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GASOLINE PRICES AND THE DEPRECIATION OF USED AUTOMOBILES

Brian Ritchie

WHITMAN COLLEGE

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Abstract

This project analyzes the relationship between gasoline prices and the depreciation rates of used automobiles with different fuel economy characteristics. The hypothesis to be tested is that when gas prices are high, consumers will place a higher premium on fuel economy, leading to a gain in value for fuel-efficient used cars relative to less fuel-efficient models. I use vintage-asset price data from newspaper classified advertisements to construct depreciation schedules for two car types, the Honda Civic and Ford Explorer, and observe how these schedules change over time in relation to gas price fluctuations. The empirical results confirm that high gas prices induce a relative increase in the value of the more fuel-efficient Civics and a decrease in the value of Explorers.

Introduction

The dramatic rise in the price of gasoline that occurred in 2005 appears to have generated serious repercussions on the market for automobiles. With gas selling for $3 per gallon or more, auto manufacturers were forced to offer massive rebates on gas-guzzling sport utility vehicles, while consumers paid large dealer markups and endured long waiting lists in order to acquire fuel-efficient hybrid vehicles like the Toyota Prius. Many buyers have turned to the used car market as an alternative to these waiting lists, with used Priuses in such high demand that some have sold for more than the list price of a new vehicle (Chang 2005). At the same time, resale values for some large SUVs fell as much as 10% during 2005, according to one report (Goo and Morse 2005). This sort of anecdotal evidence suggests that many consumers will change their used car buying choices to favor vehicles with greater fuel economy in times of high gas prices. Since the supply of used vehicles is essentially fixed in the short run, substantial price changes will be necessary to clear the market when consumer demand changes. Specifically, high fuel prices will presumably lead to a decline in the market value of fuel-inefficient vehicles and an increase of fuel-efficient ones.

If such a systematic pattern of consumer behavior does exist, it suggests important economic and environmental consequences. When gas prices are high, owners of gas-guzzlers clearly take a financial loss from the higher costs they pay to operate their vehicles, yet they might face an additional blow to their wealth if the resale value of their car falls. Conversely, owners of fuel-efficient vehicles might see a financial windfall as their car appreciates, which might conceivably outweigh the higher driving costs and cause a net increase in wealth. Higher gas prices may thus impose a de facto tax on the owners of fuel-inefficient vehicles by reducing the value of their assets, quite apart from the more obvious costs at the fuel pump. From an environmental point of view, this effect appears desirable as it provides an additional incentive to own fuel-efficient vehicles. In economic terms, this would promote social efficiency by helping to internalize the external costs − pollution, oil dependency, and so forth − imposed by the users of fuel-inefficient vehicles.

In addition to the effect on car prices at one point in time, we can also inquire as to how gas prices affect the value of cars as they age. If the prices of all model years of a gas-guzzling vehicle decline relative to more fuel-efficient models, this can be viewed as an acceleration of depreciation. Since cars are scrapped when their economic value becomes negligible, an increase in the depreciation rate will lead to earlier retirement of used gas-guzzlers. Again, the reverse is true for fuel-efficient cars: higher gas prices would slow depreciation and lead to a longer service life. If consumers observe a strong relationship between fuel economy and depreciation, they may be more inclined to buy fuel-efficient cars due to their better prospective resale value. Over time, these processes could alter the general makeup of the automobile market, so that a long period of sustained high gas prices might lead to a more fuel-efficient car stock. This possibility suggests an environmental rationale for high gas prices, in addition to the more intuitive notion that people will simply drive their cars less when fuel is more expensive.

This paper will empirically examine the relationship between gasoline prices and vehicle depreciation. It will use vintage asset prices to construct depreciation schedules for two different car types, the Honda Civic and Ford Explorer, and will observe how these schedules shift over time in response to the gas price and other economic variables.

Theory of Depreciation

Depreciation is the loss in market value sustained by a capital asset due to aging and wear-and-tear. Strictly speaking, depreciation is caused by only two factors: nearly all assets have a limited lifespan, after which they are no longer productive, and many assets also become less productive over the course of their lives. Other determinants of asset prices, such as technological obsolescence and inflation, pertain to revaluation rather than depreciation. To mathematically decompose depreciation and revaluation, we begin with a simple expression for the price change of an asset from one period to the next, where s represents the age of the asset in the initial time period t:

$$\Delta P = P(t, s) - P(t\text{-}1, s\text{-}1) \tag{1}$$

We may then add a term $[P(t, s\text{-}1) - P(t, s\text{-}1)]$ to the equation and rearrange terms to reach:

$$\Delta P = [P(t, s) - P(t, s\text{-}1)] + [P(t, s\text{-}1) - P(t\text{-}1, s\text{-}1)] \tag{2}$$

The term in the first set of brackets denotes depreciation: the price change as an asset's age increases by one year, holding constant other economic factors that vary across time periods. The second term, which represents revaluation, holds the age of an asset constant and measures the effect of changes in technology, inflation or other ambient factors from one period to the next (Storchmann 2004).

As inputs in the production process, capital assets derive their value from their role in the production of final goods, as well a possible scrap value for the asset once its productive capacity is exhausted (scrap value may be positive or negative). Mathematically, the market value of an asset equals the present value of the discounted benefits it generates for the remainder of its life, plus its appropriately discounted scrap value. The following equation describes the market value of an asset with a remaining lifetime of T years. The term f represents the benefits generated by a given period, summed for each remaining period τ. A constant discount rate r is applied to discount future periods, and the equation assumes no scrap value (Hulten and Wykoff 1996).

$$P_{t,s} = \sum_{\tau=0}^{T} \frac{f_{t+\tau,s+\tau}}{(1+r)^{\tau+1}} \tag{3}$$

Rates of depreciation are largely determined by the changes in efficiency experienced by assets as they age. As some types of assets age they may partially wear themselves out or may decline in reliability, leading to a diminished productive capacity. To include efficiency changes, we can add a new term to the equation: φ represents the productive efficiency of an aged asset, as a ratio of the efficiency of a new asset.

$$P_{t,s} = \sum_{\tau=0}^{T} \frac{(\varphi_{s+\tau})\,(f_{t+\tau,s+\tau})}{(1+r)^{\tau+1}} \tag{4}$$

Different types of assets will exhibit different efficiency changes, so there is no single depreciation schedule universal to all asset types. The simplest case, called the *one-horse shay* model, assumes that an asset operates with constant efficiency until the end of its lifetime. In this case the efficiency term φ simply equals one throughout the asset's lifetime, so it may be omitted as in Equation 3. A common example of a one-horse shay asset is a light bulb, which produces a constant stream of light until it burns out and becomes worthless. Table 1, adapted from Storchmann (2004), derives the market value for a one-horse shay asset with a ten-year life and a discount rate of 10%.

As it approaches the end of its life, a one-horse shay good exhibits an accelerating depreciation rate due to the discounting effect; this leads to a price-age curve that is concave down.

Other models of depreciation assume that assets become less efficient as they age. For example, old cars suffer in reliability and performance relative to new ones, and often require more maintenance to operate. Since the depreciation schedule is closely linked to the pattern of declining efficiency, an endless array of depreciation paths are theoretically possible. Two important and commonly-used models, however, are *straight-line* and *geometric* depreciation. Under the straight-line model, an asset loses a fixed dollar value each year until becoming worthless at the end of its life. As a simple example, an asset with a five-year life and a starting value of $100 will depreciate by $20 each year. This is the simplest way to estimate a dollar value for depreciation, making the straight-line method popular for accounting purposes, but it may not be the most accurate measure for many types of assets.

Table 1: One-Horse Shay Depreciation (Discount Rate 10%)

Year	Rental	Value of Discounted Rental at Beginning of Year									
		1	2	3	4	5	6	7	8	9	10
1	10	10									
2	10	9.09	10								
3	10	8.26	9.09	10							
4	10	7.51	8.26	9.09	10						
5	10	6.83	7.51	8.26	9.09	10					
6	10	6.21	6.83	7.51	8.26	9.09	10				
7	10	5.64	6.21	6.83	7.51	8.26	9.09	10			
8	10	5.13	5.64	6.21	6.83	7.51	8.26	9.09	10		
9	10	4.67	5.13	5.64	6.21	6.83	7.51	8.26	9.09	10	
10	10	4.24	4.67	5.13	5.64	6.21	6.83	7.51	8.26	9.09	10
Value of Asset		67.59	63.35	58.68	53.55	47.91	41.70	34.87	27.36	19.09	10.00
Normalized Value		100.00	93.73	86.82	79.23	70.88	61.69	51.59	40.47	28.25	14.80
Depreciation		----	6.27	6.90	7.59	8.35	9.19	10.11	11.12	12.23	13.45
Depreciation Rate		----	6.27	7.36	8.74	10.54	12.96	16.38	21.55	30.21	47.62

Source: Storchmann (2004)

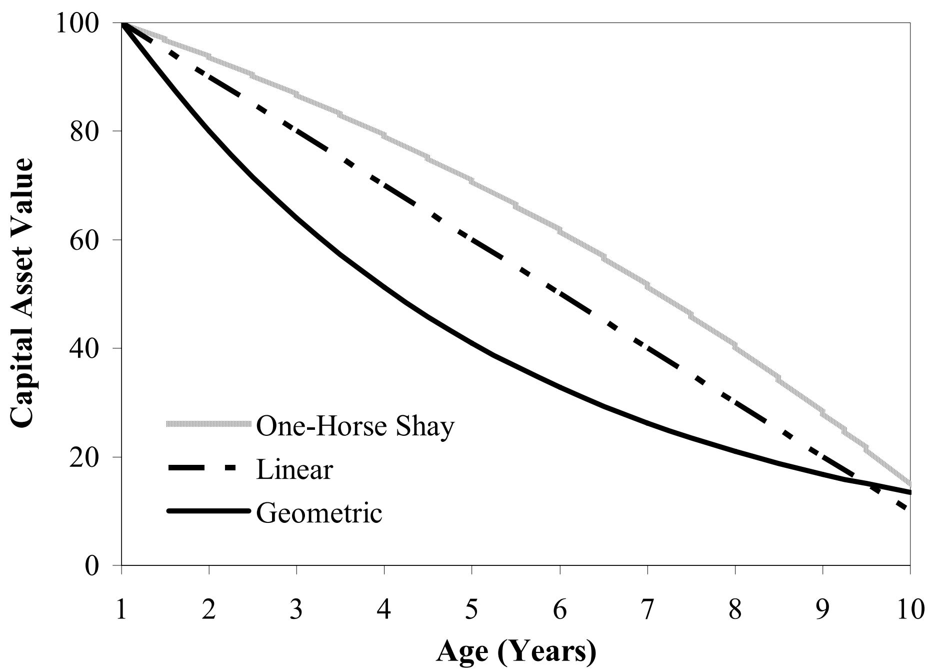
Geometric depreciation assumes that an asset loses a constant *percentage* of its value each year. A unique property of geometric depreciation is that the asset's efficiency, as well as its price, declines by a fixed percentage each year (Storchmann 2004):

$$\boldsymbol{\varphi}_0 = 1;\ \boldsymbol{\varphi}_1 = (1-\delta);\ \boldsymbol{\varphi}_1 = (1-\delta)^2;\ldots\ \boldsymbol{\varphi}_t = (1-\delta)^t \tag{5}$$

This produces an exponential (concave up) depreciation function, where an asset deprecates quickly early in its life but later levels off in value A major empirical problem with geometric depreciation is that asset prices never actually reach zero; thus it is not well suited to predicting the total service life of an asset or when applied to very old assets.

To compare the three cases discussed above, Figure 1 displays the depreciation paths for a hypothetical asset originally worth \$100. The One-Horse Shay path uses the data from Table 1 (ten year life; 10% discount rate). The linear path assumes constant depreciation of \$10 per year, and the geometric path assumes an annual depreciation rate of 20%. Note that these values are arbitrary and have no mathematical relationship with each other; this graph is intended only to demonstrate the different shapes taken by the various models.

Figure 1: Asset Age-Price Paths for Various Depreciation Models



In an important study, Hulten and Wykoff (1981) use the Box-Cox power transformation, which allows for more flexible depreciation functions, to test the viability of these common models. They construct empirical depreciation schedules for several classes of capital from observed market values of used assets, and employ the Box-Cox method to fit the best possible curve. The authors have found that using a constant geometric rate of depreciation tends to slightly exaggerate depreciation early in a good's life, and underestimate it later − in other words, the "true" curve generally lies between the linear and geometric cases. Nonetheless, they have concluded that the geometric model is a reasonably accurate approximation for many categories of capital goods, including automobiles. Numerous studies of vintage automobile prices have confirmed a close fit to the geometric model, so it remains the standard approach for empirical work. The present study will assume a geometric depreciation pattern for used cars.

The efficiency of an asset of a given age, and hence its rate of depreciation, is also subject to changes in the operating costs associated with the asset. If the price of an input required to operate the asset increases, the net benefits produced by using the asset will decrease, which can accelerate depreciation even though the asset itself has not technically changed. Gasoline, maintenance, insurance, and storage are examples of inputs necessary for the operation of automobiles. An increase in operating costs may cause an immediate change in the price of used assets. This does not represent an instant bout of depreciation (a movement along the age-price curve), but rather a change in the implicit rate at which the asset has been depreciating throughout its life (a shift of the age-price curve). Depending on the nature of the operating cost, the curve may shift in parallel or it may assume a new slope. For example, an increase in the cost of a maintenance procedure may steepen the depreciation curve by preferentially affecting the value of older cars, whereas an across-the-board hike in car insurance premiums might cause a more parallel shift.

Gas Prices and Depreciation

As gasoline is the most significant operating cost involved in automobile use, changes in its price should have substantial effects on the efficiency and asset prices of automobiles. It is an oversimplification, however, to assume that the prices of used autos will always be driven down by high gas prices. In a heterogeneous market, consumers will be able to choose between automobiles with different operating costs and different productive abilities. When the gas price changes, they will optimize from the available options to maximize the benefits they derive from automobile use − some cars will gain in efficiency relative to others and become more desirable options.

Although thus far this study has treated automobiles as inputs in a production function, at this point it will be more illustrative to treat cars as final goods purchased by households. This is because many of the choices involved in car ownership are too subjective to capture in discrete units of output. Naturally, using an automobile produces a certain amount of utility. Part of this utility is derived simply from transportation: consumers undertake travel activities as a means to engage in desirable activities elsewhere. For this purpose, all modes of transportation which reach their destinations at a given speed are equivalent. Yet the comfort, safety, prestige or excitement afforded by driving certain cars also generates utility, so consumers will not see the benefits of all cars as perfectly equal. Thus the choice of a vehicle depends on more than simply a dollar-per-mile cost parameter, and the expected effects of a gas price increase can be complex in the heterogeneous automobile market.

When the operating costs of automobiles increase, this will affect the number of cars in operation (the car stock), the overall fuel economy of the car stock, and the intensity of use (how many miles each car is driven annually). For the purposes of this study, it will not be necessary to decompose these effects, as we are mainly interested in the net asset price changes that result from all three forces acting collectively. Conceptually, however, it will be useful to differentiate between the substitution and income effects caused by a gas price increase.

In general terms, a substitution effect occurs because consumers will demand less of a good when its price, relative to other prospective goods, increases. When gas is expensive the relative price of driving a fuel-intensive is high, consumers will substitute away toward more fuel-efficient alternatives. Some consumers might reduce their use of gas-guzzling vehicles and drive fuel efficient cars instead. Other consumers, however, might reduce their use of car services altogether; some might switch to other modes of transportation such as mass transit or walking, while some might simply decide to take fewer trips. In sum, the substitution effect should reduce demand for fuel-intensive cars, but the effect on fuel-efficient models is ambiguous.

The income effect occurs when a price increase diminishes a consumer's real income − the total amount of goods that person can buy. High gas prices will increase the transportation costs for nearly everyone who uses motorized transport, effectively reducing users' incomes. To compensate for their reduced incomes, consumers will gravitate away from relatively superior goods toward relatively inferior goods. The intuitive conclusion − that large cars are superior goods relative to small cars, while new cars are likewise superior relative to used models − is generally supported in the literature

(Blomqvist and Haessel 1978). The fact that small cars tend to be more fuel-efficient further complicates the picture, since their fuel economy is not the reason they are considered inferior goods. Again, several effects are possible. Reduced incomes will shift some buyers from new cars to used models, while other consumers will buy smaller and less luxurious vehicles than before, be they new or used. Finally, since mass transit and walking are likely inferior relative to any form of car transportation, some consumers may cease driving their cars altogether. Thus all we can conclude with certainty is that the income effect should reduce demand for large new cars; the net effect for small new cars, as well as for used cars of any size, is ambiguous. The literature generally finds that depreciation and scrappage are procyclical phenomena, suggesting an inverse relationship between income and used car demand (Greenspan and Cohen 1999), but there is no conclusive evidence on the income effect for particular models of used cars, or about the income effect from gas price changes.

To summarize, we cannot determine *a priori* the net effects of gas price changes on the depreciation of either large or used cars. Bercovec (1985) and Tishler (1982) have each concluded that high gas prices diminish the net demand for used cars and accelerate scrappage rates. Blomqvist and Haessel (1978) suggest that high gas prices actually bolster the demand for small used cars. There is no clear scholarly consensus, as results seem to vary substantially when different car types and periods are examined. Nonetheless, the *relative* effect for small vs. large used cars is much clearer: both the income and substitution effects push consumers towards smaller automobiles, whichever direction the absolute prices move. In terms of depreciation, large cars should experience a greater depreciation effect relive to small cars when the gas price is high.

Review of Literature

The literature on automobile demand and gasoline prices is relatively extensive, and was an especially popular topic in the 1970s and early 1980s − presumably in response to the oil crises of 1973 and 1979, and the emergence of small, fuel-efficient Japanese cars as a threat to the Detroit establishment. However, somewhat less research has been conducted in the last decade, and it is difficult to say how well the conclusions of these earlier studies might apply to today's auto market. Additionally, most of these studies use annual price data derived from published reports like the *Kelly Blue Book.* Although this practice facilitates the collection of a large data set, I believe that direct data like newspaper classified ads are more effective to track short-term changes in the auto market.

Johnson (1978) is among the first studies of automobile demand to posit a heterogeneous car stock. Previous work had drawn distinctions between new and used cars, or between used cars of given ages, but had failed to effectively explain used car prices. Johnson assumes "the services of new cars to be considered by consumers as qualitatively superior to the services of used cars," which implies that new and used cars are imperfect substitutes; he infers that demand for new cars should be more elastic with respect to price and income changes. This study does not, however, attempt to segregate cars based on size or fuel economy, and does not consider the gas price or other operating costs. Like many other researchers, Johnson makes use of the user cost theory of asset pricing. This theory assumes that buyers of capital assets base their demand on the implicit rental price they pay to own the asset. The implicit rental price is "derived from the new and used purchase prices and the market rate of interest," and so is equivalent to the wealth lost in capital consumption (depreciation and revaluation). Johnson's analysis of used car implicit rental prices, based on U.S. data from 1954 to 1972, confirms his hypothesis about the superiority of new cars. Nonetheless, Johnson's results vary extensively when different weighting schemes are applied, which makes it difficult to establish any concrete auto demand functions from the study.

Blomqvist and Haessel (1978) further decompose the car stock by estimating "demand functions for cars by size and age class with particular attention to the effects of gasoline prices on the composition of demand." The authors assume new cars to be superior relative to large cars, but they also suggest that large cars are analogously superior goods relative to small cars, since the former tend to be more comfortable and luxurious. The study decomposes the effects of gas price changes into large-car and small-car categories in order to account for substitutions between different car types. Based on published price data for the Canadian auto market, Blomqvist and Haessel estimate separate income and price elasticities for new large cars, new small cars, and used cars as a whole. The cross-price elasticities indicate strong substitutability between cars of different sizes and ages, but small new cars and used cars appear particularly close substitutes, presumably because they share the same budget-conscious class of buyers. Large new cars are found to be much more responsive to the effects of gas price changes than small new cars, whose prices appear to be almost independent of the gas price. While the results imply that small and large used cars should experience similar effects, the study does not decompose the used car stock in the same way, so it cannot predict the net effects of gas price changes on demand for large versus small used cars.

Tishler (1982) develops a model for automobile demand that includes both user costs and operating costs such as gasoline and maintenance. According to Tishler, previous studies of automobile demand have erred by omitting operating costs, as well as the transaction costs associated with replacing vehicles: "the faster-than-average depreciation of new cars, a specific tax, a cost of preparing the older car for sale, or even the possibility of buying a 'lemon.'" Tishler also assumes that cars of different ages and sizes are not perfect substitutes for each other. In the study, automobiles are categorized by engine size "to further investigate the effect of the increase of the price of gasoline on the distribution of the stock of cars according to engine size." Tishler finds that the elasticity of auto demand with respect to gas prices increases as engine size increases; in other words, large fuel-intensive cars are more sensitive to changes in the gas price. This finding matches the assumption that new cars may be considered luxuries relative to used cars, and so should be more responsive to operating cost changes.

Bercovec (1985) attempts to simultaneously model the entire automobile market by capturing changes in the car stock due to sales of new cars and scrappages of used cars. Because environmental policies may have major repercussions on the used car market, Bercovec claims, a proper analysis of policy effects must examine the auto market as a whole. As an example, he suggests that the effectiveness of Corporate Average Fuel Economy (CAFE) standards for new cars could be undermined if they merely lead consumers to migrate to more fuel-intensive used cars. The study models the values of used cars according to a hedonic pricing system. This method derives implicit values for certain car traits based on a price regression for the entire auto market; the value for an individual car is a function of the values of its various traits. This is a fundamentally different pricing system than the user-cost approach, and is arguably better-suited for tracking subjective consumer behavior. Bercovec's model treats new car prices as exogenous (determined by the production functions of a competitive auto industry), and estimates the values and scrappage rates of used cars over time. These values are then combined into a model that simulates the entire automobile market from year to year. The study's most relevant finding is that high scrappage rates tend to coincide with high gas prices, suggesting that on the aggregate level, "gasoline price increases cause increased scrappage by lowering the aggregate demand for vehicles." This model does not, however, disaggregate this finding into different car types to examine the relation between fuel economy and depreciation or scrappage rates.

Kahn (1986) also utilizes the hedonic pricing technique as a measure of value, and employs an expectations-based approach to measure the impact of energy prices on used car valuations. His model seeks to determine the extent to which relative prices of used cars adjust "so as to equate ex ante rates of return across all car models." If automobile services are viewed as generally homogeneous, the relative prices of different car models should adjust so as to cancel out the expected gas price change and reach a uniform "rate of return" ratio between asset prices and net benefits. Such an adjustment could remain incomplete if "different types of cars are not good substitutes (so that divergences in rates of return are possible), or that substantial short-run supply responses occur." Kahn empirically compares asset price changes to his estimates of gas price expectations, using both a static and an adaptive (ARIMA) expectations model. For each year between 1973 and 1981, Kahn estimates the relative price difference between a 12 mile-per-gallon car and a 25 mile-per-gallon car resulting from changing expectations. The conclusion is that expectations of higher gas prices lead to a higher relative valuation for fuel-efficient cars, with the effect of nearly equalizing their respective rates of return. Unsurprisingly, the years 1974 and 1980 (following the major oil shocks) show the greatest such effect. Kahn's results do suggest a very high degree of substitutability between used car models, though the evidence is not strong enough to prove complete price adjustment or perfect substitutability.

Eskeland and Feyzioglu (1997) attempt to estimate the effects of prospective emissions control policies in Mexico through a model of total fuel demand. Their model decomposes total gasoline consumption into the size of the car stock and the intensity of use per car, and seeks to empirically determine each. When they examine the demand for new cars, the authors find a positive elasticity with respect to the gas price, which implies that high gas prices promote sales of new cars and scrappage of older cars. While this result is somewhat surprising, it is possible that some buyers select new cars for their greater fuel efficiency, "so that there is some substitutability between new cars and gasoline. Such an effect would heavily depend on the technological characteristics of the used car stock, and we may safely assume that used cars in a developing nation like Mexico tend to be older and less fuel-efficient than in the United States. Due to major differences in such technical traits, as well as in consumer behavior generally, it seems unwarranted to assume that a similar gas price-scrappage relationship holds in the U.S.

Hamilton and Macauley (1998) examine the relationship between automobile longevity and operating costs − specifically, the cost of maintenance, repairs and replacement parts. Over the last 40 years, the average service lifetime of the car stock has increased by some 30%. The conventional wisdom attributes this longevity to quality improvements in the way cars are constructed, but Hamilton and Macauley suggest a different explanation. They note that, during the time interval in question, the degree of competition in the industry has increased dramatically as Asian and European brands have entered the U.S. auto market. When the industry was more concentrated, automotive firms exploited their monopoly powers by charging inflated prices for parts and maintenance. The additional competition today has brought such prices closer to the competitive level, which makes operating an older car much more affordable. The relative decline in operating costs for older cars has flattened the depreciation curve for cars and led owners to postpone scrappage, which is the source of longer car longevity. This effect is somewhat analogous to a gas price change in that both represent operating costs. The main difference, however, is that maintenance costs disproportionately affect older used cars. Since fuel efficiency declines only slightly as a car ages, gas price changes should impact different vintages of a given car type more equally than maintenance costs.

Greenspan and Cohen (1999) construct another comprehensive model of the car stock, with an emphasis on forecasting future sales of new cars. While much of this study lies outside the topic in question, it makes an important contribution in developing a more precise notion of scrappage. The study decomposes scrappage into two components: engineering scrappage, a result of physical deterioration as a car's age and mileage increase; and cyclical scrappage, an adjustment to the scrappage rate based on the business cycle, gas prices, and other non-physical variables. This is analogous to the common distinction between a natural rate of unemployment and a cyclical unemployment factor that can be positive or negative. The authors observe that scrappage rates move in a procyclical manner, which indicates that in good economic times the total demand for used cars falls, implying that such cars are inferior goods. Interestingly, the study finds that "as the price of gasoline rises scrappage declines," (the opposite of the findings in Mexico) and hypothesize that this takes place because the "higher cost of driving results in fewer miles driven and hence less wear and tear." Greenspan and Cohen do not, however, attempt to prove this claim by examining gas price changes while holding constant mileage per year, nor do they address other possible mechanisms, such as an income effect shifting automobile demand towards inferior used cars.

Storchmann (2004) has assembled an international comparison of depreciation rates, based on vintage asset prices from classified advertisements. This study finds a marked variation in auto longevity, particularly in developing versus developed nations. To explain the variation across countries, Storchmann cites differences in income and intensity of usage. Particularly, richer countries tend to drive their vehicles more heavily, and can afford to replace them with new models more quickly. The econometric results also suggest "a positive relationship between fuel prices and depreciation rates," although this result is less robust than the income component. Since the sample of automobiles varies from country to country and since factors like income and gas price tend to be interrelated − gasoline is typically more expensive in poor countries − it is difficult to make strong claims about the relationship between gas prices and used car depreciation, *ceteris paribus,* from this study.

Data and Considerations

To empirically test the effects of the gas price on used car values, I have constructed models of depreciation based on the vintage prices of used cars at various times. The market prices of these cars are derived from list prices in classified advertisements, collected each month for the period 2001-2005 from the *Seattle Times*. I have chosen two car models, the Honda Civic and the Ford Explorer, as comparative cases. These models were chosen largely for their popularity, which ensures an adequate sample of ads each month. The two cars also have very different fuel characteristics: the Civic, a small economy car, is well known for its excellent mileage. The Explorer, in contrast, is a large sport-utility vehicle with relatively poor fuel economy.

For consistency, all prices were collected from Sunday editions of the *Seattle Times.* I chose 100 observations per month as a minimum sample size, which often required collecting data from several Sundays within a single month. This raised the problem of duplicate entries: some cars that did not sell immediately were listed in multiple weeks (this also occurred occasionally between different months). The main concern is that duplicate entries would be more heavily weighted in a regression than single entries. Since it is logical that overpriced cars will not sell quickly and are more likely to appear in multiple weeks than accurately price cars, this threatens to bias the overall car price upward. However, the quantity of duplicate entries is relatively small, and there is no conclusive way to differentiate between duplicate entries and separate cars carrying the same list price. Thus I did not attempt to correct for duplicates, though I did attempt to avoid selecting cars from consecutive weeks in order to minimize their presence.

Though the age of a used car plays the greatest role in determining its price, it would be ideal to consider other factors, such as overall condition, mileage, options and trim levels, as is done in the hedonic pricing models. Unfortunately, such traits are not uniformly reported in the ads, so it was not possible to include them in the depreciation function. For example, many sellers include a mileage figure for their car, but since sellers have an incentive to make their merchandise appear as attractive as possible, the ads will tend to disproportionately report low mileages. For this reason, age is the only car characteristic to be included, but this alone is still sufficient to the vast majority of the variation in prices. I did choose to remove certain cars from the sample if they did not fit the population I intend to examine: I excluded certain high-performance sports variants of the Civic (the Si, Type-R, CRX and Del Sol) because these do not share fuel-efficient, economical driving characteristics of standard Civics. Also excluded were any cars that advertised after-market modifications and those that reported major damage from an accident. These types of cars could carry prices very different from the general population due to their special attributes, which are unrelated to the normal pattern of depreciation.

One potential problem with the data set is its relatively brief duration: while the sample is adequately large from a statistical point of view, a longer period of time would help to isolate gas-price effects from other macroeconomic trends. Also, during this period of recovery from the recession of 2000-01, income, consumption, interest rates and gas prices have all followed a relatively smooth upward trend. The resulting problem of multicollinearity and its effect on model construction will be discussed in depth later. Unfortunately a larger sample period was unavailable, both for reasons of practicality and because of underlying limitations in the available data. The Explorer was only launched in 1991, which limits the available sample of vintages to that year and later, a problem that becomes worse as the sample date is extended backward in time. Very few car models have a long enough model history, as well as a large enough population of ads, to make a much longer study feasible.

Other problems are characteristic in using the prices of marketed assets as proxies for the values of all similar assets. Censored-sample bias, also called survivorship bias, results from the fact that classified listings generally omit individual cars that have already died and are thus unmarketable. The market sample will exaggerate the mean price and underestimate depreciation for an asset class since it does not account for members whose value has already reached zero. Hulton and Wkyoff (1981) have proposed a method for correcting for censored-sample bias: they estimate the survivorship rate from a statistical distribution based on the mean lifetime of an asset, and correct the market value of a given vintage by compensating for assets that have already died. However, this approach rests on rather arbitrary choices for the mean service life and the mortality distribution, so its usefulness for bias correction is limited. Since the present study is more concerned with the change in depreciation over time than with the absolute rates, as long as automobile mortality has not changed drastically over the five years of the sample, the effects of survivorship bias should be minor enough to neglect this issue.

Another issue with classified prices concerns the “lemons” hypothesis introduced by Akerlof (1970). This model assumes that sellers of used cars will generally know if their car is an unreliable “lemon,” whereas buyers will not. If all used cars sell for the same market price, sellers will be inclined to exploit their information advantage, selling their lemons (whose true value is below the market price) but keeping the more reliable models. While buyers do not know if a given individual car is a lemon, they will come to assume that *any* car a seller wishes to dispose of is a lemon, and will be disinclined to buy anything. The threat of lemons will drive down the market price even for reliable cars, which means that resale prices will exaggerate depreciation relative to the intrinsic productivity of the average car. Nonetheless, Akerlof concluded that both parties have an interest in enforcing honesty, and so have created institutions to protect consumers and hold sellers of lemons accountable. For example, one reason for the existence of major brands is that companies will have an interest in defending their brand’s reputation for quality. Most scholars agree that the lemons problem is not serious and may safely be disregarded (Storchmann 2004). As evidence they observe that the used car market − even when transactions are often unprotected by warranties, brands or other safeguards − remains large and vibrant.

Even if we accept that market transaction prices accurately measure the real value of used assets, one additional problem remains: classified ads represent the asking prices of sellers, not actual transaction prices. It is logical to assume that sellers begin by quoting a price higher than true market value, expecting to haggle with buyers down to a more reasonable sum if necessary. If this is the case, classifieds would systematically exceed the true price at which the market clears. Here we have little choice but to assume that these figures are reasonable proxies for transaction prices, as there is no way to tell which prices are accurate and which are not. Fortunately, sources like the *Kelly Blue Book* provide buyers and sellers with a wealth of information about the appropriate market value for a given vehicle, so sellers will have little incentive to quote an outrageously high price. And again, since this study is concerned with changes over time, the effect of this issue should be negligible as long as the aggressiveness of sellers has not changed substantially across the sample period.

As a final issue, we should consider whether the difference in price between used vehicles of different model years results from quality improvements as well as depreciation. Civics and Explorers built today are somewhat different than those built fifteen years ago − we can expect newer models to include CD players, advanced safety systems and other amenities. If new cars are superior in quality to older ones, they will naturally sell for higher prices, independent of the effect of depreciation. This phenomenon will tend to exaggerate the falloff in price as we compare cars of different vintages. Other studies have proposed various corrections: some use a system of dummy variables for each model year, which can become quite cumbersome with a long time period. Alternatively, Jorgenson (1996) suggests that "changes in quality may be incorporated into price indices by capital goods by means of the 'hedonic technique,'" which may be used to determine a dollar value for the specific quality improvements present in new cars. Unfortunately, this requires a great deal of raw data on the prices and features of cars from different years, which was not available in the present study. Price changes from quality improvements should, however, be partially captured by the inflation rate as measured by the CPI. Indeed, a major criticism of this index is that it fails to differentiate between quality and inflation effects on prices, but here this trait is actually an advantage. Since this study is not greatly concerned with differentiating between the two, using the CPI as a deflator should help to cancel out the effects of both quality improvements and inflation. The resulting real prices should approximate the effect of holding quality constant across the sample.

Variable Choice and Multicollinearity

My macroeconomic variables are all taken from published data sets. Wherever possible I selected regional data sets to better reflect the Seattle area auto market. The gas price is the average monthly price for regular unleaded sold in Oregon and Washington, as reported by the United States Department of Energy. My measure of inflation is the Consumer Price Index for the Western United States, provided by the Bureau of Labor Statistics. Since it logical to assume that car prices will be affected by changes in income unrelated to the gas price, I have introduced consumption as a proxy for disposable income (income data was not available at monthly intervals). Monthly data for national consumption expenditures for all goods, as well as expenditures for only durable goods, is adapted from the St. Louis Federal Reserve's online database. The full data sets are reproduced in Appendix A.

As noted above, multicollinearity presents a significant problem for the variables and time interval under consideration. Multicollinearity occurs when the independent variables in a regression are highly correlated with one another. This phenomenon makes it difficult for the regression process to distinguish which of the independent variables is affecting the dependent variable. As a result, a model with strong multicollinearity will suffer a lack of precision in its estimations, and may even produce the wrong signs for some coefficients. A related concern is that strongly linear variables, even if not correlated with other variables, may tend to capture trend-type changes that overshadow the actual parameter in question. Table 2 lists the correlations between the independent variables used in my study before any correction for inflation. The "trend" variable is a linear function describing the number of months elapsed since the beginning of the time interval.

Table 2: Correlation Matrix for Nominal Variables

	Gas Price	CPI	Consumption (Total)	Consumption (Durable)	Trend
Gas Price	----	0.968	0.922	0.724	0.921
CPI (West)	0.968	----	0.979	0.787	0.978
Consumption (Total)	0.922	0.979	----	0.818	0.995
Consumption (Durable)	0.724	0.787	0.818	----	0.835
Trend	0.921	0.978	0.995	0.835	----

Table 3: Correlation Matrix for Real Variables

	Real Gas Price	Real Cons. (Total)	Real Cons. (Durable)	Trend
Real Gas Price	----	0.808	0.279	0.804
Real Cons. (Total)	0.808	----	0.615	0.983
Real Cons. (Durable)	0.279	0.615	----	0.550
Trend	0.804	0.983	0.550	----

As the Table 2 indicates, the correlations between many variables are quite strong. An arbitrary but common rule of thumb is that correlations over 80% can be considered potentially problematic; in this case, correlations between every variable except durable goods consumption exceed that threshold. Unfortunately, there is no precise econometric test for the extent of multicollinearity, nor is there a simple transformation to correct for the problem. This forced me to alter my model in order to avoid using strongly correlated variables in the regression. I originally intended to include the CPI as a separate independent variable to measure inflation effects on car prices, but chose instead to combine the CPI with the nominal variables as a deflator. Table 3 reports the correlations when the resulting real variables are used instead. Because this has removed the common movement of the variables due to inflation, the correlations are significantly lower, but the possibility of multicollinearity issues still exists.

Multicollinearity also induced a revision of the consumption term. Total consumption is the more theoretically proper measure, as the regression coefficient for this variable would produce an income elasticity for used car prices, and provide information about the prevailing income effect. We see in the table that real total consumption has an 80% correlation to the gas price and a 98% correlation to the linear trend, sufficient to create a potential for inaccuracy. As a possible substitute I have included consumption on durable goods. This variable is considerably more volatile than total consumption, and has a much lower correlation to the other variables, but is less appropriate from a theoretical standpoint. The regression coefficient for this variable describes how used car prices react to spending on new cars and other durable goods, which can be viewed as an indicator of substitutability between these classes. For comparison purposes, I have run separate copies of each of my models, alternatively using total and durable consumption. I have additionally included equations which leave out consumption entirely; this eliminates the possibility of multicollinearity, but at the risk of introducing an omitted variable bias. Finally, I originally intended to include the trend term as an independent variable to capture miscellaneous phenomena such as quality improvements in cars and preference changes. The trend variable was left out due to its significant correlation with consumption and the gas price, and because the other highly-linear variables will probably capture such effects on their own.

Econometric Models

My most basic model of depreciation is a series of monthly cross-sections. For each month and car type, car prices are regressed against age (the current year minus a car's model year). To produce a geometric depreciation curve we use the natural logarithm of the car price as the dependent variable. The regression equation is as follows:

$$\ln(P_i) = \beta_0 + \beta_1 * S_i \tag{6}$$

where P_i is the price and S_i is the age of each car i in a given month. The absolute value of β_1 can be interpreted as the annual rate of depreciation. The intercept term β_0 represents the predicted price of a zero-year-old used car. It is important to note that this is *not* equivalent to the new car price, since vehicles undergo a substantial depreciation as soon as they are driven off the dealership lot. The intercept term thus captures overall depreciation of all used cars relative to new cars. A sample of the cross-section process, Figure 2 is a scatter-plot of ages and prices for both car types in January 2001. The curves represent the geometric depreciation functions fitted on the data by the regressions. Tables 3 and 4 reproduce the regression results for Civics and Explorers, respectively, and include R^2 values and the number of observations n for each month. To make the results more readable, the tables also report the month's predicted price for a 5-year-old car. The results are also displayed in graphical form in Figures 3-5.

A few observations of the results are in order. R^2 values for the various cross-sections generally range from 0.8 to 0.9 − a very strong result for cross-sectional data − indicating that the geometric model is indeed an accurate measure of depreciation. As Figure 5 demonstrates, value of used cars exhibits a pronounced stair-step effect with a yearly interval: the predicted prices fall throughout a given year and then jump up at the beginning of the next year. For example, in the year 2001 a two-year-old car of vintage 1999 will decline in price as it ages month by month. When the next year begins, however, the two-year-old car group now consists of 2000 vintages, which explains the abrupt jump upward in price. We also notice that much of this stair-step pattern is derived from changes in the intercept term (Figure 3), whereas the depreciation rate shows no identifiable pattern over time (Figure 4). This suggests that some changes in used car demand shift *all* used car values up or down, rather than disproportionately affecting either older or newer used cars. This observation will be tested in the next series of models.

Figure 2: Data and Regression Functions from January 2001

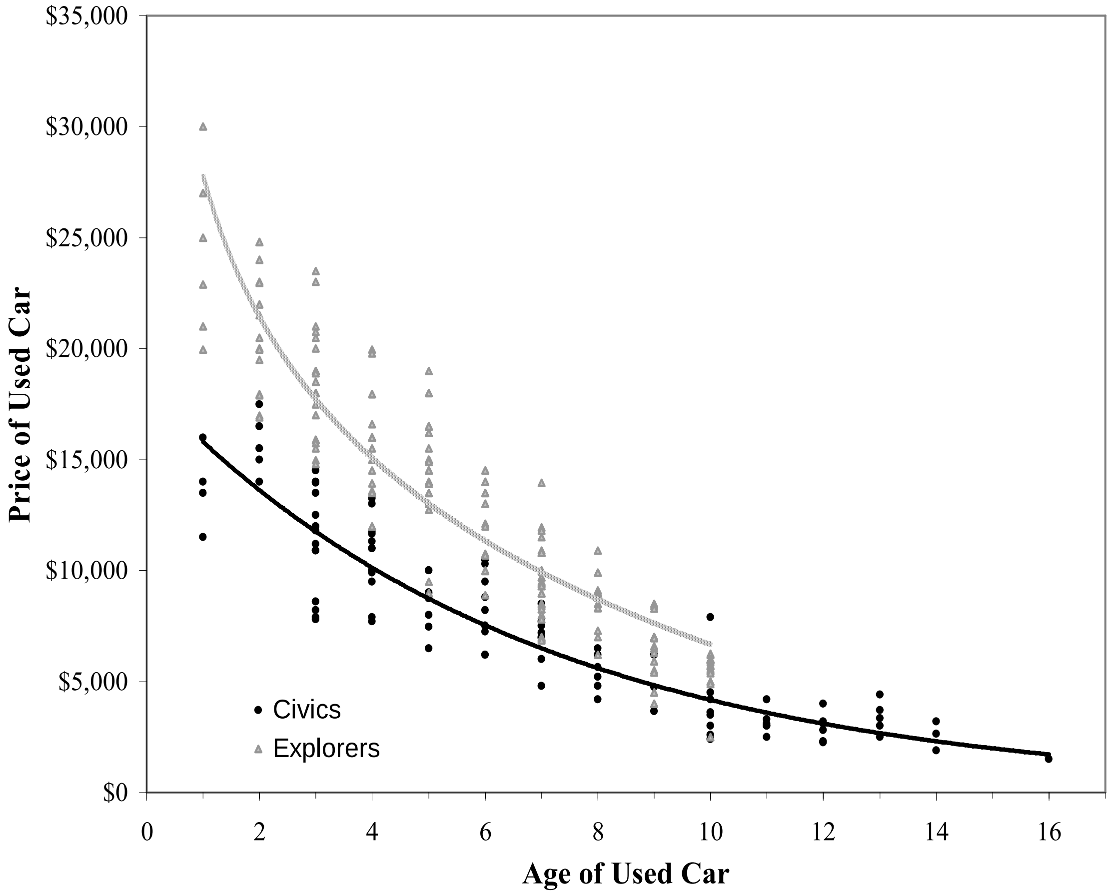


Table 4: Cross-Section Regressions for Civics

Month	*n*	β_0 (Int)	β_1 or -(δ)	Price (5 year)	R^2
Jan 2001	103	9.816	-0.1481	$8,737	0.8652
Feb 2001	128	9.897	-0.1627	$8,803	0.9070
Mar 2001	131	9.839	-0.1581	$8,503	0.7980
Apr 2001	128	9.797	-0.1515	$8,431	0.8569
May 2001	143	9.794	-0.1501	$8,465	0.8872
Jun 2001	163	9.752	-0.1446	$8,343	0.8524
Jul 2001	145	9.773	-0.1547	$8,095	0.8870
Aug 2001	139	9.826	-0.1651	$8,109	0.8897
Sep 2001	136	9.781	-0.1600	$7,949	0.8939
Oct 2001	131	9.696	-0.1465	$7,817	0.9074
Nov 2001	125	9.708	-0.1549	$7,583	0.8942
Dec 2001	136	9.747	-0.1627	$7,580	0.8175
Jan 2002	114	9.744	-0.1414	$8,409	0.9032
Feb 2002	135	9.810	-0.1558	$8,359	0.8954
Mar 2002	153	9.794	-0.1515	$8,407	0.8576
Apr 2002	135	9.790	-0.1592	$8,057	0.9035
May 2002	143	9.748	-0.1481	$8,166	0.8706
Jun 2002	127	9.746	-0.1451	$8,267	0.9067
Jul 2002	132	9.772	-0.1558	$8,049	0.8687
Aug 2002	154	9.738	-0.1504	$7,986	0.9000
Sep 2002	152	9.686	-0.1448	$7,804	0.8722
Oct 2002	155	9.773	-0.1656	$7,670	0.8746
Nov 2002	129	9.736	-0.1597	$7,616	0.9123
Dec 2002	120	9.744	-0.1650	$7,470	0.8851
Jan 2003	269	9.816	-0.1546	$8,462	0.8834
Feb 2003	266	9.792	-0.1487	$8,509	0.8871
Mar 2003	256	9.765	-0.1430	$8,520	0.8679
Apr 2003	240	9.809	-0.1552	$8,372	0.9279
May 2003	249	9.818	-0.1633	$8,113	0.9043
Jun 2003	249	9.726	-0.1490	$7,950	0.9239
Jul 2003	274	9.684	-0.1452	$7,773	0.9078
Aug 2003	152	9.708	-0.1534	$7,642	0.8926
Sep 2003	289	9.662	-0.1424	$7,711	0.8834
Oct 2003	247	9.662	-0.1501	$7,420	0.8913
Nov 2003	223	9.601	-0.1424	$7,252	0.9175
Dec 2003	238	9.610	-0.1497	$7,059	0.8973
Jan 2004	166	9.730	-0.1446	$8,163	0.9049
Feb 2004	176	9.733	-0.1489	$8,013	0.8426
Mar 2004	167	9.750	-0.1541	$7,941	0.8706
Apr 2004	159	9.643	-0.1350	$7,849	0.8495
May 2004	131	9.601	-0.1270	$7,830	0.8273
Jun 2004	157	9.689	-0.1433	$7,883	0.8980
Jul 2004	191	9.669	-0.1292	$8,294	0.8730
Aug 2004	164	9.659	-0.1348	$7,982	0.8889
Sep 2004	182	9.650	-0.1348	$7,910	0.8845
Oct 2004	151	9.634	-0.1374	$7,681	0.8512
Nov 2004	206	9.629	-0.1333	$7,800	0.8529
Dec 2004	196	9.616	-0.1369	$7,563	0.9123
Jan 2005	177	9.565	-0.1312	$7,396	0.8910
Feb 2005	196	9.795	-0.1477	$8,578	0.8489
Mar 2005	197	9.769	-0.1415	$8,621	0.9020
Apr 2005	164	9.732	-0.1349	$8,585	0.9169
May 2005	176	9.740	-0.1346	$8,668	0.8206
Jun 2005	192	9.739	-0.1438	$8,267	0.8165
Jul 2005	154	9.774	-0.1403	$8,713	0.8235
Aug 2005	149	9.686	-0.1302	$8,394	0.8641
Sep 2005	139	9.746	-0.1321	$8,824	0.8788
Oct 2005	152	9.772	-0.1336	$8,988	0.8420
Nov 2005	184	9.665	-0.1234	$8,505	0.8702
Dec 2005	162	9.701	-0.1332	$8,391	0.8844

Table 5: Cross-Section Regresions for Explorers

Month	n	β_0 (Int)	β_1 or -(δ)	Price (5 year)	R^2	Month	n	β_0 (Int)	β_1 or -(δ)	Price (5 year)	R^2
Jan 2001	193	10.3465	-0.1704	$13,287	0.8617	*Jan 2004*	155	10.1947	-0.1767	$11,064	0.8840
Feb 2001	166	10.4327	-0.1860	$13,393	0.8847	*Feb 2004*	133	10.2007	-0.1815	$10,866	0.8742
Mar 2001	198	10.2654	-0.1682	$12,386	0.8794	*Mar 2004*	127	10.2071	-0.1865	$10,662	0.8244
Apr 2001	106	10.2296	-0.1655	$12,113	0.8799	*Apr 2004*	119	10.1802	-0.1763	$10,924	0.8757
May 2001	229	10.1924	-0.1642	$11,748	0.8605	*May 2004*	118	10.1676	-0.1806	$10,556	0.8697
Jun 2001	105	10.2612	-0.1720	$12,102	0.8764	*Jun 2004*	154	10.1745	-0.1804	$10,642	0.8791
Jul 2001	135	10.2344	-0.1729	$11,729	0.8581	*Jul 2004*	132	10.0914	-0.1706	$10,283	0.8657
Aug 2001	141	10.1907	-0.1723	$11,261	0.8177	*Aug 2004*	139	10.1407	-0.1847	$10,070	0.8094
Sep 2001	121	10.1365	-0.1668	$10,963	0.8571	*Sep 2004*	113	10.1377	-0.1829	$10,132	0.8278
Oct 2001	110	10.1188	-0.1702	$10,591	0.8654	*Oct 2004*	125	9.9947	-0.1621	$9,742	0.8700
Nov 2001	127	10.0544	-0.1661	$10,139	0.8423	*Nov 2004*	136	9.9809	-0.1666	$9,393	0.8524
Dec 2001	141	10.1460	-0.1829	$10,213	0.8445	*Dec 2004*	145	9.9889	-0.1678	$9,412	0.8740
Jan 2002	102	10.2691	-0.1763	$11,936	0.7957	*Jan 2005*	126	10.1425	-0.1688	$10,920	0.8271
Feb 2002	100	10.1913	-0.1701	$11,393	0.8380	*Feb 2005*	150	10.1277	-0.1616	$11,155	0.8217
Mar 2002	108	10.2365	-0.1825	$11,201	0.8605	*Mar 2005*	154	10.1150	-0.1582	$11,204	0.8547
Apr 2002	121	10.2040	-0.1740	$11,316	0.8588	*Apr 2005*	129	10.0661	-0.1584	$10,657	0.8617
May 2002	124	10.2001	-0.1729	$11,336	0.8394	*May 2005*	110	10.0825	-0.1605	$10,721	0.8803
Jun 2002	114	10.1999	-0.1776	$11,071	0.8579	*Jun 2005*	101	10.1047	-0.1655	$10,693	0.8917
Jul 2002	101	10.2084	-0.1758	$11,266	0.7921	*Jul 2005*	103	10.0605	-0.1647	$10,270	0.8948
Aug 2002	102	10.1646	-0.1697	$11,115	0.8667	*Aug 2005*	110	10.0614	-0.1629	$10,373	0.8707
Sep 2002	106	10.1583	-0.1764	$10,684	0.8729	*Sep 2005*	134	10.0408	-0.1609	$10,264	0.8498
Oct 2002	115	10.1098	-0.1739	$10,303	0.8671	*Oct 2005*	126	9.9568	-0.1501	$9,957	0.8652
Nov 2002	114	10.0885	-0.1713	$10,219	0.8628	*Nov 2005*	120	9.9822	-0.1568	$9,881	0.9171
Dec 2002	121	10.0533	-0.1608	$10,398	0.8481	*Dec 2005*	131	10.0736	-0.1701	$10,128	0.8830
Jan 2003	219	10.2064	-0.1675	$11,717	0.8531						
Feb 2003	123	10.1670	-0.1600	$11,697	0.8619						
Mar 2003	122	10.1774	-0.1702	$11,229	0.8789						
Apr 2003	128	10.1869	-0.1723	$11,218	0.8664						
May 2003	134	10.1264	-0.1658	$10,909	0.8617						
Jun 2003	129	10.0882	-0.1660	$10,491	0.8852						
Jul 2003	101	10.1877	-0.1790	$10,854	0.8829						
Aug 2003	105	10.1307	-0.1762	$10,404	0.8865						
Sep 2003	119	10.1095	-0.1746	$10,263	0.8654						
Oct 2003	116	10.0374	-0.1720	$9,678	0.8504						
Nov 2003	113	10.0730	-0.1795	$9,659	0.8233						
Dec 2003	169	10.0097	-0.1727	$9,378	0.9019						

Figure 3: Intercept Terms by Month

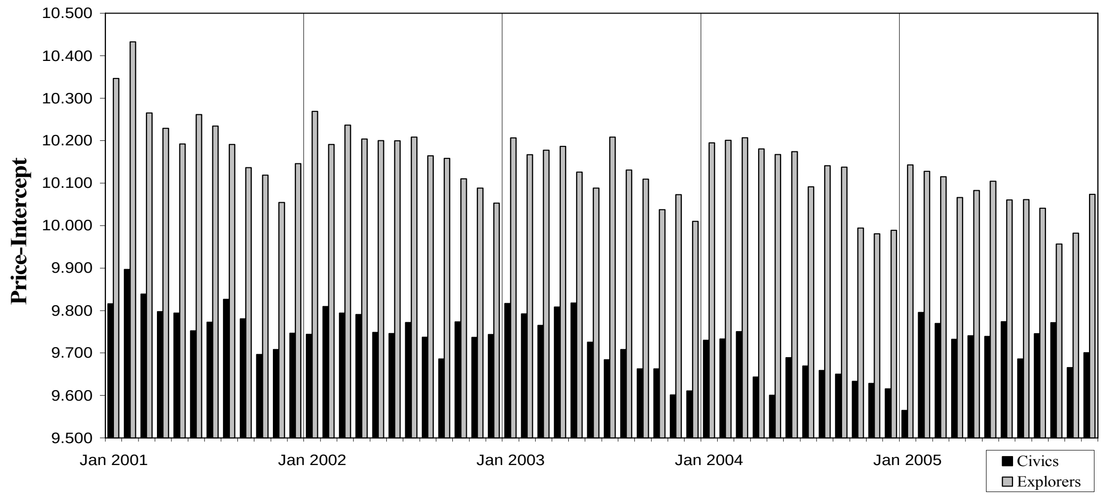


Figure 4: Geometric Depreciation Rates by Month

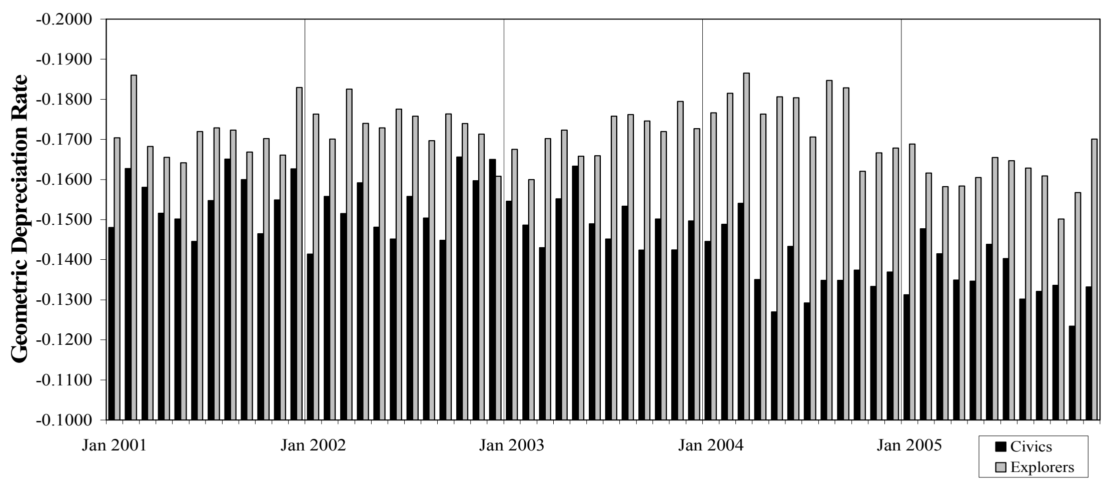
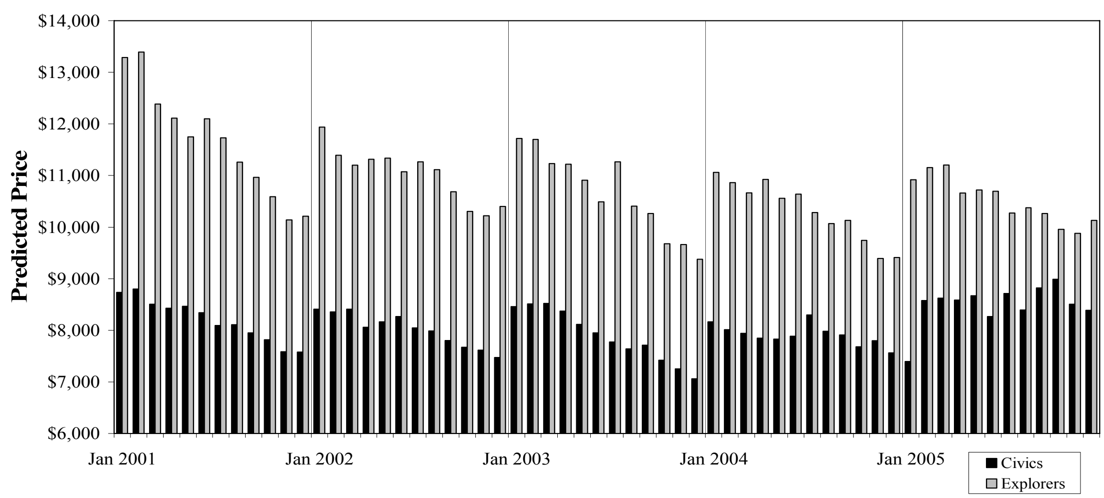


Figure 5: Predicted Price for 5-Year-Old Car by Month



To investigate the effects of gas prices and other macroeconomic variables over time, the information derived from the cross-sections is used as the basis of a set of time-series models. The coefficients produced by each cross-section are regressed against the gas price and once-lagged consumption for the corresponding month. Lagged consumption was chosen on the assumption that it takes some time for macroeconomic conditions to percolate into the used car market. Gas prices, on the other hand, are readily apparent to all observers and should have a virtually instantaneous effect. To correct for inflation, all nominal variables are divided by the CPI for the Western United States. The intra-year depreciation discussed above is captured with a "month counter" variable, a trend function that resets every year − each January has a value of zero, each February one, and so on. In the first time-series, I have used the logarithm of the depreciation rate (δ, or the inverse of β_1 from the monthly cross-sections) as the independent variable. Logarithms were selected to produce constant elasticities from the coefficients; results from a purely linear model were virtually identical and so are not reported here. The regression function is:

$$\ln(\delta_{\mathrm{m}}) = \beta_2 + \beta_3 {*} G_m + \beta_4 {*} C_{(m\,-1)} + \beta_5 {*} T_m \tag{7}$$

In this equation δ is the observed depreciation rate (the absolute value of the age coefficient from the cross-sections), *G* is the real gas price, *C* is lagged real consumption, and *T* is the month counter variable, all for a given month *m*. Separate equations use real consumption, total consumption and no consumption variables, respectively. Table 6 displays the coefficients and corresponding t-statistics produced by the regressions. A bold typeface denotes coefficients that are significant at the 5% confidence level.

To identify possible complications arising from heteroscedasticity, I performed the White heteroscedasticity test on each equation. The table reports the $n\mathrm{R}^2$ term produced by the test as well as the corresponding degrees of freedom for a χ^2 test. If this test indicated the presence of heteroscedasticity at the 5% confidence level, the $n\mathrm{R}^2$ term is shown in bold. And to compensate for the increased potential for measurement error, the t-statistics have been adjusted to account for heteroscedasticity effects according to White's method.

The results of this equation are rather mixed and much stronger for Civics than for Explorers. While gas prices are significant in each case, none of the other explanatory variables appear to be. These results suggest that the gas price has an inverse relationship on the depreciation rates of both car types; in other words, that both will hold their value better in times of high gas prices. As expected, however, this effect is stronger for Civics than for Explorers, implying a relative slowdown in depreciation for the smaller car under high gas prices.

Table 6: Time-Series Regression: Dependent Variable = ln (δ)

	n	Real Gas Price	Durable Consumption	Total Consumption	Month Counter	Intercept	R^2	Adjusted R^2	SSE	White's {DF}
Civic	60	**-0.3056** (**-6.57**)	--------	0.0012 (0.14)	0.0005 (0.24)	**-1.6867** (**-5.66**)	0.5395	0.5148	0.1450	3.81 {6}
Civic	60	**-0.2877** (**-6.84**)	-0.0422 (-1.11)	--------	0.0004 (0.22)	**-1.4452** (**-8.19**)	0.5490	0.5248	0.1420	5.06 {6}
Civic	60	**-0.3029** (**-8.18**)	--------	--------	0.0005 (0.25)	**-1.6437** (**-43.73**)	0.5393	0.5231	0.1451	1.05 {4}
Explorer	60	**-0.1173** (**-3.45**)	--------	0.0002 (0.04)	-0.0006 (-0.34)	**-1.6483** (**-9.44**)	0.2130	0.1708	0.0990	5.30 {6}
Explorer	60	**-0.1300** (**-3.85**)	0.0340 (1.22)	--------	-0.0016 (-0.30)	**-1.8153** (**-14.14**)	0.2287	0.1874	0.0970	5.58 {6}
Explorer	60	**-0.1177** (**-3.83**)	--------	--------	-0.0006 (-0.34)	**-1.6554** (**-59.57**)	0.2130	0.1854	0.0990	3.46 {4}

[White-compensated t-statistics in parentheses]

As we have discussed, however, the geometric depreciation rate alone may not be a measure of depreciation, especially if market forces tend to affect the prices of all used models in a similar manner. For example, if a change in market conditions were to reduce the value of all used cars by 50%, the geometric depreciation rate would be unchanged but the intercept term (the price of a zero-year-old used car) would be reduced by half. Thus it may be necessary to account for changes to the intercept term to fully measure depreciation effects. A relatively crude method is to use the model's predicted price for a used car of a given age. Since the cross-sectional models estimate price in terms of a constant term (the intercept) and an age term, this approach should capture any potential changes in either parameter. We may define the predicted price, intercept and age coefficient for a given month as P_i, B and δ, respectively. Rearranging the logarithmic depreciation function into an exponential function with base e, we find the predicted price for a 5-year-old used car as:

$$P_5 = e^{(B + 5\delta)} \tag{8}$$

The regression function is identical to the first time-series equation; except that the independent variable is now the natural log of the predicted price for a 5-year-old car for the given month:

$$\ln(P_{5,\,m}) = \beta_6 + \beta_7 {*} G_m + \beta_8 {*} C_{(m-1)} + \beta_9 {*} T_m \tag{9}$$

Since the natural log of the predicted price is equal to the term (B + 5δ), we can also rewrite Equation 9 to directly use the results of the cross-sectional regressions:

$$(B + 5\delta) = \beta_6 + \beta_{7*}G_m + \beta_{8*}C_{(m\text{-}1)} + \beta_{9*}T_m \tag{10}$$

Table 7: Time-Series Regression: Dependent Variable = ln (P_5)

	n	Real Gas Price	Durable Consumption	Total Consumption	Month Counter	Intercept	R^2	Adjusted R^2	SSE	White's {DF}
Civic	60	-0.0563	--------	**0.0121**	**-0.0097**	**3.4044**	0.3765	0.3413	0.1269	10.03
		(-1.56)		**(1.99)**	**(-4.40)**	**(16.09)**				{6}
	60	0.0226	**-0.1422**	--------	**-0.0098**	**4.5057**	0.5142	0.4882	0.0989	**16.42**
		(0.66)	**(-3.35)**		**(-5.38)**	**(21.93)**				{6}
	60	-0.0286	--------	--------	**-0.0096**	**3.8356**	0.3439	0.3209	0.1336	**10.60**
		(-0.88)			**(-4.42)**	**(121.71)**				{4}
Explorer	60	**-0.3335**	--------	**0.0256**	**-0.0164**	**3.4776**	0.6893	0.6727	0.1835	**27.03**
		(-7.35)		**(2.58)**	**(-6.35)**	**(10.38)**				{6}
	60	**-0.2118**	**-0.1749**	--------	**-0.0165**	**5.2139**	0.7277	0.7132	0.0161	**18.82**
		(-5.76)	**(-3.10)**		**(-7.59)**	**(18.41)**				{6}
	60	**-0.1114**	--------	--------	**-0.0157)**	**9.4779**	0.6343	0.6214	0.1257	**9.76**
		(-4.81)			**(-7.92)**	**(340.33)**				{4}

[White-compensated t-statistics in parentheses]

Table 7 presents the results of this regression, again with three separate equations for the consumption possibilities. Although the R^2 is slightly lower for the Civics compared to the previous model, it has improved significantly for Explorers. Furthermore, the coefficients for both consumption and the month counter (intrayear depreciation) are now highly significant. The White test indicates heteroscedasticity in all but one of the equations, but this does not appear to have a large detrimental effect on the accuracy of the results. Interestingly, while for Explorers the gas-price elasticity is negative and significant in both cases, for Civics it is insignificant. In my opinion, this suggests that the positive and negative demand effects introduced in the theory section tend to cancel each other out. Yet we still see a substantial *relative* increase in the value of Civics vis-à-vis Explorers when the gas price increases. However, we should remember that this is a relatively crude measuring technique: the choice of a 5-year-old used car is arbitrary, and the intermediate step of using calculated values as independent variables has removed us somewhat from the source data. Both of these factors reflect poorly on the explanatory power of this regression.

These problems can be mitigated, however, by directly relating gas prices and auto prices without resorting to the intermediate step of the cross-section models. To do this I have constructed a pooled model that includes all the observed prices for each car type. The listed prices of the cars are regressed against the cars' ages, as well as against the economic conditions for the month in which they were marketed. Due to the very large sample size and the lack of intermediate equations, this model should produce more accurate results than either time-series. The pooled equation is:

$$\ln(P_{i.m}) = \beta_{10} + \beta_{11*}S_i + \beta_{12*}G_m + \beta_{13*}C_{(m\text{-}1)} + \beta_{\ 14*}T_m \tag{11}$$

where P is the price of a car *i* sold in a given month *m*, S is the age of car *i,* and G, C, and T are the gas-price, lagged consumption, and monthly counter variables, respectively, for month *m*.

Table 8: Pooled Regression: Dependent Variable = ln (Car Price)

	n	Age	Real Gas Price	Durable Consumption	Total Consumption	Month Counter	Intercept	R^2	Adjusted R^2	SSE	White's {DF}
Civic	10358	**-0.1457** **(-193.95)**	**0.2825** **(11.25)**	--------	**-0.0269** **(-11.57)**	**-0.0093** **(-13.14)**	**5.3822** **(69.11)**	0.8744	0.8744	610.04	**426.81** {8}
	10358	**-0.1459** **(-194.43)**	**0.9893** **(6.16)**	**-0.1377** **(-9.39)**	--------	**-0.0098** **(-13.95)**	**5.1460** **(72.98)**	0.8740	0.8739	612.33	**416.38** {8}
	10358	**-0.1460** **(-194.70)**	**0.0528** **(3.49)**	--------	--------	**-0.0096** **(-13.59)**	**4.4947** **(307.04)**	0.8729	0.8729	617.57	**407.22** {6}
Explorer	7771	**-0.1702** **(-205.82)**	**0.1821** **(7.30)**	--------	**-0.0494** **(-21.80)**	**-0.0162** **(-22.27)**	**6.8644** **(91.76)**	0.8642	0.8642	380.45	**110.64** {8}
	7771	**-0.1710** **(-205.15)**	**-0.1709** **(-10.64)**	**-0.2123** **(-14.17)**	--------	**-0.0175** **(-23.90)**	**6.2426** **(86.50)**	0.8598	0.8598	392.80	**88.45** {8}
	7771	**-0.1715** **(-203.97)**	**-0.2421** **(-15.83)**	--------	--------	**-0.0174** **(-23.38)**	**5.2442** **(347.91)**	0.8564	0.8563	402.57	**77.01** {6}

[White-compensated t-statistics in parentheses]

The results are shown in Table 8**,** again using three separate equations for each car type**.** In this model the R^2 terms are very high throughout. Every coefficient is significant, even after correcting for the clear presence of heteroscedasticity. The gas price coefficient is now positive for Civics in all cases, but for Explorers it is positive when paired with total consumption and negative otherwise. Despite the high t-statistic, however, the total consumption equation is somewhat suspect due to the multicollinearity problem, so the results with durable consumption appear more credible. Most importantly, when we compare the results for Civics and Explorers with either consumption variable, the gas price coefficient is always greater for Civics, and the standard errors for these coefficients are small enough for both cars to ensure that this difference is significant. This means that, regardless of the absolute price effects, the depreciation of Civics will slow relative to that of Explorers when the gas price increases.

Summary and Conclusion

Using several modeling techniques, I have demonstrated that high gasoline prices have consistently resulted in a net gain in the value of used Honda Civics relative to used Ford Explorers. Theory suggests that an asset's market value is based on the future benefits it will produce. These benefits are a function of the asset's efficiency, which is in turn a function of associated operating costs such as gasoline use. When the gas price increases, small cars like Civics gain in efficiency relative to large cars like Explorers. This change results in a shift in the value of used assets, slowing the depreciation for fuel-efficient cars and accelerating it for fuel-intensive ones (again, in relative terms). The pooled model also suggests a substantial possibility of an *absolute* gain in price for the Civic and a loss for the Explorer, though this cannot be concluded with certainty.

While these results do not offer a complete picture of the automobile market − for example, they do not shed light on the choice of whether to purchase a new or used vehicle − they do offer important evidence on the environmental characteristics of the car stock. As we have discussed, fuel consumption (and hence pollution output) can be decomposed into three elements: the number of vehicles in the car stock, miles driven per car, and fuel intensity per car. Johansen and Schipper (1997) have found that a high gas price has a negative effect on each: it reduces the size of the car stock, induces drivers to travel less, and makes the car stock more fuel-efficient. The depreciation effects we have identified provide a mechanism for adjusting the fuel economy of the car stock. When gasoline is expensive, gas-guzzling vehicles depreciate at a faster rate relative to their fuel-efficient counterparts. The former will tend to be retired sooner, whereas the latter will be kept in service for longer periods. Independent of any effects on the purchases of new cars (which can logically be conjectured to likewise favor fuel-efficient cars), relative depreciation effects will tend to attune the car stock toward the prevailing gas price level.

This supports the idea that policy measures like excise taxes on gasoline may generate additional environmental benefits. By keeping the cost of gasoline at a high level, such initiatives could alter the relative depreciation rates of used cars so as to promote a fuel-efficient car stock. Gas taxes are already seen as a way to internalize the external costs of driving, to pay for transportation projects, and to discourage frivolous travel; long-term improvements in the car stock's fuel efficiency provide another economic purpose for this policy tool. Such effects, however, could require many years of high gas prices to fully manifest themselves, so it may not be politically feasible to use excise taxes for this purpose.

Numerous avenues for further research are apparent. The most obvious extensions involve accumulating a larger data set. If the problem of limited model-year availability could be overcome, a longer time-span could mitigate the multicollinearity problem and test whether the results shown here hold in different time periods. With a greater number of cars, it would be possible to identify a more precise relationship between the miles-per-gallon of a vehicle and the impact of the gas price on its resale value. Examining newspapers in other regions and countries would test the broader geographical validity of this phenomenon.

This model could also be refined by applying the more sophisticated theoretical tools developed in other studies of automobile demand to the study of short-term gas prices. Models that include changes to the car stock over time via sales and scrappage, such as that of Bercovec (1985), could be useful to include the evolutionary effects on the car stock resulting from changes in new car sales. If more data about the composition of the used car market were available, the hedonic pricing method could be useful to determine the exact value imputed on fuel economy.

Appendix A: Monthly Data Sets

Month	Gas Price	CPI (West)	Total Consumption	Durable Consumption
Jan 2001	153.04	178.3	6938.2	859.8
Feb 2001	152.875	179.3	6969.2	883.8
Mar 2001	154.925	180.1	6960.1	872.6
Apr 2001	155.3	180.4	6978.5	852.2
May 2001	159.85	181.3	7029.1	862.0
Jun 2001	161.675	182	7045.0	880.0
Jul 2001	153.86	182	7064.1	867.4
Aug 2001	147.825	181.9	7098.6	882.3
Sep 2001	163.3	182.5	7012.7	845.6
Oct 2001	154.56	182.5	7222.0	975.5
Nov 2001	139.475	182.3	7177.2	932.3
Dec 2001	122.14	181.6	7165.9	890.8
Jan 2002	119.05	182.4	7196.5	909.3
Feb 2002	118.55	183.2	7242.0	924.1
Mar 2002	126.6	184	7252.3	912.3
Apr 2002	141.46	185.1	7330.2	939.7
May 2002	142.275	184.8	7296.2	899.7
Jun 2002	144.3	184.5	7342.6	917.3
Jul 2002	145.96	184.7	7396.4	944.9
Aug 2002	145.125	185.3	7411.0	959.1
Sep 2002	143.1	185.7	7382.3	916.4
Oct 2002	139.7	185.8	7414.3	905.2
Nov 2002	140.075	185.8	7443.6	912.4
Dec 2002	137.18	185.5	7501.3	946.9
Jan 2003	140.575	186.6	7523.4	926.3
Feb 2003	161.1	188.1	7539.9	906.1
Mar 2003	184.04	189.3	7602.2	926.8
Apr 2003	176.35	188.8	7605.8	938.7
May 2003	163.3	188.5	7621.5	938.2
Jun 2003	163.4	188.1	7678.8	949.8
Jul 2003	164.3	188.4	7714.5	955.7
Aug 2003	176.625	189.2	7819.8	995.6
Sep 2003	186.44	189.6	7812.8	972.8
Oct 2003	168.1	189.4	7812.6	947.5
Nov 2003	163.7	188.5	7870.4	964.5
Dec 2003	158.82	188.3	7916.8	978.7

Month	Gas Price	CPI (West)	Total Consumption	Durable Consumption
Jan 2004	163.325	189.4	7997.1	964.6
Feb 2004	173.125	190.8	8016.6	972.5
Mar 2004	185.9	192.2	8083.1	985.3
Apr 2004	195.575	192.3	8076.6	962.3
May 2004	217.38	193.4	8186.7	993.1
Jun 2004	214.325	193.3	8173.6	968.5
Jul 2004	200.475	192.9	8244.2	1004.9
Aug 2004	196.48	193	8250.2	987.6
Sep 2004	200.375	193.8	8295.1	988.9
Oct 2004	209.1	195	8371.0	994.7
Nov 2004	206.46	195.1	8409.8	1000.9
Dec 2004	192.8	194.2	8467.6	1030.1
Jan 2005	184.92	194.5	8483.1	1003.8
Feb 2005	198.35	195.7	8541.6	1017.5
Mar 2005	215.65	197.1	8582.6	1030.7
Apr 2005	240.35	198.6	8646.6	1046.4
May 2005	237.92	198.8	8647.2	1008.9
Jun 2005	228.425	198	8737.3	1051.2
Jul 2005	240.625	198.6	8858.0	1130.0
Aug 2005	258.68	199.6	8819.1	1031.7
Sep 2005	293.5	201.7	8854.8	990.9
Oct 2005	279.86	202.6	8867.8	960.4
Nov 2005	245.125	201.4	8916.4	994.4
Dec 2005	223.45	200	8996.6	1042.2

Key

Gas Price: nominal, in cents

CPI (West): 1982-1984=100

Total Consumption: nominal, in $ billion; annualized

Durable Consumption: nominal, in $ billion; annualize

References

Akerlof, George. "The Market for 'Lemons': Quality Uncertainty and the Market Mechanism." *The Quarterly Journal of Economics,* 84 (3) (1970): 488-500.

Bercovec, James. "New Car Sales and Used Car Stocks: A Model of the Automobile Market." *The RAND Journal of Economics,* 16 (2) (1985): 195-214.

Bloomqvist, Akeg. and Walter Haessel. "Small Cars, Large Cars, and the Price of Gasoline." *The Canadian Journal of Economics,* 11 (3) (1978): 470-489

Bureau of Labor Statistics. *Consumer Price Index Home Page.* http://www.bls.gov/cpi/home.htm.

Chang, Alicia. "Used Prius Drives Past Sticker Price of New One." *The Seattle Times,* 13 May 2005.

Eskeland, Gunnar and Tarhan Feyzioglu. "Is Demand for Polluting Goods Manageable? An Econometric Study of Car Ownership and Use in Mexico." *Journal of Development Economics*, 5 (3) (1997): 423-445.

Federal Reserve Bank of St. Louis. *Economic Data − Fred.* http://research.stlouisfed.org/fred2

Goo, Sara and Dan Morse. "Gas Prices Help Drive Down SUV Resale Value." *The Washington Post*, 14 September 2005.

Greenspan, Alan and Darrel Cohen. "Motor Vehicle Stocks, Scrappage and Sales." *The Review of Economics and Statistics,* 81 (3) (1999): 369-383.

Hamilton, Bruce and Molly Macauley. "Competition and Car Longevity." Working Paper (1998).

Hulten, Charles and Frank Wykoff. "Issues in the Depreciation of Automobiles: Introductory Remarks." *Economic Inquiry,* 34 (1996): 10-23.

Hulten, Charles and Frank Wykoff. "The Estimation of Economic Depreciation Using Vintage Asset Prices: An Application of the Box-Cox Power Transformation." *Journal of Econometrics,* 15 (3) (1981): 367-396.

Johansson, Olof and Lee Schipper. "Measuring the Long-Run Fuel Demand of Cars: Separate Estimations of Vehicle Stock, Mean Fuel Intensity, and Mean Annual Driving Distance." *Journal of Transport Economics and Policy,* 31 (3) (1997): 277-292.

Johnson, Terry. "Aggregation and the Demand for New and Used Automobiles." *The Review of Economic Studies,* 45 (2) (1978): 311-327.

Jorgenson, Dale. "Empirical Studies of Depreciation." *Economic Inquiry,* 34 (1996): 24-42.

Kahn, James. "Gasoline Prices and the Used Car Market: A Rational Expectations Asset Price Approach." *The Quarterly Journal of Economics,* 101 (2) (1986): 323-340.

Storchmann, Karl. "On the Depreciation of Automobiles: An International Comparison." *Transportation*, 31 (2004), 371-408.

United States Department of Energy, Energy Information Administration. *U.S. Retail Gasoline Historical Prices.* http://www.eia.doe.gov/oil_gas/petroleum/data_publications/wrgp/mogas_history.htm.

Tishler, Ashton. "The Demand for Cars and the Price of Gasoline: A User Cost Approach." *The Review of Economics and Statistics,* 64 (2) (1982): 184-190.