EXPLAINING THE U.S. PETROLEUM CONSUMPTION SURPRISE

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### Contents

Executive Summary........................................................................................................................................... 2

I. Introduction: Overview of the U.S. Consumption Surprise ........................................................................ 4

II. Historical and International Perspectives .................................................................................................. 6

   Historical Context for the Consumption Surprise .................................................................................. 6
   The U.S. Consumption Surprise from an International Perspective ....................................................... 7

III. Decomposing the U.S. Consumption Surprises .................................................................................... 9

   Decomposition by Sector and Fuel ........................................................................................................ 9
   Decomposition of the Vehicle Fuel Consumption Surprises ................................................................ 13
   Summary of the Consumption Surprises .................................................................................................. 14

IV. A Closer Look at Vehicle Fuel Consumption ....................................................................................... 15

   Decomposition of Vehicle Fuel Consumption by Vehicle Type ............................................................ 15
   Gasoline Prices, Fuel Economy Standards, and Light-Duty Fuel Consumption Rates ......................... 15
   Why Have Household Vehicle Miles Traveled Started to Decline? ................................................... 19

V. Conclusion ................................................................................................................................................ 22

References .................................................................................................................................................... 23

Appendix ......................................................................................................................................................... 24

   Comparison of EIA and Other Projections .............................................................................................. 24
   Methodology for Decomposing EIA Projections .................................................................................... 25
      Sum of Parts Decomposition ............................................................................................................. 25
      Log-Product Decomposition .............................................................................................................. 25
   Overview of the Recent Household VMT Literature ............................................................................ 26
   Household VMT Data ............................................................................................................................. 27
   VMT Methodology .................................................................................................................................. 28
Executive Summary

U.S. oil production has transformed fundamentally in the past decade. After two decades of steady decline, domestic crude oil production grew by nearly 75 percent between 2008 and 2014, and each month since October 2013 production has exceeded net imports, which hadn’t happened since the mid-1990s. While developments in oil production have been widely reported and appreciated, far less attention has been paid to the remarkable and surprising decline in U.S. petroleum consumption relative to both recent levels and past projections. This report identifies the mechanisms behind the surprising decline. Quantifying the underlying causes improves understanding of why the consumption path has changed, how it might evolve in the future, and the role that the President’s clean energy strategy and other public policies might play in further change. We find that:

- **U.S. petroleum consumption was lower in 2014 than it was in 1997, despite the fact that the economy grew almost 50 percent over this period.** Petroleum consumption peaked in 2004 and the subsequent decline was one of the biggest surprises that has occurred in global oil markets in recent years. Actual consumption in 2014 was 6.4 million barrels per day (b/d) below the 2003 projection of 2014 consumption, which we refer to as the 25 percent consumption surprise for 2014. This consumption surprise is nearly twice as large as the 3.4 million b/d U.S. production surprise in 2014, and it frees up roughly $150 billion for spending on other purposes (2014 dollars).

- **The U.S. petroleum consumption surprise is expected to grow over the next decade, from a 25 percent downward revision in petroleum consumption in 2014 to a projected 34 percent downward revision in projected consumption for 2025, both relative to the projections made in 2003.** Just about a decade ago, petroleum consumption was expected to increase steadily through at least 2025. After falling in actual terms, the trajectory for consumption going forward is now expected to be flat in overall terms and declining as a share of the economy. As a result, the petroleum consumption surprise is expected to grow from 6.4 million b/d in 2014 to 10.0 million b/d in 2025.

- **The U.S. petroleum consumption surprise exceeds that of nearly all other advanced economies.** The consumption surprise for European OECD countries is about half that of the United States, amounting to about 13 percent in 2015 and declining slightly to a projected 12 percent in 2025. For other OECD countries, the surprises are even smaller, at 7 and 11 percent in 2015 and 2025. The consumption surprises for Japan lie just below those of the United States.

- **The transportation sector accounts for 80 to 90 percent of the 2014 and 2025 petroleum consumption surprises.** The industrial sector accounts for most of the remainder, at around 20 percent in 2014 and 7 percent in 2025, while the residential and commercial sectors account for a combined 4 percent of the surprise in both years. While other sectors have
experienced similar percentage surprises as the transportation sector, because they consume considerably far less petroleum, they do not contribute nearly as much to the overall story.

- **Within the transportation sector, declining vehicle miles traveled (VMT) has had a greater effect on consumption than rising fuel economy to date, but the role of fuel economy grows through 2025.** In 2014, rising fuel economy explains roughly 25 percent of the consumption surprise, and VMT explains the remaining three quarters. In 2025, however, the factors are more comparable, accounting for 45 percent (fuel economy) and 55 percent (VMT).

  - *Fuel economy standards and fuel prices explain large shares of the increase in light-duty fuel economy.* Fuel economy standards explain up to 43 percent of the increase in fuel economy between 2003 and 2014 and will explain an even larger portion going forward. Higher-than-projected gasoline prices explain at least 17 percent of the fuel economy increase through 2014.

  - *Demographics and economic factors explain most of the household VMT decrease.* Our new analysis suggests that demographics and economic factors more than fully explain the decline and, if anything, other factors like preference shifts slightly offset these changes and by themselves would have led to more VMT.

- **The surprise reduction in the consumption of oil derived from fossil fuels is even larger than the surprise reduction in petroleum consumption because of the increasingly large portion of petroleum derived from renewables like ethanol.** The main analysis includes renewables such as ethanol in total petroleum products consumption, finding that the United States consumed 6.4 million b/d less petroleum in 2014 than projected. But 0.8 million b/d of that consumption was in the form of ethanol and other renewables, as compared to the 0.2 million b/d of this fuel that were consumed in 2003. At the time ethanol consumption was expected to remain constant; the increase was largely due to the Renewable Fuels Standard. As a result, the total surprise reduction in oil consumption is closer to 7 million b/d in 2014 when accounting for ethanol.

The increasing importance of fuel economy over time in lowering petroleum consumption demonstrates the vital role of public policy in shaping energy consumption. For example, the fuel economy standards for cars, light trucks, and heavy-duty trucks implemented by President Obama have already reduced the amount of petroleum that our economy is expected to consume in coming years. More broadly, other policies championed by the President like the Clean Power Plan, emissions reductions commitments at the G7, and tax credits for renewable energy are helping to shift the U.S. economy to a low-carbon future.
I. Introduction: Overview of the U.S. Consumption Surprise

U.S. oil production has transformed fundamentally in the past decade. Between 1970 and 2008, U.S. crude oil production fell by nearly half as conventional wells were depleted. Since 2008, however, production has rebounded from 5 million barrels per day (b/d) to an average of 8.7 million b/d in 2014. The almost entirely unexpected increase—largely attributable to technological innovations such as advances in horizontal drilling, hydraulic fracturing, and seismic imaging—has helped the United States become the world leader in oil production.

Whereas the developments in oil production have been widely reported and appreciated, far less attention has been paid to U.S. petroleum consumption’s remarkable decline relative to both recent levels and past projections. Petroleum consumption in 2014 was actually slightly below consumption in 1997, despite the fact that the U.S. economy grew nearly 50 percent over the 17-year period. This levelling off of consumption was largely unanticipated. In 2003 the U.S. Energy Information Administration (EIA) projected that consumption would steadily grow at an average annual rate of 1.8 percent over the subsequent two decades; consumption in 2025 was projected to be 47 percent percent higher than its 2003 level. The actual path that consumption has taken, however, diverges dramatically from this projection. Consumption in 2014 was actually slightly below 2003 consumption, and about 25 percent below the projections for 2014 that were made in 2003. Moreover, the difference between the actual and projected consumption in 2014—6.4 million b/d—is almost double the unexpected production increase over the same period (3.4 million b/d). The surprise reduction frees up roughly $150 billion dollars for spending on other purposes (2014 dollars). There is even greater divergence in longer-term projections; the most recent projection for 2025 is 34 percent lower than the projection made in 2003 (freeing up roughly $250 billion).

The changes in production and consumption have had significant impacts on the U.S. economy. The dramatic turnaround in U.S. production has boosted GDP growth. The combination of increased production and reduced consumption has reduced net petroleum imports, improving U.S. energy security, and the reduced consumption has contributed to the nearly 10 percent reduction in greenhouse gas emissions since 2005 (CEA 2015).

The objective of this report is to identify the mechanisms behind the large decrease in U.S. petroleum consumption relative to past projections. Quantifying the underlying causes helps us understand why the consumption path has changed, and also has implications for what is likely to happen in the future and for public policy.

Petroleum consumption accounts for about 40 percent of U.S. energy-related carbon dioxide emissions, and projections of long-run greenhouse gas emissions from petroleum consumption are highly dependent on the drivers of the consumption decline. If the Great Recession were the primary driver, for instance, we would expect petroleum consumption to return to past trajectories as the economy recovers, causing consumption-related emissions to rebound. On the other hand, if fuel economy standards were the primary driver, consumption and associated greenhouse gas emissions might continue to decline.
For this exploration, we focus on two specific quantities: the gap between consumption that was projected in 2003 and actual 2014 consumption, to which we refer as the 2014 consumption surprise; and the gap between the 2003 and 2015 projections of 2025 consumption, the 2025 consumption surprise. We focus on projections made by EIA, not to criticize those projections, but because of EIA’s prominence as a highly-respected source of analysis in this area. In fact, EIA projections are qualitatively similar to other projections made at around the same time (see Appendix). Moreover, the conclusions are broadly robust to the choice of projection year—consumption in 2014 fell below all EIA projections made in the early 2000s. In this analysis we focus on the 2003 projections because it is the earliest year that consistent and sufficiently detailed data are available. This allows us to consider the full array of factors that have affected consumption.

Before attempting to document the source of the consumption surprises, we begin by providing historical and international perspectives on the U.S. experience. In percentage and absolute terms, the 2014 and 2025 surprises in the United States are much larger than those observed in many other countries and regions of the world. By source, declining vehicle gasoline consumption is the biggest source of both surprises, followed by industrial consumption of petroleum products.

Focusing on vehicle fuel consumption, we compare the effects of vehicle miles traveled (VMT) and fuel economy. While VMT per household was projected to increase steadily with rising income, in fact, VMT per household peaked in the mid-2000s and has since declined slightly. Rising fuel economy explains a smaller portion of the 2014 consumption surprise than does VMT, but fuel economy and VMT explain similar shares of the 2025 consumption surprise, demonstrating the growing role of public policies, like the fuel economy standards implemented by the Obama Administration, in shaping fuel use. Throughout the analysis, petroleum consumption includes fossil fuel and renewable fuels, but we also note that ethanol has further reduced U.S. consumption of fossil fuel-based petroleum products.

After documenting the sources of the consumption surprises, we further explore the factors underlying the rise in vehicle fuel economy and the drop in household VMT relative to past projections. Based on recent estimates of the effect of gasoline prices on passenger vehicle fuel economy, we estimate that high gasoline prices—relative to 2003 projections—explain a substantial share of the overall increase in passenger vehicle fuel economy. Fuel economy standards explain a large and growing share of the increase in vehicle fuel economy. Changes in demographics and economic variables appear to explain much of the change in the trajectory of VMT, but there is also evidence that the effects of demographics on VMT have changed as well. For example, individuals below 40 years old drove 5 percent less in 2009 than did individuals who were below 40 years old in 1990. Because demographics themselves are easier to project than the changes in their impacts, the importance of these changes presents a challenge to projecting future petroleum consumption.
II. Historical and International Perspectives

**Historical Context for the Consumption Surprise**
We begin the analysis by placing the consumption surprises in a historical context. Figure 1a shows total U.S. petroleum consumption since 1949 and illustrates that consumption grew at a steady rate from 1949 through the early 1970s, but decreased when oil prices were high in the late 1970s and early 1980s. Consumption began rising again in 1984, but through the early 2000s the pace of growth was much slower than it had been historically. Consumption peaked in 2004 and decreased in conjunction with rising oil prices, but since the end of the recession consumption has been flat even though the economy has grown and oil prices have remained steady or declined. Therefore, although economic growth is strongly correlated with petroleum consumption growth (e.g., Hughes et al. 2008), the fact that consumption remained flat while income grew suggests that other factors besides the recession explain the surprises.

Figure 1a shows three broad regimes: 1) consumption and GDP grow proportionately (1949 through the early 1970s); 2) consumption grows at a slower rate than GDP (late 1980s through the early 2000s) and 3) consumption decreases (2004 through 2014). Illustrating the dramatic turnaround in the most recent period is the fact that petroleum consumption in 2014 was lower than it was in 1997, despite nearly 50 percent real GDP growth over the 17-year period. This has been possible because, as Figure 1b shows, petroleum intensity (barrels of petroleum consumption per dollar of GDP) has decreased steadily since the mid-1970s.

Focusing on the third of our three regimes, 2004 to the present, and on consumption projections for the next 10 years, Figure 2a shows a) projections made in 2003 for total U.S. petroleum consumption through 2025; and b) actual consumption between 2003 and 2014, and updated 2015 projections for consumption between 2015 and 2025. Projections and data are from EIA’s Annual Energy Outlook (AEO) (throughout the analysis we use the AEO Reference Case, which contains EIA’s baseline assumptions). In 2003, EIA projected steady growth in petroleum consumption, but actual consumption has fallen since 2004. Looking ahead, the 2015 AEO projects that consumption will remain virtually steady through 2025. The 2014 consumption...
surprise reflects a 6.4 million b/d reduction in petroleum consumption, relative to the 2003 projection of 2014 consumption, a 25 percent decline. The 2025 surprise amounts to a 10.0 million b/d, or 34 percent, difference between the 2003 and 2015 projections of consumption in 2025.

Figure 2b shows that the two consumption surprises have emerged because of gradual changes in the AEO projections over time. The horizontal axis represents the AEO years 2003 through 2015. The vertical axis plots the projected consumption in the corresponding AEO year. For each projection year, the blue curve shows projected consumption in 2015 and the red curve shows projected consumption in 2025. Projections for 2014 consumption declined fairly steadily between the 2003 and 2013 projection years. Projections for 2025 consumption show a similar downward trend, with an additional noticeable drop between the 2007 and 2008 projection years. Starting in 2008, the consumption projection flattens, despite projected growth in real GDP, implying an ongoing decline in the petroleum intensity of U.S. output. Some of the larger year-to-year declines in forecasts can be attributed to changes in fuel economy standards, which are discussed in a later section.

The U.S. Consumption Surprise from an International Perspective
Looking at petroleum consumption from an international perspective shows that the U.S. experience has been different from that of Europe and many other OECD countries. Figures 3a through 3d compare projections and actual data from the EIA International Energy Outlook (IEO), which projects petroleum consumption for the United States and other regions. Data availability allows us to compare the 2006 and 2014 projections for the United States, Europe, Japan, and other OECD countries. Figure 3a shows that using the IEO data, the surprise between the 2006 and 2014 projections for 2025 consumption in the United States—i.e., the 2025 consumption surprise—is about 27 percent, which is consistent with the AEO data used in the other parts of this analysis. The surprises for European, as well as non-U.S. and non-Japan, OECD countries, however, are less than half as large in percentage terms—just 12 and 11 percent, respectively. In percentage terms, the 2025 surprise for Japan lies just below that of the United States. Table 1 shows the 2015 and 2025 consumption surprises for each region, in percentages.
Figure 3a: U.S. Petroleum Consumption: Historical and Projected, 2002-2025

Figure 3b: Europe OECD Petroleum Consumption: Historical and Projected, 2002-2025

Figure 3c: Japan Petroleum Consumption: Historical and Projected, 2002-2025

Figure 3d: Other OECD Petroleum Consumption: Historical and Projected, 2002-2025

Table 1: Percent Decline in Consumption by Region

<table>
<thead>
<tr>
<th></th>
<th>United States</th>
<th>Europe OECD</th>
<th>Japan</th>
<th>Other OECD</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>19.7</td>
<td>12.9</td>
<td>19.5</td>
<td>6.7</td>
</tr>
<tr>
<td>2025</td>
<td>27.3</td>
<td>12.1</td>
<td>24.0</td>
<td>11.3</td>
</tr>
</tbody>
</table>
III. Decomposing the U.S. Consumption Surprises

Decomposition by Sector and Fuel
Returning to the United States, we next decompose the overall consumption surprises into the contributions of individual sectors and fuels. Figures 4a and 4b illustrate the contributions to the 2014 and 2025 surprises of the four major energy-consuming sectors. The two black curves show the AEO projections from 2003 and 2015 and actual petroleum consumption (repeated from Figure 2a).

Total consumption equals the sum of consumption by sector, and we decompose the consumption surprise into the effects of the individual sectors. The detailed methodology for this “sum of parts” decomposition can be found in the Appendix, the basic notion being that we can express the change in overall consumption as the sum of the change in consumption in each of the individual sectors.

Figure 4a shows the contributions of each sector to the consumption surprises. The vertical height of the blue region is the difference between the two transportation projections, and the interpretation is the same for the red (industrial) and green (residential and commercial) regions. The sum of the vertical height of the three regions is equal to the difference between the 2003 and 2015 total consumption projections. For example, the total vertical height of the 3 regions in 2014 equals the 2014 consumption surprise. The figure shows that industrial consumption explains a larger share of the two surprises than residential and commercial consumption, but the transportation sector is clearly the biggest contributor (see Table 2 for the percentages of each surprise accounted for by each sector).

Though the transportation sector clearly represents the largest share of the 2014 and 2025 surprises, Figure 4b shows that the size of the surprises in each sector, relative to projected consumption, are more similar to one another in 2014 than in 2025. In the transportation, industrial, and residential and commercial sectors, between 20 and 30 percent less petroleum was consumed in 2014 than had been projected in 2003. By 2025, however, while the size of the surprises for transportation and residential and commercial increase to about 40 percent each, the magnitude of the surprise actually falls for the industrial sector. Overall, the transportation sector accounts for a large share of the 2014 surprise, and the contribution of the transportation sector to the consumption surprise is even larger in 2025.
Breaking consumption down by fuel type and sector, Figures 4c and 4d show the contributions of specific fuels to the total consumption surprises. Gasoline consumption in the transportation sector is responsible for the biggest contribution to the surprises, accounting for a larger share of the 2014 surprise than industrial petroleum and transportation diesel fuel combined. Gasoline’s contribution is even greater in 2025, illustrated by the widening of the blue region. The red and green sections, on the other hand, show that petroleum consumed in the industrial sector and transportation sector diesel fuel consumption explain roughly equal amounts of both the 2014 and 2025 surprises. The “other” category shows the contribution of other transportation petroleum products, such as jet fuel, as well as petroleum products consumed in the residential and commercial sectors. Table 3 shows the percentages of each surprise accounted for by each fuel. As in Figure 4b, above, Figure 4d shows the relative size of the surprise for each fuel. Although the size of the surprise for the “other” category is comparable to that of gasoline, the size of the gasoline surprise increases the most of any of the fuels between 2014 and 2025.

The preceding decomposition has focused on the consumption of fossil fuel-based fuels, and Box 1 discusses the effect of ethanol consumption on gasoline consumption. In short, actual ethanol consumption has been higher than the 2003 projections, and ethanol consumption has reduced fossil fuel-based gasoline consumption. So accounting for ethanol, if anything, would make the petroleum consumption surprise even larger than the featured magnitudes in this report.
Figure 4c: Decomposition by Fuel in Select Sectors

Figure 4d: Percent Consumption Surprise by Fuel

Table 3: Percentages of 2014 and 2025 Surprises by Fuel

<table>
<thead>
<tr>
<th></th>
<th>2014</th>
<th>2025</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation gasoline</td>
<td>50</td>
<td>61</td>
</tr>
<tr>
<td>Industrial petroleum</td>
<td>18</td>
<td>7</td>
</tr>
<tr>
<td>Transportation diesel</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Other</td>
<td>21</td>
<td>21</td>
</tr>
</tbody>
</table>

Source: Energy Information Administration; CEA Calculations.
Box 1: Ethanol and Gasoline Consumption

In recent years, fossil fuels have been increasingly displaced with renewable fuels such as ethanol and biodiesel, which can have energy security and environmental benefits. The displacement is largely due to the Renewable Fuels Standard (RFS), which the EPA administers under the Energy Independence and Security Act, and which mandates usage of increasing volumes of renewable fuels. For various reasons, our analysis focuses on total petroleum consumption, which includes petroleum products refined from fossil fuel feedstocks, such as diesel fuel and jet fuel, as well as fuels refined from renewable feedstocks, such as ethanol. This box discusses how displacement of fossil fuel-based fuels by renewable fuels fits into the rest of the story, in particular, focusing on fuel ethanol and gasoline consumption.

Currently, most gasoline is sold in the form of E10, which contains 10 percent ethanol by volume. The 2003 AEO projected very little ethanol consumption by 2025, but the RFS and other factors have dramatically changed the outlook for ethanol consumption. The figure on the left, below, plots the actual and projected ethanol consumption from the 2015 AEO, illustrating both the percentage of ethanol in total consumption (left axis) and the total ethanol consumption itself (right axis). Between 2000 and 2025, ethanol consumption is projected to increase by roughly 0.8 million b/d. Thus, the rising ethanol consumption has caused a small but noticeable additional reduction in U.S. fossil fuel consumption. The figure on the right shows the same decomposition as in Figure 4c, but illustrates the ethanol displacement assuming ethanol displaces gasoline one-for-one on an energy-equivalent basis. Unlike the surprises for other fuels and sectors that we discuss, the ethanol surprise is negative meaning that we actually consumed more ethanol than had been expected. This implies that, excluding ethanol, the size of the overall petroleum consumption surprise is increased by the amount shown in the green shaded region—a roughly 0.6 million b/d addition to each of the 6.4 million b/d and 10.0 million b/d surprises in 2014 and 2025.
Decomposition of the Vehicle Fuel Consumption Surprises

Because vehicle fuel consumption contributes so much to the 2014 and 2025 surprises (Figure 4), we turn our attention to vehicle fuel consumption. We define the 2014 and 2025 vehicle fuel consumption surprises analogously to the petroleum consumption surprises, as the difference between projected and actual fuel consumption in 2014 and the difference between 2003 and 2015 projections for fuel consumption in 2025.

We begin by breaking down these surprises into two factors: 1) rising vehicle fuel economy; and 2) changes in VMT. The fuel consumption rate, in gallons per mile, is the reciprocal of fuel economy, in miles per gallon; an increase in fuel economy implies a reduction in the fuel consumption rate. To extract the relative contribution of each of the two factors to the change in vehicle fuel consumption, we employ what we refer to as a “log-product decomposition.” The Appendix provides the details of the methodology, but, generally speaking, the calculation exploits the fact that, by definition, fuel consumption can be written as the product of VMT and the fuel consumption rate. Using properties of the natural logarithm, this definition allows us to rewrite the log of the fuel consumption surprise as the sum of the change in log VMT over time and the change in the log fuel consumption rate over time, thereby illustrating the factors’ relative contributions to the log consumption change.

Figure 5a illustrates this decomposition. The vertical axis is the log of transportation sector gasoline and diesel fuel consumption. The light blue section in Figure 5a shows the contribution of VMT to the fuel consumption surprise, and the dark blue section shows the contribution of fuel consumption rates. Comparing the two factors, VMT explains a larger share of the 2014 surprise than does the fuel consumption rate. However, the effect of the fuel consumption rate increases over time. Table 4 shows that the fuel consumption rate explains 25 percent of the 2014 consumption surprise and about 45 percent of the 2025 consumption surprise (the percentages refer to the ratio of the vertical height of the corresponding region to the total log consumption surprise, multiplied by 100).

![Figure 5a: Transportation Sector Fuel Consumption Rate and VMT Decompositions](image)

![Figure 5b: Percent Transportation Consumption Surprise by VMT and Fuel Consumption Rate](image)

Source: Energy Information Administration; CEA Calculations.
Summary of the Consumption Surprises

Summarizing the results so far, Figure 6 illustrates the contributions of each sector to the overall petroleum consumption surprises. In the figure, the transportation sector petroleum consumption surprise is decomposed further into the vehicle fuel consumption rate, VMT, and other factors such as aircraft consumption (as an approximation, for the transportation sector we multiply the percentages in Figure 5b by the total gasoline and diesel fuel contribution in Figure 4c). In 2014, VMT is the single most important factor, accounting for just under half of the total petroleum consumption surprise. The importance of the fuel consumption rate doubles (in percentage terms) between 2014 and 2025. Because the transportation sector accounts for 80-90 percent of the two consumption surprises, and vehicle fuel consumption dominates consumption of other fuels in the transportation sector, the remainder of this report focuses on the factors that explain vehicle fuel consumption rates and miles traveled.

Table 4: Percentages of 2014 and 2025 Transportation Fuel Consumption Surprises by VMT and Fuel Consumption Rate

<table>
<thead>
<tr>
<th></th>
<th>2014</th>
<th>2025</th>
</tr>
</thead>
<tbody>
<tr>
<td>VMT</td>
<td>75</td>
<td>55</td>
</tr>
<tr>
<td>Fuel Consumption Rate</td>
<td>25</td>
<td>45</td>
</tr>
</tbody>
</table>

Figure 6: Overview of Contributions to the 2014 and 2025 Consumption Surprises

Source: Energy Information Administration; CEA Calculations.
IV. A Closer Look at Vehicle Fuel Consumption

Decomposition of Vehicle Fuel Consumption by Vehicle Type
We can further refine the focus on transportation sector fuels by decomposing the fuels surprises into the contributions by vehicle type—light, medium, and heavy-duty. These categories are defined based on vehicle weight, with light-duty vehicles weighing below 8,500 pounds and heavy-duty vehicles weighing above 10,000 pounds. This decomposition is similar to the sectoral decomposition above, using the “sum of parts” decomposition described in the Appendix. Figure 7a shows the results of this decomposition and indicates that, at around 90 percent, light-duty vehicles make a far greater contribution to the consumption surprises than do the other vehicle types (see Table 5). That said, as Figure 7b illustrates, the magnitude of the surprise as a percentage of consumption for light-duty vehicles was actually slightly smaller than the size of the percentage for medium-duty trucks. With the new fuel economy standards for heavy-duty trucks announced in June 2015, fuel consumption by vehicle type may further change in the coming years.

![Figure 7a: Decomposition of Motor Vehicle Fuel Consumption by Vehicle Type](image1)

![Figure 7b: Percent Motor Vehicle Fuel Consumption Surprise by Vehicle Type](image2)

| Table 5: Percentages of 2014 and 2025 Motor Vehicle Fuel Consumption Surprises by Vehicle Type |
|-------------------------------------------------|--------|--------|
| Light                                           | 89     | 89     |
| Medium                                          | 5      | 4      |
| Heavy                                           | 6      | 7      |

Gasoline Prices, Fuel Economy Standards, and Light-Duty Fuel Consumption Rates
Because of the importance of light-duty vehicles in explaining the consumption surprises (Table 5) the remainder of the analysis focuses on fuel consumption by light duty vehicles. As discussed above, fuel consumption is the product of VMT and the fuel consumption rate. In this section we investigate the underlying causes behind the decrease in the fuel consumption rate relative to
projections, and the next section focuses on changes in light-duty VMT. Of course, the two can be interrelated; for example higher gasoline prices would be expected to increase fuel economy and reduce VMT.

For background, Figure 8a shows actual and projected fuel consumption rates for the entire light-duty fleet between 2000 and 2014. Whereas the EIA projected a steady increase in the fuel consumption rate, the actual fuel consumption rate has decreased since 2003. Figure 8b shows that real gasoline prices began increasing—both in absolute terms and relative to the 2003 projection—around 2003, decreased in 2008, and then increased to roughly pre-recession levels from 2009-2014. We briefly discuss the factors that could cause light-duty fuel consumption rates to fall below 2003 projections. Box 2 provides background on vehicle fuel economy standards in the 2000s, which caused fleet-wide light-duty vehicle fuel economy to increase starting in 2005 and caused fleet-wide medium and heavy-duty vehicle fuel economy to increase starting in 2014.

Changes in gasoline prices may have affected the fleet-wide average vehicle fuel economy since 2003 by inducing: a) households to scrap older vehicles with low fuel economy; b) households to purchase new vehicles with high fuel economy and c) manufacturers to increase the fuel economy of the vehicles they offer. The gasoline price increase since 2003 may have raised new vehicle fuel economy for all three reasons.
In principle, other factors besides fuel prices and fuel economy standards may have affected vehicle fuel economy over this time period. For example, because vehicles with high fuel economy tend to be smaller and less expensive than vehicles with low fuel economy, the Great Recession may have induced consumers to purchase vehicles with higher fuel economy than they would have otherwise. An example of other policies that may have affected fuel economy is Cash-for-Clunkers, which President Obama implemented in July and August of 2009, offering subsidies to consumers who scrapped old vehicles and purchased new vehicles with high fuel economy. Isolating the independent effects of gasoline prices, fuel economy standards, and these other factors is challenging and we are not aware of any research that has attempted to do this.
However, we can obtain some rough estimates of the independent effects of gasoline prices and fuel economy standards on average fuel consumption rates.

A recent literature has linked gasoline prices and vehicle fuel economy, which allows us to estimate the contribution of gasoline prices to the declining fuel consumption rate displayed in Figure 8a. Klier and Linn (2010) and Busse et al. (2013) estimate that a gasoline price increase of $1 per gallon raises new vehicle fuel economy by approximately 1 mile per gallon. Li et al. (2009) estimate that a 10 percent gasoline price increase raises average fleet fuel economy by 0.2 percent in the short run and by 2 percent in the long run.

These estimates allow us to quantify the contribution of gasoline prices to changes in fuel consumption rates over time. For each year, we multiply the difference between the actual and projected gasoline price from Figure 8b by the estimated effect of gasoline prices on new vehicle fuel economy. We estimate retirement rates from the full fleet using EIA data on the size of the fleet and new vehicle sales, and assume that gasoline prices do not affect the average fuel consumption rate of retired vehicles. This represents a conservative assumption because, in reality, an increase in gasoline prices is likely to delay scrappage of vehicles with low fuel consumption rates (Jacobsen and van Benthem 2015). Combining these estimates and assumptions, we compute the effect of the gasoline price changes from 2003-2014 on the fleet-wide average consumption rate. We find that gasoline prices explain at least 17 percent of the decline in 2014 fuel consumption rate relative to the 2003 projection. Using the same approach, we estimate that gasoline prices explain at least 11 percent of the difference between the 2003 and 2015 projections of the fuel consumption rate in 2025.

For comparison, using the same set of assumptions on vehicle retirements, combined with the actual fuel economy standards for cars and light trucks, we estimate the effect of the standards on average fuel consumption rates. This estimate represents an upper bound if we assume that—absent any deviations from projections in gasoline prices, income, or other factors that affect vehicle fuel economy—actual average fuel consumption rates would have been equal to the 2003 projection shown in Figure 8a. This is an upper bound because higher-than-projected gasoline prices have likely contributed to the fuel economy increase, as the preceding calculations suggest. We estimate that the fuel economy standards explain up to 43 percent of the overall decrease in fuel consumption rates between 2003 and 2014. The gasoline price estimates imply that gasoline prices may explain much of the remainder, but other factors such as the recession may have played a role. Nonetheless, if gasoline prices remain low and stable, as is currently projected, tightening passenger vehicle standards between 2015 and 2025 will become increasingly important and will continue to reduce average fuel consumption rates. In fact, the standards are responsible for up to 89 percent of the overall decrease in the projected 2025 fuel consumption rate that occurred between the 2003 and 2015 projections; Table 6 summarizes the results.
Table 6: Percentages of 2014 and 2025 Fuel Consumption Rate Improvements from Fuel Prices and Fuel Economy Standards

<table>
<thead>
<tr>
<th></th>
<th>2014</th>
<th>2025</th>
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<tbody>
<tr>
<td>Fuel prices (lower bound)</td>
<td>17</td>
<td>11</td>
</tr>
<tr>
<td>Fuel economy standards (upper bound)</td>
<td>43</td>
<td>89</td>
</tr>
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</table>

Why Have Household Vehicle Miles Traveled Started to Decline?
People are driving less than they used to, and economic developments do not fully explain this phenomenon. This reduction in VMT was largely unexpected by the 2003 AEO model which, based on past history, projected VMT largely based on income and unemployment. As Figure 9 shows, however, starting in the late 1990s there has been a striking divergence between VMT per licensed driver and the paths of per capita disposable income and employment.

The dramatic change in the VMT trajectory has been noted by researchers and the public. In 2014, EIA published a short study examining changes in light-duty VMT. Although EIA concluded that economic factors still play a dominant role in driving behavior, shifting demographic, technological, social, and environmental factors may have caused a decoupling of travel behavior and traditional correlates. In general we are aware of very little quantitative analysis of this phenomenon, and only a few studies have asked whether changes in preferences, demographics, or economic factors are the main explanations.

A popular demographic hypothesis has to do with the aging population. The elderly typically drive fewer miles than younger adults, and the share of elderly in the population has increased over the past decade as the baby boom generation has aged. The aging population could help explain the slowdown and reversal of VMT growth. Another possibility is that driving patterns,
conditional on age and other demographics, have changed. For example some have speculated that “millennials” (commonly defined as individuals born after 1980, CEA 2014a) may drive fewer miles than young adults did in past generations because of cultural shifts. Other possible changes in behavior that affect household VMT are tied to the internet: greater online shopping, for example, reduces shopping trips (and may induce a partially offsetting increase in commercial truck miles traveled); social networking reduces travel associated with social visits; and greater telecommuting reduces driving too and from work.

Economic factors such as gasoline prices, income, or employment status could also affect the amount people drive. Figure 8b illustrated that gasoline prices have been higher than previously projected. In addition, real incomes for many households fell in the 2001 to 2007 recovery and then dramatically fell during the most recent recession. In recent years, the sharp decline in employment during the Great Recession and its aftermath may also have affected levels of travel (CEA 2014b), as commuting to and from work accounts for roughly one-quarter of VMT.

Although recent studies on household VMT have identified some correlations between VMT and economic factors and demographics, the studies have not clarified whether changes in demographics and economic factors explain the changes in VMT (the Appendix contains a more detailed discussion of the literature). More specifically, do the changes in demographics themselves, such as the aging of the U.S. population, explain the turnaround? Or have the effects of demographics and economic factors on VMT changed, such as a decrease in driving by millennials compared to previous generations of young adults?

CEA used panel data for the driving patterns of households from 1990 through 2009. The Appendix describes the analysis in greater detail. The analysis projects the path of VMT since 1990 given only information on demography and economic factors like income and gasoline prices. Absent such information a linear trend would have simply predicted a continued increase in VMT from 1990 forward as shown in Figures 10a and 10b. But because of the aging of the population and other demographic factors, the model predicts that VMT levels out in the late 1990s and starts to fall after 2001. The age structure explains a large share of this turnaround, as changes in the age distribution between 1990 and 2009 roughly offset the growth in real income and vehicle ownership over the same time period. But changing demographics and economic factors are not the entire story. In fact, actual VMT was slightly higher than this prediction suggesting that, if anything, the factors that are omitted from this model—including preference changes—have led to more driving and not less. There is also some evidence that driving behavior by age group has changed. For example, in 2009 individuals below 40 years old drove 5 percent less than did individuals below 40 years old in 1990. Thus, using data from 1990 to 2009, we find that changes in demographics and economic factors explain much, but not all, of the VMT turnaround. Nevertheless, more recent household data than are currently available may indicate larger changes in driving behavior by demographic group, or greater effects of telecommuting and online shopping on household VMT and overall petroleum consumption; these are questions for future research.
Figure 10a: Actual and Predicted VMT per Household Using Changes in Household Demographics and Economic Factors

Source: National Household Travel Survey; CEA Calculations.

Figure 10b: Actual and Predicted VMT per Person Using Changes in Household Demographics and Economic Factors

Source: National Household Travel Survey; CEA Calculations.
V. Conclusion

This report documents the surprising decline in U.S. petroleum consumption, both in absolute terms and relative to past projections. We show that the transportation sector explains most of the surprise between previous projections of petroleum consumption and actual data, as well as the surprise between previous and the most recent projections. Miles traveled by passenger vehicles plays an important role in the transportation sector, but rising fuel economy (and declining fuel consumption rates) has a large influence that is growing over time.

Between 2003 and 2014 gasoline prices explain a large share of the fuel economy increase of the light-duty fleet. However, over time we expect fuel economy standards to have a growing influence on fuel economy—both for the light and heavy-duty fleets. Fuel consumption from the heavy-duty fleet accounts for one-fifth of total transportation sector consumption, and is the fastest growing component of the transportation sector. New heavy-duty fuel economy standards that the Administration is announcing will reduce actual transportation sector consumption relative to even the 2015 projections, which do not reflect these new standards.

Given the importance of miles traveled in explaining the surprises, we use household survey data to present new evidence on the factors underlying the changes. Demographics appear to explain a very large portion of the VMT developments, but we also find evidence that the effects of demographics and economic variables on VMT have changed over the past 20 years. Such changes present a major challenge to projecting future petroleum consumption.

Turning to ethanol, we report a large unexpected increase in ethanol consumption relative to 2003 projections. Given the large and growing importance of fuel economy standards and ethanol, this analysis suggests that Federal policy has and will continue to have a substantial effect on U.S. petroleum consumption and on overall carbon emissions reductions by the transportation sector.

As discussed above, President Obama’s clean energy strategy has made concrete strides to reduce petroleum consumption and shift the U.S. economy to a low carbon future through policies like fuel economy standards and tax credits for renewable energy (CEA 2015). The President remains deeply committed to providing a clean and secure energy future for our children and will continue to act to reduce carbon emissions through policies like the Clean Power Plan and engagement with international allies.
References

Energy Information Administration (EIA, various years). Annual Energy Outlook.
EIA (2014). Light-duty vehicle energy demand: demographics and travel behavior.
Appendix

Comparison of EIA and Other Projections

This report focuses on the EIA petroleum consumption projections because EIA’s projections are some of the most influential and well-regarded. Importantly, the projections of rising petroleum consumption that we remark upon in this analysis were not unique to EIA. At around the same time as the EIA published the 2003 AEO, other organizations made similar projections of global petroleum consumption, several of which are shown in Table A1. At the individual country level, the reports are not standardized in their inclusion of changes in inventories to country consumption, so, for the purpose of comparing the projections, we focus on global consumption. Although EIA’s projected annual growth rate for consumption is at the high end of the range of projections, most organizations expected similar increases of around 2 percent per year. Despite the differences in projected growth rates, the projected 2020 consumption levels are quite similar across the projections shown in the table.

Table A1: Comparison of World Oil Demand Projections

<table>
<thead>
<tr>
<th>Source</th>
<th>2010 (million b/d)</th>
<th>2020 (million b/d)</th>
<th>2000-2020* (percent annual growth)</th>
<th>2010-2020 (percent annual growth)</th>
</tr>
</thead>
<tbody>
<tr>
<td>International Energy Agency (IEA)</td>
<td>90</td>
<td>106</td>
<td>1.8</td>
<td>1.8</td>
</tr>
<tr>
<td>Energy Information Administration (EIA)</td>
<td>91</td>
<td>110</td>
<td>1.8</td>
<td>2.1</td>
</tr>
<tr>
<td>Organization of the Petroleum Exporting Countries (OPEC)</td>
<td>89</td>
<td>106</td>
<td>--</td>
<td>1.9</td>
</tr>
<tr>
<td>Institute of Energy Economics, Japan (IEEJ)</td>
<td>--</td>
<td>102</td>
<td>1.9</td>
<td>--</td>
</tr>
<tr>
<td>European Commission</td>
<td>87</td>
<td>104</td>
<td>1.9</td>
<td>2</td>
</tr>
</tbody>
</table>

*Average annual growth rate from 2000-2020, except IEA, which is 2002-2020.
Source: IEA (2004), Comparison of World Oil Demand Projections.
Methodology for Decomposing EIA Projections
We provide additional details on the decompositions of the EIA projections. There are two types of decompositions: a decomposition into the sum of parts and a log-product decomposition. We use the first decomposition in cases where total consumption is expressed as the sum of two or more terms, such as a decomposition into consumption by sector. We use the second decomposition in cases where consumption is expressed as the product of two terms, such as the product of VMT and the fuel consumption rate.

Sum of Parts Decomposition
We use a sum of parts decomposition when consumption is expressed as the sum of consumption across components. We express the 2003 projection of consumption in year $t$, $C_{03; t}$, as:

$$C_{03; t} = T_{03; t} + N_{03; t} + R_{03; t}, \quad (A1)$$

where $C_{03; t}$ is the 2003 projection of petroleum consumption in year $t$; $T$, $N$, and $R$ represent consumption by the transportation, industrial, and commercial plus residential sectors. Similarly, the 2015 projection of petroleum consumption in year $t$ is $C_{15; t}$. We decompose the consumption surprise in year $t$, $C_{03; t} - C_{15; t}$ as:

$$C_{03; t} - C_{15; t} = [T_{03; t} - T_{15; t}] + [N_{03; t} - N_{15; t}] + [R_{03; t} - R_{15; t}]. \quad (A2)$$

The three terms in square brackets show the contributions of the individual sectors to the consumption surprise. That is, the consumption surprise in year $t$, $C_{03; t} - C_{15; t}$, is equal to the sum across the three sectors of the difference between the 2003 and 2015 projections.

Log-Product Decomposition
By definition, the 2003 projection of vehicle fuel consumption in year $t$ can be written as the product of VMT and the fuel consumption rate:

$$C_{03; t} = V_{03; t} F_{03; t},$$

where $V_{03; t}$ is VMT and $F_{03; t}$ is the fuel consumption rate in gallons per mile (i.e., the reciprocal of fuel economy, measured in miles per gallon). Taking the natural logarithm of the 2003 projection of fuel consumption in year $t$ and subtracting the natural logarithm of the 2015 projection of fuel consumption in year $t$, we decompose the difference between the 2003 and 2015 consumption projections into the contributions of VMT and the fuel consumption rate:

$$\ln(C_{03; t}) - \ln(C_{15; t}) = [\ln(V_{03; t}) - \ln(V_{15; t})] + [\ln(F_{03; t}) - \ln(F_{15; t})]. \quad (A3)$$

The left-hand side of equation (A3) is the surprise between the 2015 and 2003 log consumption projections for year $t$. The first term in square brackets on the right-hand side is the contribution of VMT to the consumption surprise; and the second term is the contribution of the fuel consumption rate to the consumption surprise. For small differences between the 2003 and 2015
consumption projections, the difference in the log of the two projections is approximately equal to the percentage by which the 2003 projection exceeds the 2015 projection, divided by 100.

Equation (A3) shows that, for small differences, the consumption surprise is approximately equal to the percentage difference between the two VMT projections, plus the percentage difference between the two fuel consumption rate projections (i.e., the percentage divided by 100). Note that for larger changes, the difference in logs overstates the percentage differences.

Overview of the Recent Household VMT Literature
This section summarizes the few existing quantitative studies of which we are aware that attempt to explain the recent decrease in household VMT. Baxandall (2013) documents a decrease in VMT per person since 2004, both on average and for millennials compared with other age groups. Most states have experienced a decline in average VMT per person and Baxandall analyzes whether economic or demographic factors explain the overall decline across states. The paper reports weak correlations between the change in a state’s average VMT per person between 2005 and 2011, and factors such as unemployment rates, labor force participation rates (the share of working-age population in the workforce or seeking employment), and urbanization rates. The weak correlations suggest that demographics and economic conditions alone do not explain the overall decrease in VMT. Indeed, the paper is not able to identify which factors have caused this decline, which may be due to the poor measurement of state-level VMT (Li et al. 2014 discuss the VMT data quality).

Blumenberg et al. (2012) ask whether travel behavior for young adults has changed relative to older adults. That is, younger adults typically drive fewer miles than older adults, and the authors explore whether this difference is larger for millennials than for previous generations. Rather than examining VMT, their analysis focuses on person miles traveled, which is the total annual miles each individual travels. They conclude that economic factors such as income and employment have a positive and fairly stable effect over time on person miles traveled. They also find evidence that individuals born in the 1980s drive 8 percent fewer miles than individuals born prior to the 1980s after controlling for observable differences; individuals born in the 1990s drive even less—18 percent fewer miles than previous generations.

However, the results do not directly address the question of why VMT has decreased. Although person miles traveled is highly correlated with VMT, factors that affect person miles traveled may not affect VMT, and vice versa. For example, if millennial teenagers are less likely to accompany their parents on trips than previous generations of teenagers, person miles traveled for teenagers would fall whereas VMT may not change. Therefore, the estimated differences in person miles traveled across cohorts do not necessarily translate to differences in household VMT caused by differences in driving preferences for millennials compared to other adults. More importantly, although the changes in person miles traveled for teenagers and young adults are striking, the report does not quantify how much these changes contribute to the overall household VMT trends.
Finally, McGuckin (2014) notes that VMT per capita decreased substantially between 1995 and 2009 for individuals below 40 years old. In addition, the greatest decline in driving for young people occurs in urban areas, and has been more pronounced for men than for women. However, labor force participation rates have declined at a faster rate for men than for women (CEA 2014b) and McGuckin notes the need to control for economic factors to determine whether these trends reflect shifts in preferences among young adults, or economic factors.

**Household VMT Data**

We describe in greater detail the National Household Travel Survey (NHTS) data used for the VMT analysis. We use the 1990, 1995, 2001 and 2009 surveys (the 1990 and 1995 waves are referred to as the National Personal Travel Survey). We harmonize the demographic and income variables across survey years and for each survey we include all household observations with non-missing demographic variables. For households with missing income levels, we impute household income using the mean income of other households in the same state and demographic category (defined below). Table A2 reports the number of households included in the final sample for each year, the share of sample households in total households, and the share of sample households with imputed income.

<table>
<thead>
<tr>
<th>Table A2: NHTS Sample Size by Survey Year</th>
</tr>
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<tbody>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Number of households in final sample</strong></td>
</tr>
<tr>
<td>------</td>
</tr>
<tr>
<td>17,594</td>
</tr>
<tr>
<td><strong>Share of surveyed households in final sample</strong></td>
</tr>
<tr>
<td>0.79</td>
</tr>
<tr>
<td><strong>Share of sample households with imputed income</strong></td>
</tr>
<tr>
<td>0.23</td>
</tr>
</tbody>
</table>

The 1990 survey reports total household VMT, and in other survey years we compute household VMT as the sum of VMT across the household’s vehicles. A few other variables, including MSA size, population density, and race of the survey respondent, are coded differently across survey years. Typically, the 1990 survey includes the fewest categories, in which case we aggregate across categories for other survey years.

Because the NHTS reports household income by category (0-$5,000, $5,000-10,000, etc.) rather than as a number, accounting for inflation represents the main challenge to harmonizing income across survey years. We address this challenge using the following procedure. First, we assign to each household an income equal to the midpoint of its income range—for example, households with income in the range $20,000 – 25,000 are assigned an income of $22,500. Second, we assign each household to a demographic category based on its number of household members, number of workers, Census division, MSA size, and the race and education level of the reference person. We compute the mean income across households in each category and year, and assign that income level to the household, as its imputed income. Using the consumer price index for all urban consumers from the Bureau of Labor Statistics, we convert the imputed income to 1990
dollars and assign households to income categories based on their imputed income in 1990 dollars.

Note that alternatively we could convert the boundaries of the income categories to 1990 dollars, and reassign households based on the income range in 1990 dollars. For example, households surveyed in 2009 that have nominal income between $5,000 and $10,000 have income in 1990 dollars between roughly $3,000 and $6,000. We could assign 2009 households in the $5,000 – 10,000 income range based on their nominal income to the 0 – $5,000 based on their income in 1990 dollars. That is, after the reassignment the 1990 households with income between 0 and $5,000 would be in the same final income category as 2009 households with income between 0 and $10,000. Therefore, this approach assigns all households in a particular nominal income category to the same final income category. Our preferred approach, in contrast, accounts for the fact that households with certain demographics (e.g., having two workers rather than one) are more likely to be at the upper end of their nominal income range than are other households; our reassignment accounts for this tendency by using imputed income rather than the income range to reassign households to income categories.

**VMT Methodology**

We use a Oaxaca-Blinder style decomposition to distinguish the effects of economic factors and demographics on average VMT per household or person. The decomposition consists of two steps, and the first is to specify VMT per household as a linear function of explanatory variables:

\[
V_{it} = \alpha_t + X_{it} \beta_t + \epsilon_{it}.
\]  

(A4)

In equation (A4), the dependent variable is the total VMT for household \( i \) in survey year \( t \), \( \alpha_t \) is a (possibly time-varying) intercept, \( X_{it} \) includes a set of independent variables described next, \( \beta_t \) is a vector of coefficients to be estimated, and \( \epsilon_{it} \) is an error term. The independent variables include economic factors (income and gasoline prices); geographic and urbanization factors (size of the Metropolitan Statistical Area [MSA], an urban area indicator, Census division, and population density); number of drivers, number of vehicles, and number of workers in the household; and the age and education level of the survey respondent. All of these variables, including income, are categorical, and equation (A4) includes a fixed effect (that is, a distinct dummy variable) for each set of categorical variables. We also include the interactions of the MSA size with the urban indicator. Importantly for the subsequent decompositions, a separate set of coefficients, \( \beta_t \), is estimated each survey year. We estimate equation (A4) weighting observations using the household survey weights, so that the coefficients represent national sample averages. We perform an analogous estimation using VMT per person as the dependent variable in equation (A4), which is computed as the total household VMT divided by the number of people living in the household.

In the second step, we use the estimates of equation (A4) to predict VMT per household each survey year, \( \hat{V}_{it} \). The change in predicted VMT per household between time \( t \) and \( t = 1990 \) is:
The first term on the right-hand side represents the effect of the change in economic factors and demographics on average VMT per household. The economic factors and demographics variables are weighted by the coefficients estimated for the 1990 survey year, \( \hat{\beta}_{90} \). The second term represents the changes in the effects of the explanatory variables on VMT as captured by the estimated coefficients. For example, if the highest income group drives fewer miles in 2009 than in 1990, this would be reflected as a change in the coefficient for the highest income group between the 1990 and 2009 survey years. The change in each coefficient is weighted by the level of the corresponding explanatory variable in the later time period, \( t \). For shorthand, we refer to the first term as the effect of demographics and economic factors on VMT.

We note two important considerations that apply to any decomposition of this sort. The first is that the decomposition identifies the underlying components of variation in mean VMT per household or person over time, and does not have a causal interpretation. For example, the results show that the aging population is correlated with declining VMT after controlling for other factors and holding constant the coefficients, but this does not necessarily mean that the aging of the population caused the turnaround; other factors that are omitted from equation (A4) could be correlated with age. Second, this decomposition is not unique, meaning that we could use baseline years other than 1990 in constructing the two terms in equation (A5).

We use equation (A5) to construct Figure 10, where 10a shows results using VMT per household as the dependent variable and 10b shows results using VMT per person as the dependent variable. The data series labeled “actual” represents the mean of the dependent variable in the survey year. The “predicted” series is the first term in equation (A5), plus the mean of the dependent variable in 1990, \( \bar{V}_{i;90} \). The “linear trend” is a simple extrapolation based on the annual growth rate between the 1990 and 1995 surveys.