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The Future of Mobility

Scenarios for the United States in 2030, Appendixes C–G

Peter Brownell, Thomas Light, Paul Sorensen, Constantine Samaras, Nidhi Kalra, Jan Osburg

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Preface

About This Document

This document contains the appendixes for *Future of Mobility: Scenarios for the United States in 2030*.[1] This report uses a scenario approach to develop two distinct alternative futures for the United States. All input was based on expert projections about the long-term future in five areas: demographics, economics, energy, transportation funding, and technology. These projections were provided at a series of workshops held in the spring and summer of 2012.

The appendixes consist of five papers, one for each workshop, that were prepared as background. These background papers are generally presented here as they were to the experts, with the addition of some minor editing and formatting. We have removed the introductory comments from each background paper, which explained its purpose and were common to all papers. The papers provide background information on long-term trends that informed the discussions at the workshops. The authors of the background papers are Peter Brownell ("Demographic Trends in the United States," presented in Appendix C), Thomas Light ("Economic Trends in the United States," Appendix D), Paul Sorensen and Constantine Samaras ("Energy Trends in the United States," Appendix E), Paul Sorensen ("Transportation Funding and Supply Trends in the United States," Appendix F), and Nidhi Kalra and Jan Osburg ("Technology Trends in the United States," Appendix G).

This study was sponsored by the Institute for Mobility Research, known by its German abbreviation, ifmo. The institute has conducted several similar scenario exercises for Germany and engaged the RAND Corporation to conduct a scenario process for the United States. The results should be of interest to policy- and decisionmakers concerned with the long-term future of transportation in the United States. For the Transportation Research Board, RAND is conducting other long-term studies of transportation issues in the United States, looking at the impact of adopting alternatively fueled vehicles, incorporating new technologies into the transportation system, and the impact of sociodemographic changes.

The RAND Transportation, Space, and Technology Program

The research reported here was conducted in the RAND Transportation, Space, and Technology Program, a program of RAND Justice, Infrastructure, and Environment. RAND Justice, Infrastructure, and Environment provides insights and solutions to public- and private-sector decisionmakers across numerous domains, including criminal and civil justice; public

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[1] Johanna Zmud, Liisa Ecola, Peter Phleps, and Irene Feige, Santa Monica, Calif.: RAND Corporation, RR-246, 2013.

safety; environmental and natural resources policy; energy, transportation, communications, and other infrastructure; and homeland security. RAND Justice, Infrastructure, and Environment studies are coordinated through four programs—the Institute for Civil Justice; the Safety and Justice Program; the Environment, Energy, and Economic Development Program; and the Transportation, Space, and Technology Program—and the Homeland Security and Defense Center, run jointly with the RAND National Security Research Division. The Transportation, Space, and Technology Program research portfolio addresses transportation systems, space exploration, information and telecommunication technologies, nano- and biotechnologies, and other aspects of science and technology policy. Transportation, Space, and Technology Program research is conducted for government, foundations, and the private sector.

Questions or comments about this report should be sent to the project leader, Johanna Zmud (Johanna_Zmud@rand.org). For more information about the Transportation, Space, and Technology Program, see http://www.rand.org/transportation or contact the director at tst@rand.org.

Abstract

This document contains five background papers produced for the report, *The Future of Mobility: Scenarios for the United States in 2030*. That report used a six-step process to develop two scenarios for mobility in 2030. One of the six steps was to elicit projections on descriptors, which are factors believed to influence mobility. Projections were made by subject-matter experts at five workshops, one for each influencing area: demographics, economics, energy, transportation funding and supply, and technology. The researchers developed these background papers to provide the experts with information on past trends for those descriptors whose future values they were asked to predict.

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Figures

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Acknowledgments

Abbreviations

AAA	American Automobile Association
AB	Assembly bill
ACS	American Community Survey
ADAS	advanced driver-assistance system
APTA	American Public Transportation Association
ATRI	American Transportation Research Institute
BEA	Bureau of Economic Analysis
BEES	Board on Energy and Environmental Systems
BEV	battery electric vehicle
BLS	Bureau of Labor Statistics
BTS	Bureau of Transportation Statistics
CAFE	Corporate Average Fuel Economy
CBD	central business district
CCS	carbon capture and sequestration
CCTV	closed-circuit television
CFR	completed fertility rate
CNG	compressed natural gas
CO_2	carbon dioxide
CO_2-EOR	injection of carbon dioxide to recover oil
CPI	consumer price index
CPS	Current Population Survey
CSP	concentrating solar power
CTL	coal to liquids
DARPA	Defense Advanced Research Projects Agency
DMV	department of motor vehicles
DOT	department of transportation
DSL	digital subscriber line
E85	blend of 85 percent ethanol and 15 percent gasoline
ECPA	Electronic Communications Privacy Act
EERE	Office of Energy Efficiency and Renewable Energy
EGS	enhanced geothermal system
EIA	U.S. Energy Information Administration
EOR	enhanced oil recovery

ESA	Economics and Statistics Administration
EU	European Union
EV	electric vehicle
FCV	fuel-cell vehicle
FHWA	Federal Highway Administration
FTA	Federal Transit Administration
GAO	Government Accountability Office
GDP	gross domestic product
GHG	greenhouse gas
GPS	Global Positioning System
GTL	gas to liquids
gW	gigawatt
HEV	hybrid electric vehicle
HOT	high-occupancy toll
HOV	high-occupancy vehicle
H.R.	U.S. House of Representatives bill
HTF	Highway Trust Fund
ICT	information and communication technology
IEA	International Energy Agency
IPUMS	Integrated Public Use Microdata Series
IRS	Internal Revenue Service
ITS	intelligent transportation system
kWh	kilowatt-hour
LDW	lane-departure warning
LNG	liquefied natural gas
MENA	Middle East and North Africa
mpg	mile per gallon
mph	mile per hour
NCAP	New Car Assessment Program
NCHRP	National Cooperative Highway Research Program
NHTS	National Household Travel Survey
NHTSA	National Highway Traffic Safety Administration
NPN	National Petroleum News
NRC	National Research Council
NTIA	National Telecommunications and Information Administration
NYCDOT	New York City Department of Transportation
OEM	original equipment manufacturer

PAYD	pay as you drive
PDA	personal digital assistant
PHEV	plug-in hybrid electric vehicle
PPP	public-private partnership
PRB	Population Reference Bureau
PV	photovoltaic
RFEI	request for expressions of interest
RFID	radio-frequency identification
RFS	renewable-fuel standard
SR	state route
SUV	sport-utility vehicle
TFR	total fertility rate
tWh	terawatt-hour
UCLA	University of California, Los Angeles
VMT	vehicle mile traveled
ZEV	Zero Emission Vehicle

Appendix C. Demographic Trends in the United States

This appendix explores U.S. demographic trends. It is organized topically as follows:

- total population
- fertility
- mortality
- race and ethnicity
- age
- population density and spatial distribution
- vehicle ownership
- household type and size
- gender dynamics.

Total Population

The total U.S. population grew from 281.4 million in 2000 to 308.7 million people in 2010. This growth of 27.3 million between 2000 and 2010 was smaller than the growth during the period from 1990 to 2000, both in absolute terms and as a percentage of initial population.

Figure C.1. U.S. Total Population, 1960–2010
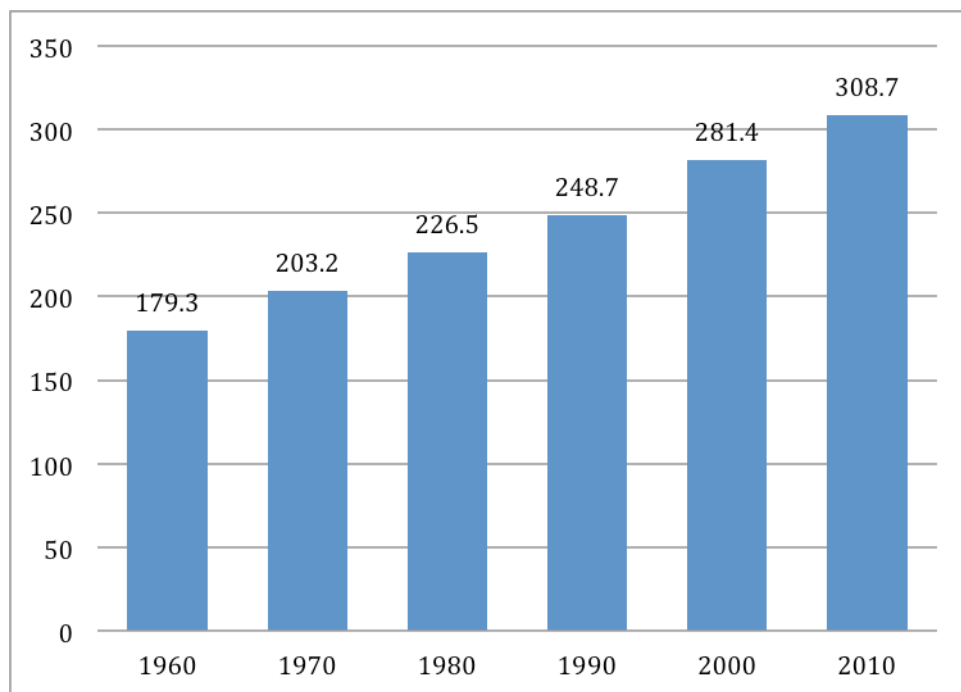
SOURCES: Hobbs and Stoops, 2002; Howden and Meyer, 2011.

The slower growth during the past decade was primarily due to the slower growth of the foreign-born population (i.e., lower levels of net migration, as shown in Figure C.2). Lower levels of fertility also contributed to slower population growth (see Figure C.5).

Figure C.2, which breaks down growth rates by nativity, shows that the total population growth as a percentage for the period 2000–2010 was considerably lower (9.9 percent) than during the period 1990–2000 (13.2 percent).[2] However, growth as a percentage of total population during the period 2000–2010 was effectively the same as the period 1980–1990 (9.8 percent). Except for the decade 1990–2000, population growth rates have declined every decade since 1950–1960. Figure C.2 also shows that the growth rate of the foreign-born population during 2000–2010 was the lowest since 1970 and that the decline in the total population growth was largely due to this decline in the growth rate of the foreign-born population. The foreign-born population changes primarily through net migration (immigration minus emigration) but also decreases through the death (in the United States) of foreign-born individuals.

A recent report by the Pew Hispanic Trust (Passel and Cohn, 2012) found that the foreign-born population grew by only 1.6 percent between 2009 and 2010 and that the annual increase in the foreign-born population was smaller during the period 2006–2010 than during 2000–2006. The slow rate of growth of the foreign-born population is due primarily to the recession and the lack of job opportunities in the United States, although increases in immigration enforcement may have contributed by slowing the growth of the unauthorized immigrant population (Passel, Cohn, and Gonzalez-Barrera, 2012). It is not clear whether a full economic recovery would lead to a return to the levels of immigration seen in the 1980s and 1990s, given a reduction in birth rates and an increase in job opportunities in major immigrant-sending countries, such as Mexico (Passel, Cohn, and Gonzalez-Barrera, 2012; Cave, 2011).

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[2] Overall population growth differs slightly between Figure C.1, based on the 2010 census, and Figure C.2, based on the American Community Survey (ACS). The ACS also includes nativity data, which are not available in the census. The 2010 ACS is not reweighted to match the 2010 census total, so the 2010 ACS gives a slightly different estimate of 2010 total population from that of the actual census count. Because Figure C.2 deals with difference in the population growth of the foreign- and native-born populations, it relies on the ACS.

Figure C.2. U.S. Population Growth, by Nativity, 1950–2010
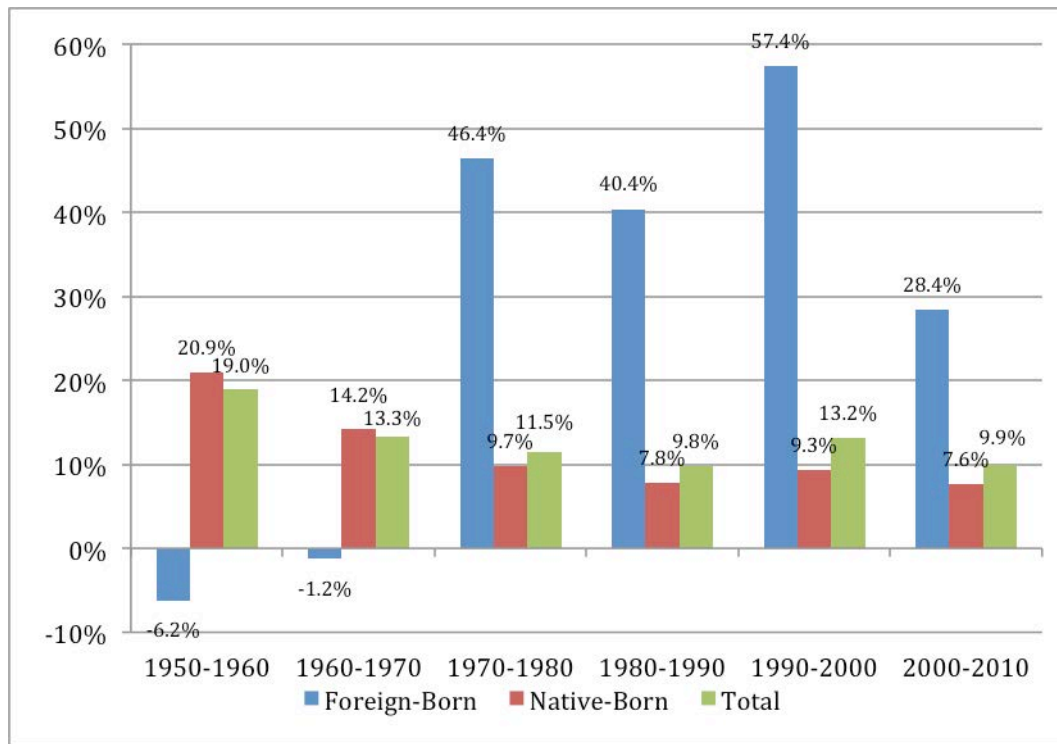
SOURCES: Gibson and Lennon, 1999; Malone et al., 2003; U.S. Census Bureau, 2010a.

NOTE: Data for 2010 are from the ACS and differ slightly from the decennial census data used in Figure C.1.

Figure C.3 shows the distribution of population by nativity (foreign-born versus native-born) for the period 1960–2010. The foreign-born population increased from 9.7 million people in 1960 to 40.0 million in 2010. Despite the slowing growth rate, the foreign-born population increased by 8.9 million between 2000 and 2010.

Figure C.3. U.S. Population, by Nativity, 1960–2010

Research indicates that immigrants, especially recently arrived immigrants, are less likely than the native-born to drive alone and more likely to carpool or use public transit. Immigrants also travel fewer vehicle miles and make fewer trips than the native-born (Chatman and Klein, 2009). Yet, the correlation between changes in travel behavior and amount of time spent in the United States has been observed—most notably, the high proportion of newcomers who use public transit and how that proportion declines over years of residence (Casas, Arce, and Frye, 2004).

Fertility

The slower growth of the native-born population during the period 2000–2010 can be attributed to lower fertility rates. The U.S. total fertility rate (TFR) was below replacement level (2.1 births per woman) for every year from 1972 to 2010 except 2006 and 2007 (see Figure C.4).[3] However, despite reaching a 35-year high in 2007, the TFR declined sharply between 2007 and 2010, due primarily to the economic recession (see Figure C.5). These developments in the TFR combined with an aging population with fewer women of childbearing ages (see Figure C.8 in the "Age" section), leading to the lower rate of increase in the native-born population observed during the period 2000–2010 than that of 1990–2000.

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[3] The TFR is a synthetic period measure of fertility that sums the period age-specific fertility rates for all (childbearing) ages. It can be interpreted as the average number of children a woman would bear if she survived through her childbearing years and experienced the age-specific fertility rates from the current period during each of those years.

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Figure C.4. U.S. Total Fertility Rate, 1935–2007
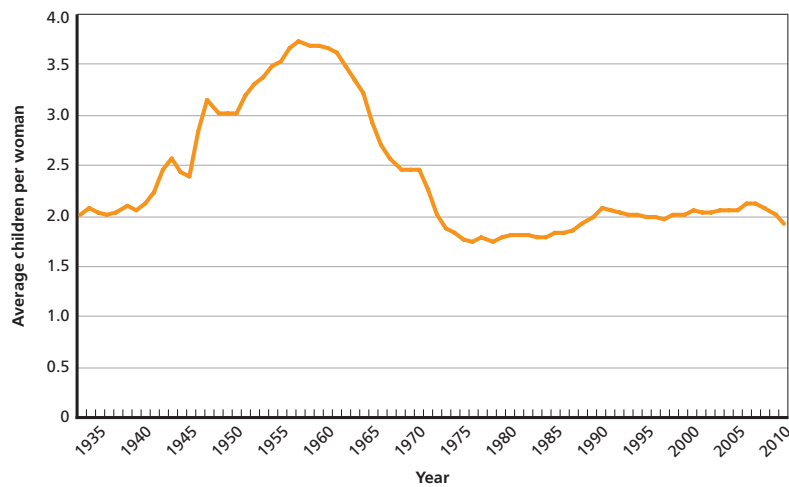
Since the all-time low TFR of 1.738 in 1976 (see Figure C.4), U.S. fertility levels have increased. One might interpret the trend in TFRs in two ways. One could describe the trend as increasing between 1976 and 1990 and then being relatively stable since that time. Alternatively, one could view 1990 as a local peak due to delayed fertility following years of stagflation and unemployment and argue that there is a steady but small increasing trend since 1976, affected by short-term variation due to economic conditions. The fact that the U.S. TFR hit a 35-year high in 2007 is consistent with the latter view, but this does not prove that fertility rates have been consistently increasing since 1990.

Regardless of which of these two views one takes, it is clear that the TFR has increased significantly since its baby-bust low in 1976 and that current levels are much higher than those of other developed industrial countries. (In comparison, the TFR in "more-developed countries," a category that includes North America, Europe, Japan, Australia, and New Zealand, is 1.7 [Population Reference Bureau (PRB), 2010]). This long-term increase in TFR and the relatively high level are explained in part by immigration from Mexico and other Latin American countries. As Figure C.5 shows, Hispanics have a considerably higher TFR than that of any other racial or ethnic group in the United States. Foreign-born (i.e., immigrant) Hispanics have higher TFRs than native-born Hispanics, although both groups have higher TFRs than non-Hispanic whites. Using three different surveys for the period 2000–2008, Parrado (2011) calculated the TFR for native-born Hispanics to be 2.0–2.2 (depending on the survey); for Hispanic immigrants, the TFR ranged between 2.8 and 3.3. Parrado (2011) and Toulemon, Pailhé, and Rossier (2008) find that recent immigrants can distort the TFR upward when fertility is low prior to migration and high following migration. Parrado (2011) reports evidence of such distortion in the case of Hispanic immigrants to the United States. In his analysis of completed fertility rates (CFRs) by nativity for the period 2000–2008, Parrado (2011) found that native-born Hispanics

ages 40–44 averaged 2.0 children, while their foreign-born counterparts averaged 2.4 children. The latter figure is considerably lower than the TFR estimates for foreign-born Hispanics in the same period, which range from 2.8 to 3.3.

However, the TFR for non-Hispanic white women in the United States is considerably higher than the 1.6 TFR in most European countries (PRB, 2010), so immigration cannot be the sole factor explaining the relatively high U.S. fertility rate. Other factors hypothesized to explain U.S. fertility levels include lower levels of contraceptive use, declining abortion rates, and religious values, especially among conservative Protestants and Mormons (Stobbe, 2008; Stein, 2007; Hout, Greeley, and Wilde, 2001). Moreover, American values and economic pressures, as well as the availability of part-time work schedules, allow and sometimes encourage U.S. women to combine motherhood and careers (Bennhold, 2010; Stobbe, 2008; Stein, 2007).

Fertility levels have declined since 2007, due largely to the economic recession and continuing high levels of unemployment (Livingston, 2011; Livingston and Cohn, 2012). A full economic recovery would likely increase fertility rates both through increases in fertility among those already in the United States and through increasing levels of immigration of higher-fertility immigrants. Together, these factors suggest that a full economic recovery would increase the rate of population growth and the demand for transportation.

Figure C.5. Total Fertility Rate, by Race and Ethnicity, 1990–2010
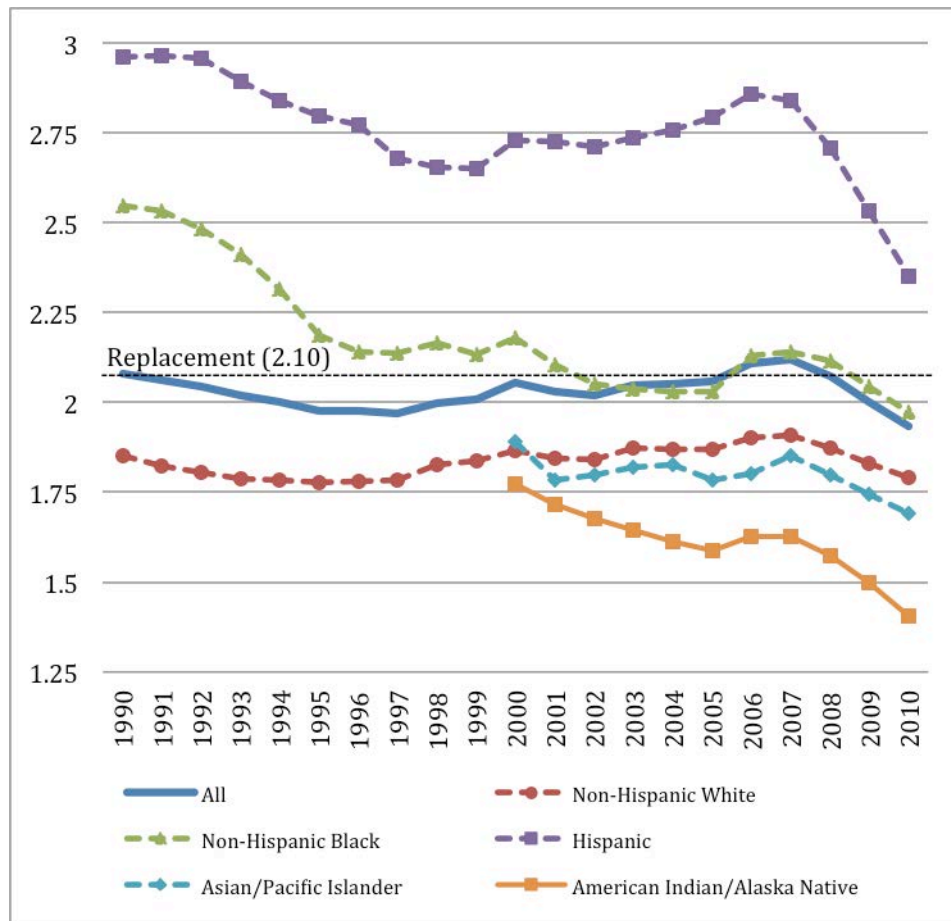
SOURCES: Martin et al., 2010, Table 8; Hamilton, Martin, and Ventura, 2011, Table S-2.

Mortality

Mortality in the United States has declined considerably in the past century. One measure of mortality levels, independent of population age structure, is life expectancy at birth.[4] Life expectancy has increased at a steady rate, with occasional one-year declines, over the past 35 years (see Figure C.6).

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[4] Life expectancy at birth is the age to which a hypothetical group of people would live, on average, if they experienced at every age the age-specific death rates pertaining in a particular year.

Figure C.6. Life Expectancy at Birth, 1975–2010
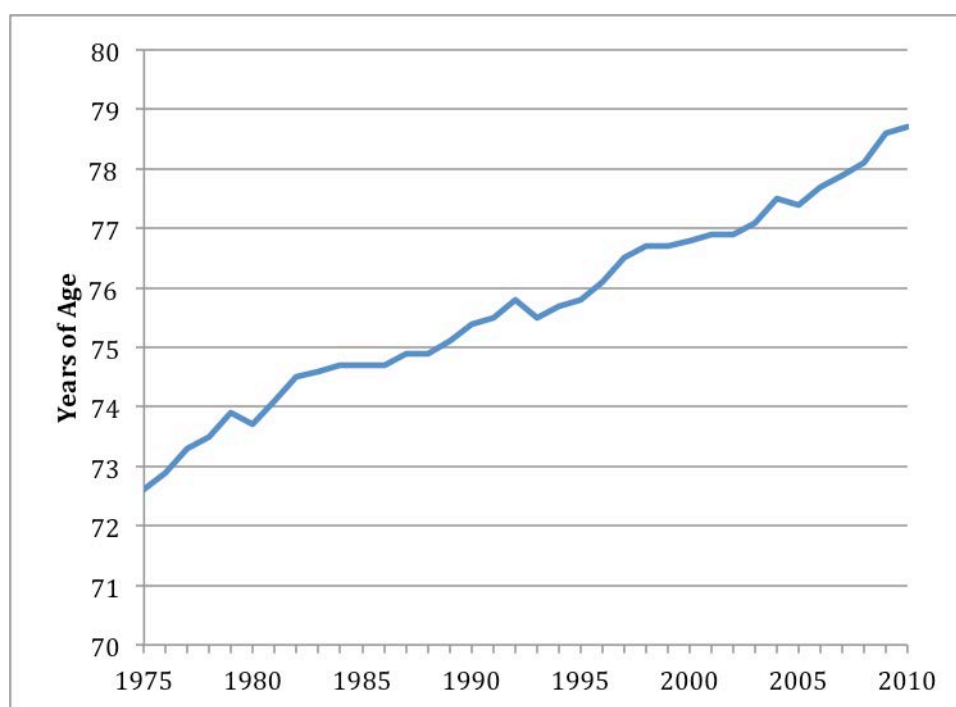
SOURCES: Miniño et al., 2011; Murphy, Xu, and Kochanek, 2012.

There is a lack of consensus as to whether life expectancy will continue to increase or is approaching some biologically fixed limit (for a review, see Sonnega, 2006). Increasing life expectancy at birth (and thus decreasing mortality rates) clearly leads to increases in the total population, all else being equal. However, the impact that changes in life expectancy at birth can have on population age structure depends on which age-specific mortality rates cause the change in life expectancy. If life expectancy increases solely because of decreased infant mortality, median age in the population would decrease, while decreases only in mortality at older ages would increase the median age in the population. Increasing the share of the population that survives infancy and childhood to reach reproductive age would increase fertility and the population growth rate, all else being equal.

Race and Ethnicity

Figure C.7 shows the distribution of the U.S. population by race and ethnicity categories from 1970 to 2010. Although the Census Bureau reports race and ethnicity separately, Figure C.7 groups the population into Hispanics of any race and non-Hispanic by specific racial categories: white, black, Asian or Pacific Islander, American Indian or Alaska native, other race, and multiple races. The multiple-races category reflects the reporting of multiple races on the decennial census starting in 2000. Readers should note that, to allow a more detailed view of the

changes taking place over the period, the minimum value shown on the vertical axis is 50 percent.

Although non-Hispanic whites still accounted for a majority of the population in 2010, their share has declined over time as other groups, particularly Hispanic and Asian and Pacific Islander populations, have grown at a significantly faster rate.

Some travel behavior and demand characteristics do vary with race and ethnicity. Non-Hispanic whites have the highest number of vehicles per household, while Hispanics have the highest average annual vehicle miles traveled (VMT). The proportion of zero-vehicle households varies from a low of 7.3 in white households to a high of 23.8 in black households. The licensure rate ranges from 90.2 percent of whites to 74 percent of blacks. Asians have the highest amount of public-transit use at more than 1,400 miles per year, while whites have the lowest at 216 miles (Contrino and McGuckin, 2009). It is possible that some of these differences are explained by income and location, as well as cultural factors; we did not identify definitive research on the roots of these differences, which likely vary depending on the particular indicator.

Figure C.7. U.S. Population, by Race and Ethnicity, 1970–2010
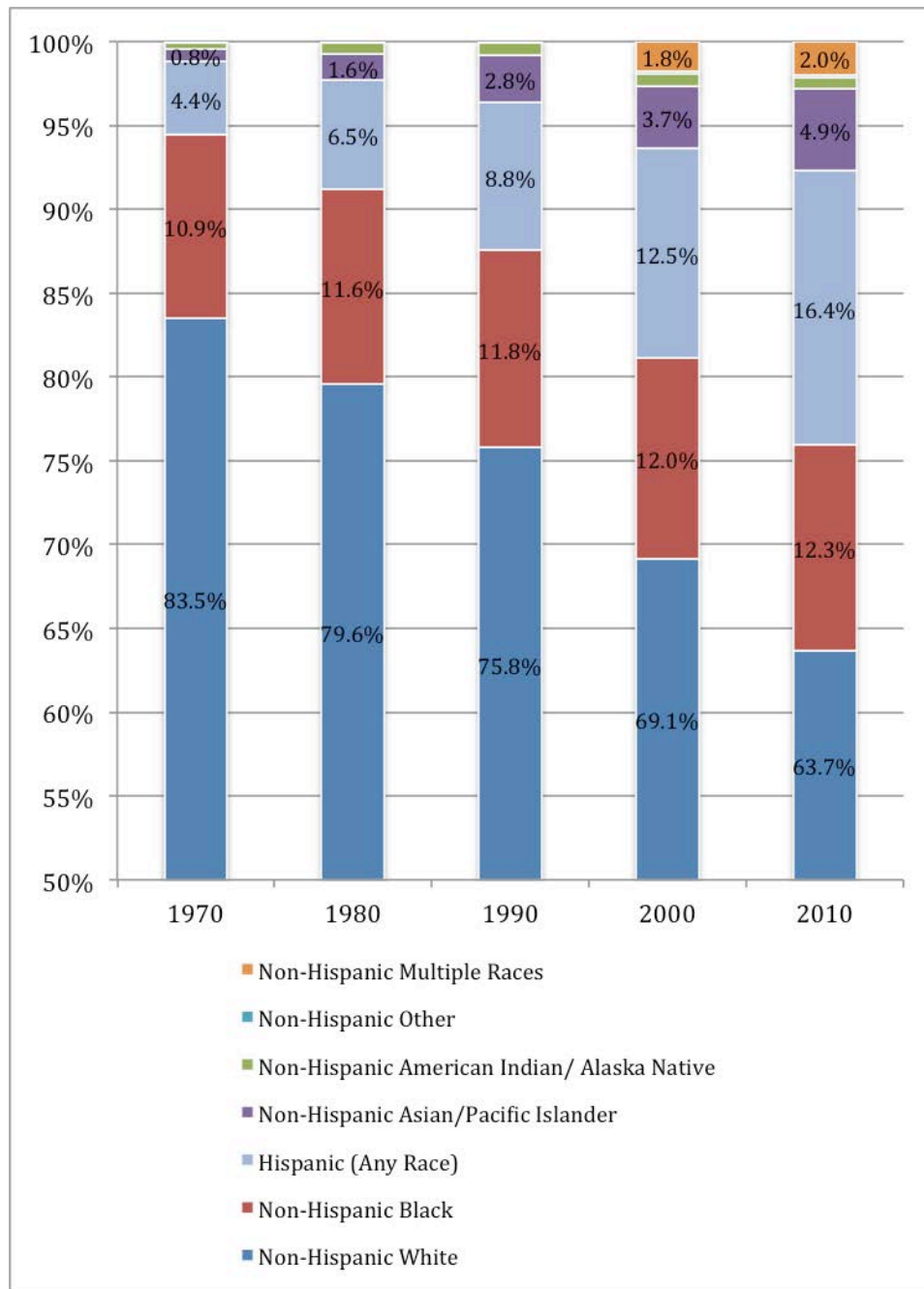
SOURCES: Integrated Public Use Microdata Series (IPUMS), decennial census (1970–2000), and U.S. Census Bureau, 2010a, available in Ruggles et al., 2010.

Age

Figure C.8 shows the age distribution by broad age groups for each census year from 1950 to 2010. Population aging is evident in the increasing share of the population in older age

categories. The share of the population age 15 and under, and thus ineligible for driver's licenses, has declined from 26.9 percent of the population in 1950 to 19.8 percent in 2010. In 2010, nearly 40 percent of the population was age 45 or older. Note that the age category 45–64 in 2010 corresponds almost exactly to the baby-boom cohort (defined by the U.S. Census Bureau as those born between 1946 and 1964). Figure C.9 makes it clear that the large baby-boom cohort is just now reaching age 65. As such, likely increases in the older population with health factors that limit driving should be considered in projecting future transportation demand.

Figure C.8. Broad Age Groups in U.S. Population, 1950–2010

Year	<15	15-24	25-44	45-64	65+
2010	19.8	14.1	26.6	26.4	13
2000	21.4	13.9	30.2	22	12.4
1990	21.5	14.8	32.5	18.6	12.6
1980	22.6	18.8	27.7	19.6	11.3
1970	28.5	17.4	23.6	20.6	9.9
1960	31.1	13.4	26.2	20.1	9.2
1950	26.9	14.7	30	20.3	8.1
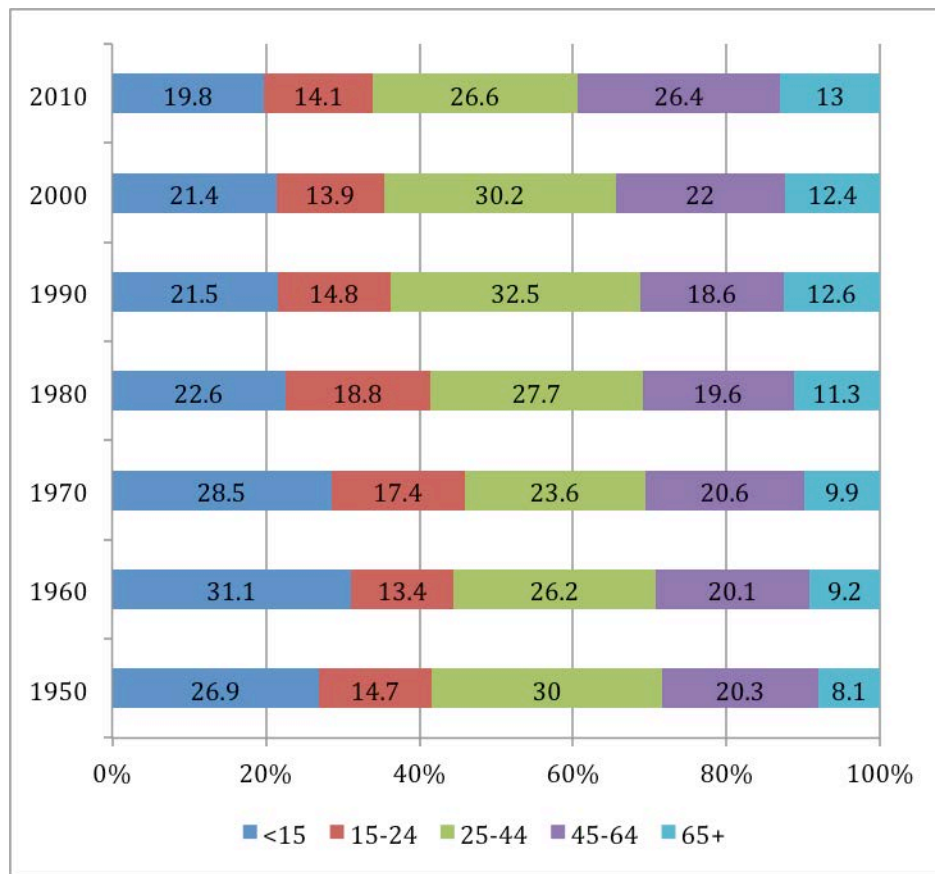
SOURCES: Hobbs and Stoops, 2002; Howden and Meyer, 2011.

Figure C.9. Population, by Age and Sex, 2000 and 2010
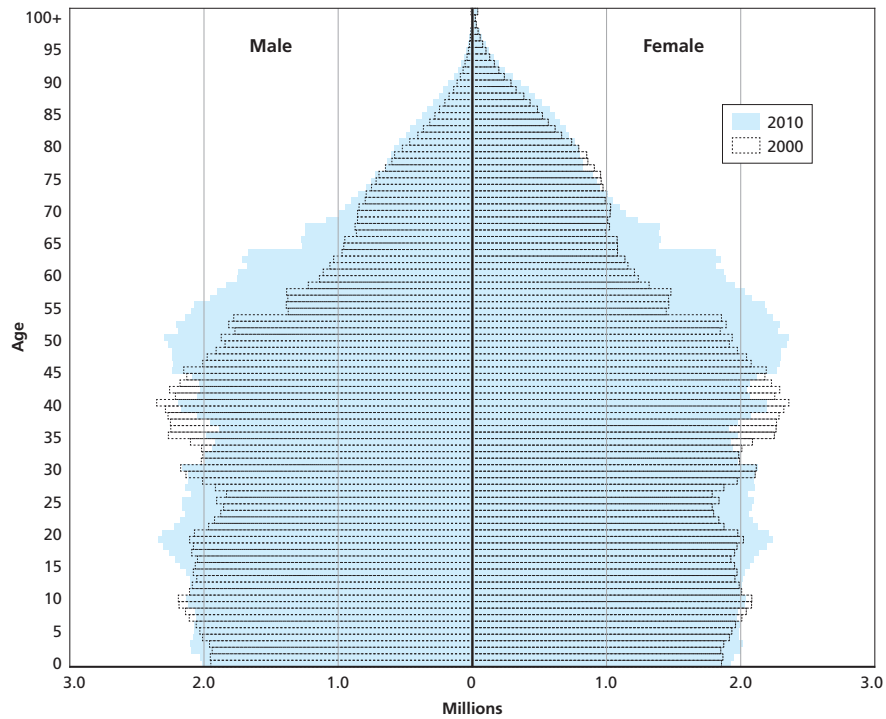
SOURCE: Howden and Meyer, 2011, Figure 2.
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Population Density and Spatial Distribution

The population density of the United States, defined as people per square mile of land area, has increased from 50.5 in 1960 to 87.4 in 2010. However, over the same period, central cities have become less dense, declining from 5,336 people per square mile in 1960 to 2,754 people per square mile in 2010. In the same period, the density of U.S. suburbs (defined here as the portions of metropolitan areas that are outside the central city)[5] and nonmetropolitan areas (largely rural and smaller towns) has changed very little (see Figure C.10). The increasing population density is entirely due to the growth of suburbs into areas that were previously nonmetropolitan (rural). In Figure C.10, the right axis represents the higher values of the central-city population, while the left axis, which is an order of magnitude smaller, represents values for the metropolitan non–central city and nonmetropolitan areas.

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[5] Note that the U.S. Census Bureau has historically identified "urban" and "rural" areas but not "suburban" areas. This appendix follows the use in Hobbs and Stoops (2002) of identifying metropolitan non–central city areas as "suburban." See Hobbs and Stoops (2002, p. 38).

Figure C.10. U.S. Population Density, by Metropolitan Status
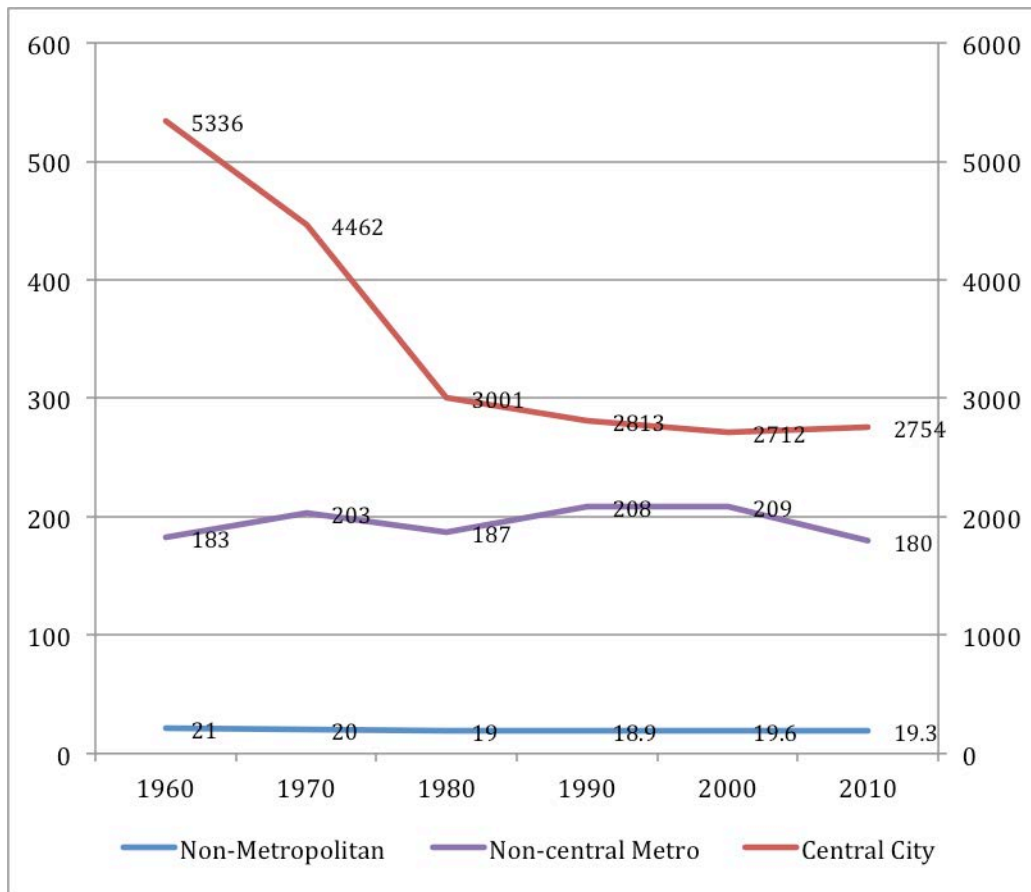
SOURCES: U.S. Census Bureau, 2010b; Hobbs and Stoops, 2002, Table 16.

Figure C.11 shows the total U.S. population by metropolitan status. The population in suburbs (non–central city metropolitan areas) has grown most quickly, followed by that in central cities. As the land area of nonmetropolitan areas has shrunk, the aggregate national population in such areas has also decreased.

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Figure C.11. Population, by Metropolitan Status
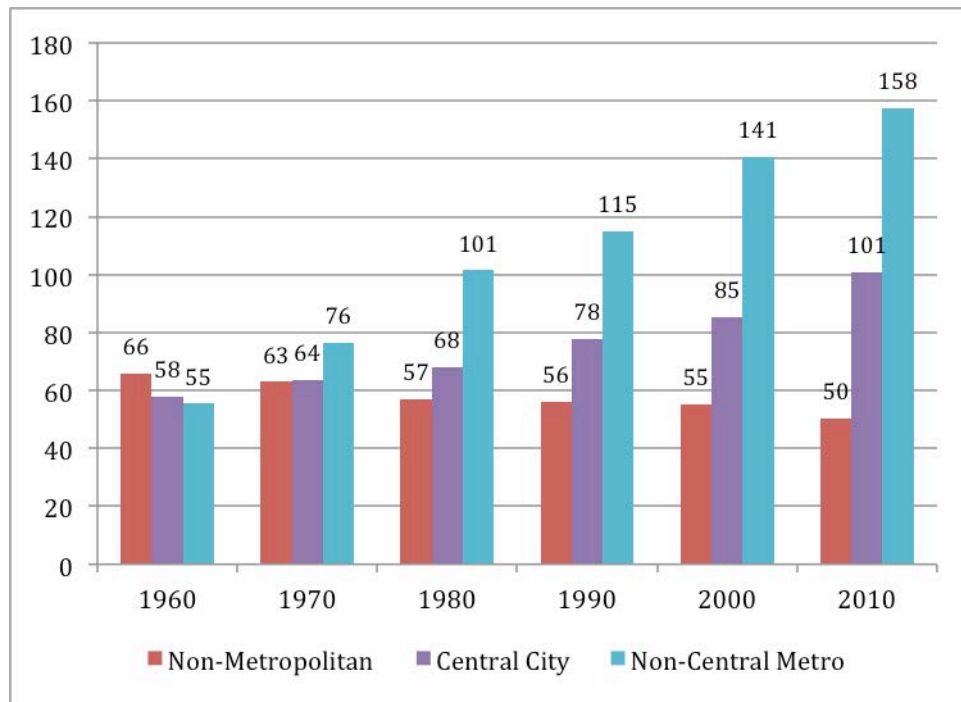
SOURCES: U.S. Census Bureau, 2010b; Hobbs and Stoops, 2002, Table 16.

Behind the total numbers, different trends are happening in suburban and urban growth. As the baby-boom generation ages, many in that cohort are choosing to remain in suburban areas; as a result, suburban populations are both growing and aging more quickly than those in center cities. In 2000, 34 percent of suburban residents were over 45; by 2010, 40 percent were. In contrast, in center cities, the population over 45 increased from 31 percent to 35 percent. However, this trend is not necessarily consistent across the country; some metropolitan suburbs have successfully attracted younger residents, while others have shed them (Frey, 2011). Among center cities in the 100 largest metropolitan regions, two-thirds gained population from 2000 to 2008, continuing a trend that began in the 1990s. Some of this was attributed to immigration, because the largest cities remain magnets for newcomers, and some to the fact that, as housing prices began to decline in 2006, center-city residents who might have moved to the suburbs instead remained in cities. It is also misleading to think of all suburbs as the same; in the past decade, inner-ring suburbs have experienced population changes more similar to those in center cities than to those in outer-ring suburbs. And many trends vary with the region of the country and the economic prosperity of the metropolitan region (Katz, 2010).

The 2009 National Household Travel Survey (NHTS) measured VMT per year and household urban/rural status. Rural households, whose members typically need to travel farther to work, school, and other destinations, averaged 27,700 VMT in 2009, compared with 17,600 VMT for urban households (Davis, Diegel, and Boundy, 2011). One might hypothesize

that urban central-city households would travel fewer VMT than the reported "urban" figure and that suburban "metropolitan, non–central city" households would fall in an intermediate level, between the reported values for urban and rural households. The trends in development patterns help explain the trends in VMT. Average annual VMT has grown substantially between 1969 and 2008, but particularly starting in the period between 1983 and 1990, when suburban decentralization rates were at their highest and jobs began to follow residents into the suburbs (Kuzmyak, forthcoming). The year 1989 marked the tipping point, when the proportion of metropolitan-area jobs in the suburbs finally exceeded that in the central cities.

Vehicle Ownership

The share of households with no vehicles has declined from 21.5 percent in 1960 to 9.1 percent in 2010, and the share with only one vehicle has declined from 56.9 percent in 1960 to 33.8 percent in 2010. During this same period, the share of households with two vehicles has increased from 19.0 percent to 37.6 percent, and the share with three or more vehicles has increased dramatically, from 2.5 percent to 19.5 percent. However, most of this change had taken place by 1990, and, as Figure C.12 shows, the distribution of vehicle ownership was fairly stable between 1990 and 2010.

Figure C.12. Number of Vehicles per Household, 1960–2010
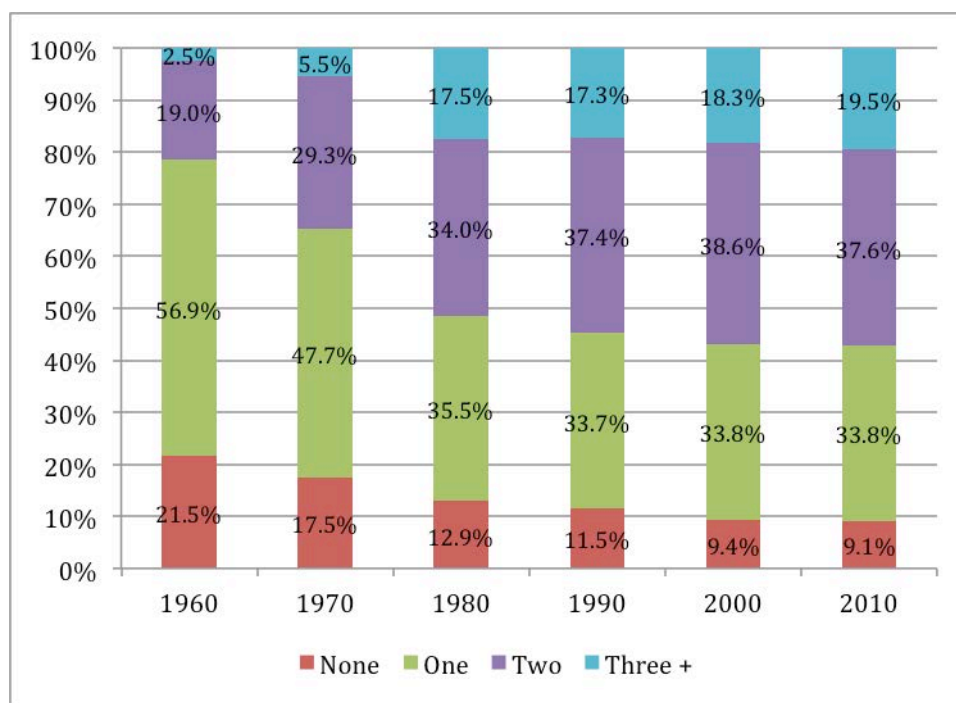
SOURCE: Davis, Diegel, and Boundy, 2011, Table 8.5.

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According to 2009 NHTS data, the rate of vehicle ownership is much higher for households living in low-density environments. Almost 30 percent of the households in areas with a population density greater than 10,000 persons per square mile did not own a vehicle in 2009, a proportion that has remained steady since 1995. Almost 70 percent of the households in the least densely populated areas owned two or more vehicles, a proportion that has also remained about the same since 1995. Forty-five percent of all U.S. households are located in areas with less than 2,000 persons per square mile (Santos et al., 2011).

Household Type and Size

The composition of households may affect transportation demand through both the number of people and their ages and relationships. The U.S. Census Bureau divides family households into married-couple families, female householders with no husband present, and male householders with no wife present. In some cases, these latter two categories represent cohabiting couples with children rather than truly "single" parents. For the purposes of relating demographics to transportation demand, the presence of minor children is likely to be more important than the marital status of adult household members. Thus, Figure C.13 divides households into family households with or without their own children under 18 years and nonfamily households with one person or two or more people.

Figure C.13. Households, by Type and Presence of Own Children Under 18 Years, 1960–2010
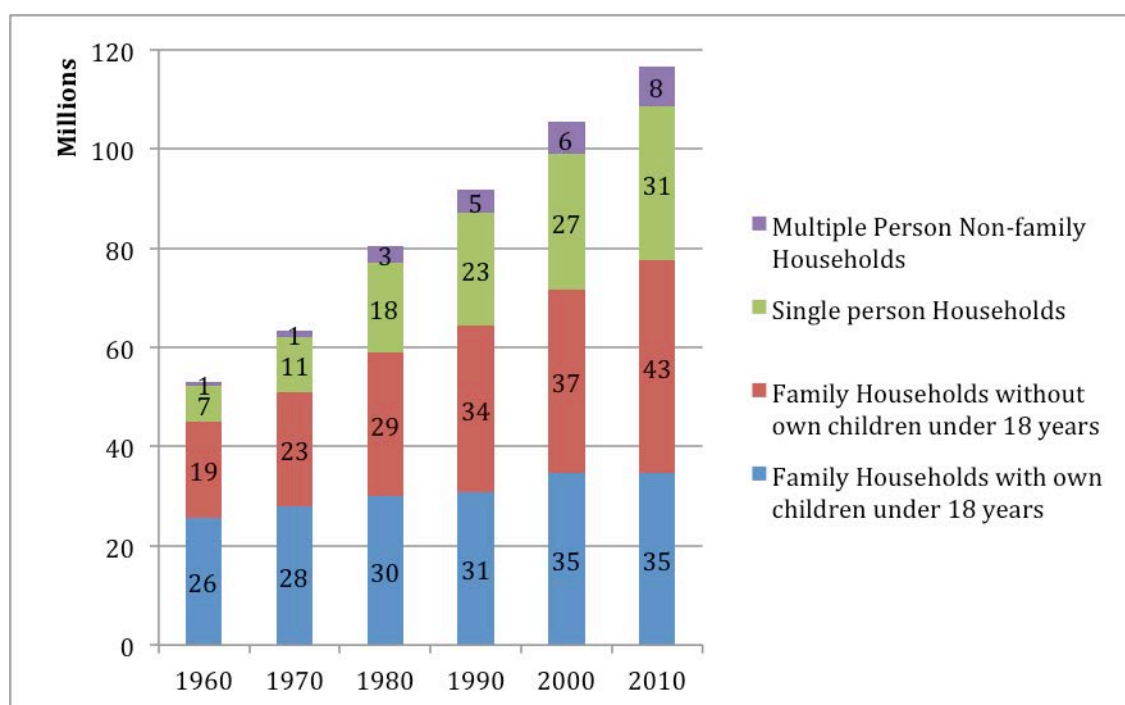
SOURCES: IPUMS, decennial census (1970–2000), and U.S. Census Bureau, 2010a, in Ruggles et al., 2010.

Of these categories, family households with own children under 18 years have grown at the slowest rate between 1960 and 2010 and, in fact, increased by only 0.5 percent between 2000 and 2010. In this same decade, family households without own children under 18 years increased by 15 percent, from 37.2 million to 42.8 million, while single-person households increased 14.6 percent, from 27.2 million to 31.2 million. Multiple-person, nonfamily households increased 23.4 percent, from 6.5 million to 8 million.

According to the 2009 NHTS, households with children averaged 30,400 VMT per year, while households without children traveled fewer than half as many vehicle miles, 14,400 per year. Households with one person averaged 7,100 VMT, two-person households averaged 17,500 VMT, and three-person households averaged 27,900 VMT. At four or more persons, the increases in VMT level off at about 33,500 VMT per year (Davis, Diegel, and Boundy, 2011).

The average size of U.S. households decreased from 3.29 people in 1960 to a low of 2.59 in 2000 and then rebounded slightly to its 1990 value of 2.63 again in 2010 (see Figure C.14). This increase is due in part to young adults responding to the economic downturn by living in their parents' households (Kochhar and Cohn, 2011; Taylor et al., 2010). Original analysis of ACS data from IPUMS indicates that, in 2006, prior to the "Great Recession," 15.2 percent of those ages 25–34 lived in the same household as one or both parents.[6] In 2010, the share among this age group living with parents was 18.0 percent, reflecting an increase since 2006 in the number of young adults (ages 25–34) living with their parents of approximately 1.27 million.

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[6] The IPUMS identifies parent-child relationships based only on the reported relationships to the household head for about 97 percent of individuals. In the remaining 3 percent of cases, IPUMS researchers use a set of rules that also utilize the ages, marital status, and order in which household members are listed on the census form to identify the most likely parent-child relationships. For more information, see IPUMS, undated.

Figure C.14. Average Household Size, 1960–2010
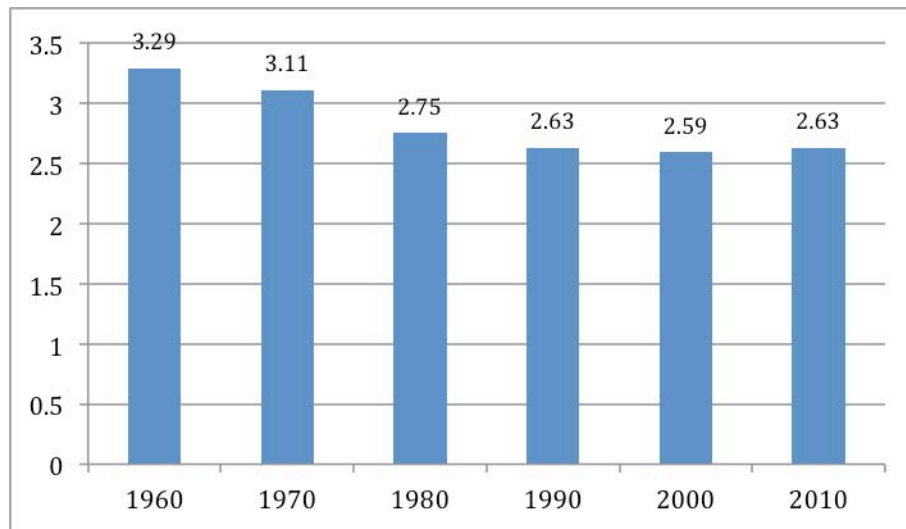
Gender Dynamics

The trends of men and women's allocation of time to paid and unpaid labor have tended toward convergence in the past 50 years without having yet converged. Women's labor force participation rate has increased from 34.5 percent in 1960 to 59.3 percent in 2010, while men's labor force participation rate has declined somewhat, from 77.6 percent to 69.8 percent over the same period (see Figure C.15).

Figure C.15. Labor Force Participation Rates, by Sex, 1960–2010
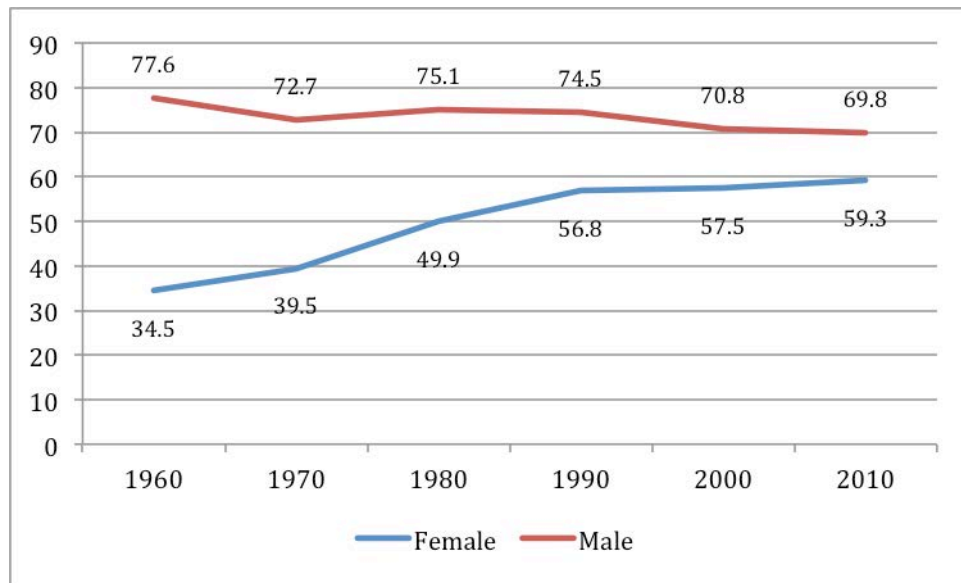
SOURCES: IPUMS, decennial census (1970–2000), and U.S. Census Bureau, 2010a, in Ruggles et al., 2010.

Analysis of the American Heritage Time Use Study by Fisher and coauthors (2007) found that women's time spent in all housework excluding child care declined from more than 250 minutes per day in 1965 to just above 150 minutes per day in 2003. As Figure C.16 shows, men's time spent in all housework except child care increased somewhat during the same period.

Figure C.16. Time Spent on Unpaid Housework, by Gender, 1965–2003
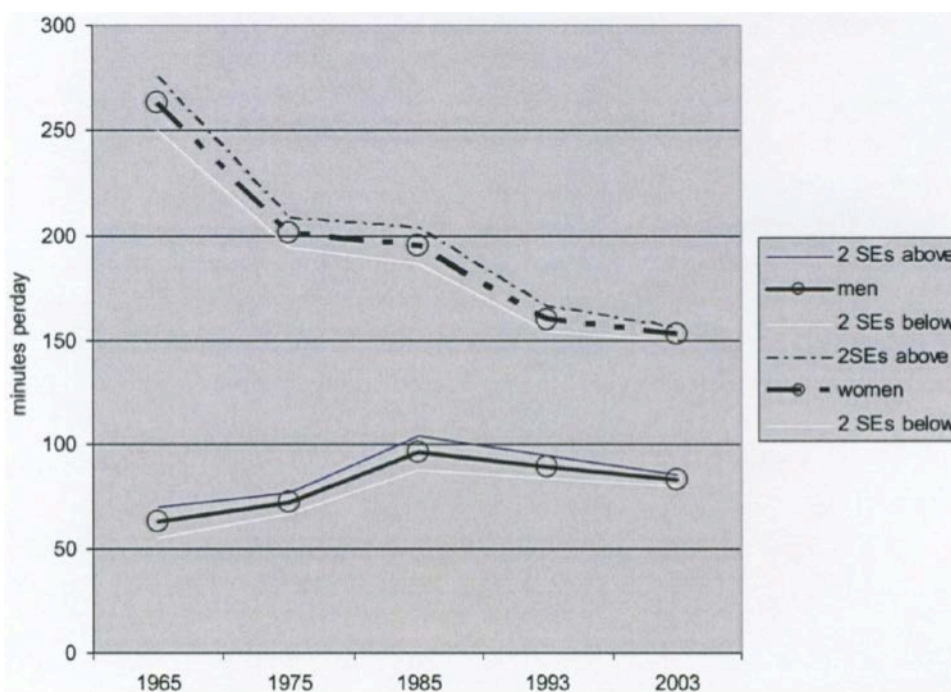
SOURCE: Fisher et al., 2007, Figure 4. Used with permission.

Among parents, Bianchi, Wight, and Raley (2005) found that mothers decreased their time spent on housework (except child care) from an average of 31.9 hours per week in 1965 to 18.1 hours per week in 2003. In this same period, fathers increased their time spent in housework from 4.4 hours per week in 1965 to 9.6 hours per week in 2003. Parents of both genders increased time spent on child care, mothers from 10.2 hours per week in 1965 to 14.1 hours per week in 2003 and fathers from 2.5 to 7.0 hours per week over the same period (see Figure C.17).

Figure C.17. Trends in Parents' Time Spent on Housework and Child Care, 1965–2003
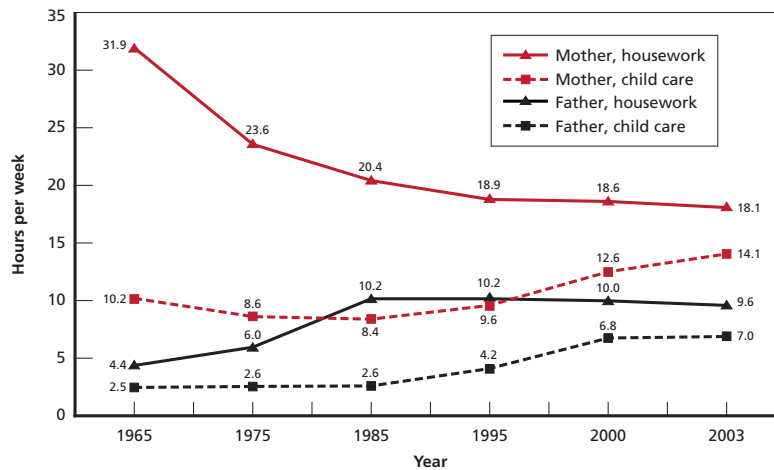
SOURCE: Bianchi, Wight, and Raley, 2005, Figure 1.
RAND *RR246/1-C.17*

The trends toward convergence of male and female labor force participation (or time in paid work) and time spent on housework may imply convergence in the travel behavior of men and women. The increase in time that parents of both sexes spend on child care does not have clear implications for travel related to the care and activities of children. If children spend more time at home, parents might reduce travel. However, if children spend fewer hours in child-care settings outside the home and instead spend this time in more extracurricular activities at different locations, this change could increase the number of trips associated with parenting activities.

Overall, men travel farther and longer than women, especially when commuting to work. Although some conclude that this gap in travel behavior is closing, further analysis reveals mixed conclusions. Women make more daily trips than men, but the research is mixed on the relationship between gender and mode choice. The effect of gender is complicated by overlapping effects of other characteristics, such as race and ethnicity, household responsibilities, and residential location.

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Appendix D. Economic Trends in the United States

This appendix explores U.S. economic trends. It is organized around the following areas:

- economic growth
- income distribution
- employment trends
- business creation
- commuting and travel expenditure trends
- freight movements.

Economic Growth

The United States has experienced decades of economic prosperity. Although there have been periods of downturn, they have tended to last only a few years and be followed by longer periods of growth. At the same time, the United States is changing in a variety of ways, including its economic focus, the composition of its workforce, and its position within the global economic environment.

Overall economic growth is most often characterized by changes in *gross domestic product* (GDP). GDP is an estimate of the market value of all final goods and services produced within a country over some specified period of time—typically a quarter or a year. To analyze how changes in GDP and other measures of economic activity change over time, economists generally put prior-year estimates in *real dollars* (e.g., adjusted for inflation). Figure D.1 illustrates change in real GDP over time. In the past 80 years, the U.S. economy has grown by a factor of approximately 15, as measured by the change in real GDP. In the past two decades (1991–2011), GDP increased by an average of 2.47 percent annually.

Figure D.1. U.S. Gross Domestic Product
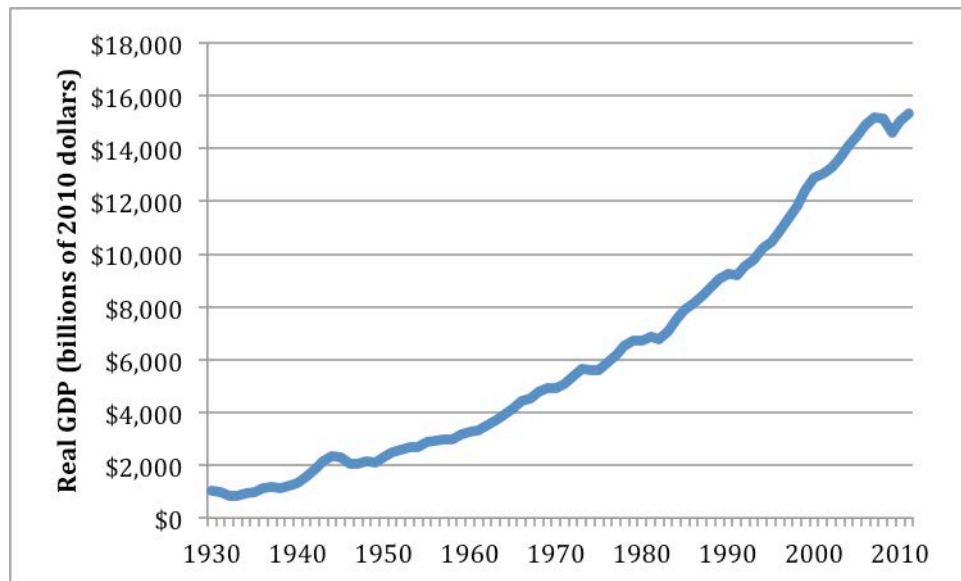
SOURCE: Bureau of Economic Analysis (BEA), 2011.

Per Capita Personal Income

Personal income differs from GDP in that it excludes economic activity that occurs in the United States that is owned by foreigners and includes U.S. economic activity that occurs in other countries. It represents income received by a country's citizens or residents from all sources, including net earnings, property income, and personal current transfer receipts. Personal income is also adjusted for depreciation and other factors.[7] When personal income is calculated in per capita terms (e.g., per person), it provides a more useful measure of the income level of individuals in the economy. Broadly speaking, GDP has a more direct impact on demand for freight movements, while personal income has a more direct impact on passenger travel demand. Figure D.2 shows real per capita personal income from 1930 to 2010 in the United States. In that time period, per capita personal income grew by a factor of approximately 5, from $8,069 to $39,945, after adjusting for inflation. This implies an average annual rate of real growth of 2.0 percent. More recently, however, the rate of growth in real per capita personal income has slowed. Although, between 1990 and 2010, real per capita personal income grew an average of 1.07 percent annually, it slowed between 2000 and 2010, growing from $38,393 to $39,945, an annual rate of growth of only 0.4 percent.

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[7] For a comprehensive discussion of the differences between GDP and personal income, see McCulla and Smith, 2007.

Figure D.2. Real Per Capita Income in the United States
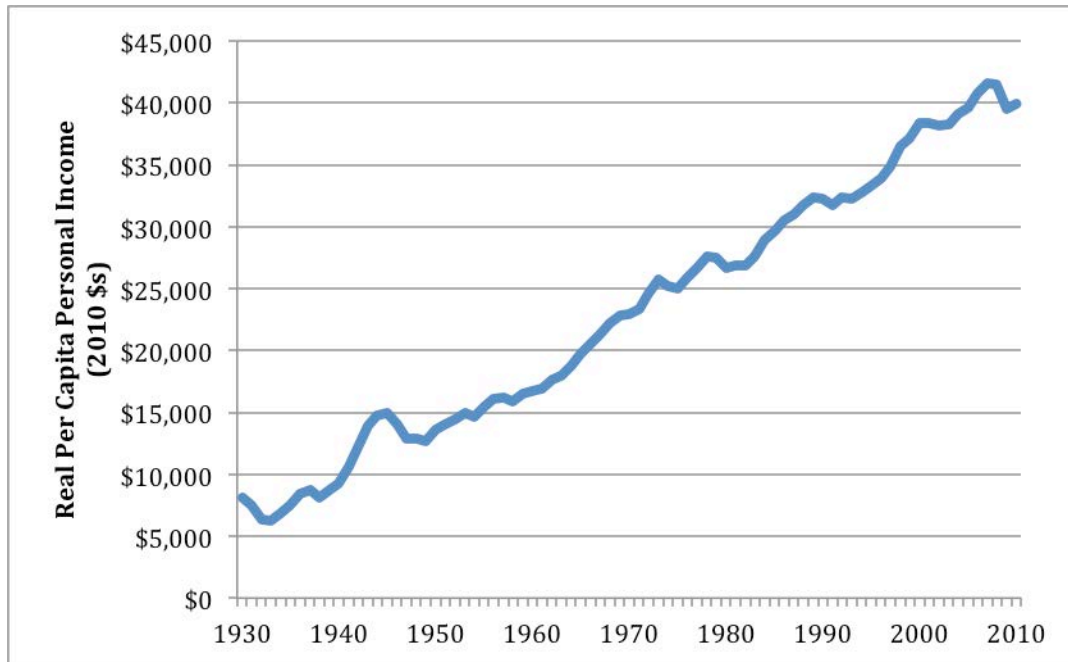
The literature on income elasticities and travel, as summarized by Goodwin, Dargay, and Hanly, 2004, suggests the following:

- VMT: A 10-percent increase (decrease) in average income is associated with growth (decline) in VMT of 2 percent in the short run and 5 percent in the longer run on an economy-wide basis.
- fuel consumption: A 10-percent increase (decrease) in average income is associated with an increase (decrease) in total fuel consumption of 4 percent in the short run and 10 percent in the longer run.

As the above elasticities suggest, longer-term impacts tend to be larger than short-term impacts. This is in part because adjustment processes require investments or changes in behavior, which take time to implement or adopt. The fact that VMT grows by less than fuel consumption when income growth is consistent with other studies, which find that, as household income grows, households tend to purchase less fuel-efficient vehicles (Pozdena, 2009). It has also been observed that higher-income households are less likely than lower-income households to use public transportation.

Causes of Economic Growth

Many factors have contributed to the United States' economic growth. When comparing countries or regions within a country, economists often emphasize the following three factors as particularly important:

- human capital: the formal knowledge and skills of the labor force
- physical capital: the machines, buildings, and infrastructure that support production of goods and services
- natural resources: access to physical inputs (e.g., timber, oil) used to produce goods and services.

Human capital is a key driver of economic growth and, ultimately, income. For a century, the United States expanded its human capital significantly through education. Between 1875 and 1975, the U.S. average years of education increased by seven grades (Delong, Goldin, and Katz, 2003). Since then, U.S. advances in educational attainment have begun to level off. Physical capital and natural resources are generally thought to be secondary drivers of growth, relative to human capital. For example, despite dramatic increases in the size of the U.S. economy since World War II, the physical capital/output ratio has remained relatively constant (Delong, Goldin, and Katz, 2003).

One key determinant of personal income that is tied to human capital is *labor productivity*. Labor productivity is measured by the amount of GDP produced per labor hour. Improvements in labor productivity enable wages to rise without creating inflation.

In the past 60 years, labor productivity has been growing, although there was a considerable slowdown in its growth during the mid- and late 1970s (see Figure D.3). Specifically, between 1947 and 1973, labor productivity grew at a rate of 2.8 percent per year, but then it fell to 1.1 percent per year between 1973 and 1979. Since 1979, the United States has seen a gradual uptick in the rate of labor productivity growth, although it has not reached a level comparable to that enjoyed in the 1947–1973 time frame.

Figure D.3. Labor Productivity Growth in the Nonfarm Business Sector and Per Capita Personal Income Growth, 1947–2010
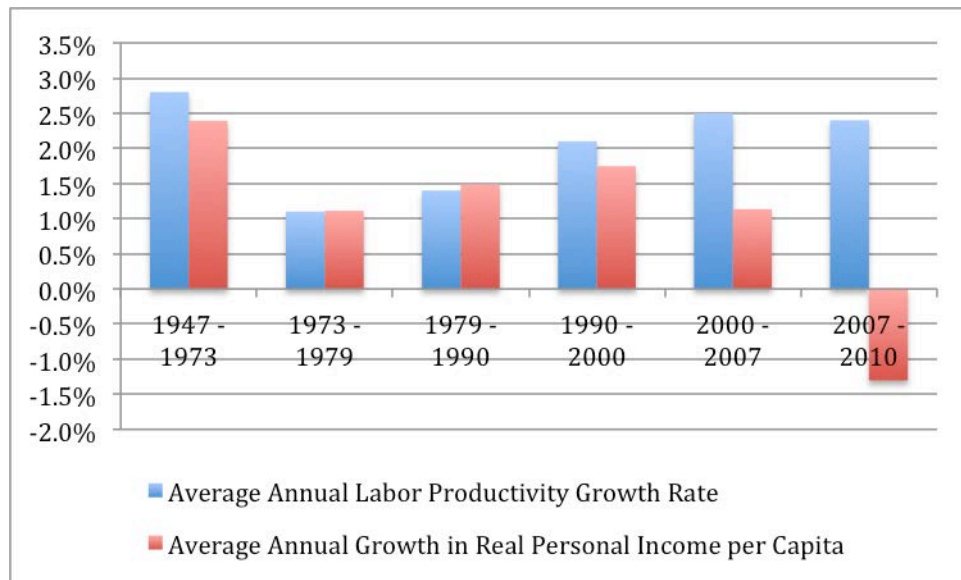
Real per capita personal income has historically grown in line with labor productivity, at least prior to 2000. Since 2000, the United States has seen labor productivity continue to grow at a rate of almost 2.5 percent per year, while personal income per capita grew at only 1.1 percent per year between 2000 and 2007 period and –1.3 percent per year between 2007 and 2010. The dramatic decoupling of personal income and productivity growth observed between 2007 and 2010 is likely temporary and is at least partially attributed to the recent recession. In particular, the recession decreased the demand for labor, leading to higher unemployment and depressed wages, both of which lowered personal income despite the fact that labor productivity grew (Congressional Budget Office, 2010).

Income Distribution

Although per capita personal income has increased substantially in the past century, the gap between the affluent and poor has widened in the United States in the past few decades (Levy and Murnane, 1992; Piketty and Saez, 2003). That is, much of the recent growth in income in the United States has accrued to the wealthy, while middle- and lower-income households have seen considerably less growth in their incomes.

Figure D.4 shows the growth in the real income of households at different percentiles on the income distribution from 1970 to 2010. It illustrates how income growth has been concentrated in the upper-income percentiles in the past 40 years; median and below-median households have experienced very limited income growth.

Figure D.4. Real Household Income in the United States at Selected Percentiles over Time
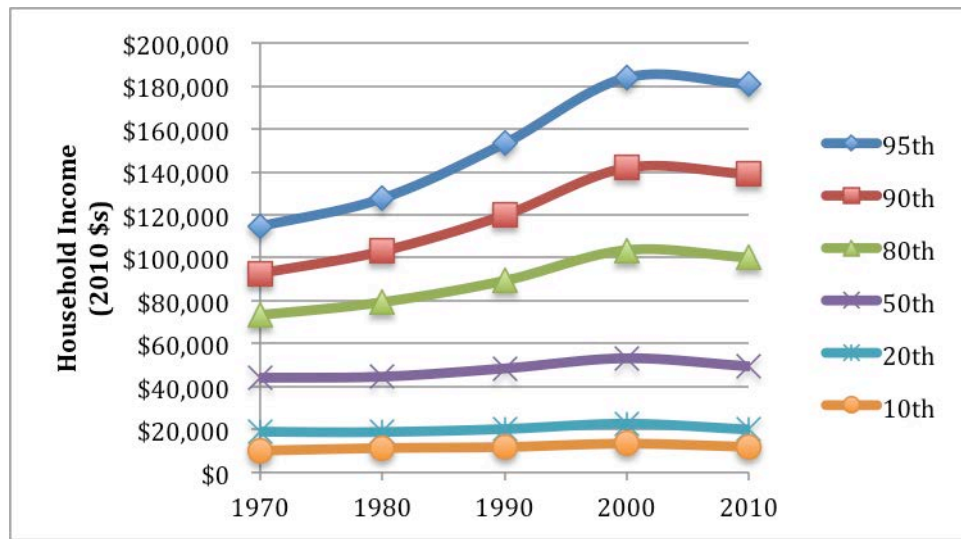
Although there seems to be virtually no disagreement among researchers that inequality has risen in the past few decades, there is not consensus about the cause of this trend. Multiple theories have been put forth and are summarized by Katz and Autor (1999):

- The demand for highly educated and "more-skilled" workers has increased with skill-biased technological changes, largely associated with advancements in computers technologies (Mincer, 1991; Bound and Johnson, 1992; Berman, Bound, and Griliches, 1994; Autor, Katz, and Krueger, 1998).[8] This has placed greater upward pressure on the wages of the skilled than on the unskilled workforce.
- Others have noted the trend toward globalization, which has increased trade with less developed countries and led to greater foreign outsourcing. This has reduced domestic employment in the manufacturing sector and other "blue-collar" sectors, leading to lower wages for less skilled individuals (Wood, 1995; Borjas and Ramey, 1995; Feenstra and Hanson, 1996).
- There has been an increased rate of unskilled immigration to the United States; this has increased the supply of and suppressed wages in lower-skilled positions (Katz and Murphy, 1992; Murphy and Welch, 1992; Borjas, Freeman, and Katz, 1992).
- Institutional and policy changes may also have exacerbated inequality in the past several decades, with the decline in unionization, slower growth in minimum wages, and changes in tax policy (DiNardo, Fortin, and Lemieux, 1996; Freeman, 1996; D. Lee, 1999).

In the next sections, we summarize data that provide insight into how income levels vary with race and ethnicity and across geographic regions in the United States.

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[8] Investment in technologies, such as computers, tends to complement skilled labor and substitute for unskilled labor. This likely explains some of the shift in demand over time toward more-skilled labor.

Variation in Income, by Race and Ethnicity

Figure D.5 shows how the median income of families varied by race and ethnicity in 1990 and 2009 (the most recent year for which these data are available). For these calculations, the Census Bureau uses the race and ethnicity of the family member who filled out the survey to classify households into groups. Asians and Pacific Islanders have experienced the highest median family incomes in both 1990 and 2009, followed closely by white families. Black and Hispanic families report considerably lower income levels in both the past and the present.

Between 1990 and 2009, the median white and Hispanic family incomes grew by approximately 10 percent, after adjusting for inflation. The median black and Asian and Pacific Islander families experienced greater real income growth, at more than 15 percent. This growth has not significantly changed the pattern of disparities in the past two decades. The income of the poorest group, black families, remains about half that of the wealthiest group, Asian and Pacific Islander families.

Figure D.5. Median Family Income, 1990 and 2009
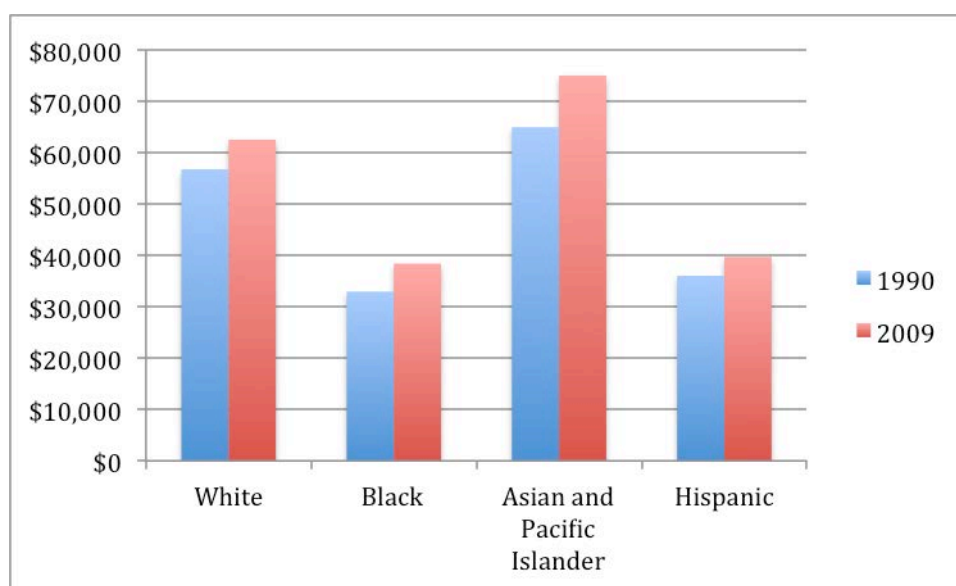
SOURCE: U.S. Census Bureau, 2012, Table 696.

Table D.1 provides a summary of the median annual income and median weekly earnings of individuals at least 15 years old by sex from 1980 to 2010. We present annual income to be consistent with figures on annual income elsewhere in this appendix. However, weekly wages are the more commonly used metric in studying income disparity. Weekly earnings control for the fact that women tend to spend less time in the labor force than men do. If a woman leaves the labor force in the middle of the year, she may have had a weekly wage equivalent to a man's at

the same employer, but her income will be less because she worked fewer weeks. So the weekly figure provides a more accurate comparison.

Two points are worth highlighting:

- The earning gap between men and women has decreased in the past three decades. This has contributed to the rise in female income over time, as has an increase in female labor force participation.
- The median earnings of men in 2010 are virtually identical to their earnings in 1980, after adjusting for inflation. The median earnings of women, on the other hand, have increased significantly.

Table D.1. Median Annual Income and Weekly Earnings, by Sex, of Individuals at Least 15 Years Old

Year	Male	Female	Male	Female
	Median Annual Income		**Median Usual Weekly Earnings (full time)**	
2010	32,137	20,831	824	669
2000	35,885	20,338	812	624
1990	32,817	16,285	802	577
1980	31,567	12,395	828	532

SOURCES: Median annual income from U.S. Census Bureau, undated (b). Median weekly earnings from BLS (2011b). Nominal dollars converted to real 2010 dollars using CPI (BLS, undated [a]).

Variation in Income, by Region

Within the United States, there are significant geographic differences in income levels. However, evidence suggests that, since 1950, personal income levels in different regions have been converging, with the greatest convergence occurring between 1950 and 1980 (Bernat, 2001).

Nevertheless, Table D.2 indicates that some regional variation in income levels persists. For example, in 2010, the Southeastern region had a per capita income level of just over $36,000. New England, which enjoyed the highest per capita income level, was 36 percent higher, at nearly $49,000. This variation can be attributed to a variety of factors, including regional differences in industry concentrations, natural resources, and amenities.

Table D.2. Geographic Distribution of Income in the United States, 2010

Region	Per Capita Personal Income (2010 dollars)
New England (Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont)	48,989
Mideast (Delaware, District of Columbia, Maryland, New Jersey, New York, and Pennsylvania)	47,057
Great Lakes (Illinois, Indiana, Michigan, Ohio, and Wisconsin)	37,434
Plains (Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota, and South Dakota)	39,473
Southeast (Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Virginia, and West Virginia)	36,111
Southwest (Arizona, New Mexico, Oklahoma, and Texas)	36,696
Rocky Mountain (Colorado, Idaho, Montana, Utah, and Wyoming)	37,772
Far West (Alaska, California, Hawaii, Nevada, Oregon, and Washington)	41,837

SOURCE: BEA, undated.

Employment and Business Trends

We now summarize employment and business trends in the United States. We begin by showing data on how the employment sectors in the United States have changed over time, moving away from manufacturing and toward more service-oriented industries. Next, we show how labor force participation, unemployment, and weekly earnings have varied by sex, age, and race and ethnicity in the United States. Finally, we conclude by looking at trends in hours worked.

Employment, by Sector

As a percentage of total employment, manufacturing's share has been sliding since the middle of the 20th century. In 1962, manufacturing employed 28 percent of the U.S. nonfarm workforce. By 2010, manufacturing's share of nonfarm employment fell to below 10 percent. At the same time, employment in service industries (e.g., information services, financial services, profession and business services, education, health services) has seen a dramatic increase and today employs more than 50 percent of the U.S. workforce (see Figure D.6).

The loss of manufacturing jobs was felt primarily in the large industrial cities, such as Detroit and Pittsburgh, which are located in the Northeast and Midwest, while cities in the West and South, which contain more service industries, saw employment growth (M. Lee and Mather, 2008). The changing employment mix experienced by the United States has been attributed to a variety of factors, including increased globalization causing a shift of manufacturing to other developing or developed countries, such as China and Japan, and increased domestic demand for services that are at least partially tied to rising income levels experienced in the United States.

Figure D.6. Share of Nonfarm Employment, by Major Industrial Sector
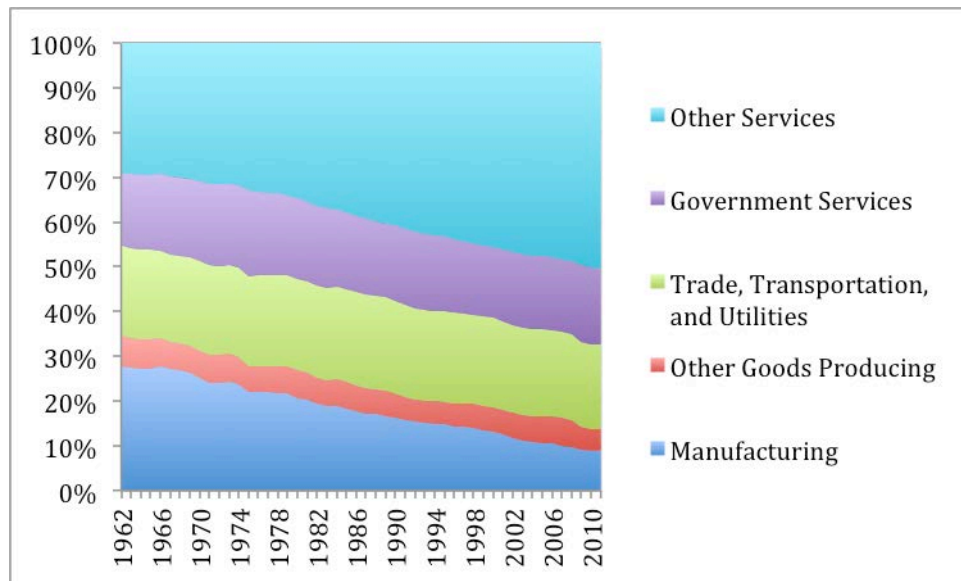
Labor Force Participation

The overall size of the U.S. labor force has been increasing over time. This has been driven primarily by increases in the United States population, as well as by increased labor force participation among women. Since 1980, the proportion of women in the labor force has increased from 51.5 percent to 58.6 percent, while the proportion of men in the labor force decreased, from 77.4 percent to 71.2 percent in 2010 (see Figure D.3). The *labor force participation rate* represents the share of the population of working-age adults (over 16 years of age) who either are employed or are not employed but are seeking employment.

The increasing parity between men's and women's labor force participation rates began more than a century ago. Marlene Lee and Mark Mather (2008) note that, in 1900, the female labor force participation rate was as low as 19 percent. Growth in female labor force participation can be attributed to a variety of factors, including the following (M. Lee and Mather, 2008):

- a general shift away from jobs that require manual labor coupled with opportunities to earn higher wages
- increased access to educational opportunities
- increased rates of divorce and separation, causing a higher share of women to become economically self-reliant
- increased ability to time and prevent pregnancy through contraception and other means
- the passage of the Civil Rights Act of 1964 (Pub. L. 88-352) and associated amendments, which have made it more costly for employers to discriminate against women.

The decline in labor force participation among older men can be at least partially explained by the expansion of retirement benefits provided by Social Security and private pensions (M. Lee

and Mather, 2008). Younger men have also seen a fall in labor force participation. This is in part due to a loss of employment opportunities in low-skilled positions and increased enrollment in higher education.

Table D.3. Labor Force Participation Rates for Men and Women in the United States over Time

Demographic	1980	1990	2000	2010
Male (in years)				
16–19	60.5	55.7	52.8	34.9
20–24	85.9	84.4	82.6	74.5
25–34	95.2	94.1	93.4	89.7
35–44	95.5	94.3	92.7	91.5
45–54	91.2	90.7	88.6	86.8
55–64	72.1	67.8	67.3	70.0
65+	19.0	16.3	17.7	22.1
Overall	77.4	76.4	74.8	71.2
Female (in years)				
16–19	52.9	51.6	51.2	35.0
20–24	68.9	71.3	73.1	68.3
25–34	65.5	73.5	76.1	74.7
35–44	65.5	76.4	77.2	75.2
45–54	59.9	71.2	76.8	75.7
55–64	41.3	45.2	51.9	60.2
65+	8.1	8.6	9.4	13.8
Overall	51.5	57.5	59.9	58.6

SOURCE: BLS, 2010.

Table D.3 shows how labor force participation rates vary both over time and across racial and ethnic groups. Labor force participation rates were generally lower in 2010 than in 2000 but higher than they were in 1980. Data for Asians are not available for years prior to 2000. In 2010, Hispanics had the highest labor force participation rate, at 67.5 percent, while blacks had the lowest labor force participation rate among the major racial and ethnic groups, at 62.2 percent.

The differences in labor force participation rates across racial and ethnic groups can reflect a variety of factors, including differences in the following (BLS, 2011a):

- educational attainment
- employment in occupations and industries
- the geographic areas of the country in which the groups are concentrated
- the degree of discrimination encountered in the workplace.

Table D.4. Labor Force Participation, by Race and Ethnicity, 1980–2010 (percentages)

Race or Ethnicity	1980	1990	2000	2010
White	64.1	66.9	67.3	65.1
Black	61.0	64.0	65.8	62.2
Asian	Not available	Not available	67.2	64.7
Hispanic or Latino	64.0	67.4	69.7	67.5

SOURCE: BLS, 2011a.

Part-Time Employment

Since 1980, approximately 25 percent of employed women have been part-time workers, while about 10 percent of employed men are part-time workers in the United States.[9] In the past few years, there has been a noticeable increase in the share of working men who are part time (see Figure D.7). This is likely indicative of the recent economic downturn and may be temporary.

There are also significant differences in the likelihood that someone takes part-time work according to age. For example, approximately 75 percent of employed individuals between the ages of 16 and 19 are employed part time, while approximately 18 percent of workers 20 years and older engaged in part-time work in 2011 (BLS, undated [a]). The overall share of workers (regardless of age) who are part time is approximately 20 percent.

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[9] An individual is defined as a part-time worker if he or she usually works less than 35 hours per week.

Figure D.7. Share of Employed Men and Women Who Work Part Time, 1980–2011
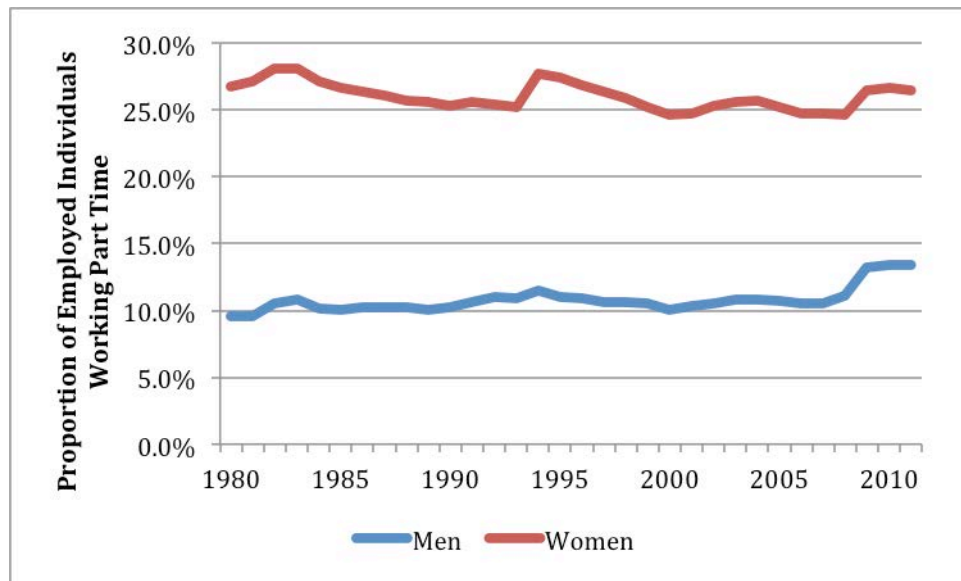
Unemployment

The *unemployment rate* represents the share of people who are characterized as participating in the labor force who are unemployed. In the past 20 years, the average unemployment rate in the United States has been 5.8 percent. However, the unemployment rate has not shown a consistent trend. Although it rose from 6.8 percent in 1991 to 9.6 percent in 2010, unemployment actually fell in most of those 20 years. For the 2007–2009 recession, unemployment reached a high of 10 percent in October 2009.

Figure D.8 shows the unemployment rate of men and women in different age groups during 2010. The figure highlights two key facts. First, higher unemployment rates tend to be experienced by younger and generally less skilled people (24 years and younger). Second, within every age group, women tend to experience a lower unemployment rate than men. Overall, in 2010, women's unemployment rate was 8.6 percent, while men experienced unemployment at a rate of 10.5 percent.[10]

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[10] The lower unemployment rate for women may be indicative of lower labor force participation rates for women than men. That is, when unemployed, women may be more likely to exit the workforce than men are, resulting in a lower female unemployment rate.

Figure D.8. Unemployment Rate, by Sex and Age, for Persons at Least 16 Years Old, 2010
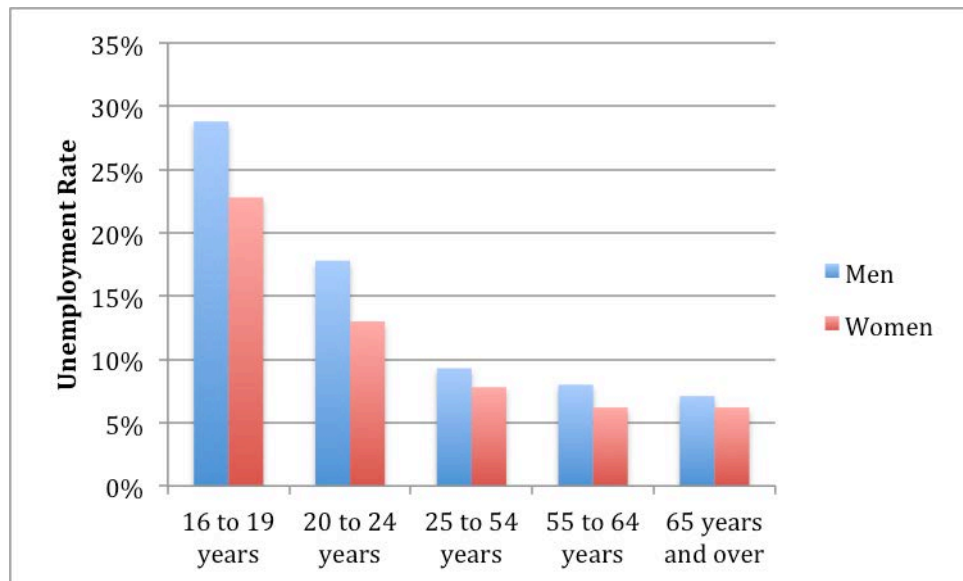
SOURCE: BLS, 2011a.

Unemployment also varies with race and ethnicity. The jobless rates for blacks (16.0 percent) was among the highest of the major racial and ethnic groups, while Asians experienced the lowest unemployment at 7.5 percent (see Figure D.9).

Figure D.9. Unemployment Rate, by Race and Ethnicity, 2010, for Persons at Least 16 Years Old
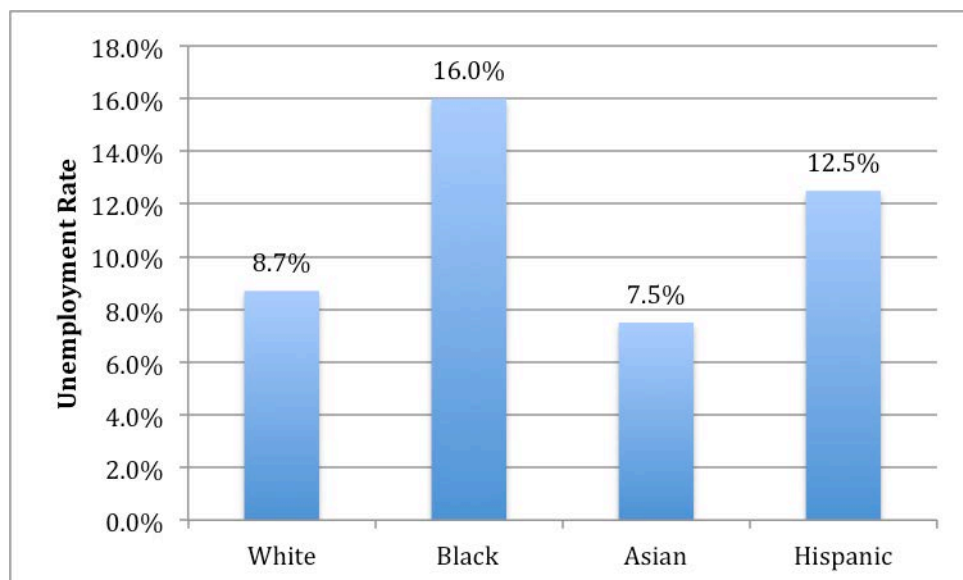
SOURCE: BLS, 2011a.

Hours Worked

Surveys and other data collected in the past century suggest that the average number of hours worked by the employed in the United States has fallen, at least until the 1980s (Whaples, 2001). However, since the early 1980s, this trend has reversed itself, with the average hours worked per week increasing by more than an hour (see Figure D.10). Approximately 20 percent of workers in the United States are part-time workers, while 5 percent of workers hold multiple jobs (BLS, undated [d]).

Figure D.10. Average Hours Worked per Week by U.S. Nonfarm Workers
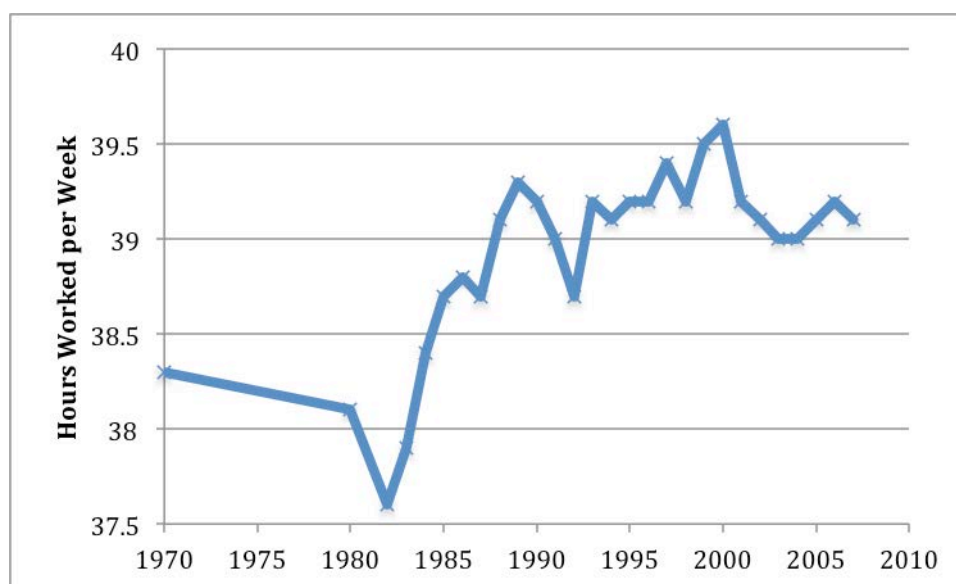
SOURCE: BLS, 2011d.

NOTE: Data represent average weekly hours worked for nonagricultural wage and salary workers who are at least 16 years old.

Data from the American Time Use Survey, which was first initiated in 2003, enables detailed tabulations of how the U.S. population spends its time on both work and nonwork days. In 2010, working men tended to work 41 more minutes per day than working women did. Other significant differences in average work hours and days of work can be identified for different demographic groups and are documented by BLS (2012).

Business Creation

Every year, businesses die while new ones emerge. Some businesses expand their offerings into new areas while other contract. Many researchers have linked this cycle and the associated entrepreneurship to economic growth (see, for example, Davis and Haltiwanger, 1992).

Between 1990 and 2006, the number of employer firms in the United States increased at a rate of one per 100 existing firms per year. It is useful to decompose the rate of firm growth into the rate at which firms are "born" and "die" each year. The average rate at which firms die is 9.8 firms per 100 firms per year, while firm births each year averaged 10.8 firms for every 100 firms in the economy between 1990 and 2006 (Reynolds and Curtin, 2009). This is roughly in line with earlier estimates generated by Davis and Haltiwanger (1992) for the manufacturing sector. Spletzer (2000) finds that 40 percent of new businesses die within three years of birth.

Cumming and Li (2010) identify a variety of factors that can affect business creation and deaths, including the following:

- market conditions (e.g., changes in product demand, input prices, competition)
- access to capital
- local spillover and agglomerative effects
- tax policy
- bankruptcy laws
- property laws.

Although some studies have analyzed the relationship between these factors and business creation and deaths, it is difficult to rank and quantify the relative importance of each.

Freight Movement

As both a major manufacturer and consumer of goods, the United States is heavily dependent on its freight system to move goods throughout the country. According to recent Bureau of Transportation Statistics (BTS) data, 12.5 billion tons of freight were carried 3.3 trillion ton miles in the United States in 2007 (the most recent year for which complete data are available). The value of commodities carried during those shipments is estimated at $11.6 trillion (BTS, 2010).

Freight is moved via a variety of modes, including trucks, rail, air, and water. Table D.5 reports the value and volume of freight movements shipped in the United States. Among the modes of transportation, trucks carry the most value and ton miles of all the modes. Rail ranked second in terms of ton miles moved but below some other modes when evaluated based on the value of the cargo that was moved. Air, which ranked the lowest in terms of ton miles moved, is used primarily for high-value express delivery.

Table D.5. Commercial Freight Activity in the United States, by Transportation Mode, 2007

Mode	Value (billions of dollars)	Tons (millions)[a]	Ton Miles (billions)
Truck	8,336	8,779	1,342
Rail	436	1,861	1,344
Water	115	404	157
Air	252	4	5
Pipeline	400	651	46
Multiple modes	1,867	574	417
Other	279	272	34
Total	11,685	12,545	3,345

SOURCE: BTS, 2010.
[a] Total in source for this column is 12,543.

The share of freight carried via alternative modes has changed somewhat over time, as illustrated by Table D.6. Trucks have seen their mode share, as measured by ton miles, increase by more than 4 percent, from 35.9 percent to 40.1 percent, between 1993 and 2007, while water's mode share decrease from more than 11 percent to less than 5 percent during this period. The share of freight moved via multiple modes increased from 7.9 percent in 1993 to 12.5 percent in 2007 measured on a ton mile basis. The share of freight moved via rail increased slightly.

Table D.6. Percentage of Ton Miles Moved, by Transportation Mode, in the United States, 1993 and 2007

Mode	1993[a]	2007
Truck	35.9	40.1
Rail	38.9	40.2
Water	11.2	4.7
Air	0.2	0.1
Pipeline	2.0	1.4
Multiple modes	7.9	12.5
Other	3.8	1.0

SOURCE: BTS, 2010.
[a] Because of rounding, column does not sum to 100.

For the period of 1980 to 2007, the BTS data suggest that freight ton miles in the United States grew at an average annual rate of 1.1 percent per year (BTS, 2010). Ton miles moved via air grew at the fastest rate over this period, yet air services only a small fraction of movements of goods. Trucking ranks second in terms of ton mile growth between 1980 and 2007, followed

closely by rail. Movements via pipeline remained relatively flat during this period, while freight movements via water actually declined.

Figure D.11. Growth in Ton Miles Shipped in the United States, by Transportation Mode, Since 1980
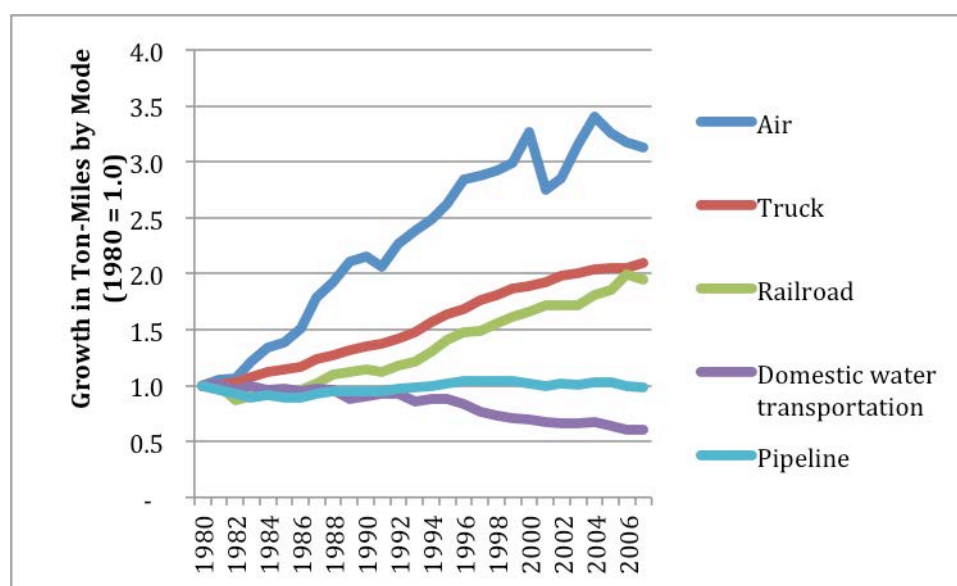
SOURCE: BTS, 2012.

Commuting and Travel Expenditures

Figure D.12 shows the percentage of trips to work by mode in 1989, 1999, and 2009. The share of trips in single-occupancy vehicles remained constant between 1989 and 2009 at 76 percent, while the share of commuters who carpooled dropped from 12 percent to 10 percent. Use of public transportation for travel to work increased slightly from 4.6 percent in 1989 to 5.0 percent in 2009. Walking declined from 3.4 percent to 2.9 percent of commute trips during that same period. Work at home increased from 2.6 percent to 4.3 percent in the past 20 years.[11]

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[11] Computers and telecommunication advancements have enabled a greater fraction of the U.S. employed population to work from home, although the fraction of workers who work from home remains relatively small. In 2004, rates of working at home per week were as high as 30 percent in selected occupations, including management, professional, and related occupations. Occupations with lower work-from-home rates include production, transportation, and material moving. Two-thirds of self-employed workers had home-based businesses in 2004. These data come from a special supplement of the Current Population Survey, collected in 2004 (BLS, 2005).

Figure D.12. Percentage of Trips to Work, by Mode, 1989, 1999, and 2009
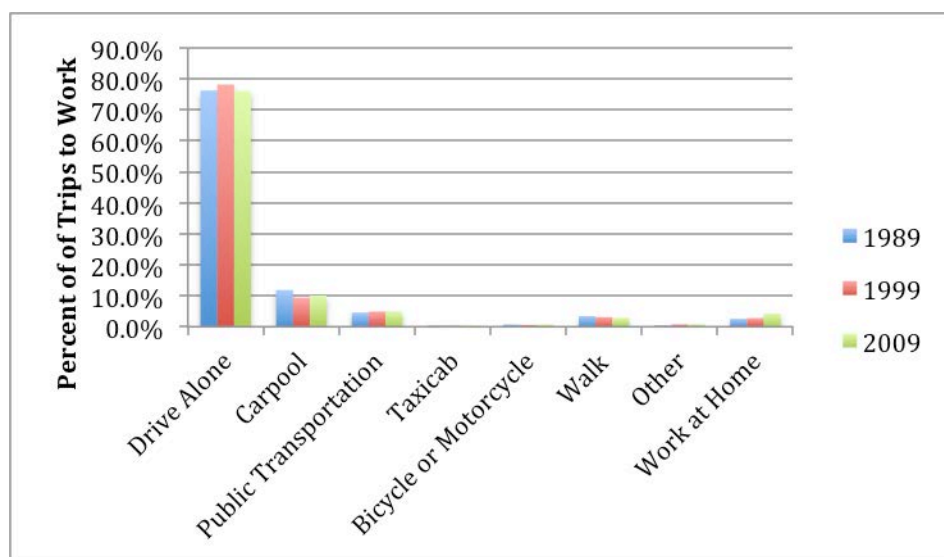
According to data from the Consumer Expenditure Survey, average spending on transportation by household in the past five years has ranged from 12 to 14 percent of pretax income. During 2010, approximately one-third of expenditures on transportation went toward vehicle expenditure expenses, and another third went toward other vehicle expenses that include maintenance, insurance, and other transportation charges. Twenty-seven percent of transportation expenditures covered spending on gasoline and oil, while 6 percent of transportation spending (or approximately $500 per year) was for public transportation in 2010 (BLS, 2011c).

Table D.7. Household Expenditures on Transportation, 2006–2010 (dollars)

Expenditure	2006 (share before tax: 14%)	2007 (share before tax: 14%)	2008 (share before tax: 14%)	2009 (share before tax: 12%)	2010 (share before tax: 12%)
Vehicle purchases	3,421	3,244	2,755	2,657	2,588
Gasoline and motor oil	2,227	2,384	2,715	1,986	2,132
Other vehicle expenses	2,355	2,592	2,621	2,536	2,464
Public transportation	505	538	513	479	493
Total	8,508	8,758	8,604	7,658	7,677

NOTE: Other vehicle expenses are vehicle finance charges, maintenance and repair expenses, vehicle insurance, vehicle rental, leases, and licenses.

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Appendix E. Energy Trends in the United States

This appendix considers factors related to energy supply and demand that may affect future mobility scenarios. The topics are as follows:

- oil production and consumption
- alternative-fuel vehicles
- electric power
- carbon pricing.

Oil Production and Consumption

The rapid growth of automotive travel in the United States in the past several decades has been supported by relatively inexpensive oil prices during much of this period. Comparatively low fuel taxes, along with gradual improvements in vehicle fuel economy, have further contributed to the low cost of automobility. This section examines recent trends in the cost of oil, gasoline, and diesel; in the domestic production and consumption of petroleum; and in fuel economy for the passenger vehicle fleet.

Price of Oil, Gasoline, and Diesel Fuel

The 1970s were characterized by extreme volatility in world oil markets. Two major crises—the Arab oil embargo of 1973 and the Iranian Revolution in 1979—led to rapidly escalating oil costs. Following this turbulent period, the price of oil declined considerably and remained relatively stable for much of the next 25 years. The latter part of the past decade, however, has witnessed a return of high and volatile oil prices. Owing in part to surging demand in developing nations, such as China and India, world oil prices reached historical highs in the 2007–2008 period, only to decline precipitously again with the ensuing recession.

Fluctuations in the price of gasoline and diesel are, of course, strongly linked to variations in the price of oil. As of October 2011, according to data from the U.S. Energy Information Administration (EIA) (2011e), about 69 percent of the retail cost of gasoline reflected the underlying cost of unrefined crude oil. Of the remainder, 11 percent was based on refining costs, 8 percent was based on distribution and marketing costs, and 12 percent was the result of federal and state fuel taxes. For diesel fuel in the same period, 62 percent of the retail price reflected the cost of crude. Figure E.1 shows how world oil prices (on the left axis, in 2005 dollars) and the average retail price for gasoline and diesel in the United States (on the right axis, including applicable taxes, in 2011 dollars) fluctuated together in a recent 30-year period. Since 1990, the annual rate of increase in oil prices has been roughly 4.1 percent, while gasoline prices have grown at 2 percent.

Figure E.1. World Oil Prices and U.S. Gasoline and Diesel Prices, 1980–2010
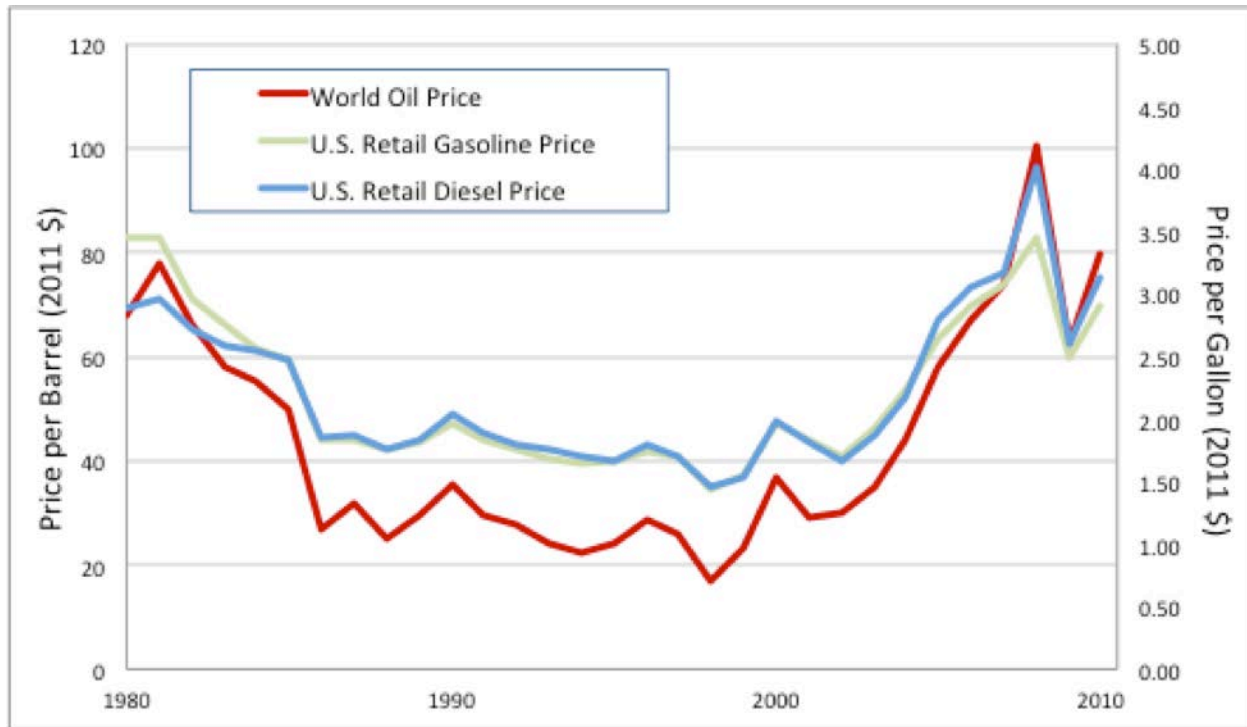
SOURCES: EIA, 2011d; Davis, Diegel, and Boundy, 2011, Figure 1.3.

Oil Production and Consumption

U.S. oil consumption is closely related to the state of the economy. Consumption declined considerably, for example, in the recession of the early 1980s, declined modestly in the recession of the late 1980s and early 1990s, and experienced another steep decline in 2008 and 2009 with the recent severe recession. For most of the past 30 years, however, oil consumption has grown at a relatively steady rate. Even with the sharp declines that bookend the past 30 years, the aggregate rate of oil consumption in the United States has still risen from about 16.8 million barrels of oil per day in 1980 to about 19.1 million barrels of oil per day in 2009 (Davis, Diegel, and Boundy, 2011, Figure 1.6), an annual increase of roughly 0.4 percent.

Much of the rise in U.S. oil consumption can be attributed to passenger vehicles. The transportation sector accounts for more than two-thirds of oil use in the United States, and light-duty vehicles (passenger cars and light trucks) consume nearly two-thirds of the transportation total. Whereas total U.S. oil consumption increased by about 13 percent between 1980 and 2009, use by the light-duty vehicle fleet rose by nearly 42 percent (Davis, Diegel, and Boundy, 2011, Figure 1.6 and Table 11.3).

In contrast to consumption trends, the production of petroleum in the United States has declined in the past 30 years. As recently as 1988, the United States produced enough petroleum to meet its transportation needs, though not enough to meet total U.S. consumption. By 2002, it

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no longer produced enough petroleum to meet the needs of just the light-duty vehicle fleet (passenger cars and light trucks), let alone other transportation uses (Davis, Diegel, and Boundy, 2011, Figure 1.6 and Table 1.13). In just the past few years, U.S. petroleum production has begun to rise again—a result of new discoveries, advances in drilling technology, and the ability to exploit more challenging resource deposits enabled by higher oil prices. However, the share of imported oil remains fairly high, with 2007 imports constituting 58 percent of total consumption (Crane, Goldthau, et al., 2009).

Figure E.2 graphs U.S. petroleum production and consumption in different sectors for a recent 30-year period.

Figure E.2. U.S. Petroleum Production and Consumption, 1980–2009
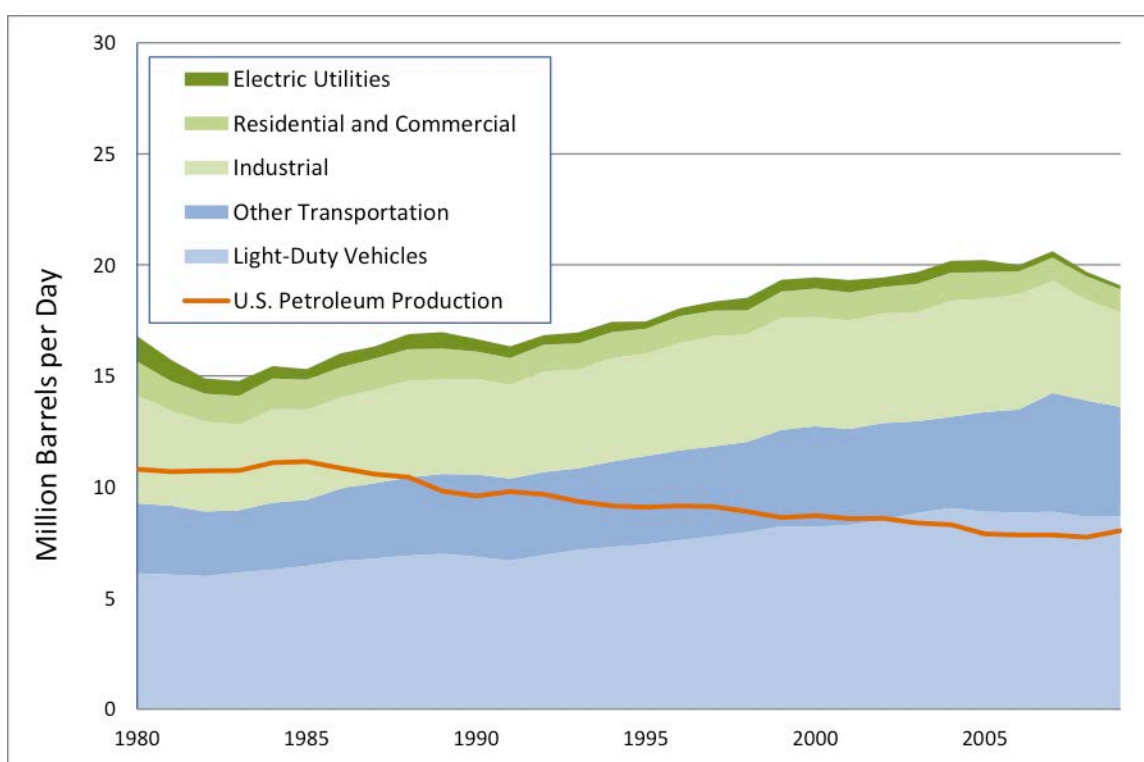
SOURCE: Davis, Diegel, and Boundy, 2011, Figure 1.6 and Table 1.13.

Long-Term Oil-Supply Cost Curve Estimates

Despite concerns that growing demand for oil will lead to severe shortages and rapidly escalating prices, researchers expect considerable untapped oil resources to be economically recoverable over the long term. As of 2008, the total worldwide production was approximately 1.1 trillion barrels, a relatively small fraction of the 9 trillion barrels estimated to be potentially economically recoverable. The remaining resource base can be divided into several categories: conventional resources produced conventionally (oil pumped from underground reservoirs in

reasonably accessible locations); conventional resources produced through unconventional technology (enhanced oil recovery [EOR]) or from unconventional locations (deepwater and ultra-deepwater, Arctic); unconventional oil sources (extraheavy oil, oil sands, and oil shales); and synthetic fuels (gas to liquids [GTL] and coal to liquids [CTL]). The descriptions of these sources, as well as estimates of their sizes, are drawn from the International Energy Agency (IEA) (2008):

- **Conventional resources.** Remaining long-term recoverable resources in this category, more than half of which are located in the Middle East and North Africa (MENA), are estimated at about 2.1 trillion barrels.
- **EOR.** This category is made up of additional production from existing reservoirs (production beyond traditional rates of recovery) enabled by carbon dioxide (CO_2) injection (CO_2-EOR) and other techniques, such as thermal recovery and chemical flooding. EOR could account for as much as 400 billion to 500 billion barrels of future production.
- **Deepwater and ultra-deepwater resources.** Potential production from offshore deposits in deepwater (400 to 1,500 meters deep) or ultra-deepwater (more than 1,500 meters deep) locations is estimated to be in the range of 160 billion to 300 billion barrels.
- **Arctic resources.** Expanded drilling in the Arctic region, potentially facilitated by receding ice coverage, could provide 90 billion barrels.
- **Extraheavy oil and oil sands.** These sources, most of which are located in Canada (in the province of Alberta) or Venezuela (in the Orinoco Belt), are generally more expensive to produce but could provide as much as 1 trillion barrels of oil.
- **Oil shales.** Oil shales are rocks found at shallow depths that contain a large proportion of solid organic compounds (kerogen); heating the rock pyrolyzes the kerogen into oil. Further advances in technology will likely be necessary to exploit this type of resource, but it could provide on the order of 1 trillion barrels over the longer term.
- **GTL and CTL.** Both natural gas and coal can be processed to produce synthetic liquid fuels, though there will be competition for their uses in other applications (e.g., power generation) as well. Together, though, they could account for up to 2.4 trillion barrels of future production.

Long-Term Cost Curves

As noted above, most of the 1.1 trillion barrels of oil produced to date has come from conventional reservoirs in readily accessible locations. The remaining resources, though vast, will tend to be more expensive to exploit and will, in many cases, involve greater environmental costs or risks. As indicated by the recent Deepwater Horizon spill, for example, the technology to safeguard deepwater drilling installations has yet to be perfected. Production of oil sands, as another example, can involve surface mining and generate large volumes of contaminated wastewater. And, unless carbon is sequestered in the production process, the well-to-tank carbon intensity of GTL and CTL is much higher than that of traditional petroleum-based fuels.

Figure E.3 illustrates IEA's estimates of the amount of oil or similar synthetic fossil fuels that are likely to be economically recoverable from different sources in the coming decades. The

overlap of the two boxes for GTL and CTL indicates significant uncertainty with respect to production potential; this stems in part from the fact that both natural gas and coal have other competing uses as well (IEA, 2008).

Figure E.3. Long-Term Oil Supply Cost Curve
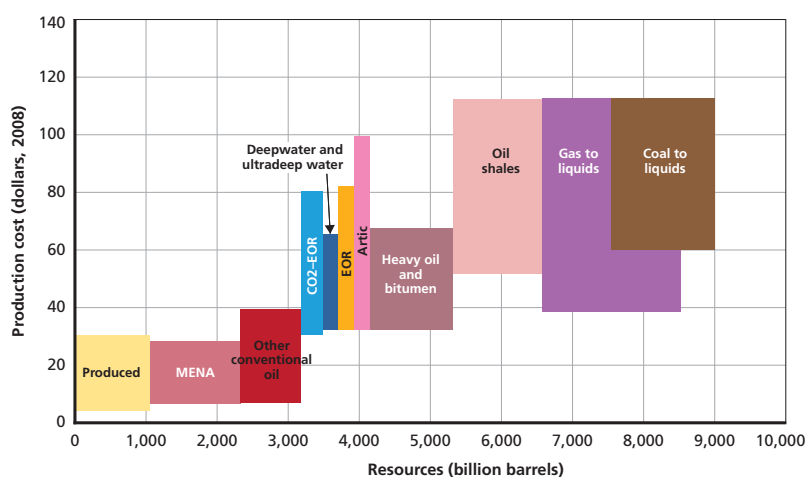
SOURCE: IEA, 2008, Figure 9.10.

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Drawing on the data graphed in Figure E.3, along with supplementary text in IEA (2008), Table E.1 summarizes the expected long-term costs of producing oil or oil alternatives from the sources enumerated above, as well as the potential size of the resource expected to be economically recoverable. Here again, GTL and CTL are viewed as the most uncertain, so Table E.1 includes potential ranges for these rows.

Table E.1. Long-Term Oil Supply Production Costs

Resource	Per-Barrel Production Cost (2008 dollars, approximate)	Potentially Recoverable (billions of barrels, approximate)
Past production (pre-2008)	5–30	1,100
Conventional, MENA	10–30	1,300
Other conventional	10–40	800
CO_2-EOR	20–70	250
Other EOR	30–80	200
Deep and ultra-deepwater	30–65	160
Arctic	40–100	90
Extraheavy oil and oil sands	40–80	1,000
Oil shales	50–110	1,000
GTL	40–110	1,400–1,800
CTL	60–110	500–1,400

SOURCE: IEA, 2008 (approximated from data graphed in IEA, 2008, Figure 9.10 and accompanying text).

Passenger Vehicle Fuel Economy

As indicated in Figure E.2, much of the increase in U.S. oil consumption in the past 30 years has resulted from greater use within the light-duty vehicle fleet. The increase in U.S. consumption of gasoline and diesel has been mitigated to some extent, however, through gradual improvements in the fuel economy for passenger vehicles. Consider that, between 1980 and 2009, the total miles driven by light-duty vehicles in the United States increased by about 88 percent, which corresponds to an average annual growth of about 2.2 percent; over this same period, as noted above, fuel consumption by light-duty vehicles grew by about 42 percent, for an average annual growth rate of about 1.2 percent (Davis, Diegel, and Boundy, 2011, Tables 1.13 and 1.6).

Gains in passenger vehicle fuel economy in the past several decades can be attributed largely to federal Corporate Average Fuel Economy (CAFE) standards for light-duty vehicles. Created by Congress as part of the Energy Policy and Conservation Act (Pub. L. 94-163) in 1975 as a means of reducing the nation's dependence on imported oil in the wake of the Arab oil embargo of 1973 and the ensuing economic turmoil, CAFE standards require auto manufacturers to achieve specified fuel-economy targets for the vehicles they sell in the United States each year. The National Highway Traffic Safety Administration (NHTSA) sets the fuel-economy targets for cars and light trucks (vans, sport-utility vehicles [SUVs], and pickup trucks), with the latter being somewhat less stringent. Compliance with the standards is then determined by the sales-weighted average fuel economy of the models sold by each auto manufacturer in a given year. Manufacturers that fail to comply with the standards are assessed a significant penalty, the size of which depends on both the number of vehicles that they sold and the degree to which their average fuel economy fell short of the applicable target. To provide for some flexibility in

meeting the fuel-economy goals, however, the law allows manufacturers to gain credits for exceeding the fuel-economy targets in one year that can be used to offset shortfalls in another (within a three-year window).

CAFE standards are generally viewed as having been successful in helping to reduce U.S. oil consumption. A detailed review of the CAFE program conducted by the Board on Energy and Environmental Systems (BEES) of the National Research Council (BEES, 2002) concluded, for example, that fuel consumption in the United States would have been 14 percent higher absent the standards. Additionally, as shown earlier in Figure E.1, world oil prices were extremely low throughout much of the late 1980s, 1990s, and early 2000s; without CAFE standards, auto manufacturers would have had relatively little incentive to focus on improving fuel economy during this period.

Even with these successes, however, many argue that CAFE standards have fallen short of their potential to improve fleet-wide fuel economy in the past three decades, for two main reasons. First, although CAFE standards for passenger cars and light trucks were increased rather aggressively until the mid-1980s, the targets were then left relatively unchanged for the next 20 years. This resulted in part from effective political pressure from auto manufacturers and other stakeholders that opposed the program but also stemmed from concern over the potentially adverse safety consequences of building lighter vehicles as a means of achieving improved fuel economy (BEES, 2002). Auto manufacturers continued to improve the efficiency of their vehicles over this period, but the enhanced efficiency was applied to greater size and power rather than higher fuel economy. Second, the market share for light trucks as a percentage of new light-duty vehicle sales increased significantly in the past several decades, growing from roughly 16.5 percent in 1980 to more than 50 percent by 2004 (Davis, Diegel, and Boundy, 2011, Figure 4.1). Because CAFE standards are lower for light trucks than for passenger vehicles, the increased market share for light trucks led to reductions in the average fuel economy for new light-duty vehicles as a whole. To illustrate these themes, Figure E.4 graphs, for a recent 30-year period, CAFE standards for passenger cars and light trucks, estimated fuel economy for the new vehicles and for the existing fleet, and the market share of light trucks as a percentage of all new light-duty vehicle purchases.

Figure E.4. Corporate Average Fuel-Economy Standards and Fuel-Economy Performance, 1980–2009
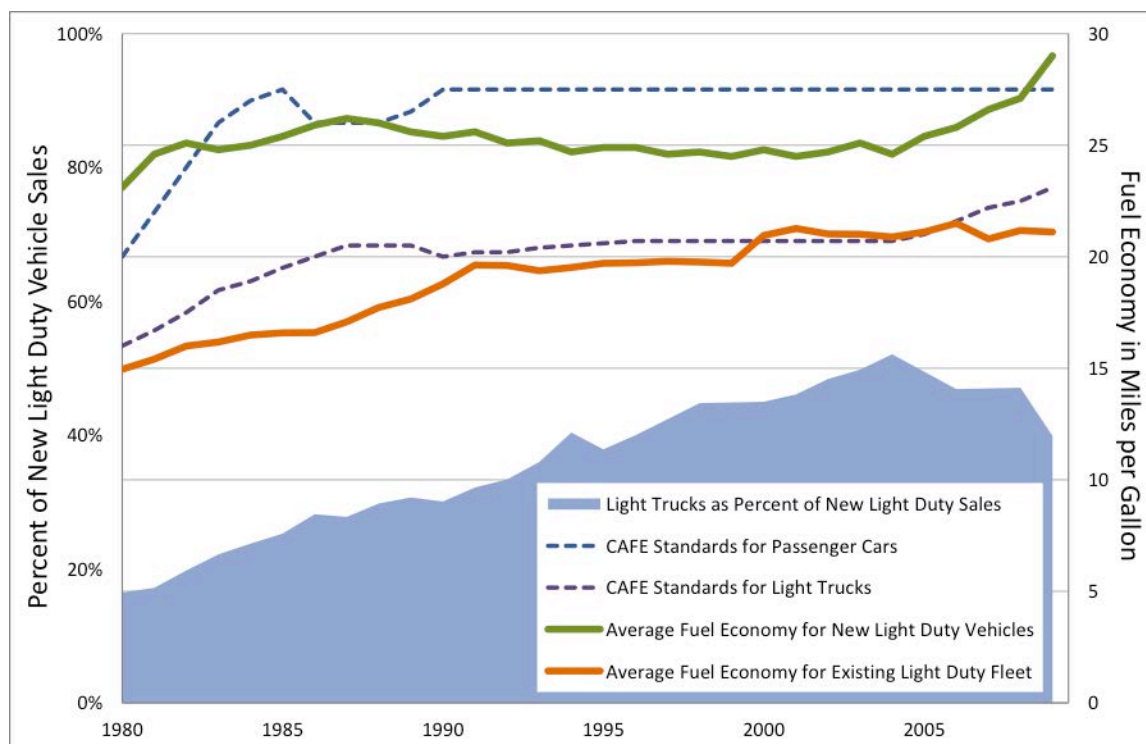
SOURCES: Davis, Diegel, and Boundy, 2011, Figure 4.1 and Tables 1.13, 2.11, 3.6, 4.20, and 4.21.

NOTE: MPG = mile per gallon. The dip in estimated average fuel economy for the existing light-duty fleet following 2007 is an artifact of changes in the way that the Federal Highway Administration (FHWA) estimates annual VMT, as documented by Davis, Diegel, and Boundy, 2011, Table 3.6.

As shown in Figure E.4, the average fuel economy for new light-duty vehicles (the green line) actually declined between 1985 and the early 2000s as a result of the growth in market share for light trucks. The average fuel economy for the existing vehicle fleet (the orange line), however, continued to increase—albeit at only a modest rate—because the newer passenger cars and light trucks were still more fuel-efficient than the older vehicles being replaced. Beginning in 2005, this trend began to shift. First, motivated by spiking fuel prices followed by the deep recession, consumers began to purchase more fuel-efficient passenger cars and fewer light trucks. Additionally, more-stringent fuel-economy standards for light trucks that were developed under the George W. Bush administration began to take effect. In combination, these two factors led to a sharp rise in the average fuel economy for new vehicles purchased in the past several years.

More recently, spurred by the goals of fostering greater energy independence and reducing greenhouse gas (GHG) emissions, Barack Obama's administration has issued even more-stringent fuel-economy standards for both passenger cars and trucks. Per the most recent NHTSA rulemaking, average fuel-economy standards are scheduled to rise to 54.5 mpg by 2025.

Alternative-Fuel Vehicles

A parallel strategy for reducing oil imports and GHG emissions has been to promote the development and adoption of alternative fuels and vehicle propulsion technologies, including such options as natural gas, biofuels (ethanol and biodiesel), hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), battery electric vehicles (BEVs), and hydrogen fuel-cell vehicles (FCVs). This section presents the main types of alternative-fuel vehicles, discusses some of the current challenges that will need to be overcome to achieve broader market penetration in the future, and provides recent trends in the adoption of alternative-fuel vehicles.

Alternative-Fuel Vehicle Technologies and Barriers to Adoption

Collectively, alternative-fuel vehicle technologies offer an impressive range of potential benefits: reducing reliance on imported oil, decreasing emissions of local air pollutants and GHGs, and lowering the per-mile cost of driving. Yet they also face considerable challenges that will need to be overcome to achieve broader adoption. Although the specific combination of obstacles varies by fuel type and vehicle propulsion technology, the most common hurdles include higher vehicle costs, limited range capabilities, and the need to develop extensive fuel distribution and refueling infrastructure. For options promising the most significant environmental benefits—including electric, hydrogen, and potentially biofuels as well—another important challenge is to develop processes for producing the fuel or power that are cost competitive and yield little or no criterion pollutants and net GHG emissions.

In the remainder of this section, we briefly comment on the specific obstacles that confront each of the main alternative-fuel vehicle types mentioned above. More detailed discussions can be found in such works as National Academy of Engineering Committee on America's Energy Future (2009) and Ogden and Anderson (2011).

Natural Gas

As indicated in Figure E.5, natural gas was the first alternative fuel to make significant inroads in the transportation market, mainly in the context of fleet vehicles that can refuel at a central natural gas fueling depot. Because the domestic supply of natural gas is relatively abundant in comparison to that of petroleum, a shift to natural gas–fueled vehicles would promote the goal of greater energy independence. Additionally, natural gas results in significant reductions in the emission of harmful local air pollutants and modest reductions in the emission of GHGs. On the negative side, the additional cost of natural gas vehicles is considerable; the natural gas version of the Honda Civic, for example, costs roughly $7,000 more than the base Civic model (Honda, undated). This is due in part to the high cost of the tank for storing compressed natural gas on the vehicle and in part to the relatively limited current production volume. Additionally, current natural gas vehicles suffer from range limitations, as well as reduced acceleration power. Finally, the availability of natural gas fueling stations remains quite

limited. Because of these limitations, the market share for natural gas vehicles has not been growing in recent years. Indeed, the number of natural gas–fueled model options offered by auto manufacturers has actually declined. On the other hand, the development of hydraulic fracturing and horizontal drilling technology—often referred to as *fracking*—has made it possible to recover vast domestic deposits of natural gas at considerably lower cost. It is possible that this may stimulate renewed interest in natural gas vehicles in the coming years.

Biofuels

Although biodiesel remains a small niche market, the production of corn-based ethanol has accelerated in recent years. This is a direct result of subsidies for ethanol, along with the nation's first renewable fuel standard, passed in 2005, which mandated the use of at least 7.5 billion gallons of biofuels in the United States each year by 2011 (Pub. L. 109-58, 2005). Ethanol is often used as an oxygenate for gasoline in blends of up to 10 percent, and it can be used in blends of up to 85 percent (E85) in "flex-fuel" vehicles designed to run on either gasoline or E85. The additional cost for flex-fuel capabilities is marginal, on the order of a few hundred dollars. Although corn-based ethanol helps to reduce petroleum imports, the environmental benefits are marginal at best. Subsequent legislation in 2007 (Pub. L. 110-140, 2007), however, called for the development of a second version of the nation's renewable-fuel standard, which was finalized in 2010. In addition to increasing the required volume of biofuels, now mandated to reach 36 billion gallons by 2022, the second renewable-fuel standard also called for the production of more advanced forms of biofuels, such as cellulosic ethanol, that are expected to offer much better environmental performance than corn-based ethanol.

Even with the revised mandate, however, questions remain regarding the future role of biofuels in the U.S. transportation system. To begin with, it is unclear whether the more advanced forms of biofuels can be produced at reasonable cost within the required time frame. Additionally, there is concern that devoting considerable acreage to the production of biofuel feedstocks could begin to displace food production. Finally, a significant shift to vehicles running on biofuels in blends exceeding 15 percent would require considerable investment in compatible refueling infrastructure, because blends with higher ethanol content cannot generally be distributed through the existing conventional-fuel infrastructure.

Battery Electric Vehicles

BEVs were first promoted in California, through its Zero Emission Vehicle (ZEV) mandate, in the late 1990s and early 2000s, though this effort ultimately failed to generate a large demand for these vehicles. With continued improvements in battery technology and reductions in cost, however, BEVs are once again viewed as a promising option for replacing conventionally fueled vehicles. Niche-market BEVs, such as the Tesla Roadster, have available since the late 2000s, and the Nissan Leaf—the first BEV aimed at a broader mass market—was released in 2011 (Nissan, undated). Many more BEV models are expected in the coming years. Propelled entirely

by electricity, which in turn is generated mainly from domestic energy sources, BEVs offer tremendous potential for greater energy independence. Additionally, depending on the source of power generation, the environmental performance of BEVs *could potentially be reduced relative* to that of gasoline- and diesel-fueled vehicles. If the electricity were renewably generated from hydroelectric, wind, solar, geothermal, or nuclear, for instance, then no harmful air pollutants or GHGs would be produced in the processes of generating the power, transmitting the power, and using the power to propel the vehicle (note that power generation is discussed at greater length in the next section of this appendix). Another advantage of BEVs is that the per-mile cost of driving, given prevailing retail electricity rates and current fuel-economy performance (on the order of 3 to 4 miles per kilowatt-hour [kWh], according to our calculations), is much lower than that for vehicles that run on gasoline or diesel, representing a savings on the order of 75 percent (of course, this differential depends on the price of electricity; past trends in electricity prices are discussed in the "Electric Power" section). And with fewer moving parts in the power train and lower operating temperatures, the standard maintenance costs associated with BEVs are expected to be much lower as well. Finally, BEVs can be easily recharged at home, a convenience likely to be viewed as attractive by many owners.

On the negative side, battery technology remains expensive, leading to a considerable cost premium for BEVs. The Nissan Leaf, for example, costs almost $17,000 more than its otherwise comparable counterpart, the Nissan Versa 1.8SL (Nissan, undated). And because battery technology is so expensive, mass-market BEVs typically offer relatively limited driving range between recharging; the Leaf, for instance, with its 24-kWh battery pack, is limited to a range of around 100 miles. The limited range, in turn, leads to a final challenge for BEVs. Though it is expected that BEV owners will typically choose to recharge vehicles at home, the limited range may occasionally make it necessary for BEVs to be recharged in between trips while away from home. To accommodate such charging, it will be necessary to deploy a network of convenient, publicly accessible charging ports. Further, to reduce the time required to recharge a vehicle, such ports should offer "fast-charging" capability, on the order of 30 minutes or less, and this will add to the expense of deploying charging infrastructure. Although some public charging stations have been built, in part through funding from the American Recovery and Reinvestment Act (Pub. L. 111-5, 2009) (i.e., the recent federal stimulus program), a nationwide network of charging stations remains far from complete. In short, the prospects for greater future adoption of BEVs will depend on some combination of reduced battery costs, improved range, and greater availability of publicly accessible fast-charging infrastructure. Additionally, producing and processing the materials required for batteries, as well as battery manufacturing, have energy, GHG, and environmental implications that require management to minimize (EPA, 2013b).

Plug-In Hybrid Electric Vehicles

PHEVs are configured with a battery pack large enough to accommodate a modest range of electric operation, along with a fuel tank and internal combustion engine to enable additional

travel between recharges. As with BEVs, the first mass-market PHEVs are just being released commercially. The Chevy Volt became available in 2011, and Toyota's Prius Plug-In was released in 2012 (Chevrolet, undated; Toyota, undated). When running in all-electric mode, a PHEV offers the same potential benefits as a BEV, including reduced reliance on imported oil and potentially improved environmental performance. The addition of the fuel tank and internal combustion engine, in turn, eliminate the range limitations of BEVs, as well as the need to deploy a network of recharging stations. The main factor that could limit broader adoption of PHEVs, then, is the additional vehicle cost premium. Because of the ability to rely on the internal combustion engine when needed, the battery packs provided with PHEVs can be smaller than those in a BEV. The Prius Plug-In, for example, offers an expected all-electric range of 15 miles (Toyota, undated), while the Chevy Volt offers a more impressive all-electric range of 35 miles. On the other hand, PHEVs, in contrast to BEVs, must include two power trains, and this raises the cost considerably. The advertised cost premium for the Prius Plug-In in comparison to the standard Prius is $8,500, while the cost premium for the Chevy Volt, with its larger battery pack, over the roughly comparable Chevy Cruze Eco is $20,000.

Electric Vehicle Charging Infrastructure

As noted above, other than the price premium, another obstacle to more widespread adoption of various types of electric vehicles (EVs) is the lack of EV charging infrastructure. In theory, multiple options exist. Vehicle owners could charge their vehicles at home, a practical option because it would generally allow vehicles to charge overnight. Charging infrastructure might also become prevalent at various places where people park their vehicles for long periods of time: office parks and office buildings, university campuses, health care facilities, airports, and hotels. Finally, as suggested above, charging stations might be located similarly to gas stations, as freestanding ports along travel corridors. These options are not mutually exclusive, but their costs and convenience may vary.

As of April 2012, 9,980 publicly available EV charging stations were in operation. This number counts each charging cable as a station, meaning that a station with four cables is counted as four stations. This number also does not include private residential stations. The stations are not evenly distributed; more than half (5,636) are in six states (in descending order by number of stations): California, Washington, Texas, Florida, Oregon, and Michigan (Office of Energy Efficiency and Renewable Energy [EERE], 2012). In comparison, the United States has roughly 160,000 gas stations (National Petroleum News [NPN], 2008).

Residential charging availability provides the greatest opportunity for EV recharging, but challenges remain. Charging an EV at a residence requires a dedicated parking space, access to an appropriate electrical outlet, and spare capacity in the residential electrical panel. Households with existing garages that have existing appropriate electrical outlets and spare electrical panel capacity will require no or minimal infrastructure investment and will be ideal charging locations for first adopters of PHEVs. Approximately 63 percent of U.S. households have garages or

carports, although there is a wide disparity between owner-occupied households and renter-occupied households (Samaras et al., 2009). The owner would be required to pay for the installation of an additional outlet and installation of upgraded electrical capabilities if required, which will vary with household age and design.

Households without existing garages but with access to off-street parking make up the next-largest subset, with 31 percent of total households. Because the Census Bureau does not further subdivide the category of access to off-street parking, this category could include household access to driveways, surface parking lots, indoor parking garages, or other spaces. Infrastructure costs would vary from installing an outdoor electrical outlet in a driveway to retrofitting existing or including outlets in new surface lots or garages. Costs of retrofitting or installing outlets in surface lots or garages would likely be borne by businesses, apartment managers, fleet managers, and municipalities considering providing capabilities for EV charging (Samaras et al., 2009).

Hydrogen Fuel-Cell Vehicles

With hydrogen FCVs, hydrogen stored in an on-board tank is processed through a fuel cell to produce electricity, which in turn drives a motor to propel the vehicle. Relative to the other alternative fuels and vehicle technologies already discussed, hydrogen FCVs are the least advanced in terms of market readiness. Some auto manufacturers have been testing out FCV prototypes in the past decade, and considerable technical advances have been achieved during this period. Still, it is expected to be several years or more yet before FCVs are available for commercial release. For FCVs to be cost competitive, further advances to reduce the cost and improve the performance of FCV component technologies—most notably the fuel-cell stack configuration and the on-board hydrogen storage tank—will be needed. Another necessary ingredient for a successful large-scale transition to FCVs will be the development of a hydrogen distribution network and refueling stations, which will involve a massive investment. Finally, as with EVs, the emission benefits stemming from a shift to FCVs will depend on the feedstock used to generate the hydrogen. If reformed from natural gas, for example, there will still be some GHG emissions. If produced via electrolysis with renewably generated electricity, in contrast, the GHG emissions produced during hydrogen production will be eliminated. To date, producing hydrogen from fossil fuels remains much cheaper than producing hydrogen from renewable electricity.

Adoption of Alternative-Fuel Vehicles

The challenges related to cost, range, and available fueling infrastructure have, to date, limited alternative-fuel vehicles to a small fraction of the overall light-duty vehicle market. As shown in Figure E.5 (which includes light- and heavy-duty vehicles), the size of the U.S. alternative-fuel vehicle fleet is currently less than 1 million vehicles. To put this in perspective, roughly 10 million new light-duty vehicles are purchased in the United States each year, and there are around 250 million vehicles in the U.S. fleet.

However, the use of alternative-fuel vehicles has increased considerably in recent years. Of the various options mentioned, biofuels have experienced the most significant growth. In particular, flex-fuel vehicles, able to run on either standard gasoline or E85, have been adopted widely. The use of natural gas as a transportation fuel, either in liquefied form (liquefied natural gas [LNG]) or in compressed form (compressed natural gas [CNG]), has also achieved some growth, and EVs are now beginning to gain market share as well. PHEVs have only been released in 2011, and a small number of hydrogen vehicles are now in use, though mainly in prototype form.

Figure E.5 graphs the estimated number of E85, CNG, LNG, and electric vehicles in use in the U.S. fleet in the past 15 years.

Figure E.5. Estimated Size of the U.S. Alternative-Fuel Vehicle Fleet, 1995–2009
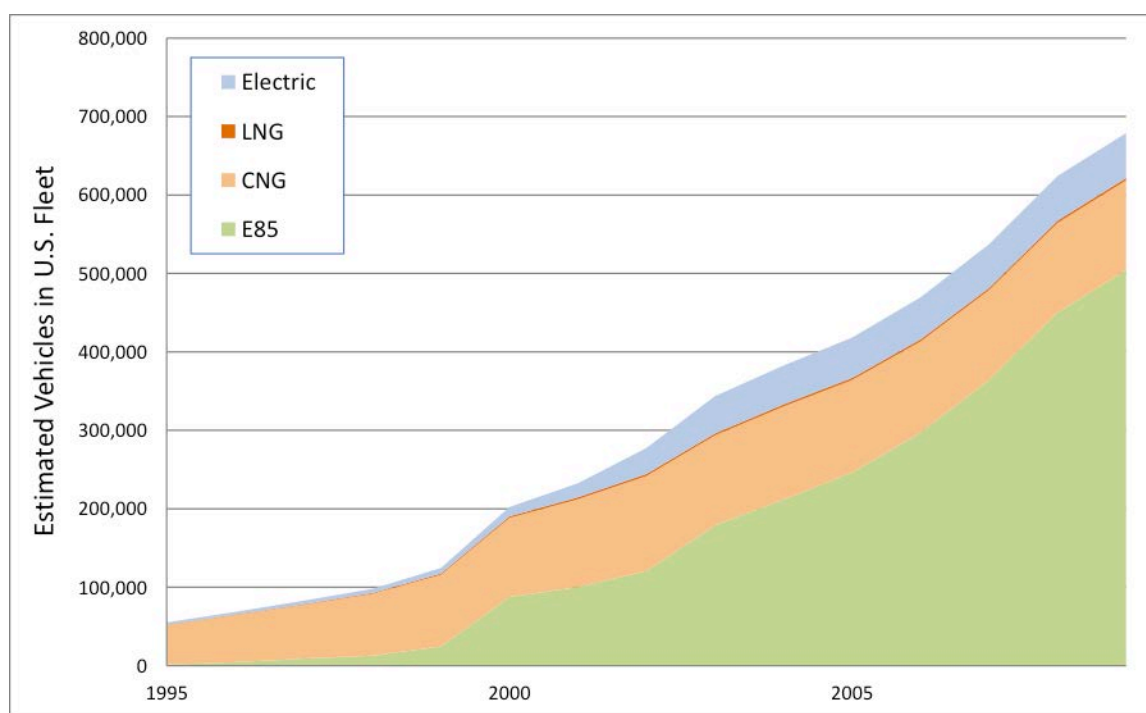
SOURCE: Davis, Diegel, and Boundy, 2011, Table 6.1.

NOTE: The estimates for E85 in this figure are intended to reflect the subset of flex-fuel vehicles that rely mainly on E85 as opposed to standard gasoline mixes.

In addition to the vehicle types identified in Figure E.5, sales of HEVs have also grown rapidly over the past decade. In 1999, when the Honda Insight was first made available in the North American market, a total of 17 HEVs were sold in the United States. Since then, U.S. consumers have bought nearly 1.9 million HEVs (EERE, 2011). Following the sharp run-up in fuel prices in 2005 and 2006, annual sales of HEVs peaked at more than 350,000 in 2007, though they have since declined (to about 275,000 as of 2010) (EERE, 2011). It is unclear whether this

recent decline marks a long-term trend, given that the size of the overall U.S. car market also contracted considerably in the past few years as a result of the severe recession.

Although HEVs represent an important innovation in vehicle technology in the past decade, they are not typically categorized as "alternative-fuel" vehicles. This is because all of their propulsion power ultimately derives from the combustion of gasoline or diesel fuel. Through such processes as regenerative braking, an HEV's battery pack and motor allow the vehicle to capture and reuse its energy to achieve much greater fuel economy; indeed, hybrid technology is likely to play a crucial role in enabling auto manufacturers to meet increasingly stringent CAFE standards in the coming decades. Still, an HEV does not receive any off-board source of power other than gasoline or diesel. In contrast, all of the other technologies mentioned above—natural gas, biofuels, PHEVs, BEVs, and hydrogen vehicles—involve fueling or charging a vehicle with something other than gasoline or diesel.

Electric Power

In this section, we turn our attention to the electric power sector, which is linked to the electrification of the vehicle fleet. Topics addressed include recent trends in retail electricity prices, the evolving mix of energy sources used to power the grid, and the challenges faced by lower-carbon electricity generation technologies that, to date, have limited the pace of their adoption on the grid.

Electricity Prices

Figure E.6 graphs retail electricity prices, in 2010 dollars, for different end-use sectors between 1999 and 2010.

Figure E.6. U.S. Retail Electricity Prices, by Sector, 1999–2010
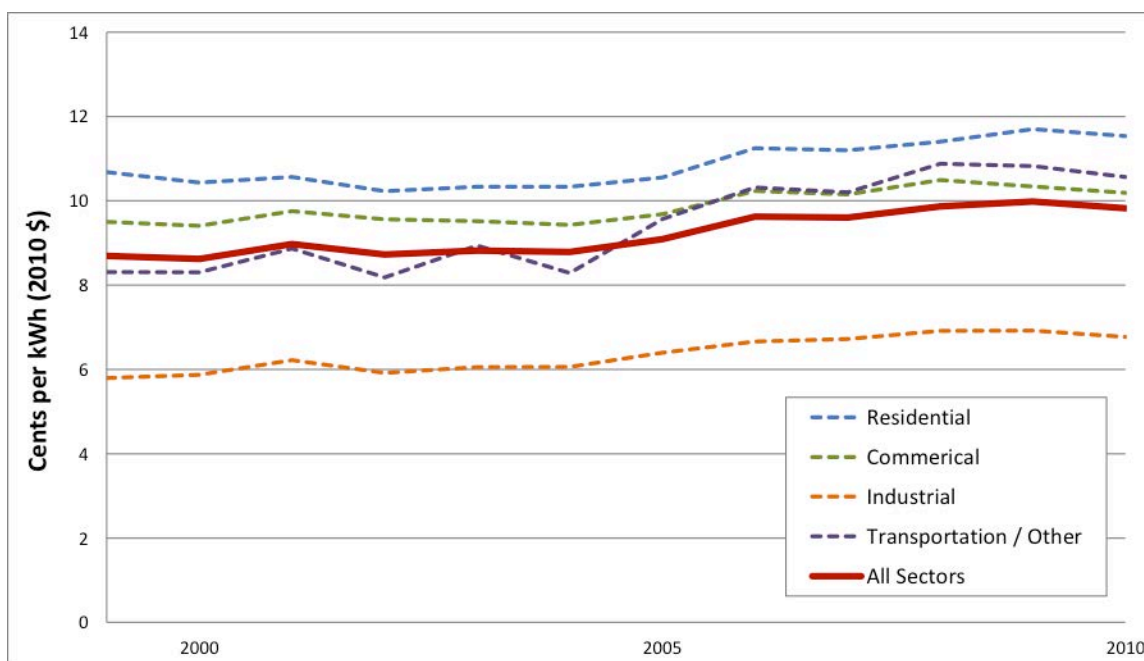
SOURCE: EIA, 2011c, adjusted by the authors to 2010 dollars per CPI data from BLS, 2011.

As indicated, retail prices grew very slowly in real terms during this period. Given that the largest source of electricity in the United States is coal, of which there is an abundant domestic supply (see EIA, 2012), electricity prices are generally expected to remain stable into the future. The greatest uncertainty is whether carbon pricing, discussed in a later section, will at some point be introduced, which would increase the price for coal power and, in turn, stimulate a more rapid transition to lower-carbon, and currently more-expensive, power generation alternatives.

Power Generation Mix

Total U.S. electric power generation has increased from about 2,300 terawatt-hours (tWh) in 1980 to more than 4,000 tWh in 2010 (EIA, 2010, Table 8.2a). This represents a rise of roughly 80 percent, though growth has been much more modest in the past decade. Generation sources are coal, petroleum, natural gas, nuclear, hydroelectric power, other renewable sources (biomass, geothermal, wind, and solar), and other miscellaneous sources. Figure E.7 illustrates the percentage of U.S. power generation from each of these sources in the past 30 years.

Figure E.7. U.S. Power Generation, by Source, 1980–2010
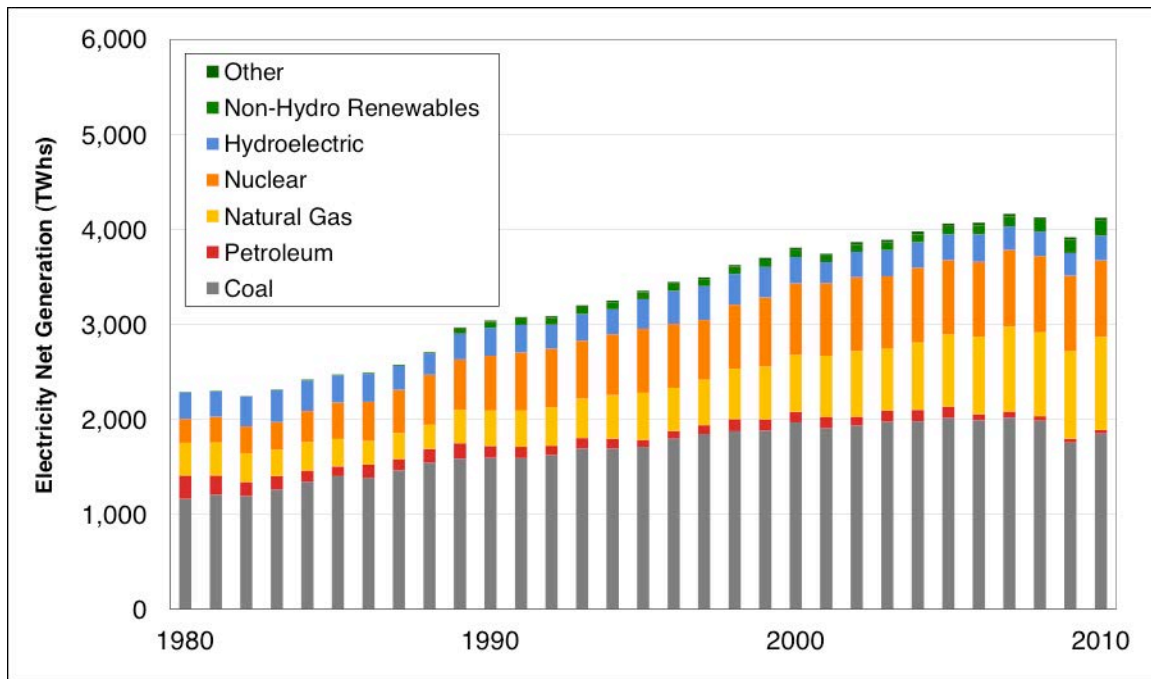
SOURCE: EIA, 2010, Table 8.2a.

As indicated in Figure E.7, coal accounts for a major share of all U.S. power production. Yet, although coal-based production has increased in absolute terms since 1980, it has declined as a percentage share of total production. The use of petroleum to generate power, modest to begin with, has declined in both absolute and relative terms. Natural gas and nuclear, on the other hand, have grown significantly in the past three decades. Conventional hydroelectric power has declined modestly; other renewable power sources, in contrast, have been expanding since the late 1980s, though they still constitute only a small fraction of total power production.

In short, although the use of some forms of renewable energy is on the rise, the reduced reliance (to date) on coal, in percentage terms, has been enabled mainly by significant increases in natural gas and nuclear. Figure E.8 provides a closer look at this trend, illustrating the percentage of total U.S. power production provided by the three most-significant noncoal sources: natural gas, nuclear, and renewables as a group (including conventional hydroelectric, biomass, geothermal, wind, and solar).

Figure E.8. U.S. Power from Natural Gas, Nuclear, and Renewables
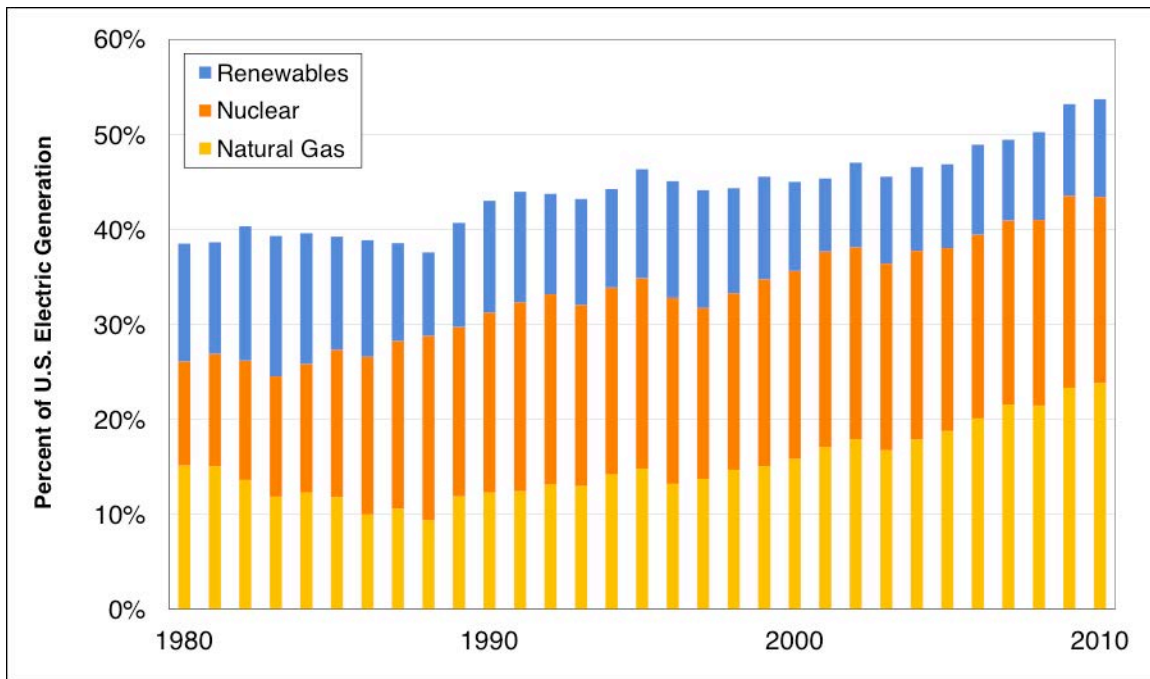
SOURCE: EIA, 2010, Table 8.2a.

As illustrated by the data in Figure E.8, the percentage share of power produced from both natural gas and nuclear grew significantly between 1980 and 2010; the share provided by natural gas rose from about 15 percent in 1980 to almost 24 percent in 2010, while the share produced by nuclear expanded from 11 percent to almost 20 percent in the same period. In contrast, the share provided by renewables as a group has actually declined, dropping from about 12.5 percent in 1980 to a bit over 10 percent in 2010.

Treating renewables as a group, though, masks several underlying dynamics. Because of the gradual retirement of older facilities and the relatively limited options for major new projects, the total power provided by large-scale hydroelectric plants has declined modestly in the past 30 years, translating to an even greater decline when measured in percentage terms. The share of power provided by other renewable sources, in contrast, has experienced fairly steady growth, increasing from about 0.25 percent in 1980 to more than 4 percent in 2010. Among the nonhydro renewables, wind currently accounts for the largest share of energy, followed by biomass and geothermal. The share of power provided by solar remains quite limited, at roughly 0.03 percent. These trends are illustrated in Figure E.9, which graphs the percentage of U.S. electric power provided by various renewable sources.

Figure E.9. U.S. Power from Renewable Sources
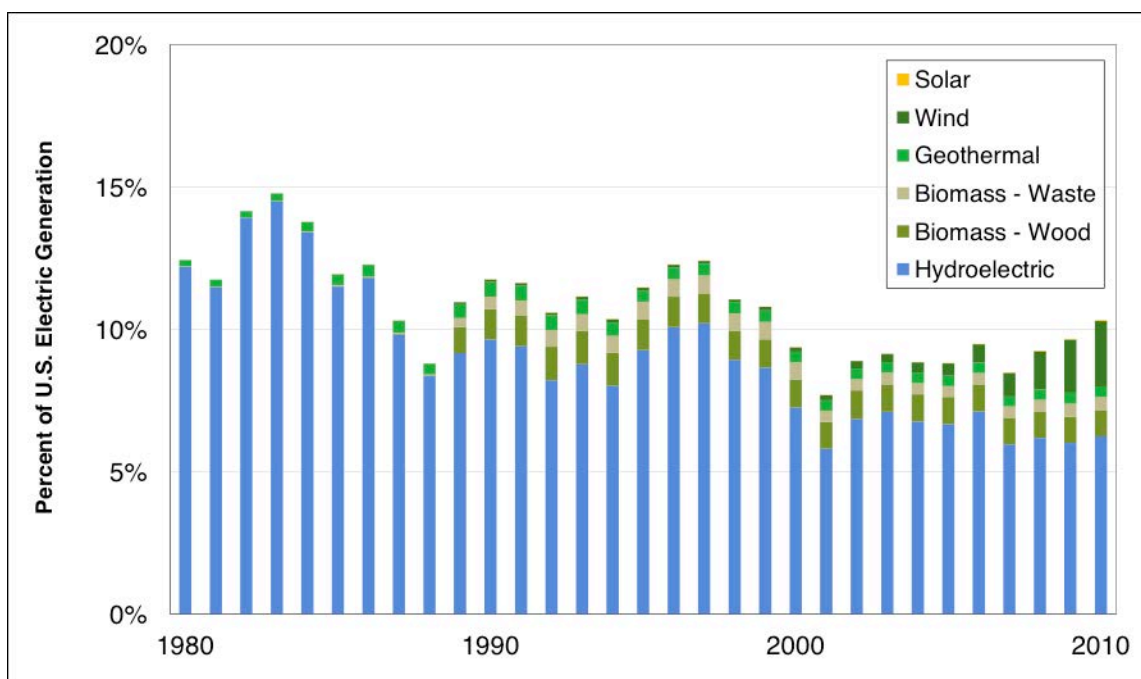
Low-Carbon Power Technologies

Given mounting concerns over the threats posed by climate change, there is great interest in accelerating the transition from coal and, to a lesser extent, natural gas to lower-carbon alternatives, including renewables and potentially nuclear power as well. In this section, we consider some of the challenges that have limited the pace of adoption for lower-carbon power generation technologies to date. Some of the more common challenges include higher capital costs, intermittency, and the need for further research and development.

Solar Power

Solar energy represents a vast potential source of clean, renewable power; harvesting incoming solar radiation on just 0.25 percent of the nation's land area would provide enough electricity to meet current U.S. consumption (National Research Council Panel on Electricity from Renewable Resources, 2010). There are two main methods for converting solar radiation to electricity: through the use of photovoltaic (PV) panels or via concentrating solar power (CSP) that uses focused solar energy to drive a steam-turbine generator. Although the cost of these technologies has declined in recent years, solar power is still more expensive than other sources of electricity. Additionally, solar generation is inconsistent—varying by latitude, by time of year, and by meteorological conditions—and unavailable at night. Any effort to significantly increase the share of solar energy on the grid would thus require a large-scale deployment of storage

capacity (e.g., batteries, flywheels) to help balance temporal variations in the supply and demand for electricity. In short, the cost of solar power technologies, including both generating modules and balance-of-system costs, will need to decline substantially over the next several decades to overcome current economic and technical barriers (National Research Council Panel on Electricity from Renewable Resources, 2010).

Wind Power

Wind is another potentially significant source of clean and renewable energy, with estimates suggesting that wind resources in the United States could produce several times the amount of electricity consumed by the nation (National Research Council Panel on Electricity from Renewable Resources, 2010; Crane, Curtright, et al., 2011). As with solar power, however, wind power is intermittent and thus creates load-balancing challenges. Onshore wind power is viewed as a mature technology, though there may be opportunities for further cost reductions with additional deployment experience and improvements in wind-turbine components (National Research Council Panel on Electricity from Renewable Resources, 2010). Offshore wind power is less developed—with some deployment in Europe but relatively little in the United States— but offers potential access to substantial wind resources. As an added benefit, offshore wind power can be located close to major population and load centers along the coasts (Kempton et al., 2007). Continued development of offshore turbines is expected to help reduce capital, as well as operation and maintenance costs (National Research Council Panel on Electricity from Renewable Resources, 2010).

Hydro and Wave Power

There are two categories of hydroelectric power: conventional and emerging hydrokinetic. Conventional hydroelectric power (e.g., hydroelectric dams) is inexpensive and offers comparatively low GHG emissions on a life-cycle basis (mainly from the production and transportation of concrete and steel but also from construction activities for building the dam). Although opportunities for large new hydroelectric dams in the United States are limited (National Research Council Panel on Electricity from Renewable Resources, 2010), there may be options for smaller-scale conventional hydroelectric projects if local environmental concerns can be managed (Hall, 2006). Unconventional hydroelectric technologies to harness energy from waves, tides, currents, and rivers are still emerging but could potentially be deployed, with considerable technological advances, on a large scale in future decades (National Research Council Panel on Electricity from Renewable Resources, 2010).

Geothermal Power

Geothermal or hydrothermal power generation technologies rely on naturally occurring reservoirs of steam, hot water, or hot rocks in the earth's crust to generate electricity. Utility-scale technologies convert the heat into steam to run a turbine in much the same way that fossil

fuels are used to generate electricity (National Research Council Panel on Electricity from Renewable Resources, 2010; Crane, Curtright, et al., 2011). Conventional hydrothermal plants make use of hot water and steam trapped in permeable rocks at depths of up to 3 km. These resources produce stable and inexpensive electricity with low life-cycle emissions, but they are geographically concentrated in the western United States and limited in quantity. An emerging technology not yet deployed is enhanced geothermal systems (EGS, also known as engineered geothermal systems), which use hot rocks at depths between 3 and 10 km. The aggregate energy potential for EGS is much greater than that for traditional hydrothermal, and the resource is more geographically dispersed. Before this potential can be realized, however, further research and innovation will be needed in the areas of deep thermal drilling, managing the resource, and avoiding the triggering of seismic activity (National Research Council Panel on Electricity from Renewable Resources, 2010; Crane, Curtright, et al., 2011).

Biomass Power

Biomass can be produced and harvested with the aim of generating electricity, but biomass has competing uses as well. These include biomass for liquid fuels and for food (including animal feed). Some biomass waste and residues, however, are best suited for power generation; recent estimates suggest that using such biomass resources for electricity could supply 10 to 20 percent of the nation's power demand. If the country were to increase the amount of biomass devoted to electric production to around 1 billion dry tons annually, the amount of the nation's electricity generated from biomass would rise to about 40 percent (National Research Council Panel on Electricity from Renewable Resources, 2010). Achieving this level, though, would require some dedicated crop production in addition to waste and residues. This would almost certainly compete with the production of biomass for liquid fuels and, potentially, with the production of food and animal feed crops as well. Near-term opportunities for biomass power include cofiring biomass in existing coal power plants (Ortiz et al., 2011), dedicated biomass power plants, and generating electricity as a coproduct in manufacturing biofuels. Longer-term opportunities include breakthroughs in the digestion and gasification of biomass to produce an economic biogas for combustion and the engineering of new biomass strains to enhance photosynthesis efficiencies (National Research Council Panel on Electricity from Renewable Resources, 2010).

Nuclear Power

Nuclear power plants provide around 20 percent of the nation's electricity, but this source has not expanded significantly in recent years. Indeed, no new capacity has been ordered in the United States since the River Bend Nuclear Station began construction in 1977, although several older projects have been completed in the interim (EIA, 2011a). Lack of growth in the nuclear industry stems from several important challenges and risks. These include the high capital costs of constructing a nuclear plant, difficulties associated with environmental permitting and

liability, unresolved issues regarding how and where to store spent nuclear fuel on a long-term basis, concerns that nuclear proliferation increases the chances that terrorists could gain access to nuclear material, and the risk of natural disasters triggering nuclear catastrophes (LaTourrette et al., 2010). The latter can lead to strong local opposition to the siting of new nuclear power plants, and the 2011 meltdowns in Fukushima following the earthquake and tsunami are likely to intensify such opposition. On the other hand, nuclear power does offer advantages as well. Once constructed, nuclear power plants provide an inexpensive source of base-load power that generates no harmful air pollutants or GHGs. With increasing concerns over the threat of climate change, the lack of emissions in particular has stimulated renewed interest in nuclear power. The most-recent projections from EIA assume that the nuclear industry will add about 10 gigawatts (gW) of new generating capacity by 2035, and, as of early 2011, the Nuclear Regulatory Commission had active applications, for a total of 28 new reactors. Given the challenges and concerns described above, however, it is unclear how many of the proposed plants will actually be built (EIA, 2011a).

Comparison of Levelized Cost for New Generation Capacity

The higher cost of power generation is a recurring challenge among many of the lower-carbon alternatives to coal. Figure E.10 presents estimates of the levelized costs—that is, the costs per unit of production taking into consideration plant operating capacity, capital cost, fixed operation and maintenance costs, variable operation and maintenance costs, and transmission investment—in 2009 dollars per kilowatt-hour for new generation resources that could be planned now and delivered by 2016. In the figure, the bars next to each technology option represent the range from low to high cost in different regions in the country; the marks near the middle of each bar represent the national average. As illustrated, some of the renewable or low-emission alternatives, such as wind, geothermal, hydro, biomass, and nuclear, are already cost-competitive, or nearly so, with new coal or natural gas plants (others, such as solar and offshore wind, are still much more expensive).

Figure E.10. Variation in Levelized Cost for New Generation, 2016
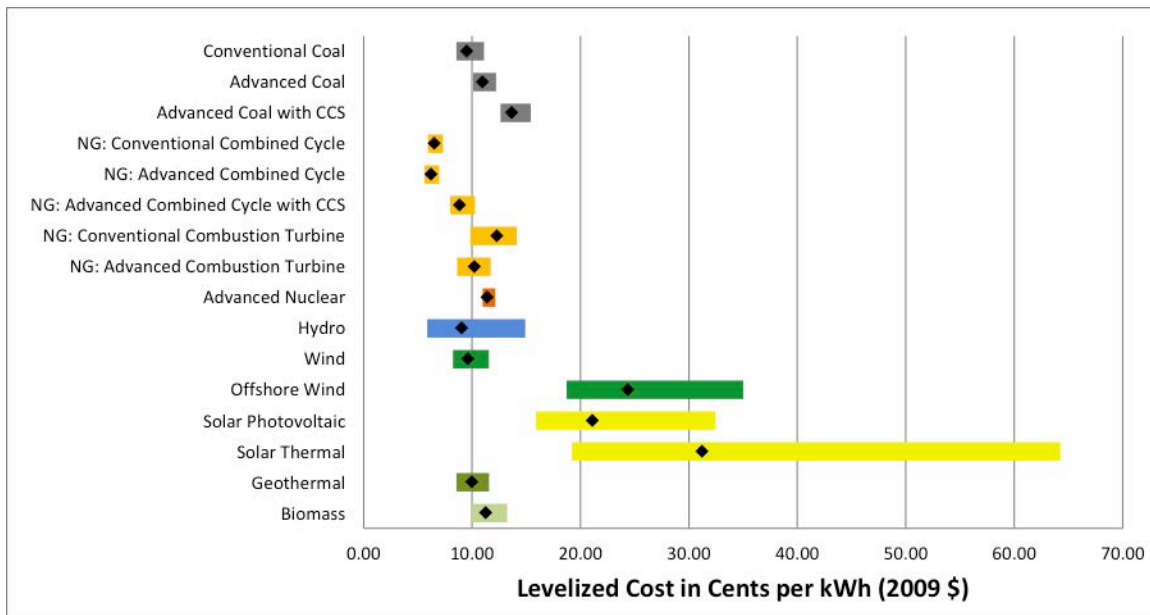
SOURCE: EIA, 2011b.

NOTE: CCS = carbon capture and sequestration.

Unfortunately, the cost-competitive estimates for some of the lower-carbon options illustrated in Figure E.10 do not imply that it would be inexpensive to pursue a rapid transition away from fossil-based electric power generation. To begin with, the cost estimates relate to constructing and operating *new* capacity, whereas much of the nation's current electricity supply is provided by *existing* coal and natural gas plants; such plants are more economical to operate than new ones given that the capital costs are already sunk. Also, as described in the preceding text, all of the renewable or low-emission options face certain challenges, such as limited resources (e.g., for current geothermal technology or new conventional hydropower projects), competition for resources (e.g., biomass), intermittency (wind and solar), or perceived safety and security concerns that translate to significant public acceptance challenges (nuclear).

Carbon Pricing

The federal government has taken several actions in recent years to lessen U.S. dependence on foreign oil and reduce GHG emissions. Among other steps, the administration recently announced significant increases in CAFE standards, which should result in a doubling of the average fuel economy of new light-duty vehicles (passenger cars, light-duty trucks, SUVs, and minivans) by 2025. Congress also passed, and subsequently strengthened, a renewable-fuel standard (RFS) that calls for increasing production of biofuels to displace petroleum. Though these programs are likely to prove helpful, many economists argue that pricing carbon directly

(that is, assessing fees or taxes on the emissions of carbon dioxide and other GHGs) would be an even more efficient strategy for reducing GHG emissions (Fischer, Harrington, and Parry, 2007).[12] From an economic perspective, carbon pricing allows greater flexibility in the manner in which GHG emissions can be reduced, in turn lowering the overall cost of achieving a certain level of reductions. Two policies involving carbon pricing have been considered to date: direct carbon fees and carbon cap and trade.

The intent of carbon fees is to tax the emission of GHGs into the atmosphere in order to create a strong financial incentive for reducing emissions. Such fees could, in theory, be imposed when fuels are extracted from the earth, when they are imported, when they are processed, or when they are consumed. From an economic perspective, the level of the fee would ideally approximate the damage caused by the emissions, although, in practice, this is extremely difficult to quantify given the uncertainty surrounding the future effects of climate change. An important effect of carbon fees would be to level the playing field such that cleaner fuels (i.e., fuels that produce less GHG) or conservation technologies could better compete in the marketplace. From the perspective of mitigating climate change, a main drawback is that the approach does not provide for a specific limit on overall emissions; that is, it is difficult to predict in advance how a given tax rate on carbon (e.g., $20 per ton of CO_2-equivalent emissions) will translate to a corresponding level of reduced overall emissions.

In contrast, cap-and-trade policy would not impose direct costs on the carbon content of fuels; rather, it would place a limit (the "cap") on overall emissions. Allowances would then be distributed, either for free or via auction, that grant the allowance holder rights to emit a certain amount of GHGs. Companies would then be free to buy and sell allowances as needed. If it were expensive for one company to reduce its GHG emissions, that company could purchase allowances from another company that could reduce its emissions at lower cost. It is this ability to trade permits, in the view of some economists, that promotes greater overall economic efficiency. As years pass, the number of permits would be gradually reduced, resulting in corresponding overall reductions in GHG emissions.

In the current U.S. debate, the cap-and-trade approach has been favored over carbon fees because of the former's perceived success in the context of mitigating acid rain precursors (EPA, 2012) and other harmful emissions under the Clean Air Interstate Rule (EPA, 2013a). Additionally, unlike carbon fees, the cap-and-trade approach provides greater certainty in the amount of emission reductions that will actually be achieved. In 2009, the U.S. House of Representatives passed H.R. 2454, the American Clean Energy and Security Act of 2009, which would have used cap and trade to reduce GHG emissions as part of an overall attempt to create clean jobs, promote energy independence, and reduce global warming. The bill was not passed by the Senate, however, and therefore did not become law (U.S. House of Representatives,

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[12] As Greene, German, and Delucchi (2008) argue, however, consumers do not always act in an economically rational manner, potentially undermining those economists' case for pricing.

2009). Absent further federal action, some states are beginning to pursue cap and trade within their own jurisdictions. California, under its landmark climate legislation Assembly Bill (AB) 32, began a cap-and-trade program to reduce GHG emissions in certain industry sectors in late 2012, and other states are now considering similar approaches.

Either form of carbon pricing—carbon taxes or cap and trade—would ultimately increase the cost of emitting GHGs based on the combustion of fossil fuels. From motorists' perspective, the effect would be to increase the per-mile cost of driving. Even with today's petroleum-powered vehicles, however, the overall effect on the cost of driving is expected to be rather modest. To illustrate, Table E.2 shows how carbon pricing, under several cost-per-ton scenarios, could affect the marginal cost of driving a gasoline-powered vehicle that achieves an average fuel economy of either 27 mpg (reflecting the current CAFE standard) or 54.5 mpg (reflecting the revised CAFE standard for 2025). Per EPA (2010) estimates, the calculations assume that each gallon of gas produces 11,294 g of CO_2-equivalent emissions on a well-to-wheels basis, such that it takes 88.5 gallons to produce 1 metric ton of emissions. To put the cost of emissions in context, the table also estimates the per-mile cost of gas to fuel the car, as well as the per-mile cost of federal and state fuel taxes. These latter calculations assume a purchase price of $4 per gallon, including $3.50 for the fuel itself plus another $0.50 in federal and state taxes (close to the average tax burden reported by the American Petroleum Institute, undated).

Table E.2. Effect of Carbon Pricing on the Cost of Driving a Gasoline-Fueled Vehicle

mpg	Marginal Cost of Driving in Dollars/Mile				
	Gasoline at $3.50/gallon	Gasoline Taxes at $0.50/gallon	GHGs at $10/ton CO_2-equivalent	GHGs at $20/ton CO_2-equivalent	GHGs at $100/ton CO_2-equivalent
27	0.1296	0.0185	0.0042	0.0084	0.0418
54.5	0.0642	0.0092	0.0021	0.0041	0.0207

SOURCE: Authors' calculations based on EPA, 2010, and American Petroleum Institute, undated.

As shown in the table, any change in the marginal cost of driving that would result from pricing GHG emissions could prove to be quite modest. For both the $10- and $20-per-ton scenarios, the incremental cost of GHGs would remain substantially lower than the cost associated with fuel taxes or fuel itself. Still, even a small increase in the cost of driving would provide some incentive for travelers to purchase vehicles with higher fuel economy or to switch to lower-carbon alternative fuels.

Looking forward, California's cap-and-trade program under AB 32 may well serve as a preview for similar programs in other states with a strong interest in mitigating climate change. Prospects for a federal cap-and-trade program, on the other hand, or any other form of carbon fees, are much less certain, because of insufficient bipartisan support for addressing the problem of climate change.

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Appendix F. Transportation Funding Trends in the United States

This appendix considers factors related to transportation funding and supply:

- cost of driving
- highway and transit funding policies
- highway and transit investment
- congestion pricing.

Cost of Driving

The cost of driving includes fixed elements (e.g., vehicle purchase or traditional fixed-premium auto insurance) largely independent of the amount of travel, as well as variable elements (e.g., fuel purchases) that increase with total travel. To provide a complete picture of the per-mile costs of driving, fixed costs can be amortized across the expected annual or lifetime mileage of a vehicle and then added to variable costs. When computed in this manner, the per-mile costs of travel depend, not surprisingly, on such factors as fuel economy and the number of miles driven each year. Figure F.1, based on data from the American Automobile Association (AAA) (2012), compares the average per-mile costs for a small sedan, a midsize sedan, and a large sedan under the assumptions of 10,000, 15,000, or 20,000 miles driven per year.[13]

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[13] Per AAA (2012, p. 2),

> Driving costs in each category are based on the average costs for five top-selling models selected by AAA. By size category, they are: Small Sedan—Chevrolet Cruze, Ford Focus, Honda Civic, Nissan Sentra and Toyota Corolla; Medium Sedan—Chevrolet Impala, Ford Fusion, Honda Accord, Nissan Altima and Toyota Camry; Large Sedan—Buick Lucerne, Chrysler 300, Ford Taurus, Nissan Maxima and Toyota Avalon.

Sport utility vehicles are not included in these estimates.

Figure F.1. Average Costs to Drive
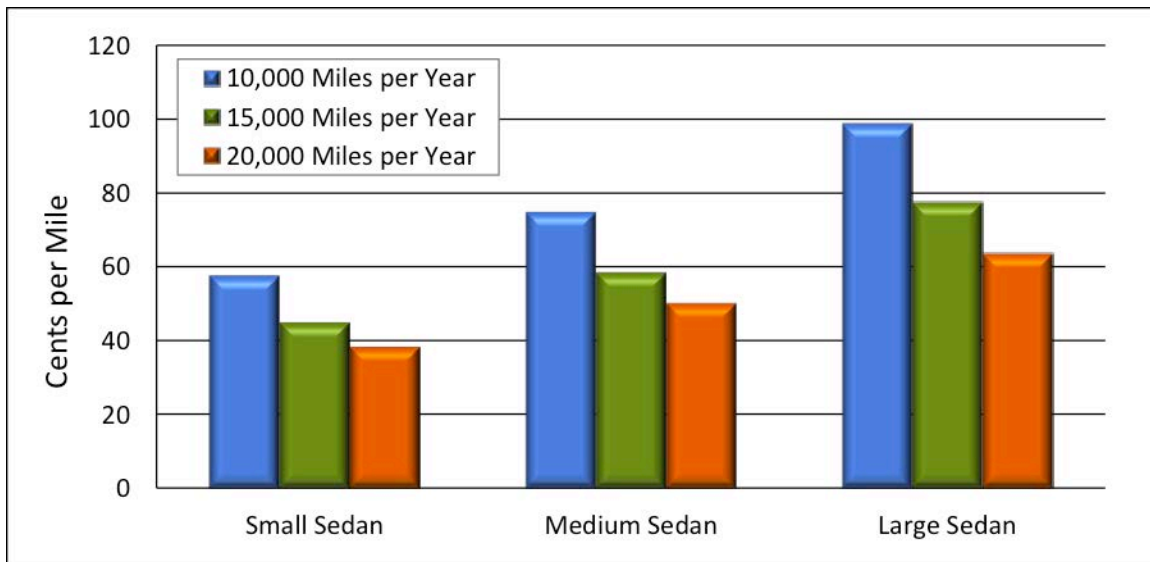
Figure F.2 shows the main elements of per-mile driving costs—in this case, for a midsize sedan that is driven 15,000 miles in a year. As indicated, the cost of the vehicle (depreciation plus finance) and fuel account for the largest share of the costs. The burden associated with transportation funding mechanisms (e.g., fuel taxes and registration fees) is relatively modest.

Figure F.2. Average Costs to Drive a Midsize Sedan 15,000 Miles per Year
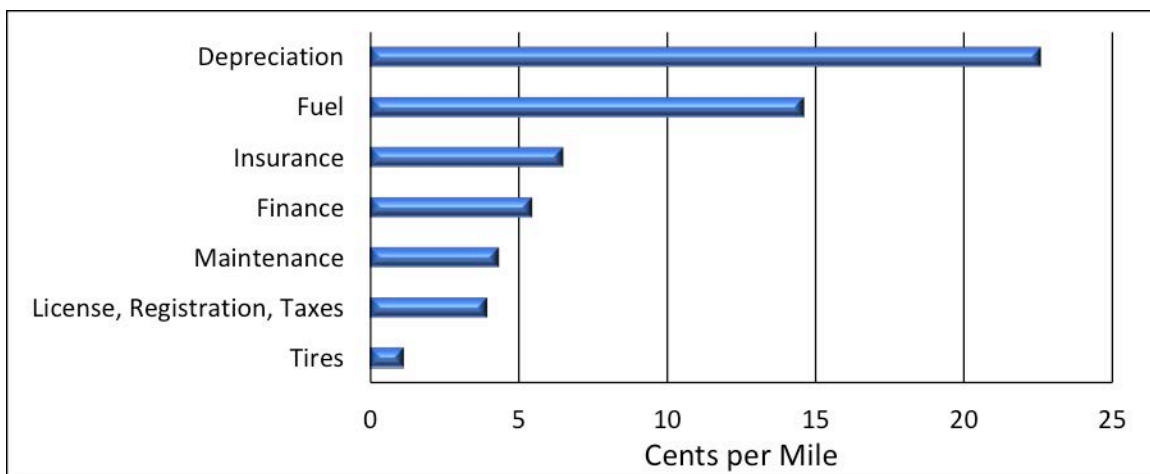
Each year, in order to determine allowable business expense deductions, the Internal Revenue Service (IRS) estimates the average cost of driving a personal vehicle.[14] As shown in Figure F.3, the real per-mile cost was relatively static through the 1990s but has risen rapidly in the past decade. The average annual growth rate between 1990 to 2012 was 0.8 percent.

Figure F.3. Nominal and Real Per-Mile Driving Costs, 1990–2012
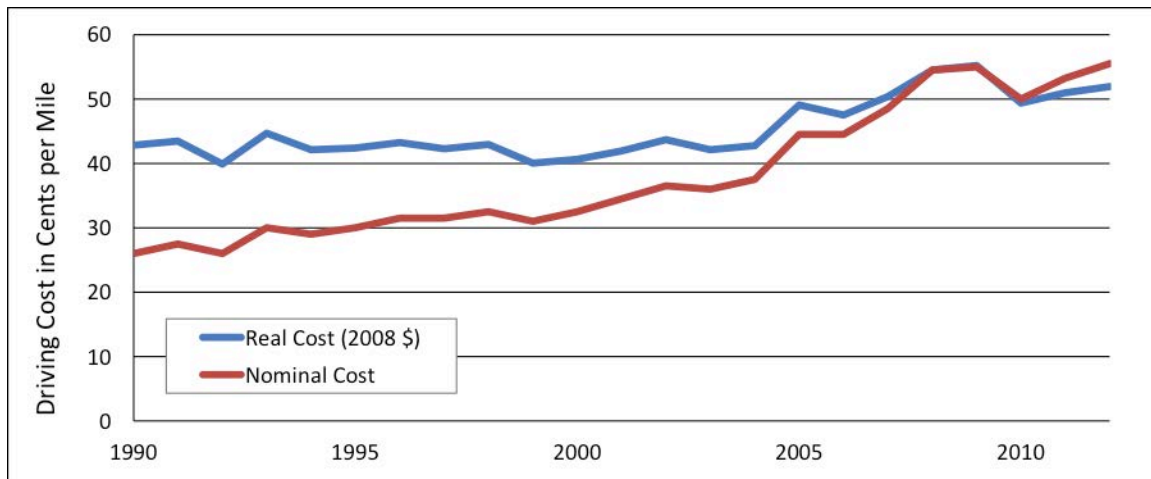
SOURCES: IRS, 1990–2012.

Much of the increase in driving costs in the past decade can be attributed to rising fuel prices, which have outpaced gains in vehicle fuel economy. As indicated in Figure F.4, retail gasoline and diesel prices were relatively stable throughout the 1990s but have risen rapidly, and become more volatile, since then.

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[14] Unlike AAA, the IRS does not distinguish between different vehicle types and sizes, and its methodology is not published.

Figure F.4. Cost of Oil and Fuel, 1980–2010
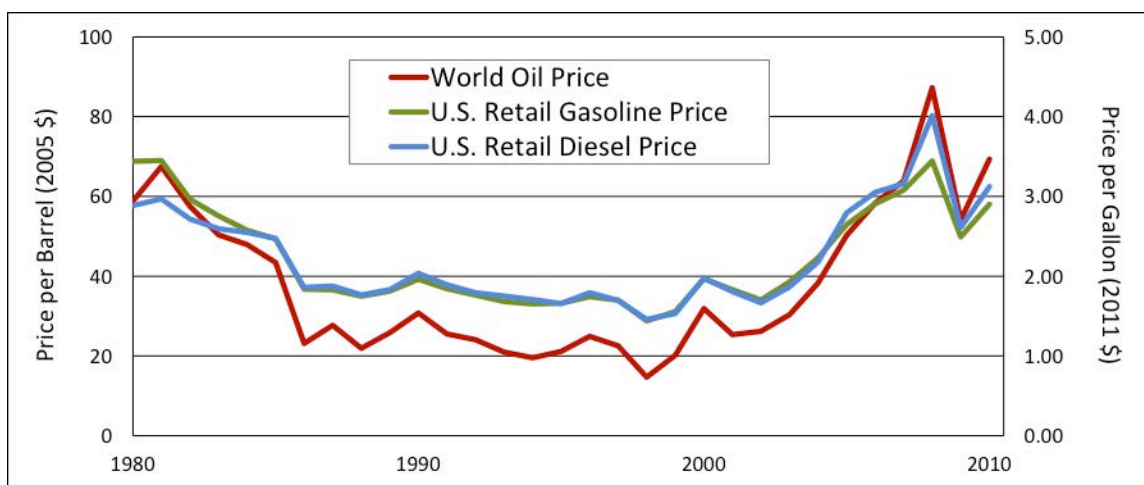
SOURCES: EIA, undated; EERE, 2011.

Looking forward, we see that numerous uncertainties, such as the following, could affect the cost of driving in the coming decades:

- With the recent increases to CAFE standards, the average fuel economy of new light-duty vehicles (i.e., passenger cars, light-duty trucks, minivans, and SUVs) sold in the United States is required to rise to 54.5 mpg—roughly double the current level—by 2025.
- Oil prices have been quite volatile in recent years, and it is unclear whether costs will rise, stabilize, or decline in the next several decades (EIA, 2010).
- EVs are now beginning to enter the market, presenting a trade-off between higher vehicle purchase price and much lower per-mile energy costs. Other alternative-fuel options, such as natural gas and hydrogen, are likely to pose similar trade-offs.
- The number of auto insurers that offer "pay-as-you-drive" policies, under which the premium depends, in part, on total annual mileage, is growing; such policies could offer significant per-mile savings to low-mileage drivers.
- As changes in fuel economy and fuel type undermine the ability of federal and state excise taxes on gasoline and diesel to provide sufficient highway revenue, it is unclear whether the nation will shift to greater reliance on general revenue sources (e.g., sales taxes) or embrace other forms of user fees (e.g., increased use of tolling). The outcome of this debate will have an obvious impact on the costs of driving.

Highway and Transit Funding Policies

Taking into account the factors introduced above, we now consider highway and transit funding policies—that is, decisions about how to raise the money to pay for highway and transit investments (as distinct from decisions about how to allocate the money across different types of investments). This section begins with an overview of the principles and themes that have guided transportation funding policies for much of the past century. It then looks at more recent shifts

that will make it difficult to sustain adequate funding in the coming decades, in turn prompting officials to consider major reforms in transportation funding approaches.

Historical Themes in Highway and Transit Funding

Roads and transit systems are typically planned and funded by the public sector based on both user fees and general revenue sources raised at federal, state, and local levels. Prominent historical themes in transportation funding policy are described in this section.

Adoption of the User-Pays/User-Benefits Principle

The State of Oregon pioneered the use of fuel taxes to fund highways in 1919. With a significant share of the population not yet owning vehicles, fuel taxes were viewed as a fairer way to pay for roads than general revenue because the tax burden would roughly align with the benefits derived from use of the road network. Fuel taxes, though less directly related to road use than tolls, could be collected from a small number of fuel wholesalers and would thus be cheaper to administer and easier to enforce than tolls. These proved to be compelling advantages, and, by 1940, all of the states and the federal government had begun to levy excise taxes on fuel (Brown et al., 1999). Fuel taxes have since evolved to become a significant source of highway revenue; in 2010, federal and state motor fuel excise taxes collectively generated roughly 43 percent of all highway revenues (Henchman, 2013). Common sources of funding for local roads and transit, including property taxes and transit fares, likewise follow the principle that those who benefit— through improved access or use—should pay to help develop and maintain the system.

Increasing Taxes and Fees as Needed

Federal and state fuel taxes, typically levied on a cents-per-gallon basis, have been periodically raised in the past century to account for inflation and, in more recent decades, improved fuel economy. Initially set at $0.01 per gallon in 1932, for example, the federal excise tax on gasoline has been increased nine times in the intervening years—most recently in 1993— and currently stands at $0.184 per gallon. Many states, in turn, have instituted similar fuel tax increases as needed or have indexed their fuel taxes to increase with inflation. The same holds for other common funding sources as well (Pirog, 2009).

Hypothecation of Transportation Revenue

To garner public support for levying and increasing fuel taxes to pay for roads, the federal government and most states have chosen to hypothecate (dedicate) fuel tax revenue by directing proceeds into trust funds (e.g., the federal Highway Trust Fund, or HTF) that support transportation investments. This approach, relatively rare outside the United States, constitutes a pact (often codified in law) between road users and the government that fuel taxes are to be treated as a user fee; road users agree to pay, through fuel taxes, to fund the road network, and

the government, in turn, agrees to invest the resulting revenue in construction and maintenance projects that benefit road users.

Diversification of Funding Sources

To augment fuel taxes and transit fares, federal, state, and local governments have gradually broadened the array of revenue sources for funding surface transportation. Other common funding mechanisms used at the federal, state, or local level include (1) direct user fees, such as tolling or container fees; (2) indirect user fees, such as sales taxes on vehicles or vehicle parts and license and registration fees; (3) charges on other system beneficiaries, such as development impact fees and special assessment districts; and (4) general revenue sources, such as income taxes and sales taxes. Cambridge Systematics et al. (2006) provide a comprehensive breakdown of the different funding sources employed at different levels of government.

Recent Trends in Highway Funding

Throughout much of the 20th century, federal and state fuel taxes offered a stable source of funding to develop and maintain the nation's highway network. This has begun to shift considerably in the past few decades, however, which have been marked by diminished emphasis on fuel tax revenue, devolution of funding responsibility, and reduced reliance on user fees overall.

Decline in Motor Fuel Tax Revenue in Relation to Travel

Most fuel taxes are levied on a cents-per-gallon basis and must be raised periodically to offset the effects of inflation and improved fuel economy. Elected officials, however, have grown less willing to take on this politically unpopular task in recent decades; federal fuel taxes were last raised in 1993, and many states have likewise not increased fuel tax rates for many years (see FHWA, 2009b, Tables MF-121T and MF-205 for details).

The net effect has been to reduce real revenue per mile of travel. Since their previous increase, for example, federal fuel taxes have lost about one-third of their value because of inflation alone (National Surface Transportation Infrastructure Financing Commission, 2009). Loss to inflation has been further compounded in recent decades by gains in fuel economy, which reduce the amount of revenue collected per VMT. Between 1980 and 2007, annual VMT on U.S. roads increased by nearly 100 percent (FHWA, 2009a), while aggregate fuel consumption rose by just over 50 percent (EERE, 2011).

Given that federal and state fuel taxes account for about half of all highway revenue, these trends have, in turn, undermined total highway revenue, in real terms, in relation to total travel. Since 1970, as shown in Figure F.5, total nominal revenue (all sources of federal, state, and local highway revenue) has increased by nearly 700 percent. During this same period, however, inflation as measured by CPI has exceeded 400 percent and total VMT has increased by almost

175 percent. As a result, real revenue per mile of travel has declined by nearly 50 percent in the past four decades.

Figure F.5. Growth in Highway Revenue, Inflation, and Vehicle Miles Traveled
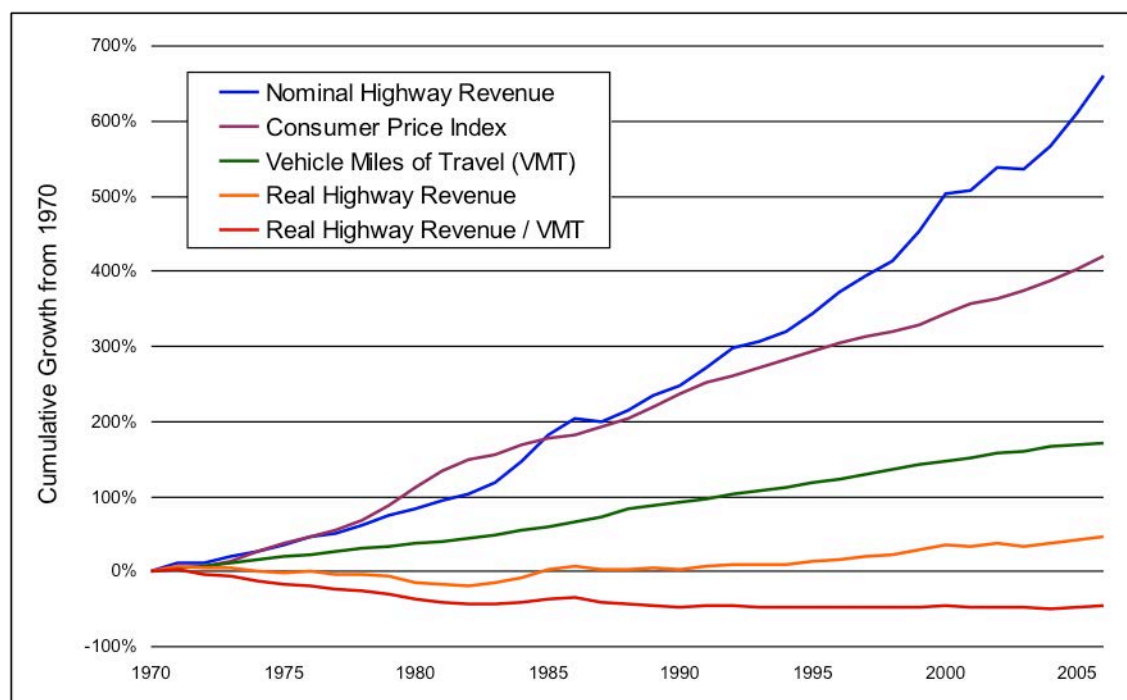
This trend has proven problematic, in that highway maintenance and investment requirements increase with total travel rather than with fuel consumption. And with the recent increases in federal CAFE standards and expected growth in the market share for alternative-fuel vehicles, any growth in VMT appears likely to outpace growth in gasoline and diesel use to an even greater degree in the coming decades (EIA, 2010). If VMT remains steady, as it has for the past several years, fuel consumption is likely to decline.

Devolution of Funding Responsibility

One effect of this trend has been to shift greater responsibility for transportation funding to local jurisdictions (Goldman and Wachs, 2003). At the height of the interstate construction era in the 1960s and early 1970s, federal and state governments accounted for about 80 percent of all highway revenue, with local governments contributing the remaining 20 percent. By 2008, with the decline in federal and state fuel tax revenues, the local share had grown to 28 percent (based on analysis of data from FHWA, 1997, Table HF-210, and FHWA, 2009b, Tables FE-210, HF-10, and HF-10A). Note, however, that the increasing share of local highway funding has not

been sufficient to offset the overall decrease in total funding in relation to travel, as indicated in Figure F.5.

Reduced Reliance on User Fees

Another effect of diminished federal and state fuel taxes has been reduced overall reliance on user fees. Since the early 1960s, user fees as a share of total highway revenue have declined from about 70 percent to just under 50 percent as of 2008. This has led to increased reliance on general revenue sources, such as sales taxes, collected by states and, especially, local governments (based on analysis of data from FHWA, 1997, Table HF-210, and FHWA, 2009b, Tables FE-210, HF-10, and HF-10A).

Illustrating this trend, Figure F.6 compares total federal, state, and local investment in roads with total federal, state, and local user-fee revenue, normalized in real (2008) dollars per 1,000 miles of travel, for 1990 to 2008. As shown in Figure F.6, real investment has been increasing slightly (though, as shown earlier in Figure F.5, it declined precipitously between 1970 and 1990), whereas the amount of user-fee revenue has been falling modestly.

Figure F.6. User Revenues and Total Investment per 1,000 Vehicle Miles Traveled, 1990–2008
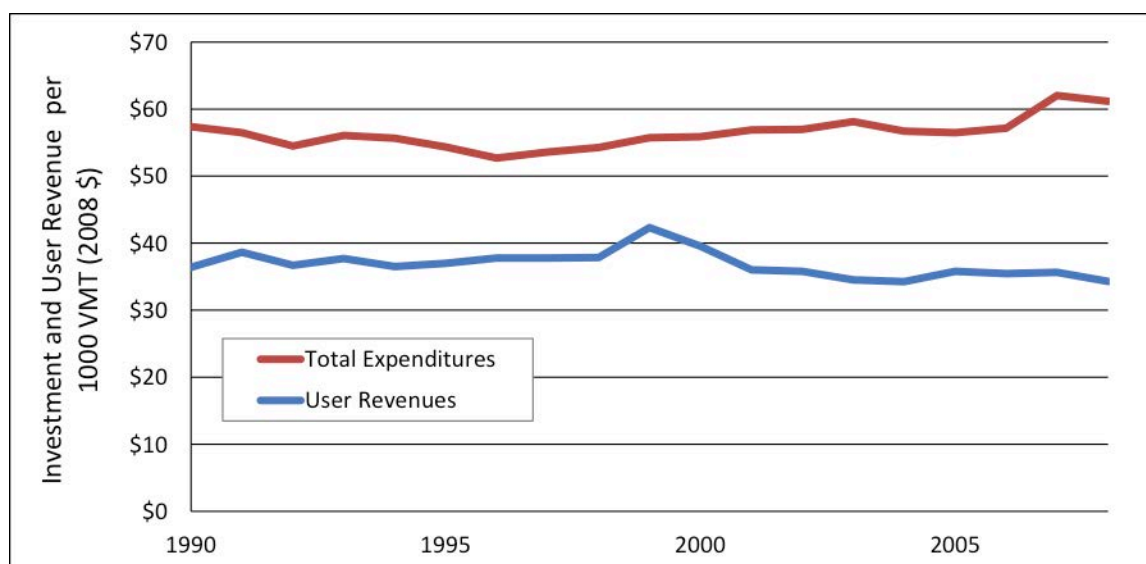
Sources: Total expenditures from FHWA, 2009c, Table 6.7; User revenues from FHWA, 2009b, Table FE-210 (federal revenues); FHWA, 1997, Table HF-210, and FHWA, Highway Statistics Series, Table HF-10 or HF10A (revisions), each year for 1996–2008 (state and local revenues); VMT from BTS, undated. Note that 2008 data were the most recent available in certain categories.

Recent Trends in Transit Funding

Transit funding likewise faces future challenges, though of a different sort. Though fare-box revenue is an important source of income for transit operators, there has been significant growth in public subsidization of transit services by all levels of government in recent decades. With

fiscal challenges at all levels of government, it is not clear that this trend can continue indefinitely.

Significant Public Subsidies

In the past several decades, according to data from the American Public Transportation Association (APTA) (2010, Tables 37 and 41), user fees in the form of transit fares (along with advertising, concessions, and other direct sources of transit agency revenue) have accounted for about one-third of all transit funding. The remaining two-thirds has been provided, in roughly equal shares, by federal, state, and local subsidies.

Growth in Transit Funding Relative to Ridership

In contrast to the decline in real highway revenue relative to vehicle travel, transit funding has risen more quickly than ridership in recent decades. According to data from APTA (2010, Tables 2, 37, and 41) and BLS (undated), transit passenger miles have increased by about 40 percent since the late 1980s, while total real transit funding has grown by about 65 percent in that same period. This suggests a troubling pair of trends: Total transit revenue in real terms (APTA, 2010, Tables 37 and 41, adjusted for inflation) has increased more quickly than transit-vehicle revenue miles (Table 7), which have, in turn, risen more quickly than ridership in passenger miles (APTA, 2010, Table 2). In other words, the marginal cost of new transit capacity has been rising, in real terms, while ridership per unit of capacity has been declining.

Highway and Transit Investment

We now shift our focus from how highway and transit revenue is raised to how it is invested, which, in turn, affects the quantity and quality of roads and transit services. At the end of this section, we also consider ongoing debates about the appropriate future trajectory for transportation revenue and investment policy. These debates are motivated by current disparities between available revenue and perceived investment needs.

Recent Trends in Highway and Transit Investment

Examination of investments in highways and transit systems in the past several decades reveals several important trends: insufficient overall investment (most notably for roads) in relation to estimated needs, increased diversion of federal highway user-fee revenue to nonhighway uses, disproportionate investment in transit relative to mode share, and diminished investment in bus service relative to other modes of transit.

Insufficient Overall Investment

In a National Cooperative Highway Research Program (NCHRP) report (Cambridge Systematics et al., 2006), the authors estimated that the gap between projected federal, state, and local revenue and the amount needed to *improve* the nation's highway and transit networks

would be $105 billion in 2007, growing to $134 billion by 2017, with a cumulative ten-year gap of $1.3 trillion. For the amount needed to simply *maintain* the current condition and performance of highway and transit networks, the revenue shortfall would be close to $50 billion in 2007, growing to $66 billion by 2017, with a cumulative ten-year gap of $635 billion. The congressionally mandated National Surface Transportation Infrastructure Financing Commission (2009) reached a similar conclusion about the gap between needs and revenues.

Diversion of Federal Highway Revenue

When the HTF was established in 1956 to help fund the interstate system, federal excise fuel taxes on gasoline and diesel were designated as the main source of HTF funding (additional truck-related fees were also hypothecated to the HTF). In the intervening decades, through a series of federal transportation bills, the share of HTF funds directed to nonhighway uses—including transit, air quality mitigation, and bicycle and pedestrian improvements—has expanded to roughly 25 percent. In addition, Poole and Moore (2010) argue that the diversion of fuel tax revenue for nonhighway investments has made it more difficult to secure the support of road user groups for increasing federal fuel taxes to keep pace with inflation and total vehicle travel.

Disproportionate Investment in Transit Relative to Use

Although total U.S. investment in highways greatly exceeds total investment in transit, the latter receives disproportionate funding relative to use.

Table F.1, based on data from the 2009 NHTS (A. Santos et al., 2011), compares mode share for private automobiles and transit in terms of person trips and person miles for total travel and commute travel. As shown, the ratio of vehicle travel to transit travel ranges from 25 to 1 (for commute travel in terms of person trips) to 59 to 1 (for total travel in terms of person miles), while the ratio of highway investment to transit investment is closer to 3 to 1 (based on data from APTA, 2010, Tables 37 and 41, and FHWA, 2009c, Table 6-7).

Table F.1. Mode Share for Private Vehicles and Transit (%)

Mode	Person Trips		Person Miles	
	Total	**Commute**	**Total**	**Commute**
Private vehicle (%)	83.4	91.4	88.4	94.5
Transit (%)	1.9	3.7	1.5	2.6
Private vehicle–to-transit ratio	44:1	25:1	59:1	36:1

SOURCE: A. Santos et al., 2011, Tables 9 and 12.

The disproportionate investment in transit relative to mode share stems from the fact that many decisionmakers view transit as an attractive and politically viable strategy for addressing numerous social goals, such as providing mobility for those unable to drive, enhancing access to employment, enabling denser and more livable development patterns, easing traffic congestion,

reducing reliance on foreign oil, and limiting the emissions of harmful GHGs and local air pollutants (Taylor, 2010).

Declining Emphasis on Bus Transit

Within the context of transit, a final trend worth noting is the diminishing share of investment devoted to bus service. In the past two decades, according to APTA (2010, Tables 35 and 38), the share of transit investment devoted to bus service has declined from more than 50 percent to about 42 percent. The share of investment in rail has grown slightly during this period, while the share devoted to other forms of transit (especially paratransit, which may include costly on-demand services for patrons facing certain mobility challenges, such as physical disabilities) has increased dramatically. The shifts in funding have been mirrored by shifts in ridership as well. Since 1984, the share of transit passenger miles served by bus has declined from about 55 percent to less than 40 percent. The share for rail has risen from 42 percent to about 55 percent, while the share for other modes of transit has gained just a few percentage points (APTA, 2010, Table 2).

Transit Supply and Quality

We now consider recent trends in the supply and quality of transit services, which are obviously influenced by available revenue and investment priorities. As a point of reference, Figure F.7 graphs the increase in transit capacity (in vehicle-miles, as a surrogate for vehicle revenue–miles) and in population dating to 1970.

Figure F.7. Growth in U.S. Transit Supply and Population
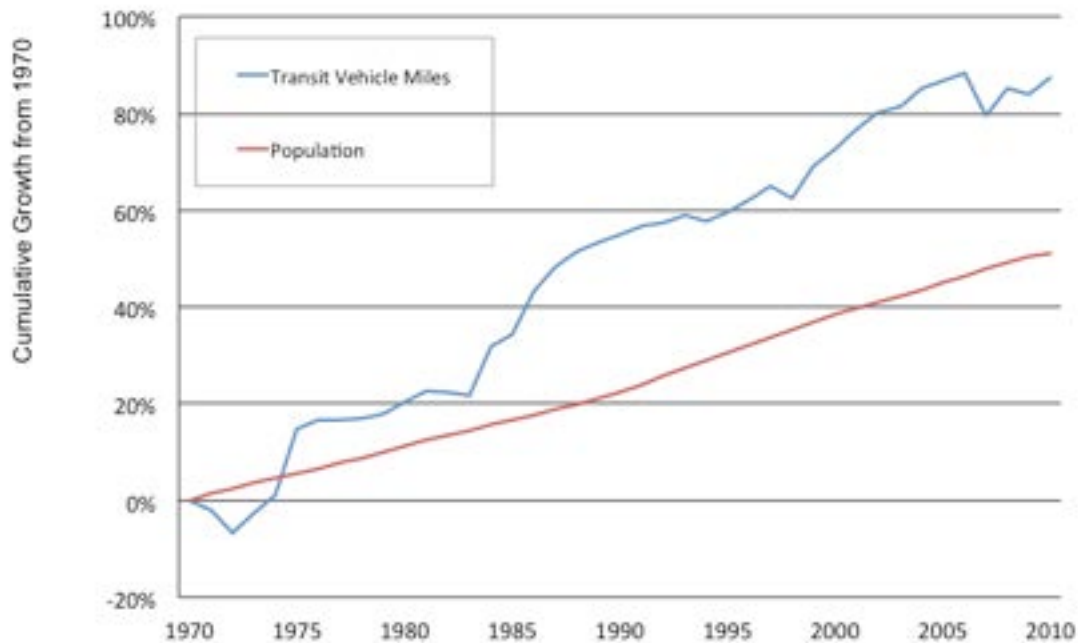
SOURCES: APTA, 2012, Table 8; U.S. Census Bureau, 2011, Table 2.

NOTE: The number of transit vehicle miles includes the categories of bus, commuter rail, heavy rail, light rail, and trolley.

Transit Service Amount and Quality

   The amount of transit service has expanded rapidly in recent decades, exceeding the level of population growth. Between 1990 and 2010, total transit vehicle miles of service in the United States grew at an average annual rate of about 1 percent.

   Although there is not a standard objective measure of quality in terms of the user's transit experience, the Federal Transit Administration (FTA) does measure the quality of transit infrastructure. This is not done through direct observation but through estimates based on vehicle age, deterioration schedules, and maintenance and rehabilitation reporting by the transit agencies via the National Transit Database. The conditions of various types of infrastructure are rated on a five-point scale, with 5 corresponding to excellent condition ("near new") and 1 corresponding to very poor condition ("seriously damaged"). Figure F.8 shows the average national conditions for urban bus fleets (i.e., excluding rural fleets and rail vehicles). Detailed time series were not readily available for other components, such as maintenance facilities. Generally speaking, the nation's fleet of transit vehicles appears to be in a reasonably good state of repair, though there has been a slight downward trend in recent years.

Figure F.8. Average Transit-Vehicle Conditions
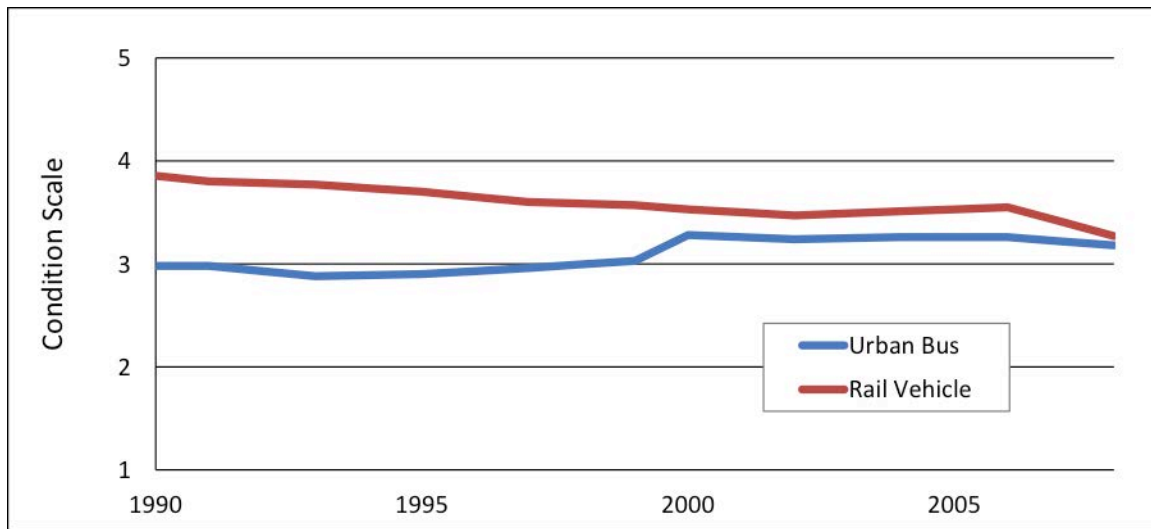
SOURCES: FHWA, 2003, Exhibits 3-38 and 3-51; FHWA, 2012, Exhibits 3-24 and 3-26.

NOTE: The urban bus series for the year 2000 breaks from FHWA, 2003 (in which it is reported as 3.07) and 2012 (3.28), without any explanation provided. We have begun the latter series in 2000.

Future Funding and Investment Policy Options

As discussed earlier, there is a considerable gap between estimated transportation investment needs—either to maintain or to improve the nation's road network and transit systems—and forecast revenue. The growing revenue shortfalls have prompted discussion of a broad range of transportation funding and investment policy directions for the future. We now briefly review some of the main ideas and concepts being considered.

Federal, State, Local, and Private Roles in Funding Transportation

With the interstate system now largely complete, some might argue that the shift toward greater local funding responsibility, already under way, makes sense. Under this line of reasoning, local officials are in a better position to judge what investments will be most helpful, and residents will be more willing to accept revenue measures when they know that the money will be invested in local improvements and can hold their officials responsible.

Yet there are also arguments for reinvigorating federal and state funding roles. Much of the interstate system is reaching the end of its 50-year design life and will soon need to be completely rebuilt, a task of national importance that is likely to be far more expensive than the initial construction (Regan and Brown, 2011). Additionally, greater reliance on local resources has, to date, corresponded with reductions in total revenue relative to total travel; that is, increases in local funding have been insufficient to offset overall reductions in state and especially federal funding. Finally, increased devolution has thus far led to greater reliance on

general revenue sources, such as sales taxes; these tend to be less equitable than user fees and do not promote efficient system use (Wachs, 2003).

Absent sufficient public funding, it is also possible that private industry (most likely through public-private partnerships, or PPPs) could take a greater role in funding and operating transportation facilities in the United States. This could include developing and operating new private tollways or transit facilities, for example, or contracting with public agencies to operate existing systems.

Level of Funding

The overall pattern in surface transportation can be described as one of increasing disinvestment (Cambridge Systematics et al., 2006), and the question is whether voters will continue to support this trajectory. On the one hand, strong arguments can be made that the nation's investment in a world-class transportation network in prior decades has been a key underpinning of its economic prosperity to date and that further investment will be critical to ensure continued success in future years. On the other hand, constituencies for lower taxes and smaller government have gained greater political influence of late, reducing prospects for significant increases in the level of public investment for at least the near term.

Funding Mechanisms

Recent technical innovations now make it possible to meter and levy precise road use fees (e.g., mileage-based user fees or congestion tolls) based on such factors as distance, time, and location of travel (Whitty, 2003; Sorensen, Ecola, et al., 2009; Sorensen, Wachs, and Ecola, 2010). Similarly, in the transit arena, the proliferation of electronic fare media allows for variable fare structures that can promote greater ridership and enhanced cost recovery (Wachs, 1981; Cervero and Wachs, 1982). Though more precise user fees can better align costs with benefits and promote more efficient system use, it remains uncertain whether decisionmakers will adopt such an approach or instead allow a continued shift toward general sources of revenue in the coming years (Sorensen and Taylor, 2006). The recent success of local transportation funding initiatives across the country reliant on sales taxes and general obligation bonds (for a history, see Goldman and Wachs, 2003; on the success of voter initiatives on transit since 2000, see Center for Transportation Excellence, 2013) suggests that the public views the funding of transportation through general revenues as acceptable; in contrast, innovative forms of user fees remain highly controversial despite their theoretical advantages.

Investment in Roads Versus Transit

Although the United States invests less in transit than it does in roads, transit systems receive a disproportionate share of transportation funding in relation to the ratio between transit ridership and automotive travel. Assuming continued budgetary shortfalls at all levels of government, and as the state of repair for roadways continues to deteriorate in many states, it is possible that

decisionmakers might choose to shift a greater share of revenue—especially revenue derived from road use fees—from transit systems back to road investments.

Congestion Pricing

Congestion pricing refers to the strategy of assessing a charge or toll on drivers who travel in congested areas or corridors during peak travel hours. This creates a financial incentive for drivers to alter their travel behavior—to shift the time, route, or mode of their travel—in turn helping to reduce traffic congestion and increase available revenue. First discussed in the early 1900s, practical implementation has become possible only with recent technology innovations in the past few decades. Depending on programmatic design, congestion pricing can involve a fixed charge that applies only during certain hours, or it can rely on variable tolls that rise and fall with prevailing traffic conditions. Congestion pricing can also produce a significant revenue stream and reduce harmful emissions of local air pollutants and GHGs.

It is possible to implement congestion pricing in different ways. Taking stock of both implemented programs and experiments conducted to date, one can discern at least four general classes of congestion pricing: managed lanes, congestion-priced facilities, cordon congestion tolls, and network-wide congestion tolls. Additionally, recent policy innovations involving variable pricing of parking spaces can also be viewed as a form of congestion pricing. In the remainder of this section, we describe each of these forms of congestion pricing and consider future prospects for implementation within the United States.

With regard to revenue, it is impossible to develop an average of how much revenue could be raised by each strategy—it depends on a variety of factors related to implementation, such as the cost of the charge, the number of drivers affected, its effect on usage, and the cost of implementation and operation. Where they were readily available, we have included some past experience on revenues raised.

Managed Lanes

In this approach, only a subset of lanes (typically one or two) on a given facility is subject to congestion pricing, while other lanes remain free. Travelers thus have a choice: They can either pay a congestion charge in return for shorter and more reliable travel time, or they can continue to use the slower general-purpose lanes for free, and this choice can vary from one trip to the next.

The concept of managed lanes was pioneered in the United States, where two distinct models have emerged. In one approach, commonly referred to as *high-occupancy toll* (HOT) lanes, congestion pricing is used to sell excess capacity in existing high-occupancy vehicle (HOV) lanes to single-occupant vehicles, with the toll rate varied to ensure (on behalf of existing carpools) that the lanes remain free flowing. The HOT-lane concept was first developed on

Interstate 15 in San Diego and has since been replicated in many other corridors in the country (Turnbull, 2007).

In the second managed-lane approach, often described as *express lanes*, congestion pricing is applied to newly constructed lanes to help fund their development, and carpools may or may not receive a break on the price of the congestion tolls. State Route 91 (SR-91) in Southern California, which consists of two priced lanes in each direction surrounded by four general-purpose lanes in each direction, represents the first implementation of the managed-lane concept. Although revenues from the first type of HOT lane have been modest (one analysis found an average of $1.7 million per year), SR-91 has generated $35.5 million per year (Poole, 2011).

The managed-lane approach has attracted increasing interest in the United States for at least two reasons. First, the use of variable tolls has proven effective in maintaining high and reliable travel speeds even during peak hours—an option valued by many drivers—while accommodating greater vehicle throughput than is possible on highly congested lanes. On the SR-91 express lanes, for example, traffic speed in the priced lanes averages 60 to 65 miles per hour (mph) during peak periods, compared with just 15 to 20 mph in the adjacent free lanes. And because traffic throughput diminishes significantly with severe congestion, the priced lanes accommodate about twice the number of vehicles per lane per hour as the congested general-purpose lanes (Obenberger, 2004). Second, the optional nature of pricing under the managed-lane approach has proven reasonably popular with voters (Sullivan, 2002; Supernak et al., 2002). Drivers are not forced to pay congestion tolls if they do not wish to do so, but they also have the option of paying tolls in return for shorter and more-reliable travel time when needed.

Given these advantages, managed lanes have proliferated in the United States in the past decade, with at least nine projects already implemented. About 20 more are currently in the planning stages ("Express Toll Lanes in High Gear," 2012), suggesting that the managed-lane concept is poised for continued expansion in the coming decades.

Congestion-Priced Facilities

As with managed lanes, this second form of congestion pricing also applies to specific facilities. In this case, however, drivers in *all* lanes must pay congestion tolls. Although this concept has been implemented in several locations around the world, application in the United States has been limited to date, typically involving the conversion of an existing tolled facility from a flat rate to a variable rate. Perhaps the best-known U.S. example is the Port Authority of New York and New Jersey, which implemented off-peak toll reductions on some of its toll facilities as a means of inducing shifts in travel time (Ozbay et al., 2005).

Although this form of congestion pricing could expand within the United States in future years, its potential is currently limited by federal restrictions that prohibit tolling on most existing interstate freeways. Even if the federal government were to remove such restrictions, however, applying congestion tolls to all lanes on an existing facility would almost certainly be more controversial than the managed-lane approach given that drivers using the facility would

not have a choice about whether to pay the toll (on public opinion about managed lanes versus congestion-priced facilities, see, for example, Swanson and Hampton, 2013).

Cordon Congestion Tolls

With cordon congestion tolls, first introduced by Singapore and subsequently adopted in London and Stockholm, each vehicle is assessed a fee for entering or driving within a congested urban core (delineated by the cordon line) during peak hours. Depending on the implementation details, the fee could be charged at most once per day, or it could be charged repeatedly each time the cordon line is crossed. Additionally, there may be a single flat rate that applies regardless of the time of day (as in London), or the charge rate may vary depending on the time and location of entry into the zone (as in Singapore).

The cordon congestion tolls implemented to date have proven extremely successful in reducing traffic delays and promoting mode shift to transit and other alternatives. When Singapore upgraded from a paper-based permit system to an electronic cordon toll implementation in the late 1990s, for example, traffic volume in its central business district (CBD) declined by 15 percent (Fabian, 2003), travel speed in the CBD nearly doubled to 36 km per hour, travel speed on the expressways increased from 45 to 65 km per hour, and average bus speeds increased by 16 percent (Goh, 2002). After London's cordon toll was initiated, total vehicle travel within its CBD declined by 15 percent, congestion delays were reduced by 30 percent, travel speeds within the zone increased by 21 percent, travel speeds from outer London to the zone increased by 12 percent, and bus delays were reduced by 33 percent (G. Santos and Shaffer, 2004).

Because cordon tolls apply to most drivers entering or driving within the charge zone and because the charge is not optional, the tolls are able to generate significant revenue: roughly US$40 million per year in Singapore (Goh, 2002) and roughly £100 million in London (US$152 million) (G. Santos and Shaffer, 2004). In both of these cases, the revenue has been devoted mainly to transportation improvements, particularly for better bus and rail transit service to offer more travel options for those seeking to avoid paying the cordon toll.

At the same time, the nonoptional nature of cordon tolls makes it more difficult to secure public support for this concept and raises important equity issues (Dennis, 2009). In particular, implementing a cordon toll in a city that lacks excellent transit service could create a financial hardship for lower-income residents who need to drive into the city (e.g., for work) during peak hours given the paucity of viable transit alternatives (G. Santos and Shaffer, 2004). This helps to explain why the cordon toll approach has yet to be adopted within the United States. New York City devoted extensive effort in developing a cordon pricing plan for Manhattan that nearly passed, and San Francisco has also studied the concept in great depth. Beyond these two examples, however, relatively few additional cities in the United States offer sufficiently extensive transit service to overcome the potential equity concerns associated with cordon tolls, suggesting that the applicability of this approach is likely to be limited in the foreseeable future.

Network-Wide Congestion Pricing

A final potential form of congestion pricing would be to apply charges across the entire road network (or at least across all freeways and major arterials) within a congested metropolitan region, where the charge rate would vary by time of day, by specific route, and by travel distance. This concept, explored by the Puget Sound Regional Council (PSRC) in its Traffic Choices Study (PSRC, 2008), would provide a powerful tool for mitigating urban traffic congestion on a systematic basis. At the same time, though, it would be extremely complex to implement technically, and securing support from the public would also be challenging.

Perhaps the most plausible scenario under which this form of congestion pricing might be implemented would be if a state or the nation as a whole instituted a system of mileage-based user fees (as a replacement for fuel taxes) capable of metering vehicle travel by route and by time of day. This would also have the potential to increase revenues. Sorensen, Ecola, et al. (2009) estimated that, at replacement-level mileage fees (that is, fees under which drivers would collectively pay the same amount they currently do in fuel taxes), mileage fees would produce $47.4 billion in revenue in 2030, as opposed to $39.2 billion in fuel taxes (in 2009 dollars). Overall, though, the prospects for implementing network-wide congestion pricing in the near term would have to be judged as remote.

Variable Parking Prices

A final policy akin to congestion pricing is the application of variable rates for on-street parking, a concept developed by Donald Shoup, professor of urban planning at the University of California, Los Angeles (UCLA) (Shoup, 2005). As Shoup observed, many municipalities routinely underprice curb parking spaces in relation to demand, resulting in a chronic scarcity of available spaces. And because the prices are so low, drivers have an incentive to circle around the block a few times searching for an available space—described as "cruising for parking"— rather than paying higher rates for private, off-street parking. This behavior, which can result in significant additional traffic congestion in busy commercial districts, wastes time, wastes fuel, and produces excess GHG, as well as local air pollutant, emissions.

The solution proposed by Shoup is to vary parking-meter rates throughout the day in accordance with prevailing demand conditions, with the goal of achieving a parking-space occupancy rate of roughly 85 percent—that is, ensuring that there are usually one or two open curbside spaces on any block (assuming that a typical block has about ten curbside spaces). Meeting this goal makes the process of parking much more convenient for visitors to an area, reduces congestion, and eliminates utterly unproductive driving time, fuel consumption, and emissions. It also typically results in greater parking revenue for municipalities. Given these advantages, this concept is beginning to gain traction around the country. Among major metropolitan areas in the United States, Washington, D.C., New York City, and San Francisco have already implemented variable parking rates, and Los Angeles is now beginning to explore

this concept. (These experiments in parking pricing are still quite new, so there have not yet been published evaluations that discuss how much revenue has changed compared with previous parking charges.) Although not assured, it thus appears quite possible that this complementary form of congestion pricing could expand significantly in the next few decades.

A Note on Congestion

Our initial list of descriptors for this influencing area included the volume and quality of roads, but, during the workshop, the expert panel determined that this descriptor added little to our understanding of the future of mobility because the road network is largely built out. Instead, they elected to create a new descriptor on congestion. Because we had not done background research on congestion, it is not included in this appendix. We have also removed the section on road supply because it did not inform any of the projections.

References for Appendix F

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Appendix G. Technology Trends in the United States

This appendix seeks to consider technology broadly as "the science of the application of knowledge to practical purposes: applied science" ("Technology," 2013). By this definition, technology that affects transportation includes self-healing pavements, improved bridge designs, new algorithms for routing traffic, and improved engines and fuels. However, in this appendix, we focus on technology applications and issues related to technology that have or may be expected to have a particularly strong impact on travel behavior:

- smart phones and computers
- use of time while traveling
- telematics
- data privacy
- safety technology
- advanced driver-assistance systems
- autonomous driving.

Three caveats apply to this appendix: First, we do not discuss technologies that are covered in other appendixes in this series, such as alternative fuels and vehicles, which are discussed in Appendix E. Second, because many of the technologies discussed here are still under development or have yet to reach their full commercialization, we have relatively little data on long-term trends. Rather, we focus on how a specific technology is currently or may be anticipated to affect travel behavior and demand. Finally, we do not attempt an in-depth discussion of the potential synergies among these technologies and issues.

Personal Use of Smart Phones, Computers, and Broadband

The past several decades have seen tremendous growth and diversity of information technology and personal use of smart phones and computers with broadband Internet access.[15] These technologies have changed every facet of people's lives: how they work, play, shop, interact with one another, and make choices. This, in turn, changes their need for and choices regarding mobility.

Figure G.1 shows the U.S. Internet user population and the number of mobile phone subscriptions over time, as a percentage of the total population.[16] Here, *Internet user* is broadly

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[15] *Broadband* refers to high-speed Internet connectivity, whether via digital subscriber line (DSL), wireless, or other technologies. There is not a specific connection speed that defines broadband, and we do not differentiate here if sources do not define it consistently.

[16] This is indicative of, but not equivalent to, the number of people who have mobile phones, given that individuals may have multiple subscriptions.

defined as a person with access to the Internet, and *mobile phone* refers to a telephone that can be used in any location with wireless telephone service (as opposed to a landline or a portable phone that can be used at only one address). This shows rapid growth in the numbers of Internet users and of mobile phones starting in the 1990s.

Figure G.1. Internet Users and Mobile Phone Subscriptions in the United States, 1980–2010
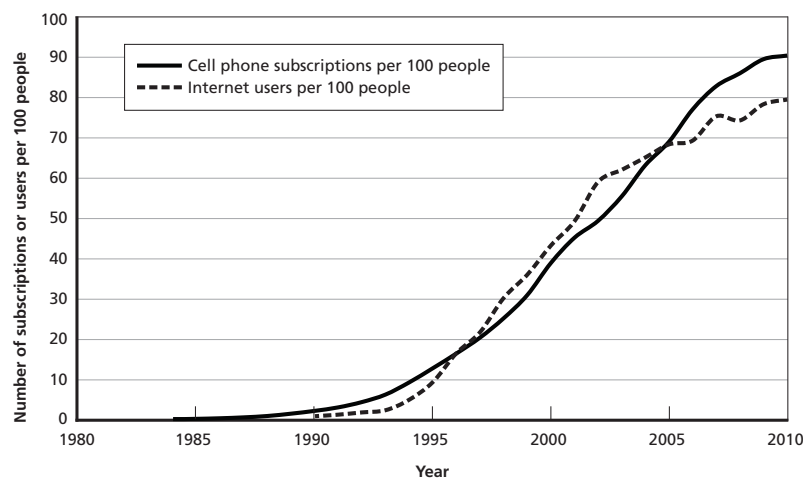
SOURCE: World Bank, undated.
RAND *RR246/1-G.1*

The Current Population Survey (CPS) is a key source of data about historical computer and Internet use among U.S. households. The CPS consists of monthly surveys of approximately 50,000 households and is conducted by the U.S. Census Bureau. Since 1984, numerous CPSs have included questions about the Internet and computer ownership. Figure G.2 shows the percentage of U.S. households that owned a computer, the percentage of households with Internet at home, and the percentage that had broadband access, based on the CPS. These data show a significant increase in computer ownership and home-based Internet use, and computer ownership seems to have accelerated in the 1990s, coincident with the mainstreaming of the Internet. Broadband was in only a very small share of households in 2000, but, by 2010, almost all households with Internet access had broadband service.

108

Figure G.2. Percentage of U.S. Households with a Computer, Internet Access, and Broadband at Home, 1997–2010
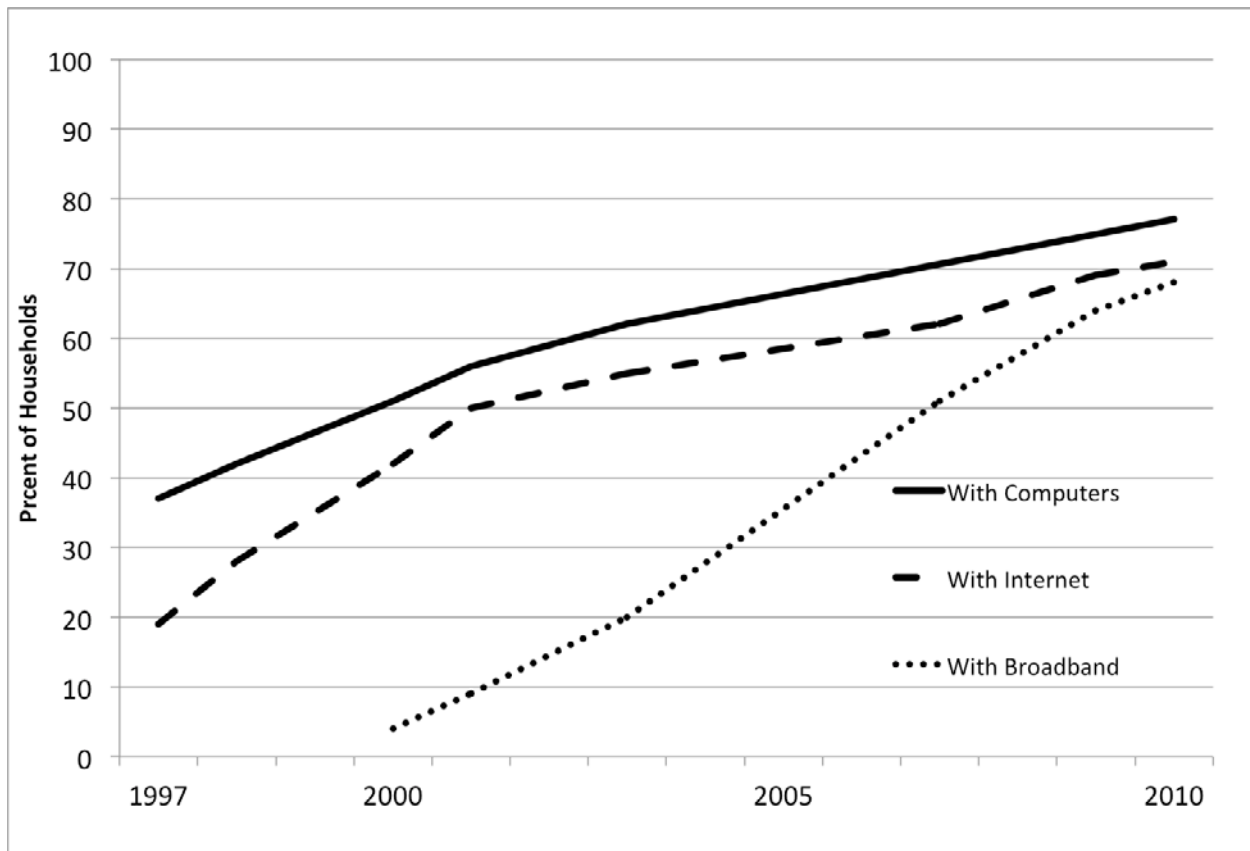
NOTE: Data were not available for every year for every category. Lines are smoothed between existing data points.

One of the key features of personal computers and smart phones is that they enable people to perform activities remotely, rather than in person. Telework, online shopping, distance or e-learning, and online social networking are all examples of information technology applications that can shape physical travel. More than 20 years ago, Salomon (1985, 1986) provided a taxonomy to describe the potential effects that telecommunication could have on travel. Telecommunications can have the following effects:

- *substitution*, online activity that substitutes for and eliminates physical travel
- *modification*, changes in travel—e.g., timing, route choice, mode choice, trip chaining—that are induced by telecommunication technology
- *complementarity* or *generation*, the phenomenon of telecommunication creating new travel
- *neutrality*, or no impact on travel behavior.

In this section, we explore these effects further, using telework and online shopping as examples.

Telework—a term generally interchangeable with *telecommuting*—means working from home or an alternative location closer to home than the worker's usual workplace. Telework has been enabled by high-speed Internet, remote online collaboration tools, smart phones, and other communication infrastructure that enable people to be productive without being in office settings.

Many surveys have been conducted to assess rates of telecommuting. However, differences in methodology, including differences in the definition of *telework* and *teleworker*, make it difficult to draw conclusions about precisely how many telecommuters are in the United States. Nevertheless, different studies consistently support the conclusion that the number of telecommuters is small but may be growing, as information technology improves and both employers and employees become familiar with and embrace teleworking.

Approximately 27 percent of total VMT in the United States are to and from work (Santos et al., 2011), making commuting the single largest contributor to driving and a significant contributor to peak congestion. However, the effect that telecommuting can have on travel is complex, and evidence is, at times, conflicting. Andreev, Salomon, and Pliskin (2010) review the literature on telecommuting and note these complex interactions (pp. 7–8):

> At the individual level, telecommuting enables travel decrease or travel outside peak hours, leading to reduction of vehicle miles traveled (VMT), traffic peak period, and traffic congestion (de Graaff, 2004; Mokhtarian, [1991]; Vora and Mahmassani, 2002). However, this substitution effect may not be significant, if at all, for some aggregation levels. Mokhtarian (1991) assumed that telecommuting may change personal travel behavior by obliterating some non-work trips that are otherwise efficiently chained with work-related travel. Hence, a multipurpose efficiently linked trip could be modified into several one-stop trips, leading to increase in VMT as well as greater traffic congestion. In addition, increased use of the telecommuter's vehicle by [his or her] household members, while the telecommuter works at home, may generate additional travel ([Kitamura, Goulias, and Pendyala, 1990]; [Kitamura, Nilles et al., 1990]; Mokhtarian, 1991; Salomon, 1986, 1998, 2000). These possibilities are in line with the timing, frequency and distance aspects presented by de Graaff (2004) in the context of the relations between [information and communication technology] (ICT)-enabled work activities and commuting, since timing of work-related travel might shift (de Graaff and Rietveld, 2004a, 2004b), depending on telecommuting frequency and telecommuter residential location.

> The extent of telecommuting substitution or complementary vis-à-vis commuting was an objective of numerous empirical studies such as Nilles et al. (1976) and [Kitamura, Goulias, and Pendyala, 1990]. Nilles et al. (1976) found substantial (65%) reduction in one-way commuting of telecommuters from 108 telecenters while other studies (e.g., [Balepur, Varma, and Mokhtarian, 1998]; Henderson and Mokhtarian, 1996; Mokhtarian and Varma, 1998), found lower substitution effect if at all.

Online shopping may be another area in which information technology offers an alternative to travel. Online retail sales remain a small fraction of all retail sales but have been growing. According to Census Bureau data, the percentage of online sales based on the total dollar value

of sales has increased from about 1.6 percent in 2003 to about 5.4 percent in 2012 (Thomas, Davie, and Weidenhamer, 2013).

A 2007 study by the Pew Internet and American Life project reported that the number of online users either buying products online since 2000 has roughly doubled, as shown in Figure G.3.

Figure G.3. Percentage of American Adults Who Have Ever Bought a Product Online
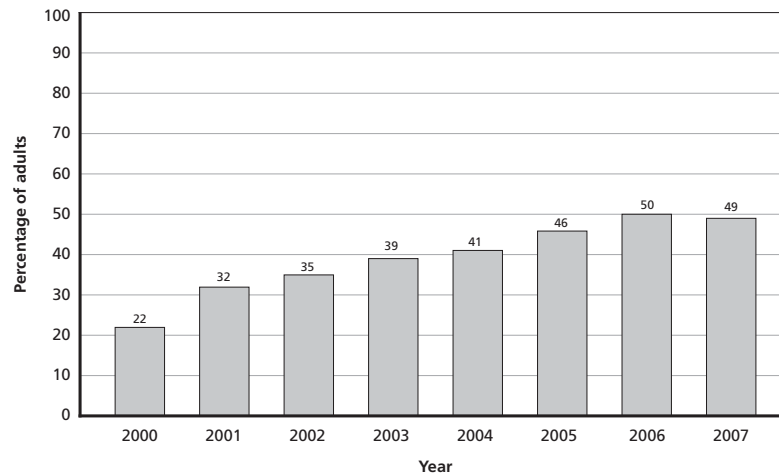
NOTE: At the 95-percent confidence level, there is a ±2.3-percent sampling error in these data. Thus, although there appears to be a decline from 2006 to 2007 in the number of Americans who have ever bought a product online, these figures are well within the sampling error.
RAND RR246/1-G.3

SOURCE: Horrigan, 2008.

Like telework, online shopping may have complex effects on transportation. Mokhtarian (2004, pp. 266–267) describes four potential sources of change to conventional shopping travel:

1. changes in shopping mode share (i.e., shifts in the proportion of shopping activities conducted through store shopping, e-shopping, and other modes), keeping the volume of goods purchased and per capita consumption spending constant
2. changes in the volume of goods purchased, keeping per capita consumption spending constant
3. changes in per capita consumption spending, independent of demographic changes
4. demographic changes, independent of other changes.

Andreev, Salomon, and Pliskin (2010) summarize the literature on online shopping and travel, suggesting that online shopping complements and may increase traditional shopping, rather than substituting for it (p. 13):

> Travel generated due to shopping activities captures about 20% of total personal trips. Moreover, VMT for shopping purposes doubled over the last 30 years [source: Pat S. Hu and Timothy R. Reuscher, *Summary of Travel Trends: 2001 National Household Travel Survey*, Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration, December 2004]. In this light,

the potential for teleshopping to substitute offline shopping, at least in part, seems promising (Rotem[-Mindali] and Salomon, 2004). . . . However, the majority of studies show that teleshopping is no substitute for travel and might be a complement to traditional shopping activities (e.g., [Casa, Zmud, and Bricka, 2001]; [Kijst and Lanzendorf, 2003], [Farag, Krizek, and Dijst, 2006]; Golob and Regan, 2001; Handy and Yantis, 1997; [Koppelman, Salomon, and Proussaloglou, 1991]; Krizek and Johnson, 2003; [Krizek, Li, and Handy, 2005]; Mokhtarian and Salomon, 2002).

Mokhtarian (2004, p. 23) describes this complementarity:

> E-shopping will substitute for store shopping at the margin, but both forms of shopping will probably continue to expand and co-exist. Thus, the dominant relationships between e-shopping and store shopping will not be replacement of the latter by the former, but interactive augmentation and modification of both.

Telework and online shopping are only two examples of how telecommunication and personal use of computers and mobile devices affect mobility. However, they are indicative of the complexity of the relationships between these technologies and travel behavior.

Use of Time While Traveling

The ability of information technology to influence travel demand is a subject of great research interest. This section touches on a few key themes in the research, drawing some tentative conclusions.

First, technology can influence travel by changing the use of travel time. Travel time has generally been thought of as a disutility; that is, the assumption was that most, if not all, travelers had a goal of minimizing travel time because it was taking time away from more-enjoyable activities. (Of course, this assumption may not always be true; see Paez and Whalen [2010] for a discussion of travelers who enjoy their commutes.)

Travel enjoyment may increase with the traveler's ability to remain connected and productive while traveling, by using such technologies as smartphones and tablet computers. The term *smartphone* generally refers to mobile phones that have features of personal digital assistants (PDAs), as well as connectivity to the Internet, navigation features, and photo or video capabilities. Phones with these features appeared on the market in the 1990s, and the first devices explicitly marketed as smartphones were released in 2000. A study by the Nielsen Company (2011) found that 44 percent of all U.S. mobile subscribers now own a smartphone, up from 18 percent in 2009. Smartphone adoption has been particularly high among younger travelers; 64 percent of Americans ages 25–34 and 53 percent of those 18–24 own smartphones (Nielsen Company, 2011).

The ability to remain productive while traveling can lead to greater use of nondriving modes. Schwieterman (2011) called these "techno-travelers," noting that this propensity is particularly widespread among younger travelers (p. 30):

> Digital technology allows this generation to "privatize" public space, eliminating one of the reasons that previous generations shunned transit over the privacy of their automobiles. The new "techno-traveler" views their electronic devices rather than cars as major status symbols. A recent study showed that technology usage during travel was higher on high-speed trains and curbside buses compared to traditional buses or airplanes.

Some evidence suggests that the desire to use these devices may encourage transit use. For example, in a survey of transit users, Frei and Mahmassani (2011) found that transit users value their time in transit because it allows them to do other things while traveling. This desire and environmental attitudes and proximity to destination were all significant predictors of whether an individual considered riding transit in Chicago "a better use of time and/or money than driving" (p. 2).

Second, technologies may change the amount of travel, although not always in the same way. Most of the publications in this area are still advancing theories about these changes but not testing them. Golob and Regan (2001) suggest categories in which technology may lead to changes in travel demand (p. 96):

> (1) online shopping (consumer ecommerce)
>
> (2) other online services, especially telemedicine
>
> (3) flexible working arrangements, including telecommuting (or teleworking)
>
> (4) self-employment
>
> (5) contingent and part-time working arrangements
>
> (6) mobile working, and
>
> (7) education.

Mokhtarian, Salomon, and Handy (2006) hypothesize that technology can have four types of impacts on leisure travel: replacement, displacement (that is, time spent using technology for new activities replaces previous activities), reallocation of time (technology saves time that can be used for new activities), and enabling (technology allows more leisure activities).

On a broad level, Choo and Mokhtarian (2007) analyzed U.S. data from 1950 to 2000 and found that telecommunications (as measured in number of telephone calls) and mobility (in VMT) were complementary, rather than one substituting for the other. As people placed more phone calls, they also traveled more.

Finally, contrary to earlier theories about a "fixed" travel time budget shared by most people, a recent review found that individual travel time budgets can vary from person to person and from trip to trip. Daily travel time is influenced by demographic factors, the attributes of activities at the destination, and characteristics of residential areas (Mokhtarian and Chen, 2004). At the aggregate level, U.S. travel times have been increasing from 47 minutes per day in 1983 to 82 minutes in 2001. This sizable change is attributed to an increase in the number of daily trips made, which is, in turn, driven by household composition, specialization of activities, income, and, to a lesser extent, technology (Toole-Holt, Polzin, and Pendyala, 2005).

Telematics

Telematics is the broad term for the integrated use of telecommunications and information technology in a variety of in-vehicle information systems. In this section, we discuss three common telematics technologies: navigation systems, real-time traffic information, and vehicle monitoring technologies.

Navigation Systems

Originally developed for military use, the Global Positioning System (GPS) has played a key role in reshaping civilian travel, as well as other sectors. GPS-based navigation systems use satellite data and a database of roadway information to provide users with information about their locations and the fastest, shortest, or otherwise preferable travel routes.[17] Such systems can also provide information about the locations of food, gas, hotels, and other services. New navigation systems often have other enhancements, such as providing real-time traffic information (discussed next) and offering route options that consider congestion, tolls, and other factors.

Navigation systems can be purchased as stand-alone devices or may come as optional features in today's vehicles. In 1995, Oldsmobile offered the first vehicle with a built-in GPS option. As of 2011, roughly 15 million vehicles were equipped with OnStar, a telematics system available in General Motors vehicles. Of these, there were 6 million active subscribers (Jeffers and Pudar, 2011).

Increasingly, navigation systems are built into personal mobile devices, such as cell phones. A 2010 market study found that, in 2010, 60 percent of mobile phones shipped globally had GPS capabilities. This survey projected an increase to 80 percent by 2011 (Rebello, 2010). Many smartphones use not only GPS signals but also cell tower signals and Wi-Fi signals for geolocation.

We found few studies that evaluate the impact that navigation systems can have on driver behavior.[18] NHTSA (Jenness et al., 2007) recently surveyed owners of in-vehicle navigation systems and asked about their behavior adaptations. When asked, "Imagine that your navigation system broke down. How would you change the way you drive if you could not use your navigation system anymore?" participants responded as follows:

- Sixty-six percent stated they would do more route planning before embarking on a trip.
- Eight percent stated they would travel to fewer unfamiliar places.
- Four percent stated they would drive less often at night.
- Two percent stated they would drive less often in heavy traffic.
- Two percent stated they would drive alone less often.

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[17] GPS per se is not a navigation system. It is a timing and positioning system (which, in turn, facilitates navigation).

[18] Most studies involving navigation systems use them to track travel behavior rather than assessing the systems' impact on travel choices.

- Thirty-seven percent reported they would not change anything about their behaviors.
- Five percent reported other changes, including using maps, the Internet, and cell phone or handheld devices.

Navigation systems may affect mobility in other ways. Travelers may use navigation systems to select shorter, faster, less expensive, or less congested routes. It may be easier for them to combine trips when they have easy access to route information. Navigation systems may also change travelers' choice of mode: Travelers may choose to drive more given that navigation systems make it easier to find destinations on one's own, or they may drive less if navigation systems suggest that alternative modes are available or if a route is complex. Navigation systems can help travelers find their destinations more quickly or effectively, potentially reducing VMT that would otherwise result when drivers are lost. One study found that VMT in unfamiliar areas was reduced by 16 percent with the use of navigation systems, although it noted that this figure would not imply that all VMT would be reduced by a similar amount (Feenstra, Hogema, and Vonk, 2008).

Navigation systems offer benefits in other modes as well. Many navigation systems provide cycling and walking routes, as well as transit information. This may affect the use, convenience, and efficiency of those other modes.

Real-Time Traffic Information Systems

Prior to the 1990s, travelers received travel information through existing media outlets: television and radio. The development and growing use of the Internet in the 1990s, however, ushered in today's real-time traffic information systems (Deeter, 2009).

Since then, real-time traffic information systems have grown in number, diversity, and sophistication. They draw on a variety of technologies to gather, analyze, and disseminate information. These systems gather and aggregate traffic data in real time from a variety of sources, such as sensors in or on the road, in-vehicle systems, mobile devices, and aerial systems. They disseminate information about delays, construction, and other traffic concerns to travelers through a variety of means: online, directly to mobile phones, through short call-in numbers (e.g., 511), roadside messages, and in-vehicle navigation systems. Like navigation systems, real-time traffic information influences principally travelers' choices of route, times of travel, or modes of travel.

Both public and private agencies are involved in real-time traffic information systems. Transportation agencies typically use loop detectors or closed-circuit television (CCTV) to gather information. Because these systems are infrastructure intensive, transportation agencies are typically limited to providing data on highways and major arteries. Transportation agencies may provide congestion information directly to consumers, often via 511 call-in services or websites, or to third parties that subsequently disseminate it to travelers, sometimes through more diverse means (Government Accountability Office [GAO], 2009).

The NCHRP synthesis report *Real-Time Traveler Information Systems* (Deeter, 2009) offers additional insights on the current state and use of these technologies. The study reports that, as of 2009, 33 states offered 511 call coverage to 128 million Americans (47 percent of the population) and every state offers traveler information online. A survey of Montana's 511 system found that most travelers use 511 as a source of pretrip information and that travelers are likely to change travel times, as well as possibly changing routes or cancel trips, in response to being informed about poor travel conditions. In a survey of Washington State 511 users, respondents reported modifying their trips based on information they received when they last called 511. A study of web-based traffic information in Pittsburgh and Philadelphia found that 68 percent and 86 percent of those surveyed changed their travel routes in response to new information and 47 percent and 66 percent changed their travel times, respectively.

Private entities are increasingly gathering and providing traffic information. Google, for example, uses crowdsourcing to provide congestion information in its Google Maps application. Google provides a mobile version of Google Maps for mobile devices. Users of the mobile app can opt into a My Location feature that sends anonymous data on the user's travel speed back to Google. By combining data from thousands of phones, plus traffic data from selected other sources, Google can provide real-time traffic information on potentially any road (Barth, 2009). Google began providing its mobile app with navigation features in 2007 and, in 2011, is reported to have provided mobile map services to 150 million discrete users (Sheffer, 2011). In 2012, Google reported that Google Maps for the Android mobile operating system has provided 50 billion km of navigation instruction (Hile, 2012).

Some efforts involve public-private partnerships. The private company INRIX collects data using devices installed in commercial fleet vehicles, as well as other technologies. Departments of transportation (DOTs) have purchased this information and incorporated it into their traffic information systems (GAO, 2009). INRIX also has a mobile phone app that provides information directly to travelers.

There has been a parallel expansion of real-time passenger information systems that serve transit riders. Until smartphones became more prevalent, most such information was provided directly at the transit station via changeable message displays showing the arrival time of the next vehicle. Newer technologies, such as NextBus, provide similar information directly to the passenger via smartphone or text message. Because these technologies have been around only a few years, most research on the impacts of such systems has focused on the station information and has not measured the ridership implications (e.g., Dziekan and Kottenhoff, 2007; Mishalani, McCord, and Wirtz, 2006).

Vehicle Monitoring Technologies

There is a great deal of interest in technologies that track various aspects of vehicle and driver performance. Some of these can track VMT, as well as the time of day that driving occurs, where driving occurs, and other driving patterns, such as frequency and magnitude of

acceleration, deceleration and lateral forces that are indicative of a vehicle operator's driving style, and risk-taking behavior. These technologies draw on GPS and other navigation technologies and may also draw on real-time traffic information systems. VMT monitoring forms the basis for a variety of systems and services. These include mileage-based user-fee systems, which seek to levy fees based on where and when a vehicle is driven, in addition to or in place of fuel taxes or with vehicle registration fees. Such fees can be used for different purposes, ranging from reducing congestion by making it more costly to drive on main routes at peak periods to making heavier and therefore more damaging vehicles pay higher taxes.

Some cities and states are seeking to use VMT monitoring technologies for a host of services to consumers, many of which may reduce costs and add convenience. For example, a recent request for expressions of interest (RFEI) from the New York City Department of Transportation (NYCDOT) noted several potential services that could be included in a pilot system that coupled VMT monitoring technologies with navigation technologies (NYCDOT, 2011). The list below is based on those suggested uses:

- *Pay-as-you-drive (PAYD) insurance* is car insurance in which drivers are charged only for the miles they drive. The idea is that, if costs vary based on vehicle use, drivers will consider the total costs and make fewer vehicle trips or switch to other modes. Users' premiums are based on estimated or actual miles driven within a certain period. Rates may vary according to traditional automobile insurance rating factors, such as driving record and age. PAYD has been implemented on a limited basis in the United States and is used in some other countries (Sorensen, Wachs, and Ecola, 2010).
- Software applications can provide opportunities for additional *financial savings to drivers*, such as personalized feedback on fuel efficiency and information on the total costs of alternative routes and modes.
- Software applications can provide *smart motorist* information (e.g., fastest route or most reliable route based on real-time traffic conditions, pretrip traffic alerts, personalized feedback on safety, summaries of overall travel covering mileage, travel time, estimated delay, fuel usage). Similar applications are already in widespread use among trucking fleets (American Transportation Research Institute [ATRI], 2011). An ongoing trial program in Minneapolis is testing driver acceptance of speed alerts (Miller, 2012).
- *Crowdsourcing applications* can enhance real-time information and provide benchmarks for individual motorists to compare their fuel efficiency, travel time, cost savings, and driving safety with anonymized data from other users.
- *Social media applications* can help interested individual drivers and groups of drivers make their travel more environmentally friendly, or greener.
- Programs can provide *mobility enhancement*, such as the ability to utilize HOT lanes on current HOV facilities, as well as make parking payments. Transponder-based systems to pay tolls automatically have been in use for some years, and some cities have begun allowing payment for parking via smartphone (see San Francisco Municipal Transportation Agency [SFMTA], undated).

Although the ideas behind these technologies and services have been in place for several decades (see, for example, Litman, 1997) and the technologies behind VMT monitoring have

matured, these systems are largely still in trial phase. This is in large part because of concerns about privacy, discussed in the next section, as well as concerns about increasing costs to consumers and the levying of new taxes, principally as a result of mileage-based user fees.

Trials involving these technologies largely focus on mileage-based user fees and PAYD insurance. Sorensen, Wachs, and Ecola (2010) provide a summary of recent trials of VMT monitoring technologies used for mileage-based user fees. Completed trials of GPS-based in-vehicle VMT technologies in Puget Sound and in Oregon in 2005 and 2006, respectively, found that drivers reduced VMT in response to mileage-based user fees and congestion tolls (studied only in the Oregon trial). Additional trials are currently or will be shortly under way in Minnesota and Oregon, as well as at the University of Iowa.

Kalra, Ecola, et al. (2012) report on trials of VMT monitoring technologies for PAYD. A 2004 pilot program in Minnesota and a study of households in Texas that participated in PAYD with Progressive Casualty Insurance Company found an average reduction in VMT of 4.4 percent and 5 percent, respectively.

Beyond keeping track of miles traveled, some vehicle monitoring technologies can also record the time of travel, as well as acceleration and deceleration rates, in order to reward drivers who practice safe driving habits with lower insurance rates (Progressive Casualty Insurance Company, undated).

Data Privacy

Navigation systems, real-time traffic information systems, vehicle monitoring technologies, and other intelligent transportation systems (ITS) gather and disseminate travel data, raising a host of concerns about data privacy. These include what kinds of data can be collected, by whom, and for what purposes. The privacy issue is further complicated by the fact that the United States has a patchwork of rights to privacy and laws pertaining to privacy, at both the federal and state levels.

Whether drivers have the right to privacy in their vehicles on public roads is affected by several factors (Douma and Deckenbach, 2008):

- whether the data are *anonymous or personally identifiable*, the latter inviting legal constraints on use, storage, sharing, and so on
- whether *consent* has been given. Consent can be given explicitly, through opt-in agreements to collect data under certain conditions of their storage, protection, and use. Consent may also be implied. For example, the act of driving implies consent to field sobriety tests and other actions taken by police.
- whether *public or private actors* are engaged in data collecting. State and federal governments typically have more restrictions than private companies on how they can collect, share, and use data.

For example, traffic counting and classification through loop detectors embedded in roads gather only anonymous data. They do not require explicit consent, and government agencies are free to

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engage in data collection without raising concerns about privacy. However, automated tolling, congestion pricing through license plate recognition, and sophisticated PAYD monitoring technologies gather information about individual vehicles. These technologies are likely to require explicit consent, and there may be significant limitations on whether these data can be shared and for what purposes.

Concerns are further raised by technologies that monitor occupants inside a vehicle. This can include automated carpool-lane enforcement systems that use cameras to count the number of individuals in a vehicle and driver-assistance technologies that monitor the attentiveness of the driver and respond when the driver appears inattentive. These technologies gather information about individuals in the vehicle, posing still greater privacy concerns.

Yet another privacy issue is raised by such systems as OnStar, which includes a two-way audio link that can be activated from a remote control station and allows for a car's engine to be switched off remotely. Although it was designed primarily as a convenience and safety feature and marketed to car owners accordingly, such a system can also be used to let law enforcement covertly monitor the conversations of a vehicle's occupants (*Company v. United States*, 349 F. 3d 1132, 9th Cir., 2003) or to allow auto dealerships to immobilize vehicles whose owners are past due in their payment (or an avenue for hackers to remotely disable a vehicle) (Poulsen, 2010). In September 2011, OnStar, a General Motors product, announced that it would continue collecting data from vehicles even if owners were no longer paying for the service, and it left open the possibility of selling anonymized data (Li, 2011). Car buyers who highly value their privacy may thus elect to purchase cars not so equipped.

In general, as technologies become more sophisticated and seek to provide increasingly personalized services, more and more identifiable data are collected. Private companies are increasingly collecting and repurposing these data, e.g., through handheld devices that track travel and through in-vehicle devices designed to provide such benefits as reduced insurance costs, personalized entertainment, and accessibility to email and other communication tools.

People's perception and expectations of privacy are complex and potentially important elements of privacy in travel data. Much research suggests that people strongly value data privacy in general (Nguyen and Hayes, 2010; Acquisti and Grossklags, 2004). However, their behaviors and attitudes in specific circumstances do not always reflect this. Nguyen and Hayes (2010), for example, analyzed attitudes about privacy in general and six everyday data-tracking technologies in particular: credit cards, store loyalty cards, electronic toll-collection systems, web-server records, store video cameras, and radio-frequency identification (RFID). They found that participants had much less concern about privacy related to specific technologies, particularly when they believed that there were benefits to using that technology. They also had more concerns about novel technologies than about familiar technologies, even when they had little information about how their data could or would be used in either case. Interestingly, their concerns were lower about electronic toll-collection systems than about any other technology. This underlines the importance of honest information and education campaigns that not only

explain how the technology works but are objective about potential downsides so customers (and policymakers) can make informed decisions.

Legal Privacy Framework

Unlike many countries, where the right to privacy is guaranteed at the national level, the United States has a patchwork of federal and state laws and regulations related to privacy. A variety of federal laws establish a minimum privacy threshold for certain types of data (typically personally identifiable data), and almost every state has augmented these laws with its own rules. In many cases, however, laws lag behind the pace of technology development, and industries are expected to self-regulate.[19] The privacy implications of advanced vehicle technologies are only beginning to be understood, and the application of privacy law to ITS and telematics remains complex and uncertain.

The following sections outline existing privacy laws that might affect the development of ITS and telematics. The sources of such law are complex and various, including federal constitutional law, federal statutory law, state constitutional law, state statutes, and state tort law. This overview identifies the most-relevant sources of law but does not consider state or federal regulations nor local regulations or statutes, which might also be relevant.

Federal Constitutional Law

This area remains unsettled. In *United States v. Jones* (132 S. Ct. 945, 2012), the U.S. Supreme Court held that the government conducted a search by attaching a GPS device to an automobile that tracked it for 30 days and that it would be generally prudent for the government to obtain a warrant prior to such use to ensure that the search would not be found to be a violation of the Fourth Amendment. However, the Court was fractured and left some important questions unanswered. Subsequent litigation over the next several terms is expected to help define the conditions under which individuals have a reasonable expectation of privacy in their movements on public roads. These rulings are likely to have substantial implications for how privacy with respect to travel on public roads is understood. This litigation may affect not only the constitutional limitations of government use of this kind of data but also influence both future societal expectations and legislation about the privacy protections that private parties collecting these data might be required to meet.

Federal Statutory Law

Although intercepting wireless communications ordinarily requires a warrant, Congress passed the Electronic Communications Privacy Act (ECPA) of 1986 (Pub. L. 99-508), which amended a previous statute on electronic surveillance, the Omnibus Crime Control and Safe

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[19] For example, the Intelligent Transportation Society of America has developed guidelines to ensure that privacy is considered in implementing systems that have the potential to collect individual data. In 1998, it published "ITS America's Fair Information and Privacy Principles" (Intelligent Transportation Society of America, undated).

Streets Act (Pub. L. 90-351, 1968). The ECPA stated that signals from electronic tracking devices did not constitute "electronic communications" and were therefore not subject to the privacy requirements that would otherwise govern such communications (18 U.S.C. 2510[12]).

The legislation that originally established the Intelligent Transportation Systems program at the U.S. Department of Transportation required that privacy be considered (Pub. L. 102-240, 1991). The Driver's Privacy Protection Act (18 U.S.C. Chapter 123) prevents state departments of motor vehicles (DMVs) or others that possess information about drivers from disclosing this information without the driver's consent. Although it includes most personal information about drivers, it does not include information about accidents, moving violations, or the current status of the driver (18 U.S.C. 2725[3]), which is not subject to this limitation.

Federal law also currently prohibits the use of automatic location identification to track wireless devices except for emergency response (47 U.S.C. 222). A separate statute, however, the Communications Assistance for Law Enforcement Act (Pub. L. 103-414, 1994; codified at 18 U.S.C. 2522 and 47 U.S.C. 229, 1001–1010) governs law enforcement access to this information. Private disclosure of this information is governed by 47 U.S.C. 222, which was motivated by concern over possible misuse of this information. It generally requires telecommunication carriers to protect these data from any disclosure. However, its application to the data collected and exchanged as part of an ITS remains unclear. It is also possible that short-range telematics would not qualify as interstate telecommunication providers and thus not be subject to this provision at all.

State Constitutional Law

Some states have adopted stricter standards regarding law enforcement use of tracking information than those under federal law. For example, in 1988, the Oregon Supreme Court ruled that using a radio beeper to locate a defendant's car was a search that required a warrant under the Oregon Constitution (*State v. Campbell*, 306 Ore. 172, 1988).

State constitutional provisions guaranteeing privacy are also substantially broader than current interpretations of federal law. The constitutions of Alaska (Article I, § 22), California (Article I, § 1), Florida (Article I, § 23), Hawaii (Article I, §§ 6–7), Illinois (Article I, § 6), Louisiana (Article I, § 5), Montana (Article II, § 10), South Carolina (Article I, § 10), and West Virginia all contain provisions that expressly guarantee a right of privacy (unlike the U.S. Constitution). The constitutions of Arkansas, New Hampshire, and New Jersey have all been interpreted to include an implied right to privacy. For example, in *Doe v. Poritz*, 142 N.J. 1, 90 (1995), the Supreme Court of New Jersey found a state "constitutional right of privacy in many contexts, including the disclosure of confidential or personal information." See also *Arkansas Dep't of Human Serv. v. Cole*, 2011 Ark. 145, 2011; and *State v. Goss*, 150 N.H. 46, 2003.

These constitutional provisions are quite broad and may be applied to both governmental and nongovernmental collection and use of ITS data. The ballot arguments that accompanied the California constitutional provision and are used to interpret it state,

> Modern technology is capable of monitoring, centralizing and computerizing this information which eliminates any possibility of individual privacy. [The right of privacy is intended to] prevent misuse of this information for unauthorized purposes and preclude the collection of extraneous or frivolous information.

These provisions are applicable to private actors and governmental agencies (*Hill v. National Collegiate Athletic Assn.*, 7 Cal. 4th, 1994). It is not clear how these provisions will be applied to ITS.

State Statutory Law

Many states (including California, Hawaii, Tennessee, Texas, Oregon, Pennsylvania, and Utah) have passed statutes that restrict the use of electronic tracking devices. For example, California Penal Code 637.7 prohibits "use [of] an electronic tracking device to determine the location or movement of a person without the consent of the registered owner of the vehicle" (Cal. Penal Code 637.7[a]). The violation of this provision is a misdemeanor. It is possible that this statute and its analogs in other states might be applied to ITSs.

Similarly, California has passed a law governing the use of data from automobile "black boxes" that record information about speed, direction, and the like (Cal. Veh. Code 9951[a]). Without consent or a court order, these data cannot be legally downloaded or retrieved by anyone other than the licensed owner of the vehicle. Under the statute, the data can be used for safety research as long as the owner of the vehicle is not disclosed.

State Tort Liability

The Restatement (Second) of Torts, which describes tort liability in most states, describes liability for "intrusion upon seclusion":

> One who intentionally intrudes, physically or otherwise, upon the solitude or seclusion of another or his private affairs or concerns, is subject to liability to the other for invasion of his privacy, if the intrusion would be highly offensive to a reasonable person. (American Law Institute, 1979, § 652B)

The intentional publication or disclosure of ITS records that showed an individual frequenting a red-light area or some other embarrassing fact might give rise to liability under this tort. Unintentional disclosure of this information or failure to adequately protect it might give rise to conventional tort liability under principles of negligence.

Liability for appropriation might also be implicated by the commercial use of data collected by ITSs. Andrew J. McClurg has argued that the commercial use of some data collected by ITSs might violate individuals' rights to their own identity (McClurg, 2003).

Advanced Driver-Assistance Systems

This section discusses changes in vehicle safety due to advanced driver-assistance systems (ADAS), as well as other safety improvements. *ADAS* refers to technologies and developments

that enable a vehicle to assist and make decisions for human drivers. Such technologies include crash-warning systems, adaptive cruise control, lane-keeping systems, and autonomous parking technology.

NHTSA reports that, in 2010, roughly 33,000 people were killed in the United States in vehicle crashes and that approximately 2.2 million were injured (NHTSA, 2012a). The vast majority of U.S. crashes are the result of human error (Choi et al., 2008). Yet the number of fatalities has been declining for at least the past 15 years, even as VMT has increased or fallen slightly (see Figure G.4), resulting in a significant decline in fatality *rates*. The number of fatalities per 100 million miles driven fell from 1.46 in 2005 to 1.11 in 2010 (BTS, undated, Table 2-17).

Figure G.4. Fatalities and Vehicle Miles Traveled, 1990–2010
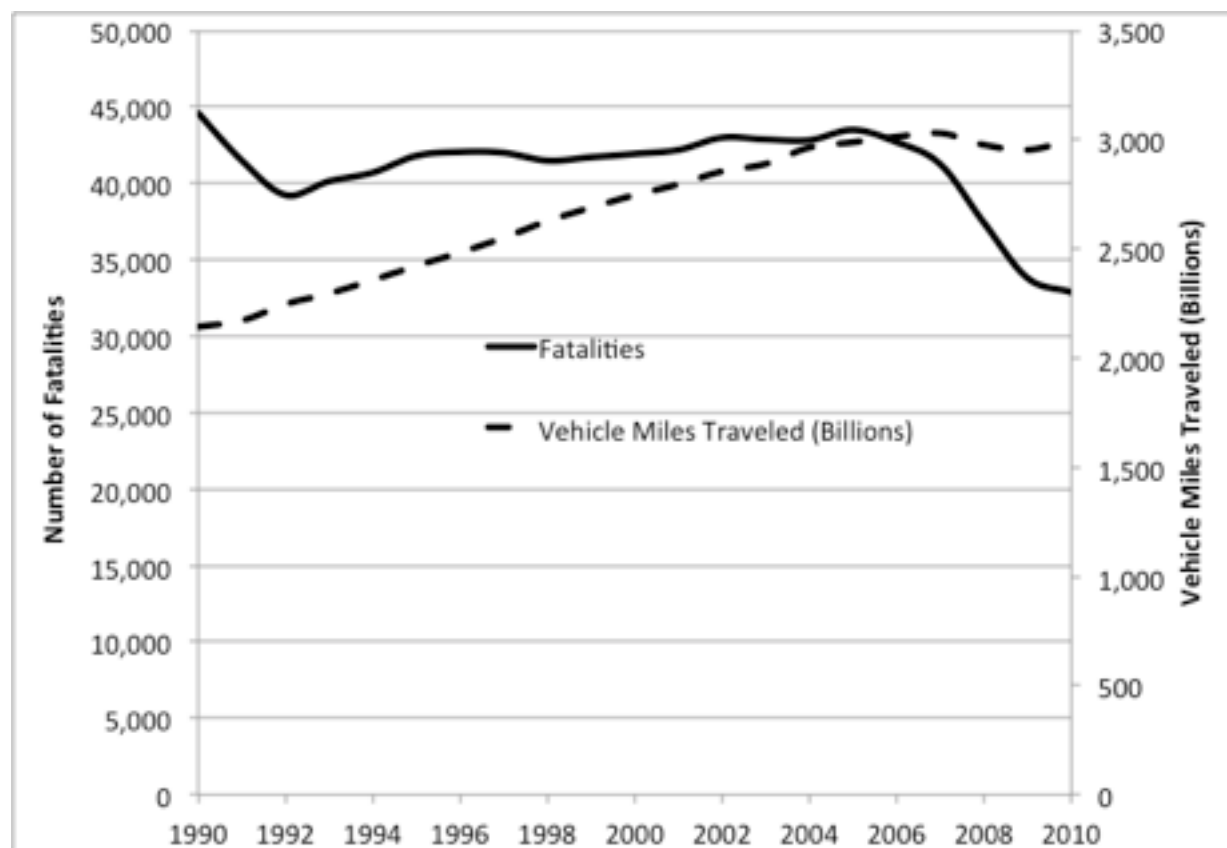
SOURCE: BTS, undated, Tables 1-35 and 2-19.

These declines are at least partly due to improvements in vehicle safety technology. Modern automotive safety technology began with seat belts, which were first offered as safety options on vehicles in the late 1940s and early 1950s, though not widely used. Airbags were the next major safety innovation and were initially introduced in the early 1970s in higher-end vehicles. At the time, they were marketed as alternatives to seat belts rather than as supplements. Resistance from

the automotive industry and the public related to new costs, new regulations, and concerns over technology performance meant that it was another 20 years before federal regulations required airbags in vehicles. Kalra, Anderson, and Wachs (2009) noted that airbag legislation finally passed in the 1990s (p. 38):

> Wetmore attributes this development to three factors: First, technology had advanced to enable air-bag deployment with high reliability; second, public attitude shifted, and safety features became important factors for consumers; and, third, air bags were no longer being promoted as replacements but as *supplements* to seat belts, which resulted in a sharing of responsibility between manufacturers and passengers and lessened manufacturers' potential liability (Wetmore, 2004).

Today's vehicles have the option of being equipped with a diverse array of safety technologies. Visual, radar, laser, and other sensors around the vehicle alert drivers to potential hazards. Nearly half of all 2012-model vehicles come with rear-facing cameras to provide drivers greater visibility when backing up, and there is debate about legislation that would mandate this technology (Naylor, 2012). Other sensors monitor the driver, alerting him or her when he or she shows signs of drowsiness. ADAS adds technologies that intervene and assist drivers, in addition to providing information.

Statistics about original equipment manufacturer (OEM) offerings of such technologies in vehicles and consumer adoption of such vehicles are not readily available. Nevertheless, their availability and adoption have grown in recent years, in part driven by legislation related to safety (Allied Business Intelligence Research, 2011):

> Increasing availability of Advanced Driver Assistance System (ADAS) features is also being driven by legislation and NCAP [New Car Assessment Program] specifications. . . . For example, in the EU [European Union], new commercial vehicles are required to have enhanced blind spot vision, lane departure warning, and automatic emergency braking. In the US, after changes to NCAP, new car stickers are now required to indicate if certain ADAS features (LDW [lane-departure warning] and forward collision warning) are available.

Some evidence suggests that these technologies improve safety. For example, a study of crash-warning systems with light and heavy vehicles found that lane departures decreased for light vehicles in particular and increased the majority of drivers' use of turn signals (Sayer et al., 2011). A study of systems that warn drivers when they show signs of drowsiness found that those randomly assigned to use the system were less likely to exhibit drowsiness behaviors than those without the system (Blanco et al., 2009). In addition to its effect on safety, adaptive cruise control may also help reduce congestion and travel time by allowing vehicles to safely travel more closely at higher speeds (Kesting et al., 2008; Arnaout and Bowling, 2011).

Simultaneously, these technologies may have unintended negative safety consequences. A recent survey of users of backup technologies found that "approximately 17 percent of rear-view camera owners and 12 percent of backing aid owners admitted backing without checking their mirrors or turning to look out the rear window within the last two weeks" (Jenness et al., 2007,

p. 2). Some users did not understand the performance limitations of the systems, and a small percentage of owners surveyed expressed concerns that they may be overly dependent on these systems. This suggests that there may be a rebound-like effect with respect to safety: In believing that a technology increases safety, drivers may relax their own safe driving behaviors. Other technologies, such as route navigation systems, may distract drivers even as they provide information that drivers seek for driving (Kun et al., 2009).

Some technologies explicitly pose a threat to safety, as in the case of cell phone use while driving. Although driving fatalities overall have declined, distracted-driving fatalities have not and have risen sharply since 2005. This is largely attributed to growing use of cell phones and texting while driving. Wilson and Stimpson (2010) provide data on the percentage of fatalities attributed to distracted driving and the number of cell phone subscriptions per capita (Figure G.5).

Figure G.5. Trends in Cell Phone Subscriptions per 100 People and Percentage of Fatalities Attributed to Distracted Driving
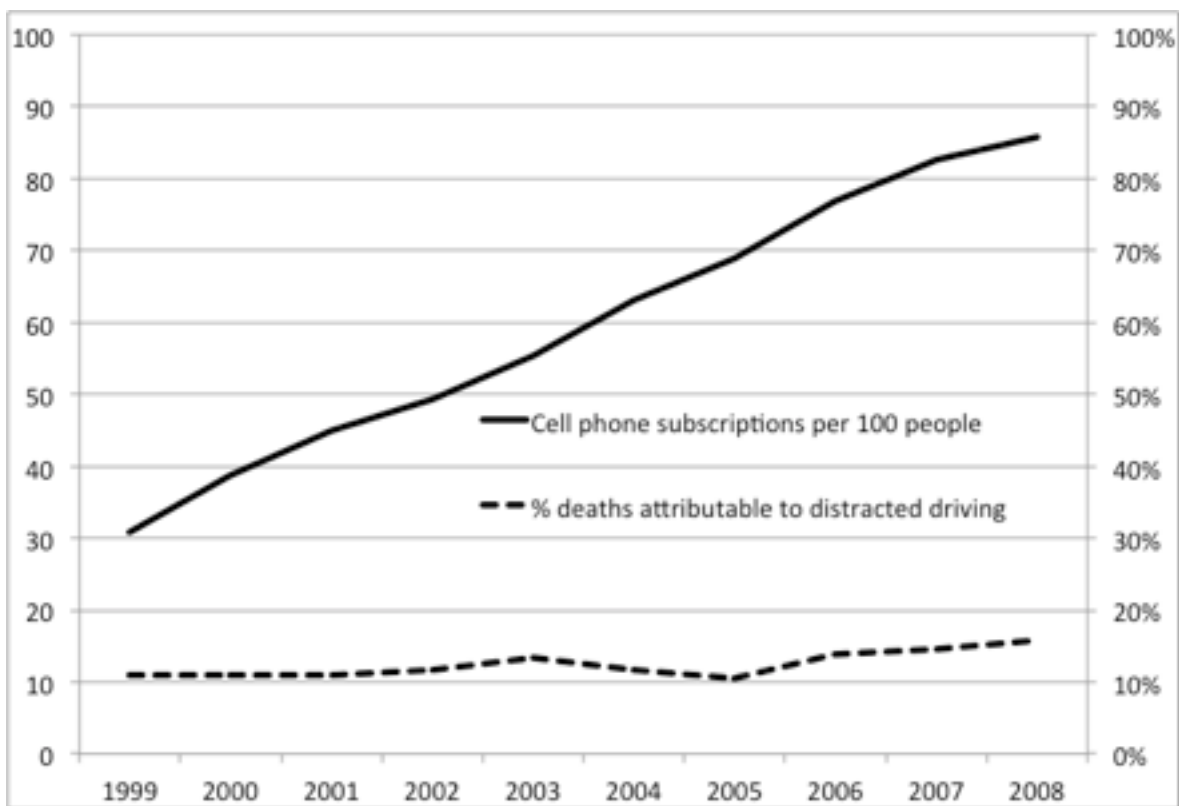
SOURCES: Wilson and Stimpson, 2010; cell phone subscription data from World Bank, undated.

One consequence of this trend is that the National Transportation Safety Board has called for a ban on all cell phone use while driving, including the use of hands-free devices (Richtel, 2011).

Autonomous Vehicles

Full-scale autonomous cars are also under development. Google has a fleet of autonomous vehicles and has driven these vehicles more than 200,000 miles over highways in California and Nevada. Nevada is the first state to have passed legislation related to such vehicles. In June 2011, the Nevada legislature passed a law allowing vehicles to be autonomously driven on public roads and allowing licensing of autonomous vehicles (Henn, 2012); on May 8, 2012, the first such car was actually licensed (Stern, 2012). Google's efforts follow heavily on the heels of the Defense Advanced Research Projects Agency (DARPA) Grand and Urban Challenge competitions that invite universities and other teams to develop and race driverless cars in desert and simulated urban environments.

These technologies can have social, economic, and environmental implications. Autonomous vehicles could one day increase safety still further, by taking driving substantially or entirely out of human control and by enabling vehicles to communicate and coordinate directly with each other to avoid crashes. These systems may also increase fuel efficiency through smoother driving, virtual road trains, and other techniques.[20] Research on these effects largely involves simulation. Fully autonomous vehicles may also offer or improve mobility for specific segments of the population, e.g., the elderly, disabled, or young.

Fully autonomous cars will also facilitate travel-related logistics, such as parking. If an autonomous car can drop off its occupants at their destination and then, in "virtual valet" mode, go park itself at a different location blocks away, this decoupling of parking space from destinations may, over time, lead to changes in architectural requirements and urban design rules.

Finally, fully autonomous cars will change, at a fundamental level, what it means to "drive somewhere." With the person in the driver's seat no longer required to actually drive, he or she will be able to use the time spent going from point A to point B in a more productive manner—getting work done, reading or watching a movie, or participating in online education, with associated societal benefits. Once autonomous cars reach an affordable price range, "being driven" somewhere in one's own car, rather than driving oneself, will no longer be a privilege of the rich and famous. This trend may actually increase VMT because it increases the likelihood that drivers will be able to use their time for a variety of other activities, so the desire to minimize the amount of time driving may decrease. It may also lead to a change in the design of car interiors, away from its current focus on driving and toward productivity and comfort as seen, for example, in first-class airplane cabins. Finally, it may lead to an increase in vehicle sharing because an autonomous taxi with a robotic "driver" will be able to offer its services for significantly less than a traditional one with a human driver.

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[20] A virtual road train is a platoon of cars that travel under the control of a lead car. The cars that make up the road train automatically travel at the same speed as the lead car. Because they can follow the preceding car more closely than under normal driving conditions, the cars can take advantage of drafting, or reduced wind resistance, and thus use less fuel.

The possibility of these changes is, of course, related to consumer adoption of such vehicles. This will depend on some as-yet-unknown factors, such as vehicle cost, the roadworthiness of the technologies, and changes in insurance and liability regulations (Kalra, Anderson, and Wachs, 2009).

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