Do Market Shares or Technology Explain Rising New Vehicle Fuel Economy?

Shefali Khanna and Joshua Linn

DISCUSSION PAPER

RESOURCES
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Abstract

By decreasing gasoline consumption, greater fuel economy could significantly reduce environmental and energy security concerns. In this paper, we show that since the year 2000, technology and market shares have contributed roughly equally to rising new vehicle fuel economy in the United States. We discuss the implications of these patterns for the safety and welfare effects of fuel economy standards.

Key Words: corporate average fuel economy standards, passenger vehicles, fuel savings, vehicle safety, greenhouse gas emissions rate standards

JEL Classification Numbers: Q4, L62

Contents

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1. Introduction

In the United States, public concerns about climate change and energy security have varied over time, but lately average new vehicle fuel economy has been improving steadily. Between 2000 and 2012, sales-weighted fuel economy increased more than 4 miles per gallon (mpg), or about 19 percent. Current fuel economy standards require about a 50 percent additional increase by 2025.[1] The increases represent a dramatic change from the preceding two decades, over which fuel economy steadily decreased, largely because of the rising market share of light trucks at the expense of cars.

This paper considers whether market shares or technology explain the recent fuel economy increases. Did the increase in fuel economy since 2000 result from consumer decisions, such as purchasing smaller sports utility vehicles (SUVs) rather than larger ones, or from manufacturers' use of technology to improve fuel economy? Market shares can explain the increase in aggregate fuel economy if the market shares of high fuel economy vehicles increased at the expense of the market shares of low fuel economy vehicles, with technology being held constant.

Alternatively, manufacturers can alter the technology in two ways. For one, they can change a particular power train to increase fuel economy, such as replacing a five-speed with a six-speed transmission. They also can change which versions of particular models they offer in the market. For example, if a manufacturer sells a four-cylinder and six-cylinder version of a particular model, it could stop selling the six-cylinder version. Either would represent a change in the set of technologies offered to consumers.

Distinguishing between the effects of technology and market shares is important for two reasons. First, if market shares explain the rising fuel economy, because vehicle weight and fuel

economy are negatively correlated, the average weight of new vehicles could decrease. This would create a disparity between the weight of new vehicles sold in the early 2000s—many of which were very large SUVs, such as the Ford Excursion—and that of new vehicles sold in more recent years. Because weight disparity is an important determinant of the severity of multivehicle accidents, such a disparity could cause multivehicle accidents to be more harmful to drivers and passengers (National Research Council 2002; NHTSA 2003b). A decline in weight in recent years would support the arguments made by some opponents of higher fuel economy standards.[2]

Second, distinguishing between market shares and technology can provide insights into the effects of fuel economy standards on consumer welfare. When estimating the costs and benefits of proposed fuel economy and greenhouse gas emissions rate standards, the responsible administrative agencies—the National Highway Transportation and Safety Administration (NHTSA) and the Environmental Protection Agency (EPA)—assume that the standards do not affect market shares. The agencies argue that it is therefore appropriate to compare the costs and benefits of increasing fuel economy for each vehicle without allowing for the possibility that consumers substitute among vehicles. Because fuel economy standards for light trucks have been tightening since 2005, examining the importance of changing market shares during that period provides some insight into whether tightening standards affect market shares and whether the EPA and NHTSA should include such welfare effects in their analysis.

We show that technology and market shares each account for half of the 4 mpg increase in fuel economy between 2000 and 2012. The importance of market shares is consistent with the leveling off of vehicle weight in recent years (EPA 2013). Fuel economy has increased much more for cars (5 mpg) than for light trucks (3 mpg). Within the car and light truck categories, there is considerable heterogeneity in the rates and sources of the fuel economy improvements, with SUVs, vans, and medium-size cars having seen the greatest increases. Among light trucks, technology explains a much larger share of the overall increase than market shares, whereas for cars, technology and market shares have roughly equal importance. The timing of the fuel economy standards is roughly consistent with the rising importance of technology.

As part of the retrospective analysis of the U.S. new vehicles market, we consider whether the light truck fuel economy changes are consistent with NHTSA's predictions for the

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[2] We thank Antonio Bento, Kenneth Gillingham, Kevin Roth, and Yiwei Wang for suggesting the importance of fuel economy standards and changes in vehicle weight.

light truck fuel economy standards that were implemented from 2005 to 2011. Prior to implementation, NHTSA predicted changes in fuel economy caused by the standards, given expected gasoline prices and other factors that could affect technology or market shares. Therefore, one might expect the NHTSA predictions to differ from what actually occurred; if there were large differences, it would be necessary to determine the underlying causes. We find that NHTSA predictions of manufacturer-level fuel economy increases are positively correlated with observed increases, but there are notable discrepancies.

Returning to the questions motivating the analysis of technology and market shares, the results suggest that new vehicles sold in the last few years are no lighter than vehicles sold 5 or 10 years ago. This mitigates concerns about safety and increasing fuel economy standards. The relative importance of technology for light trucks starting in 2005 and for cars starting in 2009 is consistent with the EPA and NHTSA assumptions about market shares, although we do not test these assumptions formally.

2. Possible Explanations for Rising Fuel Economy

Our aim is to understand the underlying sources of recent new vehicle fuel economy increases, but to provide some context for the following analysis we first briefly discuss three possible explanations for the increases: gasoline prices, rising new vehicle fuel economy standards, and the recession. The real gasoline price in 2012 was $2.30 per gallon higher than it was 10 years earlier. Recent research, such as Klier and Linn (2010) and Busse et al. (2013), suggests that average new vehicle fuel economy increases 1 mile per gallon when the price of gasoline rises by $1 per gallon. Higher gasoline prices may therefore explain a large share of the recent increase in average new vehicle fuel economy.

Rising fuel economy standards also may have played a role. Following a pattern roughly similar to that of gasoline prices, fuel economy standards were constant from the mid-1980s until 2005 and then began increasing. Between 2005 and 2012, the standards for light trucks increased from 20.7 to 25.4 mpg. The standards for cars began increasing in 2011.

The recession in the late 2000s is the final possible explanation for improving fuel economy. The recession have could contributed to rising fuel economy if the falling income and wealth caused consumers to purchase new vehicles with higher fuel economy more than they would have otherwise, either out of a desire to reduce fuel costs or because fuel-efficient vehicles tend to be less expensive than larger vehicles.

To be clear, the purpose of our paper is not to understand which explanation is correct. Rather, we want to understand how fuel economy has been changing, leaving for future research the question of why it has been changing.

3. Data

The primary data include vehicle sales and fuel economy by model and model year from WardsAuto. A model year begins in September of the previous calendar year and ends in August of the current calendar year. The data were assembled using the same methodology as described in Klier and Linn (2010) and extended through the 2012 model year.

We also obtained estimates of achievable fuel economy for model years 2005–2007 and 2008–2011 from NHTSA's Final Regulatory Impact Analyses (RIAs) of the light truck Corporate Average Fuel Economy (CAFE) standards. Before implementing the standards, the agency assessed manufacturers' possible responses to higher CAFE standards. The assessment rests on the Volpe Analysis, a computer algorithm that takes cost and performance assumptions as inputs. The agency assumed that no changes in weight, performance, or product mix would be necessary to meet the proposed standards. It used market-level sales projections for 2005–2007 and 2008–2011 from the forecasts published by the Energy Information Administration (EIA) in its 2002 and 2005 *Annual Energy Outlook*. NHTSA assumed that each manufacturer's share of the light truck market would equal its share at the start of the period.

To assess each manufacturer's responses to the standards, the Volpe Model considers the applicability of each technology to every model, engine, and transmission in a manufacturer's product line. Technologies are added based on cost effectiveness and the process terminates once each manufacturer meets the CAFE standards, when all available technologies have been exhausted, or when the costs of applying additional technology exceed the level of penalties charged for noncompliance.[3]

We have obtained the model's predicted fuel economy by manufacturer and year, which is the sales-weighted harmonic average of the estimated fuel economy of each model sold by the manufacturer. For confidentiality reasons, NHTSA did not provide model-level predictions.

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[3] Cost effectiveness is defined as the cost per percentage point fuel economy improvement; the calculation of costs is slightly different between the NHTSA analysis of the 2005-2007 and the 2008-2011 standards. The model also includes some constraints on the order in which technologies can be added.

4. Methodology

We take a straightforward approach to decompose overall changes in fuel economy into two components: technology and market shares. For a set of vehicles, J , the sales-weighted average fuel economy at time t of all vehicle models, j , in the set is $\sum_{j \in J} w_{jt} m_{jt}$, where w_{jt} is the share of sales of model j in total sales of models in set J and m_{jt} is the fuel economy of model j . In the following analysis the set J could include all vehicles in the market or it could include vehicles belonging to a particular market segment such as SUVs.

The change in the sales-weighted fuel economy between two years, s and s' , is the sum of three terms:

$$\Delta m_{s,s'} = \sum_{j \in J} w_{js} \Delta m_{j;s,s'} + \sum_{j \in J} \Delta w_{j;s,s} m_{js} + \sum_{j \in J} \Delta w_{j;s,s'} \Delta m_{j;s,s'}$$

where the first term on the right-hand side is the inner product of the market share in period s and the fuel economy change between the two periods (i.e., the sum of the product of initial fuel economy and the fuel economy change); the second term is the inner product of the change in the market share and the initial fuel economy; and the third term is the inner product of the change in market share and the change in fuel economy. The third term is the correlation between the change in market share and the change in fuel economy. For nearly all cases the vehicles and time periods we consider, the third term turns out to be close to zero.

This gives rise to a simple interpretation of the first two terms. The first term represents the change in fuel economy accounted for by within-model fuel economy changes—that is, the contribution of technology, holding fixed market shares at their initial levels. The second term is the contribution of changes in market shares to the overall change in fuel economy, holding fixed technology at its initial level. The larger the first term is compared with the second, the more technology explains the overall changes in fuel economy.

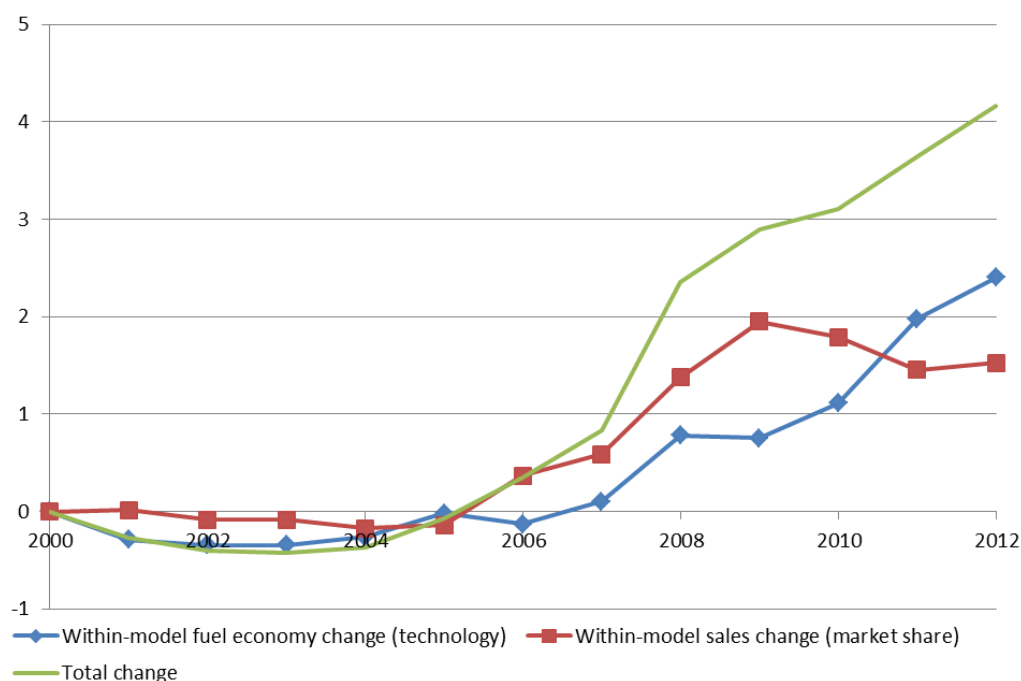## 5. Technology versus Market Shares

Figure 1 plots the change in average fuel economy since 2000 and the first two terms in equation (1). The sample includes all vehicles in the U.S. market. To compute the two terms in equation (1) and the average fuel economy change, we include vehicles sold in consecutive years. For example, to compute the first (i.e., technology) term for 2004, we use vehicles sold in 2003 and 2004, multiplying the 2003 market share by the change in fuel economy between 2003 and 2004. To compute the second (i.e., market share) term for 2004, we use the same vehicles and multiply the 2003 fuel economy by the change in market share between 2003 and 2004.

The figure plots the running sum of these calculations across years. To interpret the figure, suppose the total fuel economy change is positive over a particular time period. If the market share term is constant during this period and the technology term is rising, we conclude that technology explains the rising fuel economy.

The figure shows that average fuel economy decreased slightly in the early 2000s, and that technology explains most of this decrease. Starting around 2005, technology and average fuel economy began increasing slowly. The rate of increase for both technology and average fuel economy accelerated around 2007.

Market shares exhibit a somewhat different temporal pattern. Market shares explain increases in average fuel economy from about 2006 to 2009 but generally not in other years. Overall, market shares explain about half of the average fuel economy increase from 2000 to 2012, but the figure shows that the contributions of technology and market shares vary over time.

Figure 1. Contribution of Within-Model Sales and Fuel Economy Changes to Total Fuel Economy Change, All Passenger Vehicles


Notes: The figure plots the total change in fuel economy and the first two terms in equation (1) for the years 2000 to 2012. Within-model fuel economy change refers to the first term in equation (1), and the within-model sales change refers to the second term in the equation. The sample includes all vehicles in the U.S. market. For each year, the total change and the terms in equation (1) are computed using models with positive sales in the previous and current model years.

Figure 2 separates the market into two vehicle types: cars and light trucks. Average fuel economy for cars increased by about 5 mpg from 2000 to 2012, with most of the increase occurring after 2004. Market shares explain most of the initial increase, with technology's importance increasing at the end of the period. Klier and Linn (2010) show that gasoline prices explain much of the changing market shares prior to 2007. The standards for cars, which began increasing in 2011, were adopted in 2007. The timing of the changes in Figure 2 suggests that the standards could explain the importance of technology after 2008; although the fuel economy standards were not implemented until 2011, because of design lags the automakers may have begun designing vehicles to meet the standards ahead of time. Gas prices or the recession could also explain the importance of technology, and we leave for future research the question of which factors explain the contributions of technology from 2008-2012.

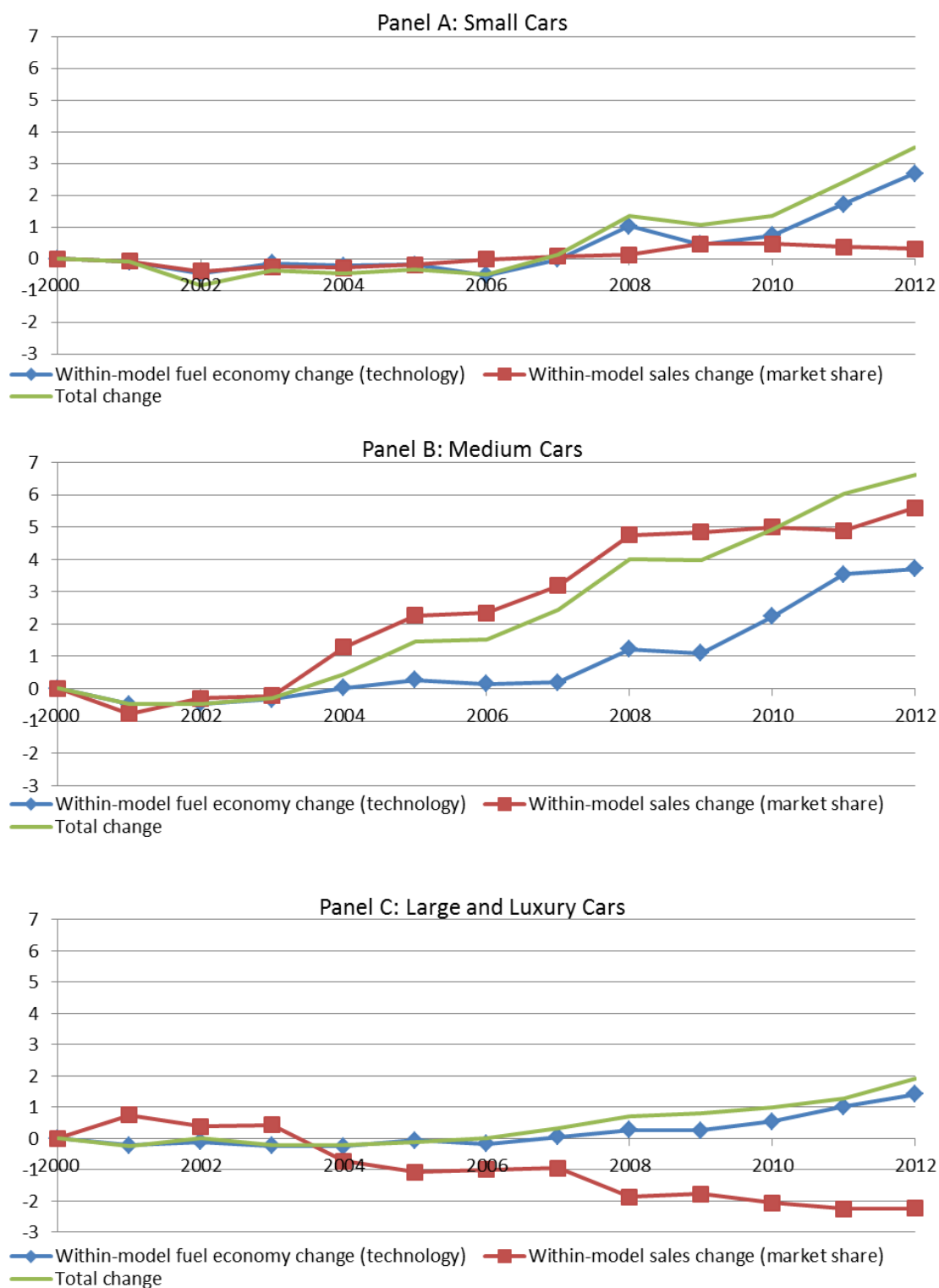**Figure 2. Fuel Economy Decomposition by Cars/Light Trucks**
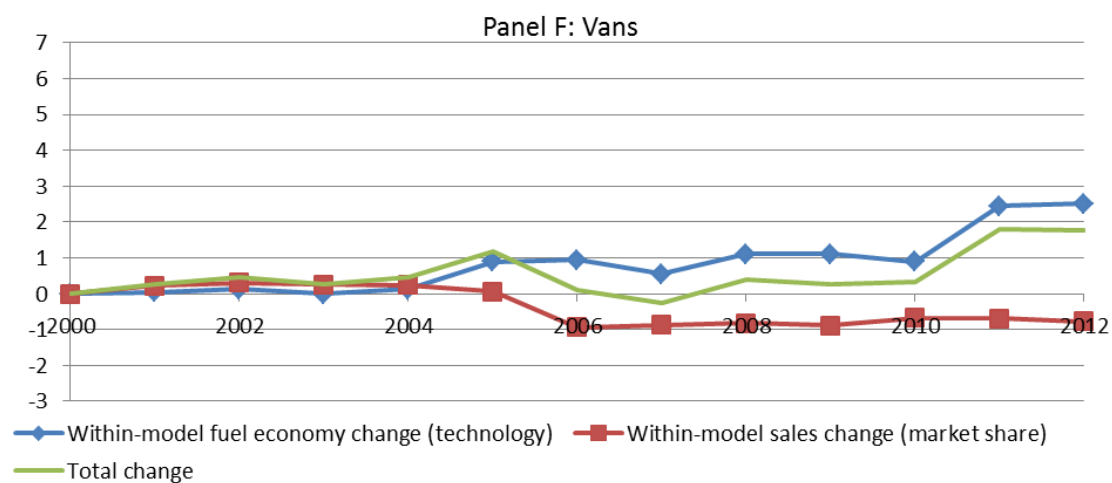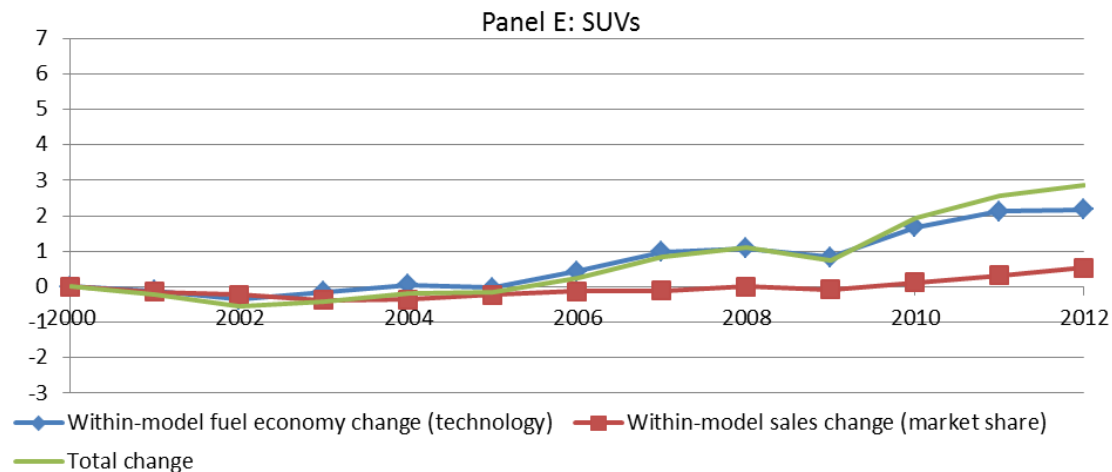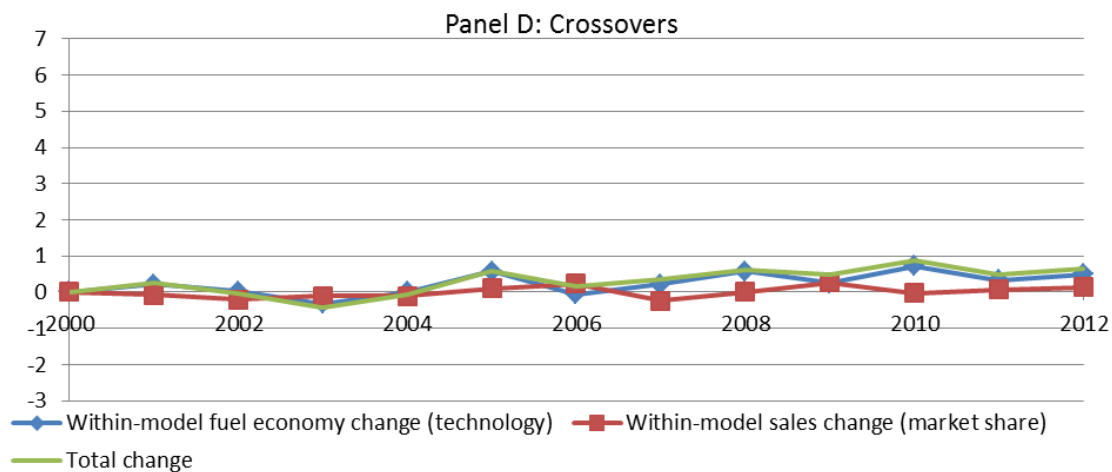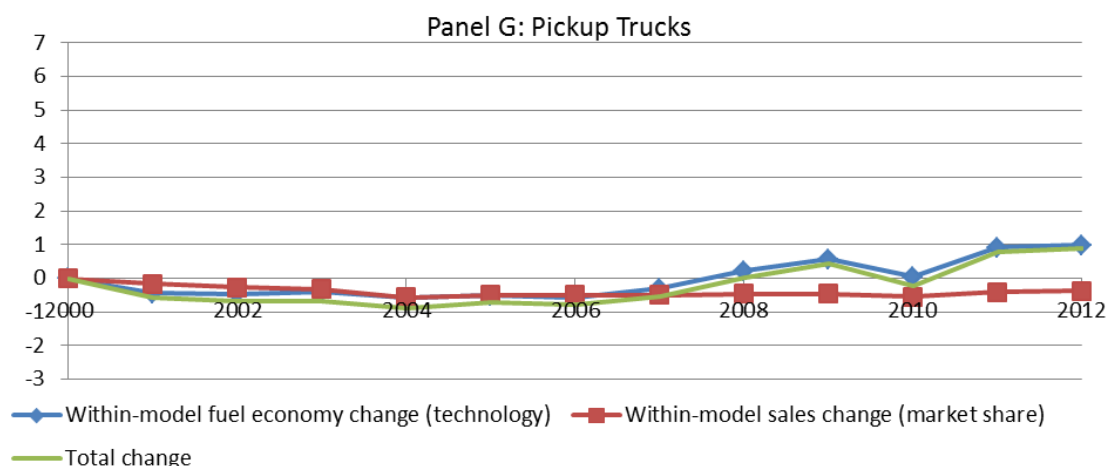
Panel B: Light Trucks
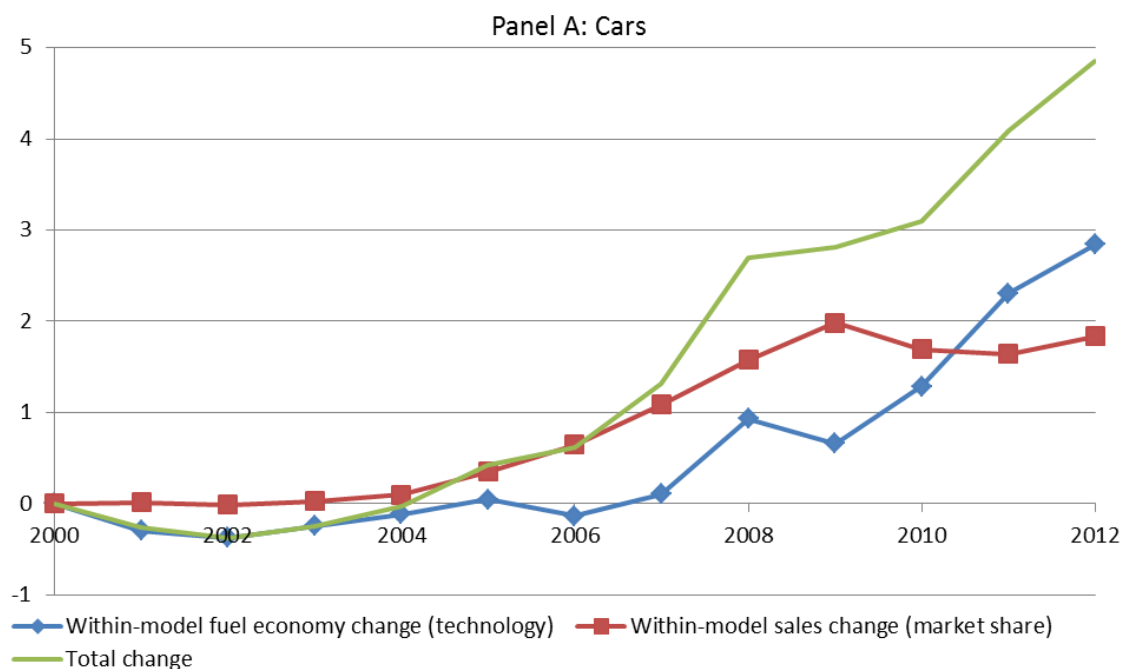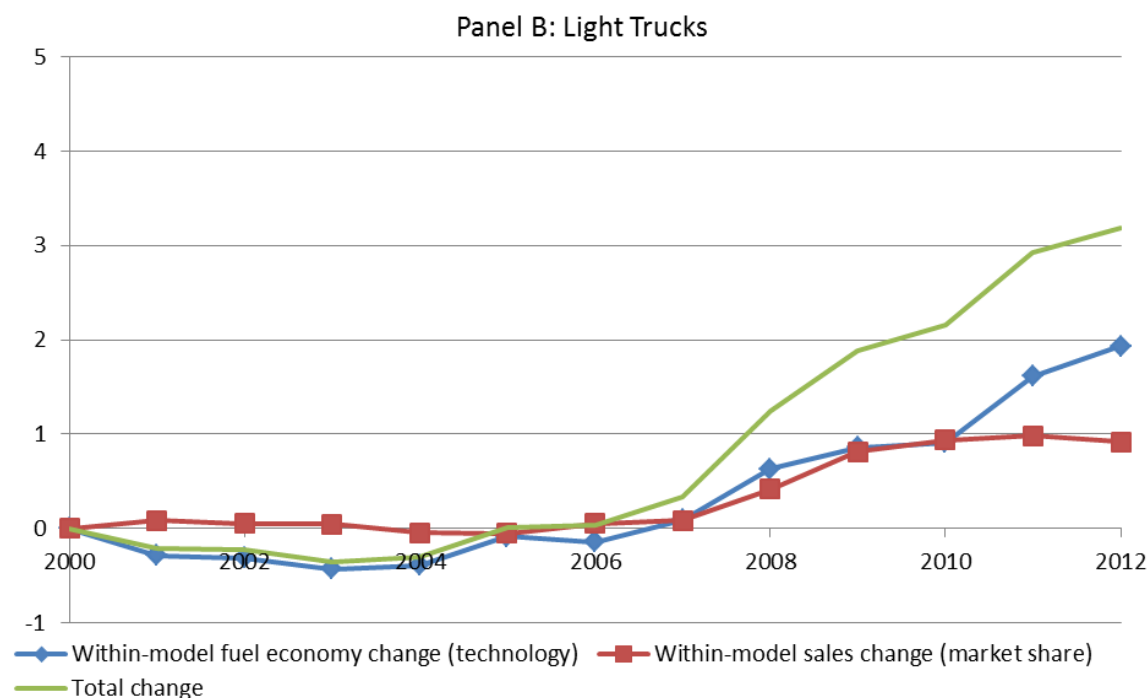
Note: The figure is constructed similarly to Figure 1, except that Panel A includes only cars and Panel B includes only light trucks.

The patterns for light trucks are somewhat different than those for cars. Technology increased light truck fuel economy beginning in 2005, rather than around 2008 as for cars (although the difference is not very large). The earlier technology effect is consistent with the fact that the fuel economy standards for light trucks began increasing in 2005, whereas the standards for cars began increasing much later, in 2011. Light truck market shares and technology contributed about equally to the overall fuel economy increase.

Figure 3 distinguishes seven market segments, as defined by Wards. The first three categories include cars, across which we observe some notable differences. Although technology raised fuel economy around the same time for all three car categories, the effect of technology was much greater for small and medium cars than for large and luxury cars. Market shares have had a much larger effect on fuel economy for medium cars than for the other categories.

Figure 3. Fuel Economy Decomposition by Market Segment

Panel A: Small Cars

Legend:
- Within-model fuel economy change (technology)
- Within-model sales change (market share)
- Total change

Panel B: Medium Cars

Legend:
- Within-model fuel economy change (technology)
- Within-model sales change (market share)
- Total change

Panel C: Large and Luxury Cars

Legend:
- Within-model fuel economy change (technology)
- Within-model sales change (market share)
- Total change

Panel D: Crossovers

Legend: Within-model fuel economy change (technology) — Within-model sales change (market share) — Total change

Panel E: SUVs

Legend: Within-model fuel economy change (technology) — Within-model sales change (market share) — Total change

Panel F: Vans

Legend: Within-model fuel economy change (technology) — Within-model sales change (market share) — Total change

Panel G: Pickup Trucks

Note: The figure is constructed similarly to Figure 1, except that each panel includes models belonging to the indicated market segment.

There is also substantial variation across the light truck segments. Fuel economy increased much more for SUVs and vans than for crossovers and pickup trucks. For the SUVs and vans, technology explains a much larger share of the overall increase than market shares. The relative importance of technology is consistent with the aggregate light truck results in Figure 2.

Figures 1–3 suggest that market shares explain a significant fraction of the overall fuel economy increase. Because vehicles with high fuel economy tend to have lower weight, the changing market shares suggest that average weight may have decreased. Given that accident severity for multivehicle crashes depends partly on weight disparity, changes in new vehicle weight could have safety implications. Figure 4 plots the change in average log weight (sales-weighted) from 2000 to 2012 for all vehicles, for cars, and for light trucks in the U.S. market. Weight of light trucks increased steadily from 2000 until about 2005, after which it leveled off. Weight of cars increased from 2000 until about 2008 and then leveled off. The fact that the inflection point for cars occurred more recently than for light trucks suggests that fuel economy standards partially explain the decrease in the growth rate of vehicle weight. Importantly from the perspective of passenger safety, the growth rate of weight has slowed down considerably, but new vehicles are not lighter on average than older vehicles. This lessens concern about the safety implications of recent market share changes.

Figure 4. Change in Log Vehicle Weight, 2000–2012
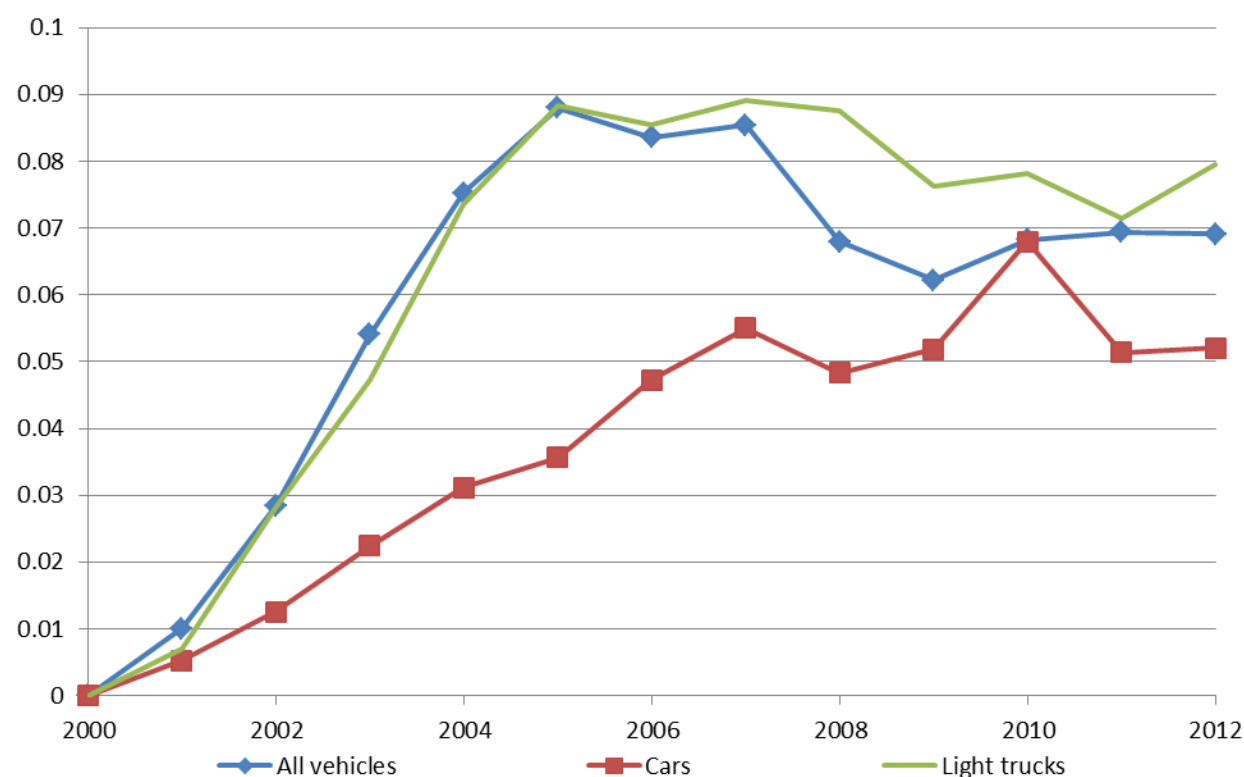
Notes: The figure plots the change in log weight since 2000 for all vehicles, cars, and light trucks. The sample includes all vehicles in the U.S. market.

To summarize, we observe substantial differences across segments and vehicle types in the amount by which fuel economy increased and in the relative contribution of market shares and technology to the overall increases. For cars and light trucks, technology and market shares had similar effects on fuel economy over the entire period, but technology has been more important than market shares in recent years. There is some indication that technology became more important earlier for light trucks than for cars. This difference is consistent with the hypothesis that the increasing light truck fuel economy standards caused technology to raise overall fuel economy starting in 2005. Finally, despite the changes in market shares, vehicle weight has leveled off since the late 2000s.

6. Comparing Actual Fuel Economy Changes with NHTSA Predictions

Having shown that technology explains about half of the total change, we turn to the NHTSA predictions of fuel economy increases under the light truck standards between 2005 and

2011. Section 5 reports substantial differences across light truck market segments in the level of the fuel economy increase as well as the contribution of technology and market shares to this increase. Here we compare the observed outcomes with the NHTSA predictions. Large differences between observed and predicted outcomes would not necessarily mean that the NHTSA predictions are faulty, but such differences would motivate a further examination of their causes.

In its cost–benefit analysis, NHTSA predicts the fuel economy change of each model in the market at the beginning of the period being analyzed. For example, the analysis of the 2005–2007 standards includes models sold in 2004. Based on reported manufacturer production plans and the computational model described in Section 3, NHTSA predicts the fuel economy change for each model. We compare predicted and actual fuel economy changes by manufacturer.

Figure 5 shows a series of scatter plots of actual and predicted fuel economy change by manufacturer for 2005–2007 (Panel A), 2008–2011 (Panel B), and 2005–2011 (Panel C). For consistency with the NHTSA predictions, we calculated the harmonic average fuel economy for each manufacturer using actual sales. Each point in the figure plots the predicted against the actual change for a particular manufacturer. The solid line in each plot is the 45-degree line. If a manufacturer's point is above the line, the predicted fuel economy change for that manufacturer is higher than the actual change. The figure shows that actual and predicted fuel economy changes are closer for the 2008–2011 period than for the 2005–2007 period. The correlation between actual and predicted changes is close to zero in the first period and close to 0.3 in the second period (excluding the outlier). Thus the correlation is greater when fuel economy was increasing more quickly. As mentioned earlier, the sales forecasts that NHTSA used to predict fuel economy were taken from EIA's 2002 and 2004 *Annual Energy Outlook*. Likely because of the recession, actual sales turned out to be much different from the 2008–2011 forecasts. The recession may therefore explain the discrepancies between actual and predicted fuel economy, but gas prices and modeling assumptions may also play a role; research is needed to disentangle these possibilities.

Figure 5. Predicted and Actual Changes in New Light Truck Fuel Economy

Panel A: 2005-2007

Panel B: 2008-2011

Panel C: 2005-2011
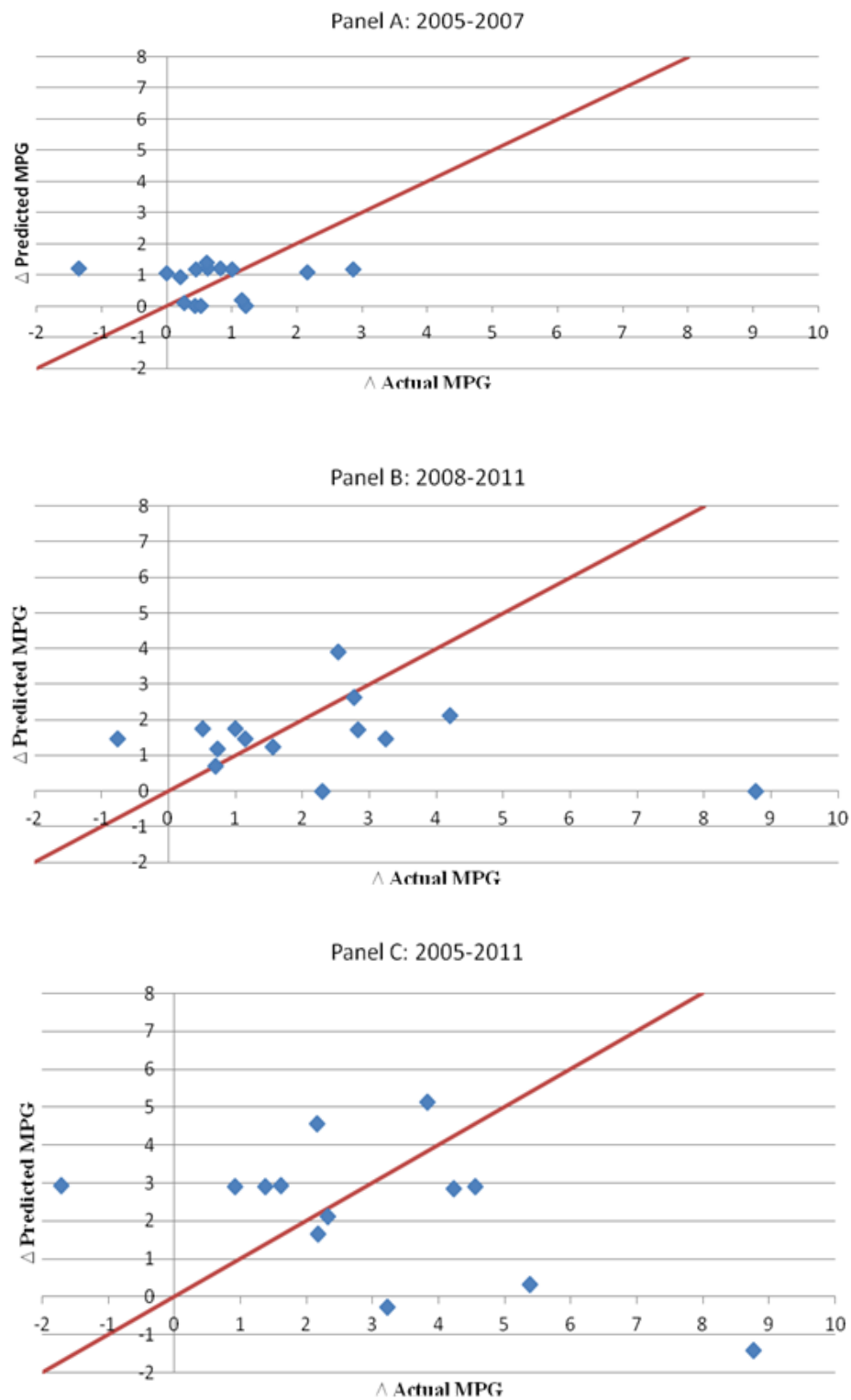
7. Conclusions

Recent increases in average new vehicle fuel economy can be explained by two overarching factors: changes in the mix and application of vehicle technologies and changes in market shares. Our results suggest that the two factors contributed almost equally to the overall increase in fuel economy over the last decade. However, there have been some differences between cars and light trucks, and larger differences within the car and light truck categories. Market shares had a substantially larger effect on the fuel economy of cars than on that of light trucks between 2005 and 2008. Roughly consistent with the adoption of the timing of the tighter fuel economy standards, technology's contribution increased for light trucks around 2005 and for cars around 2009. Mitigating concerns about the safety consequences of rising fuel economy standards, average weight has leveled off but has not decreased. Turning to the NHTSA analysis of the light truck standards, actual and predicted changes in sales-weighted light truck fuel economy from 2005 to 2011 are positively correlated, although the correlation is not very high.

The importance of technology for light trucks from 2005 to 2008 and for cars from 2009 to 2012 suggests that fuel economy standards have affected technology. The importance of technology also provides some support for the EPA and NHTSA assumption that fuel economy standards do not affect market shares. Quantitative research is needed into the causes of the changes in technology and the welfare consequences of these changes.

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