenging to tightly associate these categories of new products with different types of innovation, because carmakers may launch a new model name to refresh the image of a new generation of an existing model.

2.2.3. *Geographical variation: Ohio versus Texas*

We now exploit geographical variation across states to connect the dynamics of the dispersion of expenditures with the depth of the recession. This decomposition isolates the role of household demand for quality, because the set of products is constant across states. In particular, we observe variation in the magnitude of the drop in the dispersion of expenditures and a larger quality adjustment in states, where households were hit more strongly by the recession.

To document this pattern, we compare Ohio and Texas, for two main reasons. First, they are the two largest states in our data, and account for the bulk of transactions (approximately 80%). Second, Ohio and Texas experienced starkly different macroeconomic dynamics during the Great Recession, making the comparison of these two states insightful.

To highlight the macroeconomic differences between Ohio and Texas, we follow the approach of Gertler and Gilchrist (2018a), which analysed state-level variation in the intensity of the Great Recession, focusing on house-price and employment dynamics (see also the related approach of Mian *et al.*, 2013). The top panels of Figure 3 portray the Federal Housing Authority house-price index (top left) and total non-farm employment (top right) in Ohio (solid lines) and Texas (dashed lines). Ohio experienced a deep recession, with a 10% home price decline and an 8% employment decline. In contrast, Texas did not experience any housing bust and its decline in employment was less significant.

Geographical heterogeneity in the depth of the recession is likely associated with variation in household *demand* for durable-good quality. Accordingly, Ohio experienced a downward adjustment in the demand for quality more sizeable than Texas: the bottom panel of Figure 3 displays the SD of the distribution of transaction prices in these two states, and shows that the dispersion in Ohio (solid line) dropped more significantly than in Texas (dashed line) during the Great Recession. Consistent with a differential drop in demand for quality, we also find that the compression in the distribution of expenditures in Ohio is primarily due to a relative decline in the median and in higher percentiles, whereas these changes are less pronounced in Texas.

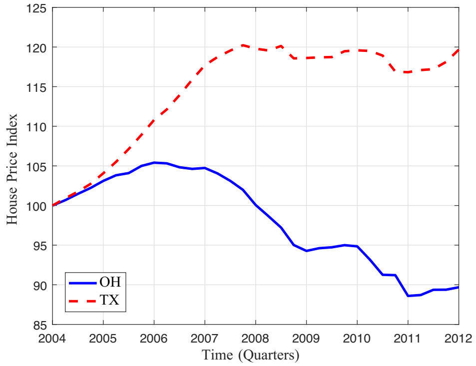
2.3. *Dynamics of the Distribution of Quality*

Our decompositions establish that the heterogeneity between models and, critically, new models are the main drivers of the dynamics of the distribution of new-car expenditures. Moreover, quality differences between new and continuing models were lowest during the recession. These patterns spur us to study vehicle characteristics.

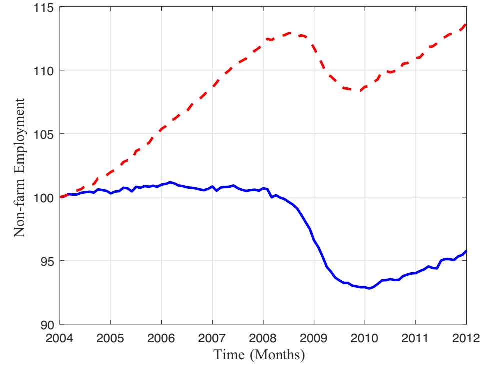
To this end, we use hedonic regressions to estimate the function that maps vehicle characteristics to prices (for a seminal contribution, see Griliches, 1961). Formally, let the average price p_{it} of car model i in year t equal

$$p_{it} = h_t(\mathbf{X}_{it}, \mathbf{W}_{it}, \eta_{it}),$$

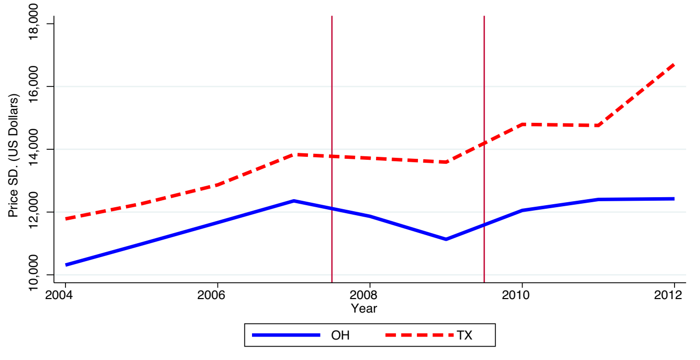
where $h_t(\cdot)$ is the hedonic function; the $\mathbf{X}_{it}$ are observed continuous vehicle attributes, such as fuel efficiency, horsepower, engine size, weight and wheelbase; the $\mathbf{W}_{it}$ are observed discrete



(a) House Price Index



(b) Total Non-Farm Employment



(c) SD of Prices

Fig. 3. *Ohio versus Texas.*

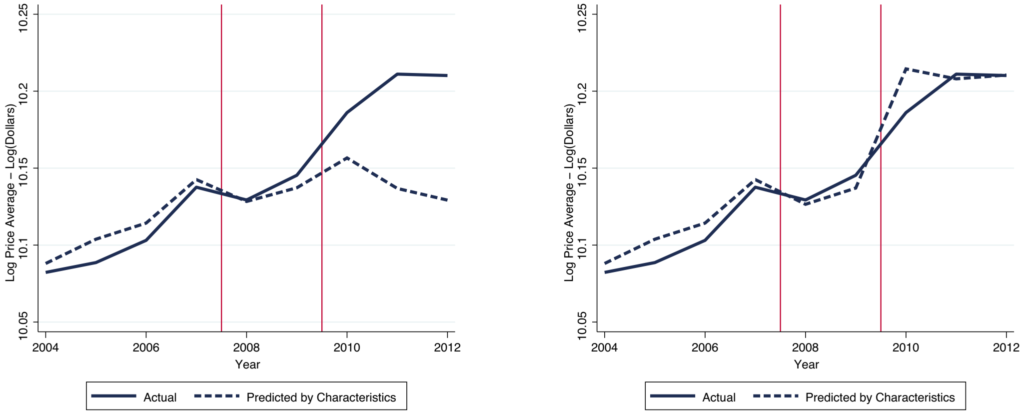
Notes: The figure displays the dynamics of house prices, employment and dispersion of expenditures on new cars in Ohio and Texas around the Great Recession. Panel (a) displays the quarterly purchase-only index of house prices from the Federal Housing Authority and panel (b) displays monthly total non-farm employment from the Bureau of Labor Statistics (Gertler and Gilchrist, 2018b). Both series are normalised to equal 100 in both states at the beginning of 2004. Panel (c) displays the SD of the distribution of transaction prices from the Dominion dataset. Horizontal axes report years. Solid lines refer to Ohio, dashed lines to Texas.

attributes, such as indicator variables for make, four-wheel drive, number of gears, manual transmission, turbo injection, the number of cylinders, diesel, the number of seats and the number of doors; and the η_{it} are unobserved determinants of prices. We transform all continuous variables into logarithms and assume that the log of the hedonic function $h_t(\cdot)$ is linear:

$$\log p_{it} = \boldsymbol{\beta}_t \log \mathbf{X}_{it} + \boldsymbol{\gamma}_t \mathbf{W}_{it} + \eta_{it}. \tag{1}$$

Here $\boldsymbol{\beta}_t$ and $\boldsymbol{\gamma}_t$ are the vectors of coefficients, or 'hedonic prices' of car characteristics.

We observe detailed characteristics of different trims of each model in the IHS dataset, whereas we observe transaction prices at a coarser level of aggregation—namely car models—in the merged dataset. Thus, we aggregate all continuous characteristics of different trims of each model, weighting different trims according to their transaction shares in the IHS dataset, whereas



(a) Constant Hedonic Prices

(b) Time-varying Hedonic Prices

Fig. 4. *Hedonics and Vehicle Quality.*
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—(1)—(dashed lines). Each model is weighted according to its transaction share in the IHS dataset. Panel (a) refers to constant pre-recession hedonic prices (2004–7); panel (b) to time-varying hedonic prices, estimated in three subsamples: pre-recession (2004–7), recession (2008–9) and post-recession (2010–2). Horizontal axes report years 2004–12; vertical lines highlight recession years (2008 and 2009).

we consider different discrete characteristics as different observations, or, equivalently, different models.

We consider three subsamples, pre-recession (2004–7), recession (2008–9) and post-recession (2010–2), assuming that the coefficients are constant within each subsample, but are potentially different across subsamples. We use these hedonic regressions to implement decompositions between the differences in the mean characteristics of vehicles over time, and the differences in the hedonic prices of these characteristics over time (Blinder, 1973; Oaxaca, 1973). We leverage these estimates to track the evolution of the distribution of quality, by assigning a predicted value based on characteristics to each model. Formally, given the estimated hedonic prices $\hat{\boldsymbol{\beta}}_{2004\text{–}7}$ and $\hat{\boldsymbol{\gamma}}_{2004\text{–}7}$, we measure the quality of vehicle j in year $t = 2004, 2005, \ldots, 2012$ as $\hat{\boldsymbol{\beta}}_{2004\text{–}7} \log \mathbf{X}_{jt} + \hat{\boldsymbol{\gamma}}_{2004\text{–}7} \mathbf{W}_{jt}$. This prediction represents the value of the bundle of characteristics contained in model j in year t, based on the dollar value of these characteristics implicit in pre-recession prices.

Figure 4(a) displays our third main finding, which relates the dynamics of average price and average quality during and after the recession. The panel shows that they grow at a similar rate until the recession and, crucially, quality predicts the decline in the average price during the recession. In fact, the decline in average quality between 2007 and 2008 is slightly larger than the decline in the average price. We relate the dynamics of prices to the dynamics of selected characteristics during the recession, analysing the evolution of several variables associated with high quality based on our hedonic regressions, such as wheelbase, horsepower and engine size. The averages of all these characteristics decline during the recession, which suggests a reallocation of expenditures toward smaller and less powerful cars, consistent with the dynamics of prices displayed in Figure 1.

However, Figure 4(a) displays a striking pattern from 2009 onward. Specifically, the average price grows at a rate of approximately 2% per year, whereas the average value implied by car characteristics declines protractedly, diverging from the average price until the end of our sample. Notably, average quality shows no growth in 2007–12, while the average price grows by 7%.

This apparent decoupling between prices and predicted quality, based on pre-recession prices, indicates that the post-recession hedonic prices of some characteristics are higher than their pre-recession values. Different car attributes or brands may have different costs or may be valued differently over time, implying that changes in the state of the economy likely affect hedonic prices (Pakes, 2003). Accordingly, we re-estimate (1) separately in the three subsamples, and use these different estimates to compute a second measure of average quality. Figure 4(b) displays the dynamics of this second measure of average quality, based on time-varying hedonic prices. The panel shows that this measure of average quality tracks the average price closely in all subperiods.

The difference between our first and our second measures of quality confirms that the hedonic prices of some characteristics increased over time. Specifically, the hedonic prices of two important characteristics—wheelbase and horsepower—increased by over 20% in the post-recession sample relative to the pre-recession sample. Changes in the hedonic prices of characteristics associated with high quality have different potential explanations, including a relative scarcity of models in the most expensive segments or time-varying markups. Nevertheless, this increase in the price of quality may partially account for the slow recovery in new-car sales after the Great Recession.

Critically, we find that pre-recession hedonic prices accurately predict the dynamics of expenditures on new models during the recession. The hedonic regression accounts for approximately 98% of the observed drop in between-model dispersion of new-model prices, though it slightly overpredicts the decrease in their average price. These results confirm that reallocation across different levels of quality accounts for the dynamics of the distributions of expenditures on all and new models.

In Online Appendix B, we analyse geographical heterogeneity in the dynamics of car quality, estimating separate hedonic regressions in Ohio and Texas. Both states experience a decline in average prices relative to their respective trends. However, in Ohio—where the recession was deeper—we observe a larger substitution toward models with lower quality, as well as a larger and more persistent gap between price and quality, which buttresses the primary role of household demand for quality.

Finally, we investigate any differential effects between US and foreign carmakers. While the hedonic regressions show that the point estimates of US carmaker fixed effects are lower than those of Asian and European carmakers, the estimates do not show differential changes across periods.

Overall, our hedonic regression analysis highlights some striking dynamics in the quality of vehicles, and confirms a reallocation in expenditures away from high-quality new models. In the next subsection we present a complementary analysis that focuses on technological trade-offs in the set of models available on the market, abstracting from information on prices. This analysis allows us to address some potential limitations of the hedonic methodology, such as the difficulty of disentangling changes in marginal costs from changes in markups, and in preferences for different models that may occur around the recession.

2.4. *New Models and Technological Progress*

We now analyse the level of technology embodied in vehicles, and document a sharp drop in the quality of new models introduced during the Great Recession. This analysis allows us to isolate the role of supply factors for the downward quality adjustment in durable goods.

We follow Knittel (2011) to measure the technological trade-off between fuel efficiency, weight and engine power, and to estimate its evolution over time. This methodology posits a marginal-cost function that depends on vehicle attributes and estimates the level sets of this function, using time fixed effects to capture the evolution of the technological frontier. Specifically, the marginal cost function for vehicle i in year t equals

$$c_{it} = c_t^1(mpg_{it}, hp_{it}, w_{it}, \mathbf{Z^1}_{it}, \mathcal{I}_{it}^N) + c_t^2(\mathbf{Z^2}_{it}),$$

where $c_t^1(\cdot)$ is the component of marginal cost related to fuel economy, which depends on fuel efficiency mpg_{it}, horsepower hp_{it}, weight w_{it} and a subset of characteristics $\mathbf{Z^1}_{it}$ that are relevant for the trade-off of interest; $\mathcal{I}_{it}^N$ is an indicator variable for new models, and $c_t^2(\cdot)$ is the component of the marginal cost that depends on other characteristics that are less related to fuel economy, $\mathbf{Z^2}_{it}$. We include a large set of indicator variables for vehicle characteristics $\mathbf{Z^1}_{it}$, such as make, diesel engine, turbo injection, manual transmission (also interacted with a time trend).

We further assume that vehicle attributes enter the marginal cost function $c_t^1(\cdot)$ in a log-linear form—i.e., the cost function takes the Cobb–Douglas form—and that time t affects this function in multiplicative form—i.e., technological progress is input neutral. Under these assumptions, we estimate the level sets of the marginal cost $c_t^1(\cdot)$ with the specification

$$\log mpg_{it} = \alpha_{hp} \log hp_{it} + \alpha_w \log w_{it} + \boldsymbol{\alpha}_\mathbf{Z} \mathbf{Z^1}_{it} + T_t + T_t \times \mathcal{I}_{it}^N + \varepsilon_{it}, \qquad (2)$$

where T_t is a year fixed effect; $T_t \times \mathcal{I}_{it}^N$ is the interaction between time fixed effects and the indicator variable for new models, which allows regression (2) to flexibly capture a differential effect of the recession on new models; and the ε_{it} are unobservables.

Whereas the hedonic approach combines the reallocation of demand and changes in the supply of quality, the marginal cost estimation likely highlights quality changes that originate on the supply side of the market. We estimate (2) in two ways, first weighting models by the number of transactions, and then without sales weights, which further isolates changes in the quality of products supplied.[11]

Figure 5 displays the estimated year fixed effects for new models (light markers) and old models (dark markers), relative to their pooled baseline value in 2004, normalised to zero. Panel (a) portrays the estimates of the sales-weighted regression and panel (b) refers to the unweighted regression. In both cases, we find that, typically, the level of technology grows over time, with new models displaying superior technology over old models. However, our fourth main finding is that, during the Great Recession, the growth rate of quality of new models declines: in 2008, the estimated quality of new models is similar to the quality of old models, which implies a halt in the adoption of frontier technologies embodied in new vehicles. Consistent with this drop in technology adoption, we estimate that the quality of continuing models also declines in 2008 due to an inferior mix of characteristics.

[11] In both cases, for consistency with our analysis of Section 2.3, we aggregate all continuous characteristics of different trims of each model at the model level, weighting different trims according to their transaction shares, and we consider different discrete characteristics as different observations.

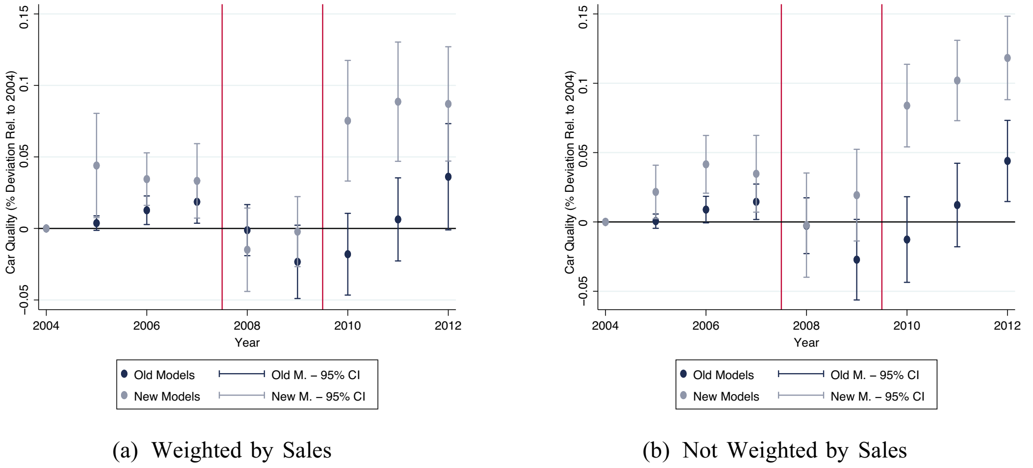


Fig. 5. *Technology of New and Old Models.*
Notes: The figure displays the estimated average level of technological efficiency for new models (light markers) and old models (dark markers), measured as the estimated time fixed effects in regression (2). Panel (a) refers to a regression with weights based on the number of transactions in the IHS dataset, whereas panel (b) refers to a regression without weights. The horizontal axis reports years 2004–12; vertical lines highlight recession years (2008 and 2009).

Quantitatively, the coefficients displayed in Figure 5 mean that the average level of technology of new models declines by almost 5% between 2006 and 2008. The similarity in panels (a) and (b) supports the notion that the main driver of this decline is that the quality of newly introduced vehicles drops in the recession.

We further estimate the technology levels separately for models introduced by European, Asian and US carmakers. We find that the drop in new-product quality is largest for European carmakers, which on average specialise in high-quality models. This finding, along with our finding on the crucial role of European carmakers for high-quality models (Section 2.2.2), supports our interpretation that the downward quality adjustment on the supply side is likely an endogenous response to the drop in demand, and less likely due to other shocks hitting carmakers, such as financial shocks, which were more severe for US manufacturers.[12]

Although the technological level of new models recovers sharply from 2010, the low quality of new models introduced during the recession—which remain in the set of available models for several years—persistently drags the average level of technology for the continuing models, which remains on a lower path throughout the recovery. Overall, the technological level of old models breaks its pre-recession 2007 level only at the end of our sample, as models introduced during the recession are gradually replaced.

Accordingly, we perform a back-of-the-envelope calculation of the effects of these dynamics on the average quality of the overall stock of registered cars, combining our estimated level of technology for new cars with information on new-car registrations during the period of our analysis. Online Appendix B.4 provides the details of this calculation. We estimate that, by 2012, the quality of the car stock was 1.3% lower than if new-car technology and new-car registrations

[12] Furthermore, we find that the technology level evolves similarly for new model names and new generations of existing model names.

had remained on their pre-recession trends. The drop in new-car quality accounts for almost one percentage point of this decline.

3. Concluding Remarks

Our analysis shows that both demand and supply factors contributed to a downward quality adjustment in expenditures during the Great Recession. Amid a decline in demand and a reallocation of expenditures away from expensive models, automakers introduced models of low quality, leading to a persistent decline in technology.

We argue that alternative mechanisms that exclusively affect demand or supply cannot fully account for all patterns on quality dynamics that we uncover. Geographical variation in expenditures highlights the critical role of household demand for quality, and is thus inconsistent with supply shocks hitting only manufacturers—such as financial shocks—determining quality dynamics. Our finding that manufacturers modified the path of technology embodied in new models points to an important role for supply, inconsistent with an explanation based exclusively on household demand, through substitution toward lower quality within a fixed set of products.

We believe that this evidence will prove useful in informing quantitative models of innovation over the business cycle.

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Additional Supporting Information may be found in the online version of this article:

Online Appendix
Replication Package

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