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## Oil, Automobiles, and the U.S. Economy: How Much Have Things Really Changed?

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### I. Introduction

Between 2002 and mid-2008, the average real price of gasoline in the United States increased more than twofold after having risen only modestly in the preceding 15 years. Not surprisingly, this run-up led to renewed interest in the effects of oil shocks on the U.S. aggregate economy. Hamilton's (1983) seminal paper documented the negative effects of oil shocks on the aggregate economy, and numerous papers since that time have extended or questioned the strength of these effects.<sup>1</sup> Most recently, several authors have argued that the effects of oil price shocks on U.S. aggregate activity have declined since the mid-1980s (e.g., Blanchard and Riggi 2009; Edelstein and Kilian 2009; Herrera and Pesavento 2009; Blanchard and Galí 2010). These papers have variously attributed the decline to improved monetary policy, a smaller share of oil in production, or more flexible labor markets. Empirical work has also shown that a more muted response in the consumption of motor vehicles to energy price shocks has played a large role in obtaining these results (Edelstein and Kilian 2009).

This paper reexamines the extent to which the impact of oil shocks on the aggregate economy—and on the motor vehicle industry in particular—has changed over time. We first discuss the array of energy cost measures that authors in the literature have used to define oil price shocks, and then we survey the theoretical contributions from a number of dynamic stochastic general equilibrium (DSGE) macro models that include various roles for oil in the economy. Using these models, there are a number of structural parameters that reasonably could have changed over time and reduced the potency with which oil price fluctuations depress aggregate output.

However, all of these macro models assume that the price of oil reflects the true cost of energy for firms and consumers. While much of the recent empirical work uses published measures of oil or gasoline prices as an indicator of the strength of the oil price shocks, we find that these measures neglect the impact of the shortages that occurred in the critical 1973–74 and 1979 oil shock episodes, due to price controls.

Using two oil shock measures that include the effects of both price and nonprice rationing, we reexamine the evidence from vector autoregressions (VARs) that oil disturbances have had less impact on the real economy in the past 20 years than in the preceding decades. The results show that the responses of motor vehicle consumption and aggregate output to shortage-adjusted oil price shocks appear just as great during the last couple of decades as they were in the 1970s and early 1980s. However, even the new measures imply that the impact on nominal variables has become noticeably muted.

Why has there been so little change over time in the response of motor vehicle consumption to oil price changes? We find that, despite the many innovations in the way the U.S. economy produces and uses motor vehicles that have occurred over the past 40 years, the primary channels through which oil prices directly affect motor vehicles have not changed much over time. Namely, we present evidence that the recent increases in gasoline prices have caused just as much anxiety in consumers now as was observed 40 years ago, and the shifts in demand across vehicle size classes have also been as disruptive to motor vehicle capacity utilization since 2000 as they were in the 1970s and early 1980s.

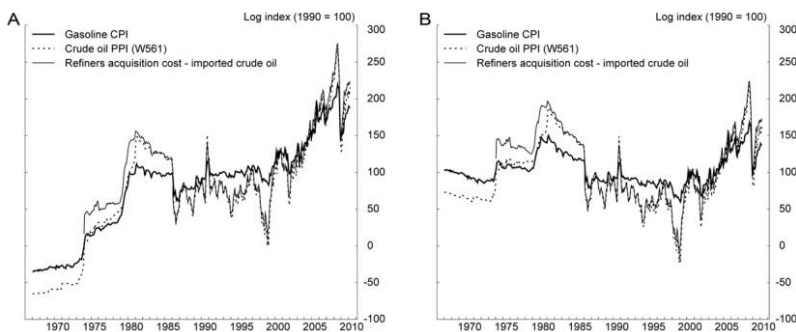
The paper proceeds as follows. Section II reviews the data available on various measures of oil prices and discusses how modern DSGE models accommodate the role of oil in the economy. It also presents evidence that the presence of energy price controls and gasoline shortages in the 1970s may cause problems in empirical work because published prices in that era do not reflect the true cost of energy. Using measures that include the cost of shortages, we find no evidence of weaker effects of oil shocks on the real economy. Because we find that the motor vehicle industry plays a central role in the propagation of the oil shocks, the remainder of the paper studies this industry in detail. Section III examines the role of the motor vehicle industry in the overall economy. Section IV discusses how gas prices affect vehicle demand, and Section V shows the ways in which these shocks affect production. Section VI concludes.

## II. Oil Shocks and the U.S. Economy

We begin by reviewing the behavior of several key measures of oil prices over the past few decades. After describing how macro DSGE models have been used to understand the role of energy costs in the economy, we present evidence that price controls may have led to a wedge between the published price of oil and the true cost of oil during the large oil price shocks in the 1970s. Using VARs that are similar to those estimated by Edelstein and Kilian (2009) and Blanchard and Galí (2010), we then show how mismeasurement of the true cost of oil in the 1970s may have caused the appearance of structural instability in the impulse-response functions of real output to oil price shocks. Using cost measures that account for shortages, we find that the impulse-response functions have not changed much over time.

### A. Overview of Oil Prices

Figure 1 displays three oil price measures: the producer price index for crude petroleum (PPI-oil), the refiner acquisition cost of imported oil (RAQ), and the consumer price index for gasoline (CPI-gas). Hamilton (2003, 2009) typically uses the PPI-oil measure, and Mork (1989) and Barsky and Kilian (2002) use versions of the RAQ measure.<sup>2</sup> Unfortunately, the RAQ measure starts only in 1974.<sup>3</sup> We include the CPI-gas measure because several authors have shown that gasoline is a large share of U.S. petroleum consumption, and gasoline prices are also the most relevant energy price measure for the automobile sector.<sup>4</sup>



**Fig. 1.** Petroleum prices, January 1967 through March 2010. *A*, Nominal price indexes; *B*, real price indexes. Data come from the Bureau of Labor Statistics. The real indexes normalize the changes in petroleum prices by the changes in headline consumer price inflation. Refiners acquisition cost data begin in 1974. For each series  $x$ , the log index is calculated as  $100 + 100[\log(x(t)) - \log(x(1990))]$ .

Oil and gas prices—displayed in log current dollars in figure 1A and in log real index points in figure 1B—have risen notably at several points in history. Four episodes stand out in particular: first, the real price of gasoline rose 27% between October 1973 and May 1974, the result of an even larger rise in the price of crude oil after the Yom Kippur War. After falling back a bit over the next 4 years, the price of crude oil began to rise again at the end of 1978. By the spring of 1980, the Iranian Revolution and the Iran-Iraq War led to losses in crude oil production that pushed up the price of imported oil 71% and the price of gasoline 46%. Between 1982 and 1985, the nominal price of gasoline grew only modestly until Saudi Arabia abandoned production quotas and the price of crude oil plunged.

Real gasoline prices continued to trend lower after 1985, and, by the end of the 1990s, real gasoline prices had receded to record low levels. This pattern changed abruptly at the beginning of 1999, when the Organization of Petroleum Exporting Countries (OPEC) members phased in several cuts to production quotas. The real price of gasoline surged 43% by the summer of 2001 before the weakening world economy put downward pressure on crude oil prices. The relief was short lived, however. Gas prices began to rise again in early 2002, when political turmoil in Venezuela shut down much of the country's crude oil production; real crude prices climbed 588% and gasoline prices climbed 127% by summer 2008, and then they collapsed when the financial crisis spread from the housing sector to the rest of the economy and interrupted aggregate demand.

### *B. Oil Shocks in Macro DSGE Models*

Economists take a keen interest in oil prices because these episodes of steep increases in prices were often followed by recessions. The literature has introduced into macro models four principle channels through which oil or energy shocks can lead to recessions: (i) energy serves as an important input to production; (ii) energy is an important consumption good; (iii) changes in energy prices lead to costly shifts in demand across sectors; and (iv) the policy response to oil price shocks includes monetary tightening, a move that depresses output. Often layered on top of these channels are forces that multiply and propagate the effects of oil price shocks on aggregate output, such as real wage rigidities (e.g., Bruno and Sachs 1982; Blanchard and Riggi 2009; Blanchard and Galí 2010), imperfect competition (Rotemberg and Woodford 1996), variable utilization rates (Finn 2000), vintage capital effects (Atkeson

and Kehoe 1999; Wei 2009), and multiplier effects created by externalities across firms (Aguiar-Conraria and Wen 2007). We will briefly discuss each of these channels and point out which parameters in these DSGE models are suspected to have changed over time.

### 1. Energy as an Input to Production

Berndt and Wood (1975), Bruno and Sachs (1982), and Pindyck and Rotemberg (1983) were among the first to study energy price shocks in a framework that accommodates energy as an input to production. The strength of this channel is limited, however, by the small share of energy in total production costs, even in the 1970s. Finn (1991, 2000) modifies the standard model to reflect the notion that the energy requirements of installed capital are often fixed, and thus energy must be used in fixed proportions to capital use. This feature makes output more sensitive to increases in energy prices.

In many of the models mentioned above, a decrease in the amount of oil required to produce a unit of output would reduce the effect of oil shocks on the aggregate economy. This result suggests that increases over time in the fuel efficiency of many types of production technology may have weakened the relationship between oil price and real output. In addition, structural parameters not directly related to the use of energy can also affect the transmission of energy price shocks in DSGE models. For example, Blanchard and Galí (2010) show that a decline in the rigidity of wages in these types of models reduces the effects of oil price shocks on output.

### 2. Energy as a Consumption Good

In addition to the consequences of reduced output in general equilibrium, increases in oil prices also have direct effects on demand. First, oil shocks can lead to declines in demand for goods for which consumption is complementary with purchases of oil. Hamilton (1988) and Wei (2009) use models of demand for motor vehicles to show this effect. Second, oil shocks introduce uncertainty into the outlook for future energy prices, and increases in uncertainty can dampen demand for goods if purchases are costly to reverse (Bernanke 1983). Third, for energy-consuming capital goods, increases in the price of energy change the desired characteristics of the capital in use. Because the energy efficiency of the existing stock of consumer durables available in the short run is largely fixed, demand for new goods can shift between

products in an exaggerated fashion and reflects the widening differential in the relative cost of ownership between different types of goods. For motor vehicles, smaller and more fuel-efficient models naturally become more desirable.

In these types of models, one parameter that has likely changed over time is the energy efficiency of consumer durable goods, including motor vehicles and other appliances. When energy efficiency rises or the share of these types of goods in total consumption falls, then we would expect the impact of oil shocks on output to diminish.

### 3. Sectoral Shifts and Costly Factor Mobility

Several papers have investigated sectoral shifts as a way in which oil price shocks affect the aggregate output. Davis (1987) and Hamilton (1988) both suggest that oil price shocks have a bigger effect on output if the shocks induce sectoral shifts and factor adjustment is costly. Bresnahan and Ramey (1993) argue that oil shocks can lead to disruptive sectoral shifts, even within narrowly defined industries. They present empirical evidence that shifts in demand between size classes of automobiles disrupted output in the U.S. automobile industry during the 1970s.

In the context of the multisector models, it is not clear that the structure of the economy has changed in a way that would weaken the transmission of oil price shocks through the sectoral-shifts channel. We find evidence in the motor vehicle industry that this channel remains quite potent.

### 4. Monetary Policy Reaction Functions

Bernanke, Gertler, and Watson (1997) argue that the endogenous response of monetary policy to an increase in oil prices is an important part of the outsized declines observed in output, a result they showed by using a structural VAR and counterfactual experiments with different monetary policy rules.<sup>5</sup> Using a calibrated DSGE model, Leduc and Sill (2004) find that 40% of the decline in output that follows a positive shock to oil prices reflects the systematic component of monetary policy.

To look for changes in policy parameters over time and assess whether these changes may have reduced the impact of oil shocks on output, a number of papers have either simulated monetary DSGE models or estimated monetary structural VARs. Blanchard and Riggi (2009), Herrera and Pesavento (2009), and Blanchard and Galí (2010)

all find evidence that oil price shocks have had less impact in recent decades, in part, because of the changes in monetary policy.

To summarize, the theoretical literature has suggested a variety of ways in which oil shocks affect the economy. Some of these effects could be weaker now, while other effects could easily be as strong.

### *C. The Importance of Nonprice Rationing in the 1970s*

In the models described above, it is assumed that the price of oil reflects the true acquisition cost of energy for firms and households. While the literature on the effects of oil shocks has debated the merits of various measures of oil prices and whether the effects are nonlinear, much of it has missed a potentially important change in the degree to which oil prices reflect oil disruptions.<sup>6</sup> In particular, other than Mork (1989), macroeconomists have not paid much attention to the embargoes, price controls, and shortages that marked the oil price disturbances in the 1970s. Helbling and Turley (1975) document that price controls were first imposed on the U.S. domestic oil industry in August 1971 as part of the general imposition of price controls. The controls on other sectors of the economy were phased out, but the controls were made more stringent on the domestic oil industry in response to the OPEC embargo of October 1973. These complex controls, which imposed a price ceiling on "old" oil that was lower than the one imposed on "new" oil, led to significant disruptions in the production of domestic oil and held the average domestic price of crude oil below the world price. Most of the effects of these controls were felt in the markets for gasoline and diesel fuel. According to some estimates, 20% of the gasoline stations ran out of gas during the height of the crisis (Frum 2000).

Pisarski and de Terra (1975) detail the policy responses to the embargo in various European countries. While most European countries did not impose the types of price controls imposed in the United States, they responded with other sorts of controls, such as bans on Sunday driving (Germany, Italy, Netherlands, Switzerland) and limits on gas purchases (Great Britain, Netherlands, Sweden, Switzerland). Almost all countries imposed lower speed limits.

Multiple oil and gas price controls also helped produce shortages after the Iranian Revolution of 1979. In April 1979, President Carter announced gradual decontrol of oil prices but proposed a windfall profits tax. In January 1981, President Reagan signed an order leading to the complete deregulation of oil and gas prices.

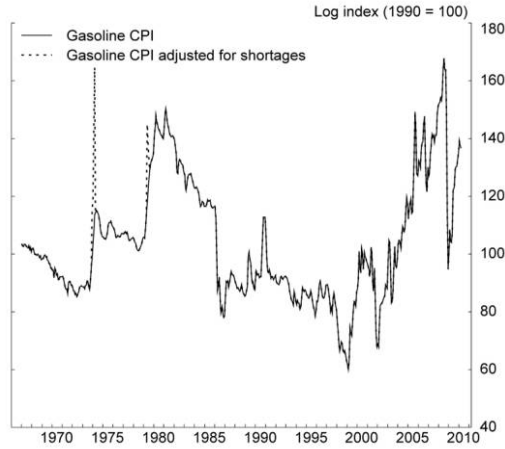


To quantify the additional cost imposed on consumers by nonprice rationing in the 1970s, Frech and Lee (1987) use data on urban and rural traffic patterns in California and estimates of the price elasticity of demand for gasoline from Lee (1980). They estimate that the time cost of the queues added between 13% and 84% to the price of a gallon of gasoline between December 1973 and March 1974; the additional time cost implicitly paid by consumers between May 1979 and July 1979 varied from 6% to 33%. Thus, the price index for gasoline shown in figure 1 potentially understates the true cost of gasoline quite severely in periods affected by the two oil shocks of the 1970s.

The PPI-oil measure suffers from the same problem because of the price controls on domestic crude oil. The refiners' acquisition cost of imported oil used by Barsky and Kilian (2002) comes closer to measuring the world price of oil. However, this measure still does not capture all of the additional costs imposed on the U.S. economy by distortions caused by price controls and the entitlement system. The reason is that price controls cause inefficiencies and deadweight loss that are larger than the gap between actual prices and market-clearing prices.<sup>7</sup>

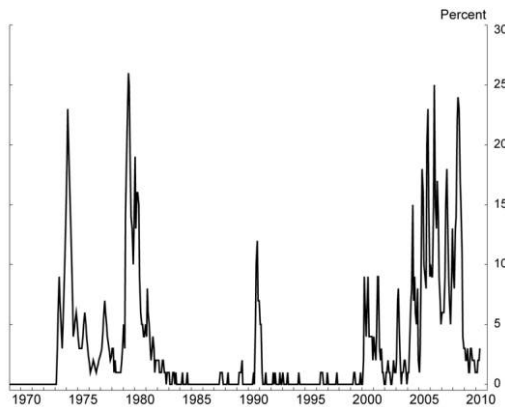
In order to capture the true cost of gasoline during these episodes, we propose two new variables: the first variable augments published gas prices with estimates of the additional time cost during the periods of gasoline lines. In particular, we use the average of the rural and urban estimates from table 1 in Frech and Lee (1987), which compares the time costs per gallon to the published price per gallon of gasoline for the months of December 1973 through March 1974 and May 1979 through July 1979. All told, rationing is estimated to have added between 8% (in July 1979) and 67% (in March 1974) to the shadow price of a gallon of gasoline.<sup>8</sup> Using these estimates, we construct a shortage-adjusted index for the real price of gasoline, which is shown as the dashed line in figure 2.

Because the rationing-by-queue cost estimates likely capture the effect of shortages imperfectly, we also consider a second measure—the special question posed by Thomson Reuters and the University of Michigan in the Survey of Consumer Sentiment. Respondents to the monthly survey are asked several questions related to car-buying conditions. The survey tracks the portion of respondents who cite the price of gasoline or possible fuel shortages as a reason that car-buying conditions are poor.<sup>9</sup> This measure is shown in figure 3. The portion of consumers that expressed anxiety over fuel prices ramped up sharply at the time of the oil price shocks in the 1970s and early 1980s. Although the rise in real gas prices was much greater in the 2000s than in the 1970s and early



**Fig. 2.** Real gasoline prices, January 1967 through March 2010. Dashed line represents the CPI (consumer price index) for gasoline augmented with the shadow cost of waiting time in gas lines in 1973, 1974, and 1979 as estimated by Frech and Lee (1987). The log index is calculated as in figure 1.

1980s, the consumer sentiment variable hit similar peaks in both periods. A CNN opinion research poll conducted in June 2008 found that consumers were more concerned about long gas lines than about high prices (CNNMoney.com, June 10, 2008). This may explain why the run-up in



**Fig. 3.** Consumer sentiment toward gasoline, January 1970 through April 2010. Share of respondents to the Thomson Reuters and University of Michigan Survey of Consumer Sentiment who cite high gasoline prices or shortages of gasoline as reasons that car-buying conditions are poor. Gasoline price question was asked on a quarterly basis before January 1978, and the series was extrapolated to a monthly frequency by the authors.

gas prices in the 2000s, although bigger than the run-ups in earlier episodes, did not cause a larger effect on consumer sentiment.

#### *D. The Responses of Output, Consumption, and Prices to Oil Price Shocks*

Using the published measures of energy prices and the two variables that account for nonprice rationing in the 1970s, we now revisit the evidence used to suggest that aggregate activity has been responding less to energy price shocks in recent years than it used to in the past. The energy price measures we consider are as follows: (1) CPI-gas, (2) Hamilton's (2003, 2009) "net oil price increases," (3) CPI-gas that has been augmented with the time cost of rationing by queue, and (4) the measure of consumer attitudes toward gasoline prices and fuel shortages.<sup>10</sup> Our strategy is as follows: first, we show that the impulse-response functions from VARs estimated by Edelstein and Kilian (2009) and Blanchard and Galí (2010) do not change much if published gasoline prices are used in place of the authors' original energy price measures. Second, we show that the impulse-response functions based on gasoline price measures that account for the effects of shortages present a different story.

We begin by estimating a VAR that is similar to the one used by Blanchard and Galí (2010). The VAR system we estimate is

$$Y_t = A(L)Y_{t-1} + U_t. \quad (1)$$

In the VAR estimated by Blanchard and Galí with quarterly data,  $Y_t$  includes the nominal price of oil, the CPI, the gross domestic product (GDP) deflator, nominal nonfarm compensation, real GDP, and nonfarm business hours. In other specifications, they also included the federal funds rate. In our version of their analysis,  $Y_t$  is built from monthly observations of the following variables (in order): (i) a selected version of one of the oil shock variables, (ii) the CPI, (iii) nominal wages of private production workers, (iv) industrial production, (v) civilian hours, and (vi) the federal funds rate. Function  $A(L)$  is a matrix of polynomials in the lag operator  $L$ , and  $U$  is a vector of disturbances. All variables except the sentiment measure and the federal funds rate are in logs. The shock to oil prices is identified using a standard Cholesky decomposition. We include a linear time trend and six lags of the variables. The data are monthly and span 1967:1–2009:12.

Blanchard and Galí (2010) compare samples that are split between 1983 and 1984, which is the typical split for studies of the Great Moderation.

**Table 1**  
The Peak Effects of Oil Shocks on U.S. Variables

	Estimation Period				Ratio (3)/(1)
	January 1967 to December 1985		January 1986 to December 2009		
	Peak Effect (1)	Month of Peak (2)	Peak Effect (3)	Month of Peak (4)	
Nominal gas price:	1.000	3	1.000	2	
Industrial production	-.202	24	-.091	20	.45
Hours	-.099	26	-.035	32	.35
CPI	.184	19	.051	25	.28
Hamilton measure:	1.000	1	1.000	1	
Industrial production	-.005	24	-.002	11	.41
Hours	-.002	26	-.001	24	.39
CPI	.003	13	.001	2	.25
Gas price adjusted for the cost of shortages:	1.000	1	1.000	2	
Industrial production	-.072	25	-.091	20	1.27
Hours	-.038	27	-.035	32	.92
CPI	.084	20	.051	2	.61
Consumer sentiment about gas:	1.000	3	1.000	1	
Industrial production	-.002	27	-.003	31	1.67
Hours	-.001	27	-.002	37	1.97
CPI	.002	15	.001	2	.30

Note: Impulse responses are based on vector autoregressions (VARs) with monthly data. The variables include (1) a selected oil price measure, (2) industrial production, (3) hours, (4) the headline consumer price index (CPI), (5) nominal wages, and (6) the federal funds rate. The VARs included six lags and a linear time trend. Shocks to oil prices are defined using a standard Cholesky decomposition with oil ordered first. The oil shocks are standardized to be the same size in each sample period. The standard deviations for the shocks to each oil price measure are as follows: the nominal gas price shock is .013 in the early period and .038 in the late period. The shock to the Hamilton measure is .797 in the early period and 1.751 in the late period. The shock to the gas price adjusted for the cost of shortages is .045 in the early period and .038 in the late period. The shock to gasoline sentiment is 1.364 in the early period and 2.028 in the late period.

Edelstein and Kilian (2009) study samples split between 1987 and 1988. We choose a split between 1985 and 1986, as this date is between the dates used by these authors, and it also coincides with the rather dramatic change in the nature of the oil market that occurred in 1986.

We summarize the results in table 1. As an alternative to showing dozens of impulse-response functions from various permutations of oil price measures and estimation periods, table 1 shows the peak response of key macro variables to a shock in each oil price indicator in each period.

The shock has been normalized so that the size of the increase at its peak is equal to one in both periods. It is important to note, however, that the standard deviations of the (nonnormalized) shocks to nominal gas prices and to Hamilton's net price gain measure are more than twice as high in the second period as in the first period. In contrast, the standard deviation of the shocks to the shortage-adjusted gas price is roughly constant across the periods, whereas the standard deviation of the shocks to the measure of consumer sentiment toward gasoline is about 50% higher in the second period.

The key comparison in table 1 is the ratio in the last column. For a given shock in the gas cost variable, it shows the ratio of the peak response of the other variables in the second period to the peak response in the first period. The results for both the standard nominal gas price measure and Hamilton's nonlinear measure show that the responses of both industrial production and hours are less than half as large in the second period as in the first period. The response of inflation appears to have declined by an even larger proportion than did the real variables. In contrast, when either the real index of gas prices adjusted for the cost of shortages or the measure of consumer sentiment about gas prices/shortages is used as the oil price indicator, the peak response of industrial production becomes greater in the second period than in the first period. For hours, the response remains slightly less in the second period than in the first period if we use as the oil price indicator the shortage-adjusted gas price index, but it becomes greater if we use the measure of consumer sentiment.<sup>11</sup> However, the response of inflation is still lower in the second period than in the first period, even if the shortage-adjusted gas price index or the gasoline sentiment measure is used as the oil price indicator.<sup>12</sup>

To examine more formally the relationship between consumer sentiment toward gasoline and the various gasoline price measures, we estimate a number of bivariate VARs and compare the relationship in the early and the late periods. We find that shocks to the published CPI for gasoline appear to have an effect on sentiment in the early period that is about twice as large as the effect in the late period. In contrast, shocks to the shortage-adjusted gasoline price index have about the same peak effect on sentiment in each period. This evidence suggests that the presence of shortages in the early period is the key difference between shocks to gasoline sentiment and shocks to the published CPI for gasoline.

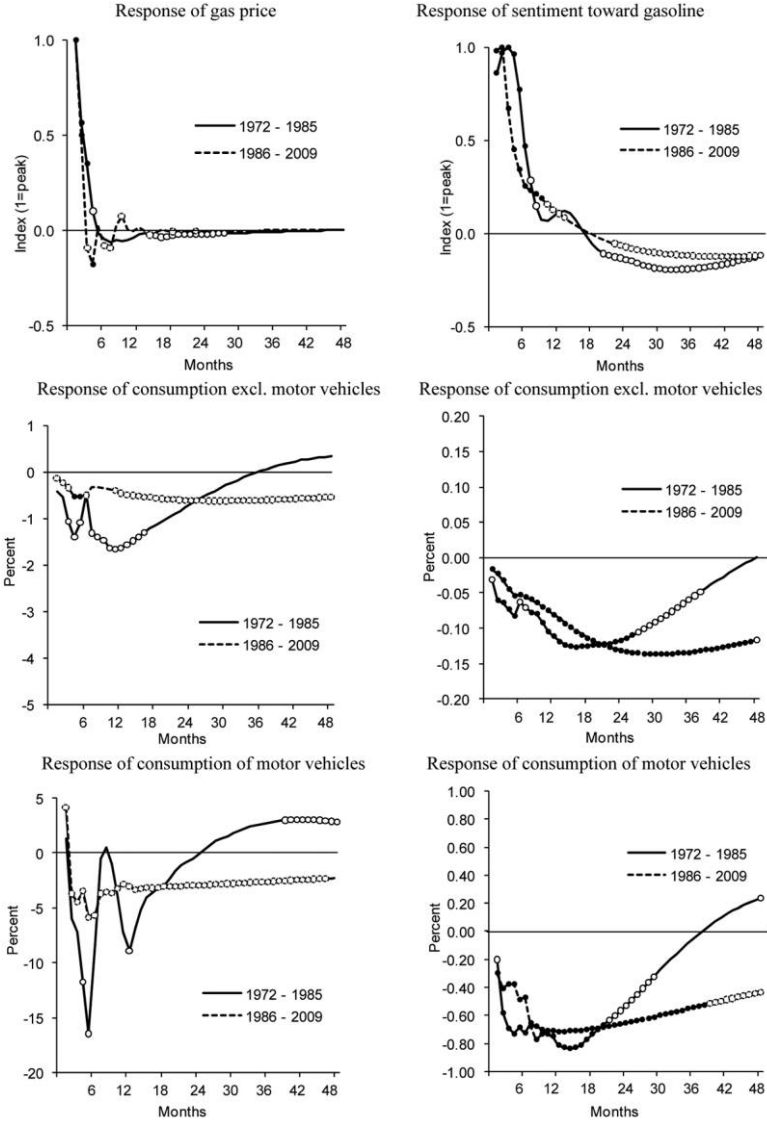
Edelstein and Kilian (2009) find that much of the decline in aggregate activity (or aggregate consumption, more specifically) that follows a

jump in oil prices comes through demand for motor vehicles. They also show that this channel has weakened over time, thereby reducing the effect of oil shocks on aggregate activity. Because this result is even more likely to have been affected by the presence of market distortions in the 1970s, we also reestimate a VAR similar to the Edelstein and Kilian (2009) model, using our shortage-adjusted measures for the true cost of gasoline.

We estimate a trivariate VAR, in which  $Y_t$  is defined by (i) one of the oil cost indicators, (ii) the log of real total consumption excluding motor vehicles, and (iii) the log of real consumption of motor vehicles. In the first set of results, we use as an energy price indicator the Edelstein and Kilian (2009) measure of the purchasing power lost to increases in retail energy prices: this measure scales the changes in real energy prices by the share of energy in consumption expenditures.<sup>13</sup> In the second set of results, we use as an oil cost indicator the consumer sentiment toward gasoline. In each set of results, we estimate the VAR in two sample periods: 1967:1–1985:12 and 1986:1–2009:12. We normalize each shock so that the peak responses of the shock variable are equal to one in each sample period.

Figure 4 shows the estimates, with filled circles indicating when the estimated response is more than 2 SD from zero and open circles indicating when the response is between 1 and 2 SD from zero. The panels to the left show responses that use the Edelstein and Kilian purchasing-power series as an oil cost indicator, and the responses to the shocks are largely consistent with those originally reported by Edelstein and Kilian. Specifically, the response of total consumption falls less sharply in the second sample period than in the first sample period, although the responses are not statistically significant in either period. To the degree that the response has changed, the bottom-left panel shows that most of the change comes from the consumption of motor vehicles: the response in the consumption of motor vehicles is much less in the second period (*dashed line*) than in the first period (*solid line*).

The right panels in figure 4 show the impulse responses obtained when the consumer sentiment toward gasoline serves as the oil cost indicator. Several comparisons here stand out. First, the responses of consumption to these shocks have not diminished between the early and the late periods; this holds true for the consumption of motor vehicles and the consumption of all other goods and services. Moreover, the responses in the second period appear to be more persistent than those in the first period. Second, the responses based on these shocks are statistically significant, an indication that real activity is more closely related to consumer



**Fig. 4.** Responses of consumption to two gasoline shocks: shock to the gas price (*left*) and shock to sentiment toward gasoline (*right*). Filled circles indicate periods in which the responses are more than 2 SD from zero, and open circles indicate periods in which the responses are between 1 and 2 SD from zero.

perceptions of the price of gasoline and its availability than it is to published fuel prices. And third, the decline in consumption of motor vehicles after a gasoline price sentiment shock is many times larger than the response of consumption excluding motor vehicles.<sup>14</sup>

For comparison, we also estimated the impulse response on the basis of other measures of energy prices. Using the Hamilton measure of net oil price increases, the responses show a significant muting between the early and the late samples. If we use the shortage-adjusted measure of gasoline prices, we find results qualitatively similar to those obtained using consumer sentiment toward gasoline as the oil cost indicator. The responses to oil shocks are only slightly smaller in the second period than in the first period; the peak impact on total consumption is 0.9 in the second period relative to the first and on motor vehicle consumption is 0.8.

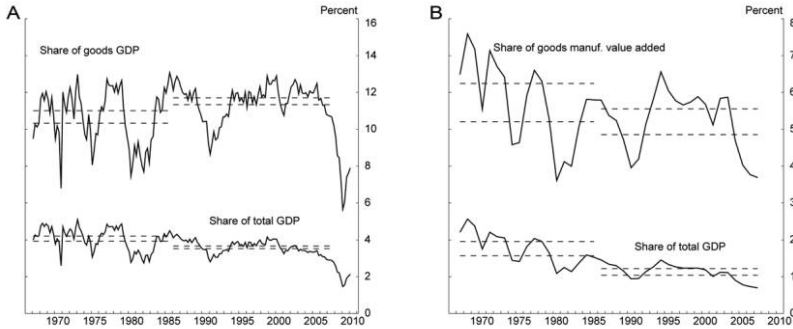
To summarize, when oil price shocks are measured as the shocks to the published price index for gasoline, the Hamilton net increase in oil prices, or the Edelstein and Kilian purchasing-power measure, we confirm the results from the literature that oil shocks have much less of an impact on the economy after 1985 than they did up until 1985. In contrast, when we measure oil shocks as either the shocks to the price of gasoline adjusted for the cost of shortages or the shocks to consumer sentiment toward gasoline, we find that the impact of these shocks on real activity has either diminished only slightly or become larger in the later period. Finally, all measures of energy price shocks produce results that suggest the motor vehicle industry is a key part of the transmission mechanism between oil shocks and real activity. Thus, the remainder of the paper presents evidence that, although the motor vehicle industry has changed in many ways over the past 40 years, this sector continues to act as an important propagation mechanism between oil price shocks and real activity.

### **III. The Contribution of the Motor Vehicle Sector to the U.S. Economy**

The contraction in the size of the Detroit three automakers in recent decades often leaves the impression that the contribution of the auto industry to the U.S. economy has declined significantly. In this section, we present some measures of the contribution of the entire domestic motor vehicle industry (the portion operated by the Detroit firms as well as the portion operated by other firms) to the U.S. economy and to the business cycle.

Figure 5 shows two measures of the contribution of motor vehicle output to U.S. GDP: Panel *A* shows the quarterly values of a statistic commonly referred to as “gross motor vehicle output,” and panel *B* shows annual estimates of the domestic value added of motor vehicle





**Fig. 5.** Motor vehicle industry in the U.S. economy. *A*, Output, 1967:1–2009:4; *B*, manufacturing value added, 1967–2007. Dashed lines represent 95% confidence intervals for the sample means in two periods: 1967–85 and 1986–2007. Expenditure shares are based on nominal data. For value added, motor vehicles and parts are defined on a North American Industrial Classification System basis from 1977 through 2007; earlier periods are plotted as best changes from the standard industrial classification definition. Goods manufacturing includes agriculture, forestry, fishing, and hunting; mining; construction; and manufacturing.

and parts manufacturing, a narrower view of the industry's contribution to GDP.<sup>15</sup> The lower line in each of these panels displays each measure of output as a share of total GDP, and the upper line plots these measures as a share of either goods GDP (for gross motor vehicle output) or total value added from goods manufacturing (for motor vehicle and parts manufacturing value added). Shares are calculated from nominal expenditures data reported in the NIPAs. The dashed lines in the figure represent the 95% confidence interval for the sample mean of each line in two sample periods: 1967–85 and 1986–2007 (before the financial crisis had affected vehicle sales).

Two features in figure 5 are worth noting: first, motor vehicle output drops abruptly in recessions, and many of these recessions followed large increases in gasoline prices. As shown in table 2, the motor vehicle sector alone accounts for between 14% and 22% of the variance of the quarterly changes in real GDP, depending on the time period. Even after the Great Moderation, these figures continue to exceed the moderate size of the motor vehicle sector.

The second feature of the graph that is worth noting is that the size of the motor vehicle industry as a share of the U.S. economy does not show a downward trend that is as striking as one might expect. As a share of total GDP (fig. 5*A*, bottom line), motor vehicles represented about 4% of the U.S. economy between 1967 and 1985, and that figure declined to

**Table 2**  
Fluctuations in Real Gross Domestic Product (GDP)

	Share of GDP (%)	SD (% Quarterly Change, Annual Rate)	Share of GDP Volatility (%)
Goods and services:			
1967–85	100	4.3	100
1986–2007	100	2.1	100
1986–2009:3	100	2.5	100
Goods:			
1967–85	37	9.2	54
1986–2007	30	5.0	51
1986–2009:3	30	5.6	50
Motor vehicles:			
1967–85	4.0	38.1	22
1986–2007	3.5	19.2	14
1986–2009:3	3.3	24.9	16

Note: Data are from the National Income and Product Accounts. Share of GDP volatility attributable to each component is calculated as 100 less the variance of growth contribution of GDP, excluding each component relative to the variance of total GDP. Figures for the early period exclude 1970:4, when a long strike severely reduced motor vehicle output and sales.

3.5% between 1986 and 2007. As a share of the goods-producing sectors of the U.S. economy, however, motor vehicle output actually increased between the two periods, from about 10.5% in the early sample to about 11.5% in the more recent sample. Manufacturing value added gives a similar picture: motor vehicle and parts manufacturers accounted for 5.7% of U.S. manufacturing value added in the 1970s and early 1980s, and this share slipped to 5.2% in the more recent period. However, as shown by the dashed lines, the decline between the two periods is not very pronounced relative to its high volatility.<sup>16</sup>

All told, the motor vehicle sector has been a modest but relatively stable share of the goods-producing sector over the past 40 years, and the declines that have occurred in its contribution to total GDP mostly reflect an increase in the size of the services sector. Most important, the auto industry continues to induce swings in aggregate activity that far exceed its modest size.

#### IV. Oil Shocks and the Demand for Motor Vehicles

We now describe theories of how gasoline prices affect vehicle demand and then present evidence in some detailed auto industry data that consumers adjust their vehicle-buying patterns in response to changes in gasoline prices. In addition, we show that this behavior has not changed much over the past 40 years.

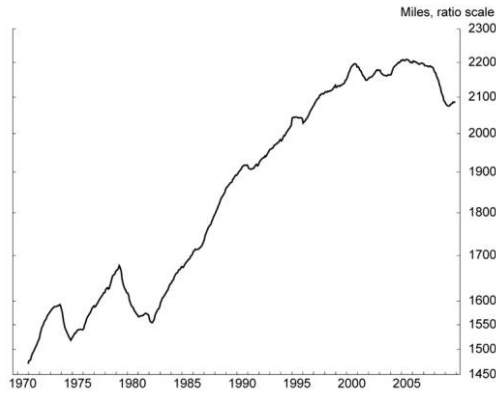
A rather large literature has developed—much of it in the late 1970s—to analyze how households respond to changes in gasoline prices by making adjustments to their vehicle stock and to their driving behavior (e.g., Dahl 1979).<sup>17</sup> More recently, Wei (2009) casts the vehicle-purchasing decision in a general equilibrium framework, in which households invest in transportation capital with a particular level of fuel efficiency and then combine it with gasoline to produce the good that ultimately enters their utility functions—personal vehicle travel. Because consumers are forward looking, changes in gasoline prices lead to dynamic effects on the vehicle stock and average fuel efficiency.

After a gasoline price shock, households respond in the short run mostly by reducing travel, although estimates from the literature suggest the response in the short run is quite low (e.g., Hughes, Knittel, and Sperling 2006). Over long horizons, households adjust their vehicle technology and reduce further their consumption of gasoline. Using her DSGE model calibrated to U.S. fuel and vehicle consumption data, Wei (2009) finds that vehicle purchases and total miles traveled decline after a permanent shock to gasoline prices, although the equilibrium fuel efficiency of new vehicles increases.

These theories suggest that permanent increases in gasoline prices lead households to reduce vehicle travel in the short run and then to replace their vehicle stock in the long run. In the very long run, gasoline prices can also affect where households choose to live and work.

To see the effects of these decisions on vehicle travel over the past 40 years, figure 6 plots total vehicle miles traveled per household in the United States between 1970 and 2009. Two features in the figure are noteworthy. First, households nowadays consume a significantly larger amount of travel than they did in the early 1970s: the average household drove approximately 1,500 miles per month in 1970, and that figure has increased 50%, to almost 2,200 miles per month during 2000–2007. Second, households do cut back on travel when gasoline prices increase, although part of the decline in travel likely also reflects the deterioration in the broader economy that also occurs at these times.

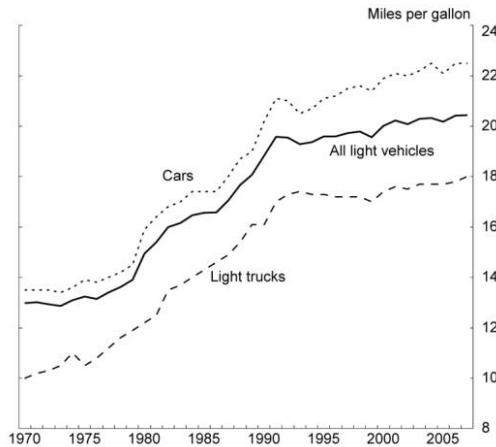
While households now drive more each month than they did in the early 1970s, they do so in vehicles that are, on average, more fuel efficient. Figure 7 shows data from the U.S. Department of Transportation on the average fuel efficiency of the registered stocks of cars and light trucks (which include sport-utility vehicles [SUVs] and vans). As seen in the plot, the average fuel economy for each type of vehicle has increased over the sample, although much of the gains occurred in the 1980s, after the United States introduced Corporate Average Fuel Economy standards



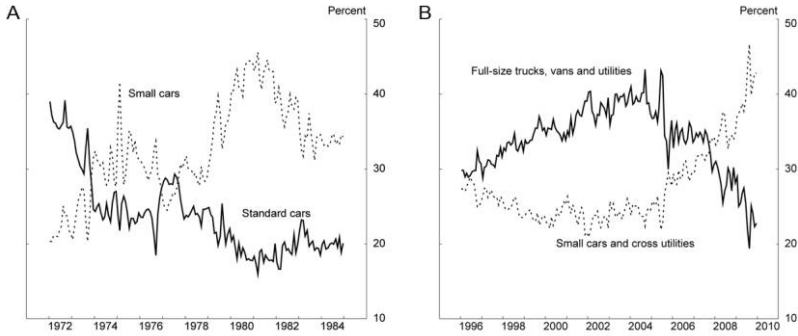
**Fig. 6.** Vehicle distance traveled per household, January 1970 to October 2009. Data on vehicle miles are from “Traffic Volume Trends,” Office of Highway Policy Information in the Department of Transportation. Data on the number of households in the United States are from the U.S. Census Bureau. Data were smoothed with a 12-month moving average.

that were met by reducing the average weight of cars and introducing some technological improvements to engine design.

One feature of figure 7 that receives lots of attention is the marked slowdown (or near halt) in the rate of improvement for average fuel economy that occurred in the 1990s. This was an era of relatively cheap



**Fig. 7.** Average fuel economy for the U.S. light vehicle stock, December 1970 to December 2009. Data are from the U.S. Department of Energy (2009). Data points for light trucks for 2003 and 2004 were interpolated. Light vehicles include cars and light trucks.



**Fig. 8.** Domestic sales shares for selected vehicle segments, percentage of domestic vehicles sold. *A*, January 1972 through December 1984; *B*, January 1996 through November 2009. Shares are calculated from U.S. sales of domestic light vehicles, which are defined as those produced in North America. The category “small cars” includes compact and subcompact cars; “standard cars” includes full-size and luxury cars. Cross-utility vehicles are small utility vehicles assembled on car chassis.

gasoline, and, likely as a result, demand shifted away from cars and toward larger SUVs.<sup>18</sup> Studies that more carefully take into account vehicle size and engine horsepower, such as Knittel (2009), conclude that the technological frontier of fuel-economy/vehicle-weight/engine-power possibilities continued to expand over this period, but these improvements are obscured in aggregate data by the shift in sales across vehicle size classes.

Shifts in vehicle demand across vehicle size classes often occur when gasoline prices move dramatically, a stylized fact that was discussed by Bresnahan and Ramey (1993). To see evidence of this, figure 8 shows the domestic market shares of vehicles of various sizes.<sup>19</sup> Figure 8A shows the key market shares in the 1970s and early 1980s. The domestic market share for standard-size cars fell noticeably in 1973 and did not stabilize until almost 2 years later.<sup>20</sup> When the second oil price shocks hit in 1979, this market share fell even further. The market share of small cars moved in the opposite direction on both occasions.

Figure 8B shows market shares of key vehicle segments in the 2000s. The patterns in market shares since 2000 have been similar to those observed in the earlier episodes of sharp gas price increases, although the scope of the variety of products available has grown considerably since the 1970s. The market share of full-size pickups, utility vehicles, and vans fell more than 15 percentage points between its peak in 2004 and early 2009. Small cars and the new cross-utility vehicle segment picked up most of this market share.<sup>21</sup>

## V. The Response of Motor Vehicle Production

Shocks that affect motor vehicle sales often lead to changes in the rate of production that are quite abrupt, and the high level of volatility in motor vehicle production has been studied extensively in the literature on inventories and production scheduling. It is well understood how changes in aggregate vehicle demand can lead to reductions in production. In this section, we show how changes in the composition of demand, such as those induced by gas price increases, can lead to further declines in output.

We begin by presenting an inventory model in which segment shifts lead to capacity mismatches and thereby reduce output. We then study this channel, using detailed auto industry data by vehicle size class. We find that segment shifts are an important channel through which oil shocks affect the U.S. motor vehicle industry and that the importance of this channel has not declined much over time.

### A. Segment Shifts and the Constraints on Capacity

Bresnahan and Ramey (1993) speculated that a shift in demand from one vehicle segment to another, with no decline in overall demand, can lead to a decrease in production and capacity utilization. They also argued that the variance of days' supply (i.e., the inventory-sales ratio) across segments reflects mismatches between capacity and demand for vehicles in some segments.

In order to formalize this hypothesis, we consider a simple model of a profit-maximizing monopolist who sells cars to two segments of demand. For each segment  $i$ , the monopolist chooses the price,  $P_t$ , and schedules production using regular time hours,  $RH_t$ , and overtime hours,  $OH_t$ . These choices determine expected sales,  $S_t$ , and expected end-of-period inventories,  $I_t$ . The firm maximizes the expected present discounted value of profits, given as

$$\Pi_0 = E_0 \sum_{t=0}^{\infty} \beta^t (P_{1t} S_{1t} + P_{2t} S_{2t} - \text{Cost}_t). \quad (2)$$

The costs of production and inventory holding are given by

$$\begin{aligned} \text{Cost}_t = & \gamma RH_{1t} + \gamma RH_{2t} + \gamma \omega OH_{1t} + \gamma \omega OH_{2t} \\ & + \frac{1}{2} \alpha_1 (I_{1t-1} - \phi S_{1t})^2 + \frac{1}{2} \alpha_2 (I_{2t-1} - \phi S_{2t})^2. \end{aligned} \quad (3)$$

Inventory stocks evolve according to

$$I_{it} = I_{it-1} + RH_{it} + OH_{it} - S_{it}, \quad i = 1, 2, \quad (4)$$

and the use of regular time hours is limited by the capacity constraints:

$$RH_{it} \leq K, \quad i = 1, 2. \quad (5)$$

The parameters of the model satisfy the following restrictions:  $0 < \beta < 1$ ;  $\gamma > 0$ ;  $\omega > 1$ ;  $\alpha_i, \phi_i > 0$ ;  $K > 0$ .

Relative to the familiar linear-quadratic production-smoothing model, the inventory-holding costs in equation (3) are the same, but the marginal costs of production are somewhat more complicated: marginal costs in this model are flat when the monopolist uses regular time hours but rise when the firm must increase its workweek of capital and use overtime hours or a second shift. This assumption induces a key asymmetry in marginal costs.

Finally, the sales processes for segments 1 and 2 are described by the following equations:

$$S_{1t} = \theta_A - \theta_B P_{1t} + u_t^{\text{seg}} + u_t^{\text{agg}}, \quad (6)$$

$$S_{2t} = \theta_A - \theta_B P_{2t} - u_t^{\text{seg}} + u_t^{\text{agg}}. \quad (7)$$

There are two types of demand shifts in these sales equations: the first,  $u_t^{\text{seg}}$ , is a variable that shifts demand away from one segment and toward the other, while the second,  $u_t^{\text{agg}}$ , is a variable that shifts the demand curves for all types of vehicles in the same direction. We assume that each of these shift variables follows an AR(1) process as shown in the following equations:

$$u_t^{\text{seg}} = \rho u_{t-1}^{\text{seg}} + \varepsilon_t, \quad (8)$$

$$u_t^{\text{agg}} = \rho u_{t-1}^{\text{agg}} + \eta_t. \quad (9)$$

The autocorrelation parameter  $\rho$  lies between 0 and 1, and the shocks  $\varepsilon$  and  $\eta$  are white noise.

An increase in gasoline prices affects vehicle sales through both  $u_t^{\text{agg}}$  and  $u_t^{\text{seg}}$ . To study the effects of the second type of shock—the shift in sales between segments—we simulate the model and evaluate the

optimal paths of key choice variables. To calibrate the simulation,  $\beta$  and  $\phi_i$  are set to match the averages observed in the data for interest rates and days' supply for light vehicles. We choose values for  $K$ ,  $\theta_A$ ,  $\theta_B$ , and  $\gamma$  to generate a price elasticity of demand of  $-1.5$  at the steady-state level of output, a figure that is in the range of empirical estimates for total vehicle demand.<sup>22</sup> Finally, we set  $\alpha_i$  and  $\omega$  so that the premium on overtime hours or second-shift hours is 10%.<sup>23</sup> The simulation considers shocks that shift the intercept of the demand curve by 10%, with  $\rho = 0.75$ .<sup>24</sup>

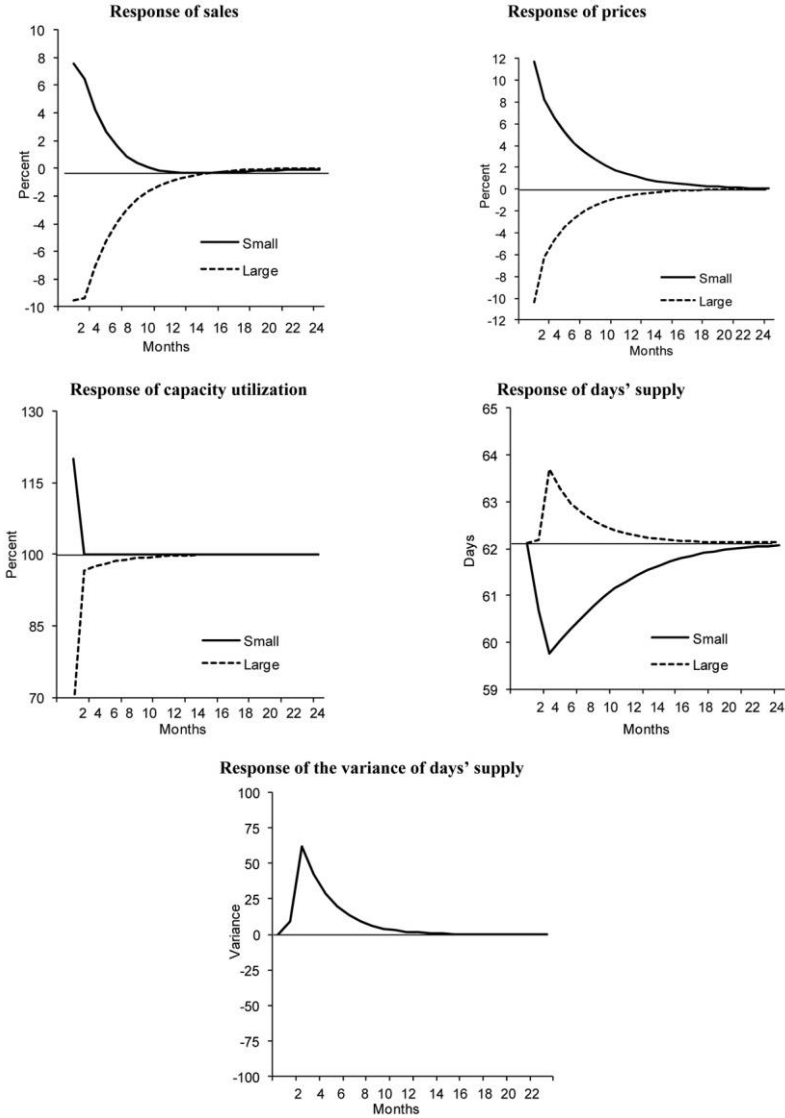
Because plants face the same cost function in each segment, the effects of an aggregate shock on inventories and production are the same in each segment. And, because the inventory-sales ratios change by equal amounts in each segment, the cross-section variance of the days' supply remains zero. This is not the case for shocks that shift demand between segments, a scenario that is shown in figure 9. If demand for segment 1 cars shifts up and demand for segment 2 cars shifts down by an equal amount, total production falls because the rise in output in segment 1 does not fully offset the fall in output in segment 2. The asymmetric response of production reflects the increase in marginal costs that occurs at the capacity constraint. Mirroring this pattern, the price of vehicles in segment 1 rises by an amount that is different from the decline in the price of vehicles in segment 2. All told, segment shifts reduce total production, sales, and capacity utilization, and they drive up the variance of days' supply across vehicle segments.

Some of these results depend critically on the increase in marginal cost that occurs when production exceeds the level of capacity.<sup>25</sup> If costs were instead quadratic, as is assumed in the standard production-smoothing model, then marginal costs would be linear, capacity utilization would have no effect on production costs, and segment shifts would not reduce total production.<sup>26</sup> The variance of days' supply would still increase in the case of quadratic costs, but the asymmetric response of production to positive and negative demand shocks requires the marginal cost function to exhibit some curvature.

### *B. Evidence of Capacity Constraints and Segment Shifts in the Auto Industry*

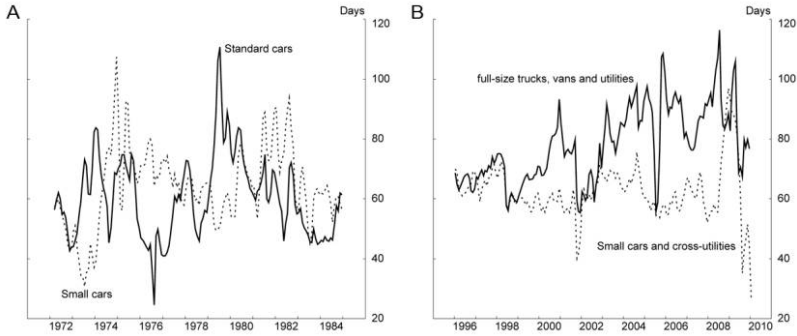
To see the effects of segment shifts in the detailed auto industry data, figure 10 plots day's supply for vehicles in selected size classes in the early and the late periods. In the earlier period, days' supply of standard cars grew to uncomfortably high levels at the time of both oil shocks, and days' supply for small cars moved down. Similarly, in the later period,





**Fig. 9.** Responses to a segment-shifting shock to sales. Impulse responses from the production model presented in equations (2)–(9) are shown.

days' supply for full-size trucks, vans, and utility vehicles climbed to critically high levels between 2000 and 2008, while days' supply for small cars and cross-utility vehicles moved down between 1998 and 2000 before edging back up in 2002. As the shift in demand between segments accelerated again at the end of 2004, days' supply for small vehicles



**Fig. 10.** Domestic days' supply of selected vehicle segments. *A*, January 1972 through December 1984; *B*, January 1996 through November 2009. Days' supply is calculated with end-of-month inventories and the 3-month moving average of sales. Inventories include finished vehicles held at dealerships and assembly plants and vehicles in transit. Domestic vehicles refer to vehicles produced in North America. "Small cars" include compact and subcompact cars, and "standard cars" include full-size and luxury cars. Cross-utility vehicles are small utility vehicles assembled on car chassis.

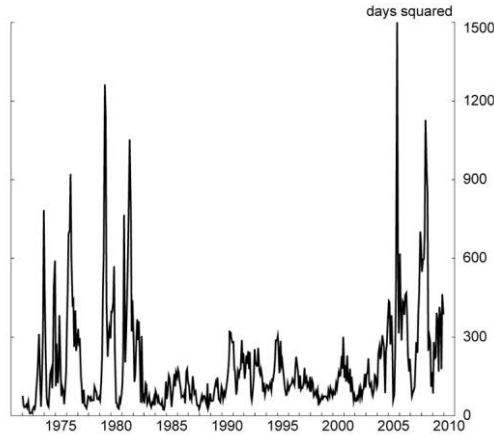
receded, and several of the models in these segments were reported to be in short supply.<sup>27</sup> The onset of the financial crisis in the second half of 2008 appears to have been a common shock that pushed up days' supply for almost all vehicle segments.

To measure these supply imbalances on a more general scale, we calculate the variance of days' supply across size categories,  $V_t^{DS}$ , that was described earlier. The formula is

$$V_t^{DS} = \sum_{i=1}^{11} \frac{I_t^i}{I_t^A} (DS_t^i - DS_t^A)^2, \quad i = 1, 2, \dots, 11, \quad (10)$$

where  $I_t^i$  denotes inventories on hand in vehicle segment  $i$  at the end of period  $t$ ,  $I_t^A$  is the aggregate inventory stock,  $DS_t^i$  is days' supply for each segment,  $DS_t^A$  denotes aggregate days' supply, and  $i$  ranges from 1 to 11, covering five car segments (subcompact, compact, intermediate, full size, and luxury) and six truck segments (compact pickups, full-size pickups, small vans, large vans, cross-utility vehicles, and full-size utility vehicles). An increase the variance of days' supply across segments indicates that the imbalance between the composition of capacity and the composition of demand has become worse.<sup>28</sup>

The variance of days' supply is plotted in figure 11 from January 1972 to December 2009. Large spikes in the variance correspond quite closely with the increases in fuel prices discussed earlier. Also, the severity of

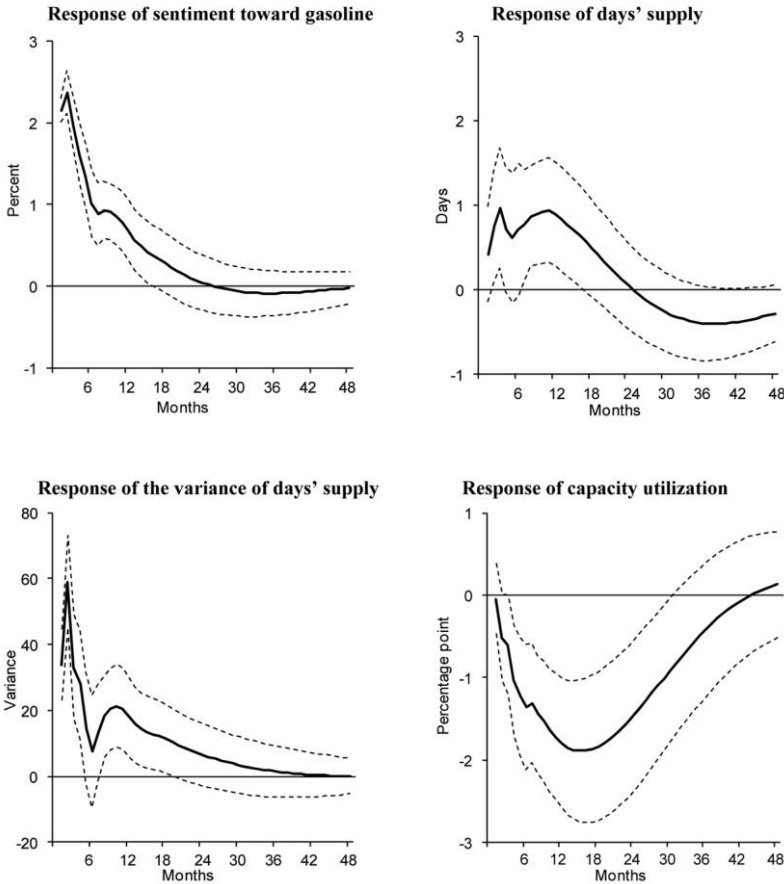


**Fig. 11.** Variance of domestic days' supply across vehicle segments, January 1972 through December 2009. Domestic days' supply is calculated from U.S. inventories and sales of vehicles assembled in North America. Variance is calculated across five car segments (subcompact, compact, intermediate, full size, and luxury) and six light truck segments (compact vans, full-size vans, compact pickups, full-size pickups, cross-utility vehicles, and standard utility vehicles).

some of the supply-demand imbalances that occurred after 2002 appear even greater than the magnitudes observed in the early 1980s.

To investigate the empirical relationship between these spikes in the variance of days' supply, the cost of gasoline, and movements in capacity utilization, we estimate a VAR in which  $Y_t$  includes four variables: (i) consumer sentiment about gasoline prices or shortages, (ii) aggregate days' supply for domestic vehicles, (iii) the variance of days supply across segments (defined in eq. [10]), and (iv) capacity utilization for light motor vehicle assembly.<sup>29</sup> The VAR also includes six lags and a linear time trend.

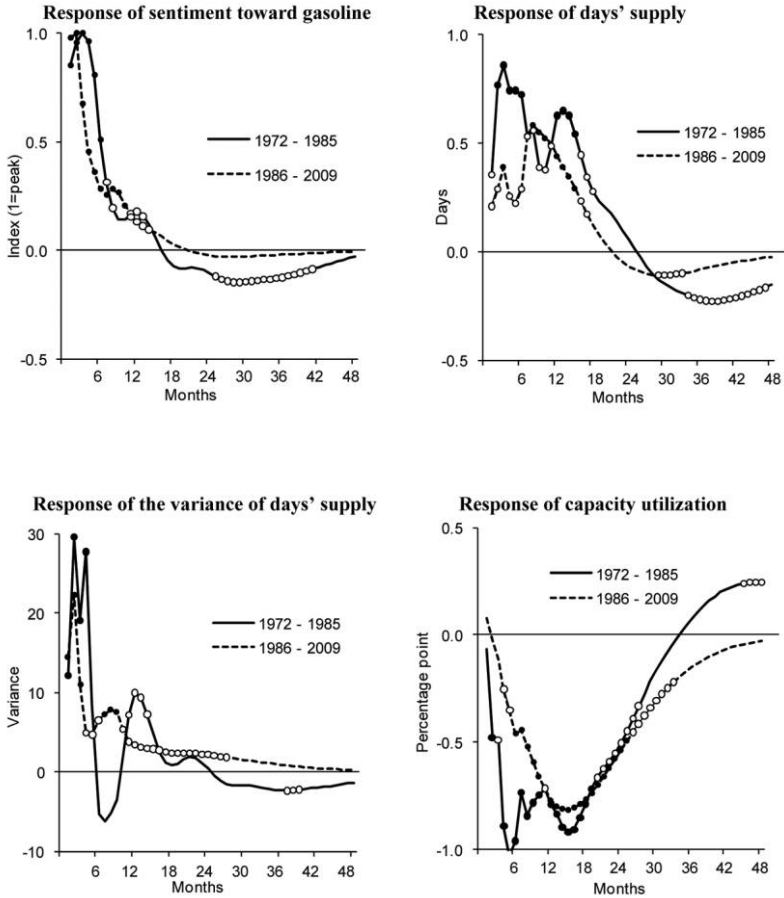
Oil shocks in the VAR play two roles: first, oil shocks reduce aggregate demand and dampen sales for all types of vehicles. In the production model described earlier, this role resembles the aggregate shock that drives up days' supply for the entire industry and reduces capacity utilization for all segments. Second, high gas prices lead to segment shifts in demand away from large vehicles and toward small vehicles. This role leads to mismatches in capacity and drives up the variance of days' supply across vehicle segments. Our production model also shows how shocks in this role can reduce capacity utilization when capacity constraints push up marginal costs for the products in demand.



**Fig. 12.** Responses to a shock to consumer sentiment toward gasoline: combined sample, 1972–2009. Dashed lines enclose 95% confidence intervals.

Figure 12 shows the responses of the variables in  $Y_t$  to a shock to the measure of consumer sentiment toward gasoline (meaning a higher percentage of consumers were worried about high gas prices), which is ordered first in the VAR. The VAR is estimated over the full sample from January 1972 to March 2009. As seen in the figure, both the level and variance of days' supply increase after a sentiment shock, indicating that shocks to gasoline sentiment affect demand both as an aggregate shock and as a segment-shifting shock. According to the last panel, capacity utilization also falls significantly.

Has the relationship between these variables changed over time? To answer this question, we compare the impulse-response functions from



**Fig. 13.** Responses to a shock to consumer sentiment toward gasoline: split samples, 1972–85 and 1986–2009. Filled circles indicate periods in which the responses are more than 2 SD from zero, and open circles indicate periods in which the responses are between 1 and 2 SD from zero.

VARs estimated separately for 1972–85 and 1986–2009 and plot the results in figure 13. The shocks to consumer sentiment toward gasoline have been normalized to reach a peak of 1.0 in both periods. As seen in the figure, the peak responses of both the level and the variance of days' supply are about 30% larger in the early period than in the later period. The response of capacity utilization, however, is about the same in both periods.

Finally, using the VAR estimates and a set of counterfactual experiments, we parse the response of capacity utilization to oil shocks into

portions that reflect the aggregate demand channel and the segment-shifts channel. In one experiment, we plot the response of utilization to a gasoline sentiment shock after we have shut down the segment-shifts channel by replacing the estimated coefficients of the days' supply equation in the VAR with zeros. The difference between the baseline response and this counterfactual response reveals the contribution of the aggregate demand channel to the transmission of gasoline shocks to capacity utilization. In a second experiment, we shut down the segment-shifts channel by setting the coefficients of the variance of days' supply equation to zero. The third experiment shuts down both channels.

Figure 14 shows the results of the each experiment; the solid lines represent the baseline response of capacity utilization to a gasoline sentiment shock, and the dashed lines represent one of the counterfactual responses. In the first panel, the counterfactual response is only half as large as the baseline response, a comparison that suggests the contraction

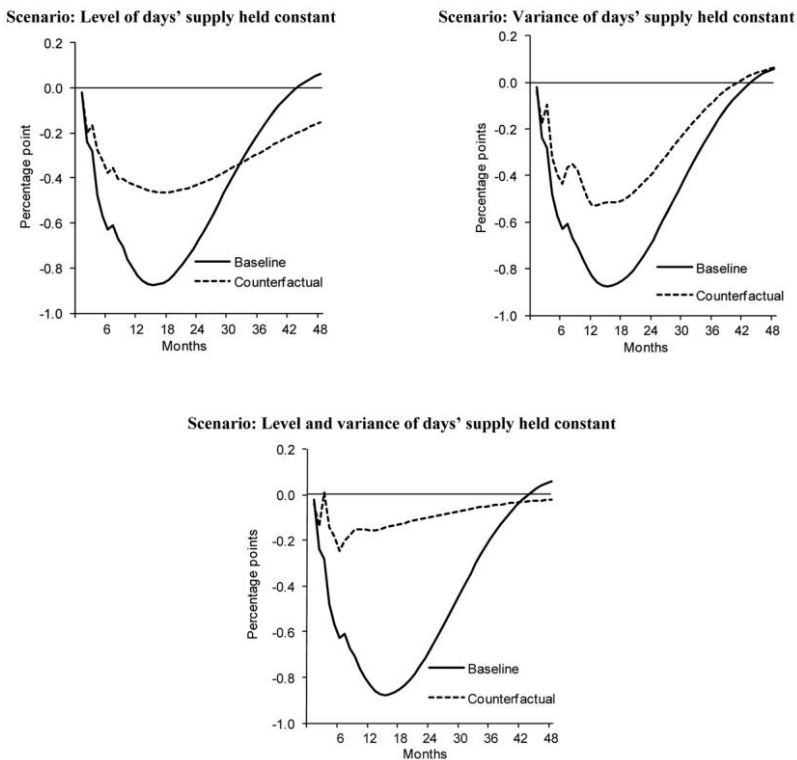


Fig. 14. Response of capacity utilization to shocks to consumer sentiment toward gasoline

in demand for all vehicles plays an important role in transmitting oil shocks to motor vehicle production. The counterfactual response in the second panel is also only about half as large when the segment-shifts channel is shutdown, indicating that this channel is also important. The counterfactual response in the third panel remains very close to zero, suggesting that omitted channels are not too important.

The counterfactual exercises indicate that the level and variance of days' supply channels are about equally important in transmitting oil shocks to motor vehicle output. These results imply that oil shocks have both aggregate effects and segment-shift effects. Moreover, the relationship between these variables appears to have been stable over time.

## VI. Conclusions

This paper has studied the impact of oil shocks on the U.S. economy and its motor vehicle industry and has examined whether these relationships have changed over time. We have found that, once the costs of queuing are added to the prices paid for gasoline during the gasoline shortages in the 1970s, real output in the United States has been as sensitive to oil price shocks since the mid-1980s as it had been in the 1970s and early 1980s. The effect on inflation, however, has diminished over time.

We have also found that the motor vehicle industry plays an important role in propagating oil price shocks to the rest of the U.S. economy and that, despite the many innovations in the ways motor vehicles are produced and consumed, the primary channels through which oil prices directly affect demand for motor vehicles have not weakened much over time. Specifically, the abrupt shifts in demand across vehicle size classes that stem from oil shocks have been as disruptive to the supply-demand relationship in the motor vehicle industry since the mid-1980s as they were in the 1970s and early 1980s.

Our results may affect the debate over which changes in the U.S. economy have led to the decline in GDP volatility since the mid-1980s, or the Great Moderation. If the relationship between oil shocks and real output had, in fact, become weaker since the mid-1980s, then this stylized fact could have bolstered arguments that structural change had reduced the sensitivity of output to these types of shocks. Our results, to the contrary, suggest that this particular relationship has been stable over time. The diminished impact of oil shocks on inflation, however, may support the theory that monetary policy has played a role in reducing volatility. Finally, our results point to another change in

government policy that may also have reduced the volatility of output since the 1970s: a decline in the propensity to use price controls.

## Endnotes

The views expressed here are those of the authors and not those of the Board of Governors or the Federal Reserve System. Sam Ackerman provided excellent research assistance. We are grateful for comments from Daron Acemoglu, Jordi Galí, George Hall, James Hamilton, Chris Kurz, Ariel Pakes, and Garey Ramey, and we thank William Lee for sending us his papers. We also thank participants at the 2008 International Society for Inventory Research session, the NBER Twenty-fifth Annual Conference on Macroeconomics, and seminar participants at Statistics Canada and University of California, San Diego. Valerie Ramey gratefully acknowledges financial support from National Science Foundation grant SES-0617219 through the NBER.

1. See, e.g., Mork (1989), Hamilton (1996, 2003), Hooker (1996), and Barsky and Kilian (2002).

2. Blanchard and Galí (2010) use the price of West Texas intermediate oil, available from the St. Louis Federal Reserve (Economic Data—FRED, <http://research.stlouisfed.org/fred2/>). This series shares the same problems with the PPI measure that we will discuss below.

3. Barsky and Kilian (2002) extend it back to 1971, but we are worried about this extension, for reasons given below.

4. Also, Kilian (2010) highlights the importance of studying gas prices separately from crude oil prices.

5. Hamilton and Herrera (2004) questioned details of their specification. Bernanke, Gertler, and Watson (2004) responded, reestimating their model in a way that attempts to deal with this critique and finding results only slightly less strong than in their original paper.

6. See, e.g., the debate between Hamilton (2009) and Kilian and Vigfusson (2009).

7. For example, Frech and Lee describe inefficiencies in the allocation of gasoline across urban and rural markets. Similarly, Davis and Kilian (2009) show that the total inefficiency costs of price controls on residential natural gas in the United States was three times larger than was the estimate of the simple deadweight loss.

8. Frech and Lee's estimates are based on data from California only, so the question arises as to how California's shortages compared to the rest of the nation. According to the February 8, 1974, *Wall Street Journal*, there was no rationing in "New England north of Boston, much of the Midwest, Denver, Nevada, and Southern California. In Northern California, the word was okay on weekdays and in daylight, but otherwise watch out. There were long lines in Washington, D.C., and the Philadelphia area ... and in New York and New Jersey, where things have been tough for quite a while now."

9. Other reasons consumers can give for this being a bad time for buying a car are (1) prices of cars are too high, (2) interest rates are too high, (3) cannot afford to buy, (4) uncertain future, and (5) poor selection or quality of cars.

10. The Hamilton measure is defined as the log change in the price index for gasoline relative to its previous 3-year high, if it is positive, or zero, if it is negative.

11. We do not show the response of nominal wages and the funds rate because their responses are not significantly different from zero, and the dynamic patterns swing from positive to negative in some cases.

12. The results are similar if we substitute the chained price deflator for personal consumption expenditures for the CPI.

13. We also considered a measure that scaled prices by the average fuel efficiency of the motor vehicle stock and the miles driven by households. The results were similar to those using the Edelstein and Kilian measure.

14. The relative magnitudes of the estimated responses imply that about 30% of the decline in total consumption that occurs 15 months after a gasoline price shock comes from the decline in motor vehicle consumption.



15. "Gross motor vehicle output" in the National Income and Product Accounts (NIPAs) is the retail value of motor vehicles sold to final consumers (households, businesses, and governments) and the wholesale value of vehicles invested in inventories. This series is adjusted for net exports of motor vehicles and has the advantage of capturing all of the value added from the production process as well as from the distribution of motor vehicles to final demand, including the wholesale and retail margins. This measure is not the same as "gross output of motor vehicles and parts" in the U.S. industry accounts, which is the sum of all sales and receipts in the industry, including sales of intermediate inputs to firms in other (or in the same) industries.

16. One additional measure of motor vehicle output that we examined (but do not report) is motor vehicle and parts output. This wider view of the industry is intended to help control for the value of imported intermediate inputs to motor vehicle production that have risen over time (see Kurz and Lengermann 2008; Klier and Rubenstein 2009). Using this adjusted measure, motor vehicle output was 12.5% of goods GDP in both the early and the late periods, and it declined from 4.75% of total GDP in the early period to 3.75% in the later period.

17. The Congressional Budget Office study from January 2008, "Effect of Gasoline Prices on Driving Behavior and Vehicle Markets," surveys much of the literature from the 1970s.

18. The average fuel efficiency of vehicles flowing into the stock each year (i.e., new sales) actually decreased during the 1990s, as the mix in sales shifted toward light trucks.

19. Figure 8 focuses on the market for domestically produced goods. An additional effect not shown in the graph is the shift to imported cars when oil prices increase; this move occurred in both the late 1980s and in the 2000s. The share of imported vehicles rose from about 15% in the mid-1970s to about 25% in the first half of the 1980s. The import share then fell back as foreign automakers began to establish manufacturing operations in North America, and the import share fell below 10% by 1996. The market share of imported vehicles turned up again in the late 1990s, and the share moved up from 17% in 2000 to 26% in 2009.

20. The domestic market share excludes vehicles imported from outside North America.

21. A cross-utility vehicle is a utility vehicle that is assembled on a car chassis. They are classified by the industry as a light truck.

22. See, e.g., Graham and Glaister (2002). Berry, Levinsohn, and Pakes (1995) find much higher elasticities (in absolute value) for particular models.

23. The statutory overtime premium is 50%, whereas shift premiums are typically 5%–10%. Trejo (1991) has found that the implicit overtime premium is substantially lower than 50%. Thus, our assumption of a 10% premium is within the relevant range.

24. The values of the parameters are as follows:  $\beta = 0.997$ ;  $\phi_i = 2.5$  for  $i = 1, 2$ ;  $K = 40$ ;  $\theta_A = 100$ ;  $\theta_B = 1$ ;  $\gamma = 19.85$ ;  $\alpha_i = 0.1$ ; and  $\omega = 1.1$ .

25. Several authors in the capacity utilization literature define full capacity as the point beyond which marginal production costs begin to rise too rapidly. See Klein (1960) and Corrado and Matthey (1997).

26. See, e.g., eq. (7) of Ramey and Vine (2006).

27. The patterns in sales and days' supply between 2000 and 2009 were influenced by occasional inventory clearance events, often targeted toward full-size trucks and SUVs. The Detroit manufacturers have typically dominated the full-size truck market segments and therefore faced significant loss in market share as sales of these vehicles sagged over this period. The large dip in days' supply in late 2001 reflects the advent of zero-interest financing, and the plunge in stocks in 2005 coincides with the extension of these firms' employee-discount programs to all customers.

28. In the theoretical model presented above, the variance of days' supply in steady state was zero because the parameters of the cost function were the same for each vehicle segment. In actual industry data, vehicle types often show distinct long-run average inventory-sales ratios. This implies that the cross-sectional variance can be positive in steady state.

29. The production theory presented above suggests that one should also include vehicle prices for each segment, but unfortunately we lack data on segment-specific vehicle prices over much of the necessary history.

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