Competition and Car Longevity

Bruce W. Hamilton
Molly K. Macauley

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1616 P Street, NW
Washington, DC 20036
Telephone 202-328-5000
Fax 202-939-3460

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Abstract

We examine determinants of the nearly 30 percent increase in the average age of domestically produced, registered automobiles since the mid-1960s. We find that very little of the increase in car longevity is attributable to improvements in the inherent durability of cars. Rather, we find that the temporal pattern of longevity improvement is highly correlated with the level of market concentration in the auto industry. In particular, we argue that the arrival of competition in the industry led to an increase in longevity largely by forcing a reduction in the price of auto maintenance and repair, which in turn induced consumers to maintain their cars into older age.

Key Words: market concentration, automobile industry, scrappage models

JEL Classification Nos.: L1, L9

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I. INTRODUCTION

The average age of domestically produced automobiles has increased by nearly 30 percent since the mid 1960s--from 5.6 years in 1969 to 7.2 years in 1991 (see Figure 1). Over the same time period, life expectancy has increased by approximately the same relative amount (see Figure 2). Using automobile registration data from R. L. Polk and Co., we construct standard life tables for domestic autos, for imports, and for various individual makes of cars. We then examine the patterns of age-specific auto mortality rates to determine some of the causes of the dramatic increase in longevity. We report two significant empirical findings.

Our first finding is that regime shifts from high to low mortality occurred approximately simultaneously across auto vintages; in those calendar years in which mortality declined, it declined for both new and old vintages. No mortality improvement appears to be statistically attributable to specific vintages. In other words, some vintages of cars began life during a high-mortality regime, and accordingly "died off" quickly. But when the shift to low mortality occurred, these erstwhile fast-dying cars saw an improvement in their mortality. Or to put it yet another way, declines in the age-specific death rates of 5-year-old cars occurred in the same calendar year as declines for 10-year-olds and 15-year-olds. Regardless of any economic explanation for this finding, it is sufficient to lead to the following conclusion: Essentially none of the improvement in car longevity is attributable to improvements in the inherent durability of cars, for such an improvement would not reduce death rates on older, pre-improvement cars.[2] The improvement in longevity must be due to some force external to the cars themselves.

Our second finding is that the temporal pattern of mortality improvement is highly correlated with the level of market concentration in the automobile industry (even after correcting for other regressors). This leads us to believe that the changing competitive environment in the auto industry is likely to be an important cause of the change in the mortality pattern. We argue below that the arrival of competition in the industry led to an

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[1] Hamilton is Professor of Economics, Johns Hopkins University, and Macauley is Senior Fellow, Resources for the Future. Correspondence: macauley@rff.org. We thank Bob Crandall, George Eads, and participants in sessions at the American Economic Association meetings, the Southern Economic Association meetings, and in workshops at Resources for the Future and Johns Hopkins University for helpful comments. Responsibility for errors or opinions rests with the authors.

[2] Indeed, as we will see, an improvement in the longevity of new cars should lead to a "premature" die-off of older, pre-regime-shift cars.

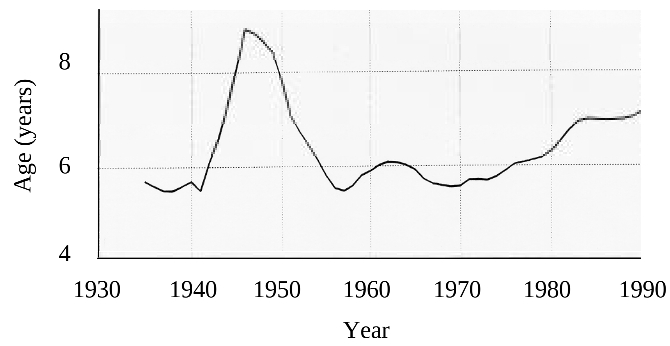

Figure 1. Mean age, domestic fleet

Source: See text, section IV

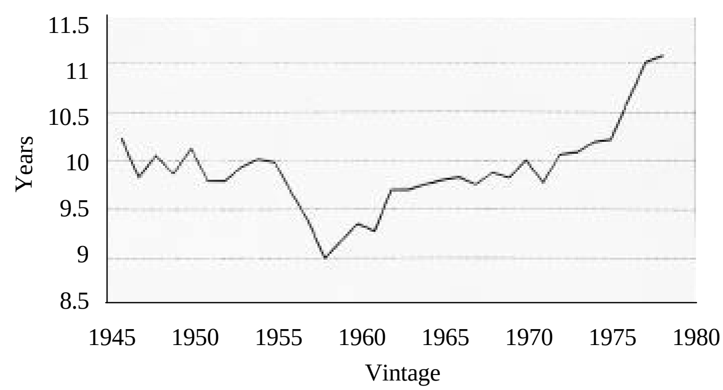

Figure 2. Auto life expectancy

Source: See text

increase in longevity largely by forcing a reduction in the price of auto maintenance and repair, which in turn induced consumers to maintain their cars into older age.

It does not appear that the erosion of industry concentration affected longevity through either of the obvious changes, namely, auto prices or inherent durability. In the case of prices, under the standard neoclassical monopoly (or the typical oligopoly) model, the arrival of competition should have led to a reduction in the price of new cars. But as is intuitive (and as we show formally), a reduction in car prices should lead to a reduction, not an increase, in longevity. Figure 3 shows the history of average retail prices for new cars, as well as an estimate of the time path of the hedonic price.[3] The hedonic price shows a steady decline, but as we will see it is the actual price, not the hedonic price, that governs the consumer's scrappage decision.

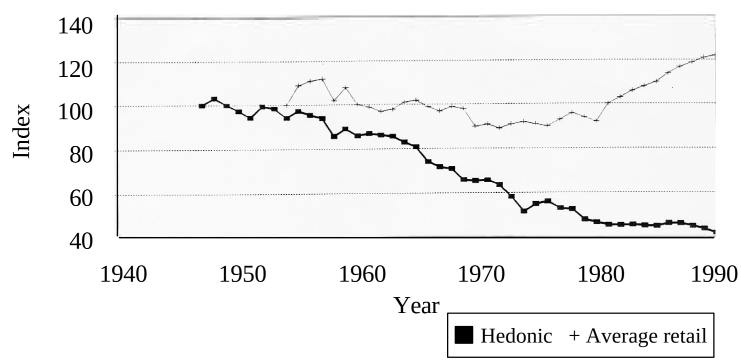

Figure 3. Average new car prices

Source: The hedonic index through 1983 is from Gordon (1990) and is deflated by the CPI; after 1983, we use the CPI. The average retail index is from Automotive Facts & Figures, various issues.

With regard to inherent durability, though the literature is inconclusive on the relationship between monopoly power and choice of durability, many observers believe that monopolists are likely to offer less durability than a competitive market. We already know, however, that the mortality improvement was not driven by changes in inherent durability because the pattern of mortality reduction is inconsistent with this hypothesis.

[3] The hedonic price is from Gordon (1990) through 1983 and then is from the CPI new car component. (Over the last few years of Gordon's series, his series and the CPI component are very similar, suggesting that the splice between the two series is likely not a problem.)

We believe that the observed pattern of mortality decline is most consistent with the following hypothesis. When the industry was more concentrated it succumbed to the "Coase temptation" to price cars near cost, placing much of its monopoly markup not on cars but on repair and replacement parts. The arrival of competition in the mid-1970s reduced this profit margin and induced consumers to maintain their cars longer. Thus we find that the industry in its high concentration was able to defy Coase and charge a supercompetitive price, but the markup was predominantly on parts rather than cars. To our knowledge, this represents the first empirical test of any version of the Coase conjecture.

In sections II and III we discuss literature that bears on our research, the relationship between longevity and industry concentration, and models of auto longevity. In section IV we describe our data and trends in auto lifetimes. Section V is a model of the scrappage decision and the effects on this decision of inherent durability and the prices of cars, parts, and gasoline. In section VI we discuss direct evidence on maintenance cost, new car prices, and fuel efficiency. In sections VII and VIII we estimate the empirical relationship between concentration and longevity and discuss other evidence regarding longevity, including the effects of imports of Japanese cars. Section IX is a summary.

II. MONOPOLY AND LONGEVITY

One of the major new forces in the automobile industry is competition. In the late 1950s and early 1960s, automobile manufacturing was the most highly concentrated major industry in the United States. As Figure 4 shows, the Hirschman-Herfindahl index of concentration stood at about 3500 to 3700.[4] By 1990, the index stood at approximately 2000. This decline in concentration could affect automobile longevity through several channels: (1) the price of new cars; (2) the inherent durability of cars; and (3) the price of auto repair and maintenance parts.

Two strands of literature address the link between monopoly power and the longevity of durable goods. In one strand, Swan (1972) argues that market structure has no effect on product durability; the demand for a durable good is derived from the demand for its services, and a monopolist maximizes profit by producing these services as cheaply as possible (i.e., using socially optimal durability) and charging the monopoly price. This independence (-of-market-structure) result rests on the assumption that longevity is a feature of the product itself and does not depend upon consumers' maintenance decisions.

[4] The Hirschman-Herfindahl index (HHI) is the sum of squares of market shares. We calculate this index based on sales of new automobiles in the United States (data from *Automotive News*, various issues). For purposes of calculating the index, a manufacturer's market share is its share of total sales of new cars in the United States in that year. Our calculations are based on the shares of both domestic and foreign manufacturers in domestic automobile sales.

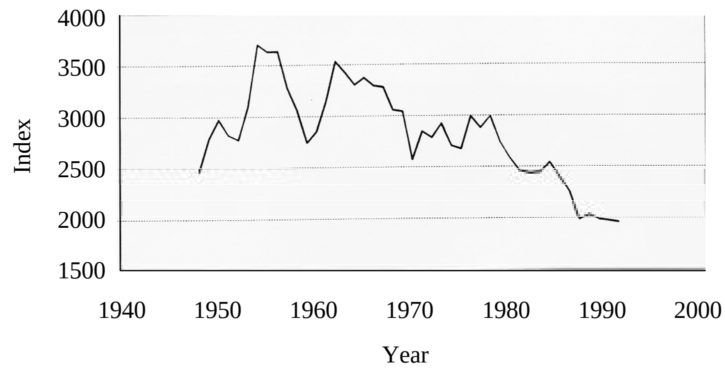

Figure 4. The HHI for the auto industry

Source: See text

As Schmalensee (1974) and Rust (1986) note, consumers who can purchase competitively priced maintenance will be induced by the monopoly price of the original equipment to maintain the good "too long." The monopolist can respond by setting a non-optimal inherent durability.[5] The likely net effect is that durable goods survive longer under monopoly than competition; the effect of the monopoly price upon consumers' maintenance decisions unambiguously raises longevity, and the effect of the monopolist's countermove is ambiguous.

The second strand of literature follows the Coase (1972) conjecture whereby a perfectly-durable-good monopolist has no monopoly power at all and is forced "in the twinkling of an eye" to price at marginal cost. In the Coase model, the good is perfectly durable; there is neither limited durability nor replacement demand. In subsequent research, Bond and Samuelson (1984) find that time-consistent monopoly power increases as the durability of the good declines exogenously. Bulow (1986) shows that a monopolist who has control over durability can partially escape the Coase problem by reducing durability (and thus reducing the Coase temptation).

Hamilton and Burke (1996) argue that a durable-goods monopolist which also has market power over some maintenance and repair parts is likely to take a much larger markup on repair parts than on original equipment. They consider a good whose longevity is determined jointly by inherent durability and the amount of maintenance provided by the

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[5] The monopolist may either raise or reduce durability from its optimum, depending upon the parameter values of the model.

consumer/owner of the good. A monopolist selling such a good faces both the Coase time-consistency and the Schmalensee excess-maintenance problems. In this case, a durable-goods monopolist with some monopoly control over repair/replacement parts can charge a relatively low markup on original equipment and a higher markup on parts.[6] In the case of automobiles, the parts-pricing monopolist sells cars relatively close to cost and in the process creates a monopoly market for consumables, for which there is no Coase temptation. By charging a high markup on maintenance parts, the original equipment manufacturer (OEM) curbs consumers' temptation to over-maintain their cars. Under reasonable parameter values, the monopoly markup on parts is several times higher than on original equipment. In this case, a decline in market power leads to substantial erosion in the parts' markup, which in turn leads to an increase in automobile lifetimes.

III. PRIOR RESEARCH ON AUTOMOBILE LONGEVITY

In two respects the empirical research we present follows several prior empirical studies of auto lifetimes. All use either the same U.S. automobile registration data or similar data from other countries, and all model auto lifetimes based on survival models using either logistic transformation of the age-specific auto death rate or simply the log of the death rate.[7]

Our approach is similar to Parks (1977). He begins with an intertemporal optimization model in which survival is driven by the ratio of the initial purchase price to maintenance cost. Instead of incorporating a logistic functional form, however, he uses a set of dummy variables to capture the effects of age. He also includes dummy variables for vintages; these coefficients are generally insignificant and show no obvious relationship to any economic variables.

Greene and Chen (1981) estimate a logistic equation separately for domestic and imported cars, and for light trucks. They find that the shapes of the domestic and import logistics are somewhat different, but life expectancies are very similar. Light trucks, on the other hand, survive much longer than cars.[8]

Several other studies include auto mortality. Berkovec (1985) estimates a scrappage model in which he regresses the log of the death rate on auto prices, price squared, and dummy variables for vintage and class (e.g., subcompact). Berkovec does not consider the economic causes of the movements in mortality. Greenspan and Cohen and (1996) estimate auto mortality as an input to the study of the demand for new cars. Another strand of research examines the effect of the aging of the auto fleet on air pollution and policy options associated with this relationship. For example, Gruenspecht (1982) estimates the effect of federal

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[6] Of course, this requires the monopolist to have power over at least some repair/maintenance parts. In the case of automobiles, there is strong reason to believe that OEM's have substantial power in this aftermarket. Perhaps the strongest evidence is that an automobile purchased one piece at a time from a dealership's parts department would be substantially more costly than a fully assembled car.

[7] In addition to the research noted above, econometric models of the auto market include Bresnahan (1981); Berry, Levinsohn, and Pakes (1995); and Goldberg (1995). These models focus on new car demand and supply; they do not explicitly address longevity and scrappage decisions, and Bresnahan examines only 1977-78 vintages.

[8] See also discussion of the logistic scrappage function in Fenney and Cardebring (1988).

emissions standards set in 1981 on the composition of the fleet (extrapolated forward to 1990) and consequently upon auto emissions. He finds that the effect of the new standards on scrappage is "not large;" nevertheless, in his simulations the imposition of the 1981 standards does increase emissions of hydrocarbons and carbon monoxide up until 1985. The increases are small (on the range of 1-2 percent), and by 1990 the standards lead to a substantial decrease in emissions (16.19 percent for hydrocarbons and 5.31 percent for carbon monoxide).

Alberini et al. (1995) and Hahn (1995) analyze cash-for-clunkers programs (government offers to purchase and retire older polluting cars to reduce aggregate emissions). Whereas these studies tend to confirm that retirement of older cars would improve air quality, they are not inconsistent with the basic conclusion of our study--that the aging of the automobile fleet over the past 25 years was brought about almost entirely by forces unrelated to the tightening of emissions standards.

Thus there is extensive research which models or incorporates auto longevity, but none of this research considers the *causes* of the substantial improvement in auto longevity since 1960.

IV. PATTERNS IN AUTO DEATH RATES

The patterns we observe in auto death rates are based on the automobile registration data base provided to us by R. L. Polk & Co. For each year since 1946, Polk reports the total number of cars registered in the United States by make and vintage (beginning in 1975, each make is disaggregated into specific models). We calculate age-specific death rates respectively for the domestically produced fleet and for six specific makes for each year since 1947, and for the import fleet, and for Japanese cars, since 1958.[9]

Polk's coverage varies somewhat from year to year. Subsequent to 1975 they report the number of registered vehicles in each vintage up to age 15, plus an open-ended "older" category. For some prior years, registration data up to age 18 plus an "older" category are included. In calculating the average age of cars reported in the Introduction, we have aggregated all cars over age 15 into a single category, and allocated this group to ages according to the following weights: {age 16; 0.3}, {age 17; 0.25}, {age 18; 0.2}, {age 19; 0.15}, {age 20; 0.1}. The time series of average age (Figure 1) is not very sensitive to the weights chosen for these vintages. We do not use this arbitrary assignment of cars to older cohorts in any other part of our analysis.

The aging of the fleet is quite dramatic. Just under 7 percent of 1957-vintage cars lived to age 15. Figure 5 shows that this fraction rose steadily to over 40 percent of 1976-vintage domestic cars in 1991. Figure 2, referenced in the Introduction, plots the *ex post* life expectancy for each vintage from 1946 through 1976.[10] Figure 2 (misleadingly) implies very

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[9] The Polk data for imports are not as complete as for domestics prior to 1975. There are no data at all prior to (calendar year) 1957, and for most years from 1957-1974 data were recorded only for age 6 and younger. Since almost all of the mortality "action" occurs at older ages, we are unable to estimate life tables for imports prior to 1975.

[10] Life expectancies are calculated *ex post* from each vintage's actual survival rates up to age 15. As noted in the text, for all vintages life expectancy is understated for failure to include older ages. This bias is clearly much more significant for more recent vintages, as a much larger fraction of recent vintages survives beyond age 15. Rough eyeball extrapolation suggests that life expectancy of 1960 vintage cars would rise by about 0.1 year if we included data from ages 16-20, and by about .75 years for 1977 cars.

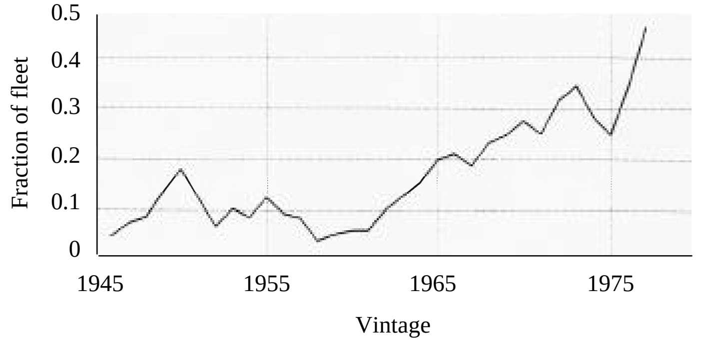

Figure 5. Fraction of domestic fleet surviving to age 15

Source: See text

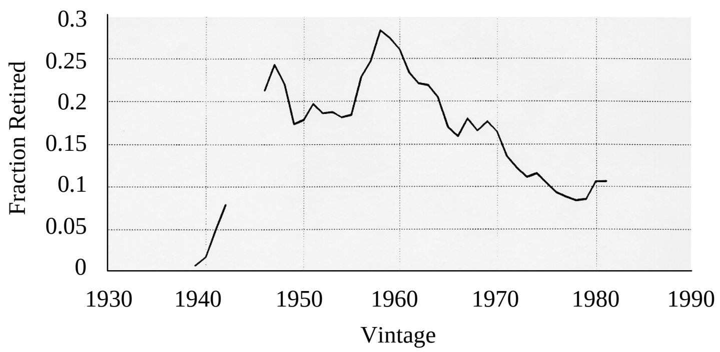

Figure 6. Death rates, 10-year old cars

Source: See text

modest improvement for vintages earlier than the mid-1970s. From Figure 6, which shows the death rates of age-10 cars, by vintage, it appears that the improvement in mortality began with the mid-60s vintages.

V. THE SCRAPPAGE DECISION

The Scrappage Model

In this section we illustrate the nature and size of possible sources of improvements in longevity, including improvements in inherent durability and other economic forces which induce consumers to maintain cars into older age. We begin with a simple nonstochastic model of scrappage in which all autos are scrapped at the same age. In this model, all cars are retired at the same age, *d*. Our purpose in this model is to develop a feel for the plausible quantitative importance of the various forces which influence the longevity of a durable. This will help us to interpret the coefficients of our empirical model.

Suppose that the price of a new car is P_0 and that the car requires maintenance according to

$$m_a = m_0 e^{ga} \tag{1}$$

where

$$m_a = \pi \cdot \mu_a$$

and π is the price of maintenance, μ_a is the quantity of maintenance required at age *a*, and *g* is the growth rate of maintenance cost. μ_0 is the (inverse) index of inherent durability (it is the "quantity" of maintenance required for an age-*0* car). The stream of costs of owning and maintaining a car until it is retired at age *d*, then replacing it with another that lasts *d* years and so on, is *V*:

$$V = \left(P_0 + \frac{m_0}{g-\rho} e^{(g-\rho)d} - 1\right) \cdot \left(\frac{1}{1-e^{-\rho d}}\right) + \frac{m_1}{\rho} \quad \text{or}$$

$$\hat{V} = \left(P_0 + \frac{m_0}{g-\rho} e^{(g-\rho)d} - 1\right) \cdot \left(\frac{1}{1-e^{-\rho d}}\right) \tag{2}$$

where m_1 is age-independent maintenance such as fuel and insurance, *d* is the retirement age, and ρ is the discount rate. $\hat{V}$ is the perpetual cost of operating a car exclusive of these age-independent terms. In the steady state the optimal time to scrap a car is found by differentiating (2) with respect to *d* and setting the result equal to zero. The solution, obviously independent of m_1, is the following (implicit) function of *d*:

$$\frac{1}{\rho}\cdot e^{gd} - \frac{g}{\rho(g-\rho)}\cdot e^{(g-\rho)d} + \frac{1}{g-\rho} = \frac{P_0}{m_0} = \frac{P_0}{\pi\cdot\mu_0} \rightarrow$$

$$\rho\cdot\hat{V} = m_0 e^{gd},\ \text{or} \qquad (3)$$

$$d = d\left(\frac{P_0}{\pi\mu_0}; g, \rho\right)$$

By (3) retirement age, d, rises as P_0 rises and as either π or μ_0 declines. Any factor which influences longevity must operate through μ_0 (inherent durability) or through one of the prices P_0 or π. The second line of (3) gives rise to a natural interpretation: the car is maintained until the rate of maintenance, $m_0 e^{gd}$, is equal to the rental rate, $\rho\hat{V}$.

Table 1. Effect of P/m_0 on Lifetimes (ρ = .03)

P/m_o	d (g = .05)	d (g = .1)	d (g = .15)	D (g = .2)
5	12.25	7.9	6.15	5.1
7	14.15	9.1	6.95	5.8
10	16.4	10.4	7.95	6.55
15	19.4	12.1	9.2	7.5
20	21.7	13.4	10.1	8.25
30	25.35	15.45	11.55	9.35
40	28.21	16.97	12.60	10.19
50	30.55	18.25	13.51	10.86
60	32.6	19.3	14.2	11.4
70	34.35	20.23	14.85	11.92

Table 1 suggests the quantitative importance of P_0/m_0 in determining automobile lifetimes. For four different growth rates of maintenance cost, the table shows the optimum lifetime as P_0/m_0 varies from 5 to 70.[11] The double-lined boxes indicate approximately the postwar variation in actual life expectancy, suggesting that the recent rise in car longevity must be due to an approximate doubling of P_0/m_0, regardless of the value of g. Below we report empirical results indicating that new emissions controls had no discernible effect on auto

[11] The average retail price of new cars was approximately $15,000 in the mid-1990s. There are three sources on auto maintenance expenditure per car: the National Income Accounts, the Survey of Consumer Expenditures, and an independent survey run by Runzheimer International. We discuss these later in the text. All of the sources suggest that maintenance expenditure is in the range of $325-$400 per car, implying that $P_0/m_0 \approx 40$. In combination with table 1, this implies that g must be at least 0.15.

mortality. The very small elasticity of life expectancy with respect to P_0/m_0 implied by Table 1 may explain this effect. We would expect a 10 percent rise in the price of new cars to increase life expectancies by about 6 weeks (for both new and grandfather cars; as we discuss below). This simple model of scrappage, in other words, is enough to tell us that any historical changes in emissions or safety standards are much too small to have had any appreciable effect on survival rates.[12]

Transition Effects

Equation (3) describes the forces which govern longevity in the steady state. Here we explore the behavior of the longevity of grandfather cars during the transition from one steady state to another. What happens to the longevity of cars which were born under one regime $\{P_0, \pi, \mu_0, m_1\}$ but then live part of their lives in a changed regime? The answer varies according to which parameter changes.

i. P_0/π: if there is a regime change in either P_0 or π (the price of new cars or the price of maintenance services), then grandfather cars behave as if they were born into the new regime. If P_0 rises, used cars will realize a capital gain, and their owners will not retire them until the flow of maintenance costs equals $\rho\hat{V}$ for the new-regime car which must be bought as a replacement. Similarly, a change in π alters the flow of maintenance cost equally for new-regime and grandfather cars, and grandfathers will be retired as if they had been born into the new regime. If the regime shift is a price change (either P_0 or π), then there is no transition; the mortality pattern of all cars jumps instantly to the new steady-state pattern.

ii. μ_0: if at some point in time there is a decline in μ_0 (the "amount" of required maintenance), then a technical improvement of this sort is embodied only in new cars. Any grandfather cars built with the old technology must behave as old-regime cars but compete with new-regime cars until they die. During the transition in which there are still grandfather cars, these cars will not behave like new-regime cars, nor will they even behave like old-regime cars would have behaved but for the regime shift. The grandfather car will be retired when its stream of maintenance costs obeys equation (4):

$$m_{0,0}e^{g\hat{d}} = \rho\hat{V}_1 \tag{4}$$

where $\mu_{0,0}$ is μ_0 for the regime-0 (old regime), $\hat{d}$ is retirement age for the grandfather car, and $\hat{V}_1$ is $\hat{V}$ for new regime cars. The left hand side of (4) gives the cost of maintenance of the

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[12] According to Crandall and co-authors (1982), emissions, safety, and fuel efficiency standards may have raised the price of a new 1984 car by as much as $2000 (relative to the no-standards baseline), though Bresnahan (1986) argues that this is a substantial over-estimate. Even the estimates in Crandall represent about a 10-15 percent increase in new car prices, enough to increase lifetimes by about 6 weeks.

old-regime car as a function of age; when this expression reaches the rental rate under the new-car regime,[13] it is time to scrap the old car. A fall in m reduces the right-hand side of (4) but not the left-hand side (since the left-hand side pertains to old-m cars). Thus (4) dictates that the old-regime car will be retired earlier than it would have had there been no regime-change (i.e., had $\hat{V}_0$ prevailed). A reduction in m increases the lifetimes of new cars relative to the old steady state and causes transition cars to die younger than in the old steady state.

The quantitative importance of this transitional effect is suggested by the following exercise: Suppose that in some year m_0 falls by 10 percent and that g = .15. The steady state lifetimes of cars increases by about 0.2 years (see Table 1). Suppose further than half of $\hat{V}_1$ is maintenance; thus $\hat{V}_1$ falls by 5 percent.[14] By (4), grandfather cars are retired about 0.3 years prematurely because they are forced to compete with more maintenance-free new cars.

iii. m_1: age-independent cost, m_1 (e.g., gas mileage) does not appear in equation (3) and has no effect on steady state longevity. But as in the case of a change in m_0, old-regime cars must compete with new-regime cars even though they cannot behave like new-regime cars. A decline in m_1 causes old-regime cars to die prematurely, for much the same reason as does a decline in m_0. Again we use the structure of the middle line of equation (3), which compares the instantaneous cost of keeping the old car with the instantaneous cost of switching to a new car. In the case of a change in m_1, this cost comparison is as follows:

$$m_0 e^{g\hat{d}} + m_{1,0} = r \cdot \hat{V} + m_{1,1} \qquad \Rightarrow$$

$$m_0 e^{g\hat{d}} = r \cdot \hat{V} + (m_{1,1} - m_{1,0}) \tag{5}$$

where $m_{1,0}$ and $m_{1,1}$, are, respectively, age-independent maintenance for grandfather and new-regime cars. The left-hand side of (5) is the instantaneous cost of keeping the old-regime car; the right-hand side is again the cost of buying a new one (recognizing the future consequences). When m_1 does not change, it drops out of this expression and, as we have seen, has no effect on longevity. If m_1 is lower for new than grandfather cars, (5) tells us that grandfather retirement is hastened to enable the owner to escape the high m_1.

To illustrate the quantitative importance of this transition effect, suppose that $r\hat{V}$ = \$1000. In the steady state the car is maintained until the rate of maintenance cost, $m_0 e^{gd}$ = \$1000. But if enhanced fuel efficiency reduces the annual fuel cost for new cars by \$300 then the old car should be scrapped when $m_0 e^{gd}$ = \$700.[15] It would be retired about 2 years

[13] Exclusive of age-independent costs such as gasoline, represented by m_1.

[14] If g = .15 and P/m_o = 40, the share of maintenance in V = .52.

[15] A consumer would save \$300/year in fuel by replacing a 12-mpg car with a 20-mpg car, assuming 10,000 miles per year (approximately the national average) at \$1/gal.

prematurely if $g = .15$. Any improvement in the operating efficiency of new cars, of the type embodied in m_1, depresses the lifetimes of grandfathers (substantially) but leaves the steady state unchanged. In fact, average fuel efficiency for new cars more than doubled (from 12 to 25 miles per gallon) between 1973 and 1983. This should have led to a large retirement of 1970s-vintages cars in the 1980s, but our data show that the opposite happened.

To summarize this discussion,

- A rise in P_0/ρ increases longevity of both new and grandfather cars; a doubling of this ratio adds about 2 years to car lifetimes, for most parameter values.
- A reduction in μ_0 raises the lifetimes of new-regime cars and reduces the lifetimes of grandfathers. Reducing μ_0 by 50 percent adds approximately 2 years to the lifetimes of new cars and causes grandfathers to be retired about 1.5 years prematurely.
- A reduction in m_1 has no effect on the lifetimes of new cars (relative to the steady state in which the grandfathers formerly lived) but depresses the lifetimes of transition grandfathers. A 30 percent fall in m_1 causes grandfathers to die about 2 years prematurely.

VI. DIRECT EVIDENCE ON MAINTENANCE COST

In principle, the most straightforward way to separate the effects of prices and innate car characteristics on auto mortality would be to regress a transformation of scrappage rates on the price of cars, the price of maintenance, and measures of inherent durability and fuel economy. Data on maintenance prices and expenditures are highly problematic, however, and there are no data on inherent durability. We have located two price and two expenditure time series on auto maintenance. The two price series are the Consumer Price Index (CPI) for auto maintenance and for auto parts. The maintenance series includes body work, the drive train, maintenance and service, power plant, and an "other" maintenance category. The Bureau of Labor Statistics notes that pricing these activities in a consistent manner is quite difficult. The auto parts series includes batteries, tires, floor mats, tune-up parts, and audio equipment. Figure 7 plots both price series. Since its introduction, the parts price series has fallen approximately 40 percent and clearly behaves in a strikingly different way from the maintenance price series.

There are also two series on maintenance expenditure. One of these series is our own estimate of auto maintenance per mile based on the auto maintenance component of Personal Consumption Expenditure (deflated by the CPI) from the National Income and Product Accounts (NIPA). We estimate auto maintenance expenditure per vehicle by dividing total auto maintenance expenditure by the stock of privately owned automobiles and trucks for each year, as reported by the Federal Highway Administration.[16] Next, we deflate by the

[16] We would like to deflate by the number of cars and trucks in the **personal** fleet, but such data do not exist. We deflated by cars plus trucks rather than just cars for two related reasons. First, in at least some years minivans are counted as trucks. Second, and related to the first, the data for cars and trucks individually show wide fluctuations, but the data for the sum are quite smooth (strongly suggesting that some vehicles are counted as cars some years and trucks in other years.) Though heavy trucks are improperly included in the series, they represent only about 3 percent of the fleet, and their inclusion will not bias the pattern of maintenance per vehicle unless the share of heavy trucks in the fleet has changed significantly. Limited data suggest that this share has been stable.

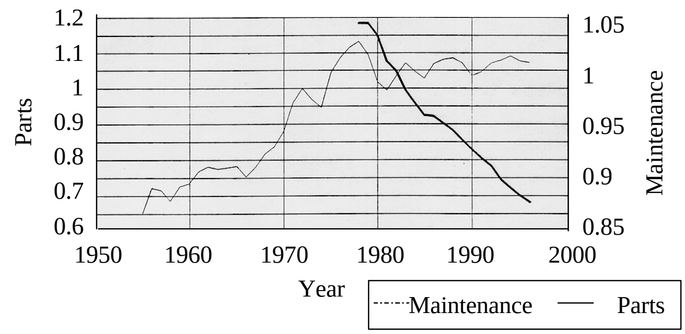

Figure 7. The CPI for auto maintenance and parts, deflated

Source: U.S. Bureau of Labor Statistics

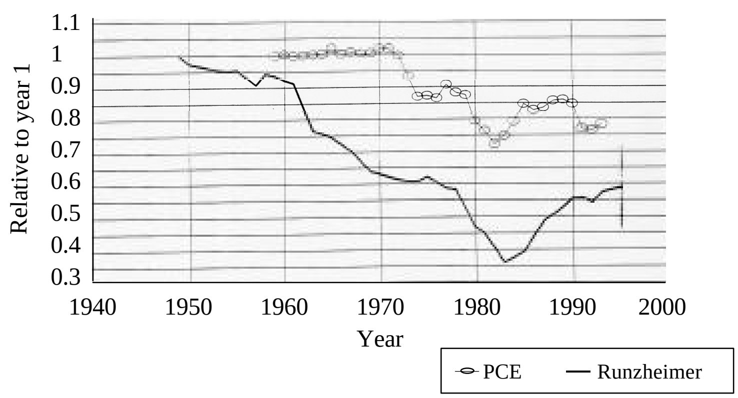

Figure 8. Auto maintenance per mile from PCE and Runzheimer

Source: See text

average number of miles per vehicle (which has risen about 30 percent, from 9000 to 12000 miles per year, between 1970 and 1995).

Our other series on maintenance expenditure is direct estimates reported in surveys of automobile dealers by Runzheimer International.[17] Runzheimer surveys dealers (but not independent mechanics) annually to estimate the cost of "normal" maintenance for a 2-year old, mid-size car. Crash repair is excluded.[18] Thus the Runzheimer series is close to a direct estimate of our m_0.[19] Figure 8 shows both of these expenditure series. They indicate the same broad pattern, though the Runzheimer data show a much more precipitous and earlier decline in expenditure per mile than does the series constructed from the NIPA. This difference is not surprising; the NIPA-constructed series covers the entire population of cars (and, unfortunately, trucks). The aging of the fleet from 1970 onward should have caused this series to decline less quickly than the Runzheimer series.

Because the Runzheimer data are gathered directly from auto dealers, these data seem to be the most reliable of the four series (though unfortunately the data are expenditure, and not decomposed into price and quantity).[20] All four series are problematic in that they include both m_0 (age-related maintenance) and m_1 (age-independent maintenance), whereas only the former influences steady-state longevity.[21] Nonetheless, if the Runzheimer data are at least approximately correct, the series suggests a fall of about 60 percent in m_0 from 1960 to 1985.

From Table 1, this decline is the right order of magnitude to be a strong candidate for explaining the secular rise in longevity. The empirical question is then whether the pattern of decline in expenditure is embodied in specific vintages (due to improvements in durability of newer cars) or disembodied (due to a decline in the price of maintenance). Given the ambiguity of the series on maintenance prices and expenditure, we address this question by trying to determine directly whether the decline in auto scrappage over the past 25 years appears to be vintage-specific (embodied) or year-specific (disembodied).[22]

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[17] Runzheimer's data are published both by the American Automobile Association and the American Automobile Manufacturers' Association. Their operating-cost data provide the basis for Internal Revenue Service mileage allowances.

[18] Runzheimer also reports average insurance premiums. Between 1975 and 1985 the average property and liability premium fell by 54 percent, and the collision premium fell by 38 percent (in real dollars).

[19] Details of the Runzheimer series were kindly provided in a telephone interview with Carl Hart of Runzheimer International, Inc.

[20] Of course, it is possible to reconcile the Runzheimer and NIPA maintenance series by postulating that the price of auto maintenance has indeed risen about 20 percent as indicated by the CPI, and that expenditure has fallen about 50 percent because, with improvements in built-in durability, the quantity of required maintenance has declined (by about 60 percent).

[21] For example, since batteries can easily be removed from scrapped cars, it is implausible that the price of batteries influences the scrappage decision.

[22] Parks (1977) and Greenspan and Cohen (1996) use the ratio of the new-car CPI to the auto maintenance CPI in auto scrappage regressions. In both studies the coefficient has the right sign and is significant. Parks' sample period is from 1947 through 1969 (almost entirely before the substantial rise in the maintenance CPI from the late 1960s through the mid-1970s), and the sample used by Cohen and Greenspan is from 1973 to 1991 (entirely after the maintenance CPI spurt). Virtually all of the postwar variation in maintenance CPI is missing from both studies. When we estimate the same regression over the entire postwar period, the sign of this coefficient becomes perverse (a rise in the relative price of maintenance leads to reduced mortality).

VII. ESTIMATION

In the model of auto mortality developed above, we assumed that the arrival of maintenance needs was continuous and deterministic. As a result, the model predicted that the age at death of a car was also deterministic, determined only by prices and the parameters of the exponential maintenance-cost function. Clearly, the actual arrival of maintenance needs is both episodic and stochastic, and as a result, the optimal time to scrap a car is stochastic. The deterministic model gives a feel (a good feel, we believe) for the magnitudes of the forces governing car longevity. But like most deterministic models it must be modified before applying it to the data.

We do not model the stochastic process that generates maintenance requirements or the formal decision calculus of a consumer faced with such a process. Rather, we follow virtually all of the automobile-mortality literature in assuming that the pattern of auto mortality can be characterized by the logistic function below. In discussing the empirical results, we assume that the life expectancy implied by our logistic coefficients is generated by the deterministic model presented above.

Accordingly, consistent with the extant literature in modeling auto scrappage, we assume that the age-specific death rates of automobiles tend to follow a logistic

$$1 - s_a^v = \frac{1}{\alpha + e^{\beta + \gamma \cdot age}} \tag{6}$$

where s_a^v is the survival rate for age-*a* cars of vintage *v*. We assume that the parameters α and β are constant across all vintages and years and that any variation in the shape of the logistic manifests itself in γ. We rearrange (6) to form (7) and then estimate (7) using nonlinear least squares:

$$\ln\left(\frac{s_a^v}{1 - s_a^v}\right) = \ln\left(\alpha - 1 + EXP(\beta + \gamma \cdot age)\right) \tag{7}$$

where

$$\gamma = \gamma_0 + \Sigma\left(X_1 \delta_1\right) \tag{8}$$

and the *X*'s are the other regressors.[23] We estimate (7) for all cars manufactured in the United States after World War II and for all ages greater than 4 years.[24]

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[23] Obviously it is possible to model the *X*'s as modifiers of α or β rather than γ. We choose γ because we are more able to approximate the actual patterns of mortality by varying γ. For example, for most reasonable values of β and γ, it is impossible to generate actual changes in life expectancy through "permissible" changes in α. When we estimate the model in a form in which the *X*'s modify α, the estimated coefficients generate "logistic" curves with negative death rates beginning at about age 14.

[24] Actual death rates of cars below the age of 4 are very low. However, the data for these younger cars are somewhat noisy. Death rates are calculated comparing the ratio of a given vintage car registered in one year to the number registered in the subsequent year. Early in a car's life, these numbers are heavily influenced by sales of new cars a year or two after their introduction.

In column (a) of Table 2 we estimate the logistic, equation (7). In column (b) we include the Hirschman-Herfindahl index of industry concentration in the current year (as opposed to the year in which the automobile was manufactured). This index (HHI_y) allows the current-year industry concentration to affect current-year death rates on all living vintages of grandfather cars. The coefficient is of the predicted sign and is highly significant.[25] As we discuss below, the point estimate is quite "large."

Table 2. Regression Results

Dependent variable: $\ln(s_a^v/(l-s_a^v))$

	A	b	c	d	e	f	g	h	i
α	4.00 (.080)	3.62 (.066)	3.70 (.066)	3.75 (.064)	3.71 (.065)	3.65 (.063)	3.71 (.064)	3.65 (.065)	3.53 (.064)
β	6.97 (.012)	6.68 (.066)	6.62 (.066)	6.65 (.065)	6.58 (.065)	6.58 (.062)	6.51 (.066)	6.58 (.064)	6.49 (.061)
γ_0	-.609 (.070)	-.295 (.000)	-.234 (.018)	-.125 (.022)	-.096 (.022)	-.135 (.021)	-3.80 (.709)	-4.49 (.081)	-5.28 (.668)
HHI_y*		-.959 (.012)	-.902 (.047)	-.836 (.044)		-.935 (.044)	-.500 (.081)	-.435 (.081)	-.425 (.078)
HHI_v*			-.247 (.060)						
HHI_v* 5 yr avg				-.647 (.076)	-.543 (.077)	-.530 (.073)	-.659 (.078)	-.643 (.074)	-.492 (.070)
HHI_y* 5 yr avg					-1.05 (.054)				
U						.013 (.001)			.014 (.001)
year								.002 (.000)	
vin							.002 (.000)		.003 (.001)
R^2	.788	.821	.826	.831	.830	.837	.833	.832	.841

* $x10^{-4}$
(standard errors in parentheses)
Sample: domestic automobile fleet: vin > 1945 & age > 4
Definitions are as follows:
a_0: The constant term in the logistic, independent of other regressors
b: The constant term in the exponential portion of the logistic
g: The age coefficient in the logistic

25 For all of the *X*'s, a positive coefficient means that a rise in *X* reduces mortality and increases life expectancy. In this case, the negative coefficient suggests that a rise in HHI reduces life expectancy.

In column (c) we add HHI_v, the index from the year in which the car was built, to test for an embodied change in inherent durability associated with competition. If competition forced manufacturers to build more durable cars, then this effect reduces death rates only for post-competition cars, not simultaneously for all vintages as with HHI_y. The coefficient is significant, of the predicted sign, and about 30 percent as large as the disembodied effect. Inclusion of HHI_v has virtually no effect on the coefficient of HHI_y.

In columns (d) and (e) we replace HHI_v and HHI_y with their 5-year moving averages. In the case of HHI_v, it seems implausible that durability responds instantly to changes in industry concentration. Indeed, the magnitude and significance of HHI_v rise when we use the moving average, as does the overall fit of the equation. HHH_y, on the other hand, performs (very slightly) better than its moving average. In the remaining regressions we use $HHI_{v(5\text{-yr. avg})}$ and HHI_y.

In column (f) we include the deviation of unemployment (U) from its linear trend. If consumers postpone new-car purchases during recessions, they are likely also to postpone scrapping old cars. The coefficient is significant and of the predicted sign, and the fit improves slightly. In columns (g) and (h) we include (separately) linear vintage (vin) and time trends, testing for embodied (vin) and disembodied (year) trends in mortality. Each is significant when entered separately, though the equation does not converge when both are included. In subsequent regressions we include vin but not year.

Column (i) includes the variables which were significant in the prior regressions. In this regression the embodied and disembodied effects of HHI are of approximately equal magnitude.

Table 3 summarizes the quantitative importance of each regressor by its contribution to variation in life expectancy. Entries in the table all report the variation in life expectancy given average values of the other variables as the indicated variable ranges from its sample minimum to its maximum. For example, in column (b) life expectancy falls by 2.14 years as HHI_y varies from 2000 to 3700.

Table 3. Effect of Regressors on Steady-State Life Expectancy

	b	c	d	e	f	g	h	i
HHI_y	-2.14	-1.74	-1.72		-1.37	-0.91	-1.00	-0.87
HHI_v		-0.48						
$HHI_{v(avg)}$			-1.34	-0.80	-0.78	-1.22	-1.55	-0.89
$HHI_{y(avg)}$				-1.54				
U					0.40			0.45
year							0.82	
vin						0.75		0.32

(all coefficients significant at 5 percent level)

Transition Effects

To this point, we have not identified any transitional effects of changes in technology. If there has been an improvement in either μ_0 or m_1 in year i, then all cars built before year i should be retired younger than in the steady state. In principle we can search for transitional effects by incorporating a series of dummies into the regression as follows:

$$\ln\left(\frac{s_a^v}{1-s_a^v}\right)=\ln\left(\alpha + EXP(\beta+\gamma_0\cdot \text{age}+\sum_j \gamma_j X_j \text{age}+\sum_i \gamma_{D_i}\cdot D_i\cdot \text{age})\right) \qquad (9)$$

where $D_i = 1$ if year $> i$ and vin $< I$; $= 0$ otherwise.

γ_{Di} represents the change in the shape of the logistic survival function, after year i, for cars that were built prior to year i. Because the equation does not converge with more than three specific-year dummies, we estimate it separately for i = 1950 through i = 1989. Table 4 lists dummy coefficients and their standard errors.

Table 4. Coefficients of Specific Disembodied Year Effects*

1950	.018 (.011)	1960	-.028 (.006)	1970	-.018 (.006)	1980	.092 (.005)
1951	.034 (.010)	1961	-.047 (.007)	1971	-.010 (.005)	1981	.086 (.005)
1952	.039 (.009)	1962	-.053 (.007)	1972	-.003 (.005)	1982	.085 (.005)
1953	.035 (.009)	1963	-.051 (.007)	1973	-.006 (.005)	1983	.076 (.006)
1954	.028 (.009)	1964	-.052 (006)	1974	-.020 (.005)	1984	.079 (.007)
1955	.002 (.007)	1965	-.060 (.006)	1975	-.011 (.005)	1985	.043 (.008)
1956	.006 (.007)	1966	-.059 (.006)	1976	.003 (.005)	1986	.024 (.008)
1957	.004 (.007)	1967	-.067 (.006)	1977	.025 (.005)	1987	.011 (.007)
1958	-.006 (.007)	1968	-.069 (.007)	1978	.053 (.005)	1988	.002 (.007)
1959	-.026 (.006)	1969	-.036 (.006)	1979	.090 (.005)	1989	.011 (.009)

*Each .01 increment in a coefficient represents approximately one month of additional life expectancy.

The 1968 coefficient indicates that an event in 1968 caused pre-'68 automobiles to suffer excess mortality, beginning in 1968, sufficient to reduce their life expectancies by approximately 0.7 years.[26] The estimated coefficients rise almost monotonically in the years just preceding 1968 and fall monotonically afterward (in both magnitude and statistical significance). If there were indeed a single threshold year, then this is the pattern we would expect. D_{67} is highly correlated with D_{68}; when D_{67} is included and D_{68} omitted, the former picks up almost all of the true effect. D_{66} is less highly correlated with D_{68} and picks up less of the effect.[27] The same pattern appears, plausibly for the same reason, just before and just

[26] Of course, these pre-'68 cars had already suffered mortality risks prior to 1968; their *ex post* life expectancies are a weighted average of their pre-1968 and post-1968 mortality risks.

[27] To test for this, we estimated equation (10) including both D_{68} and proximate-year dummies. For example, we included both D_{68} and D_{67} in one regression. In each instance, D_{68} remains significant, retaining approximately its magnitude in table 4, and the other dummy coefficient becomes small and insignificant.

after the peak year 1980. Thus there seems to be one event which caused pre-'68 cars to do badly after 1968 and one which caused pre-'80 cars to do well after 1980.[28]

We next estimate (9) with both D_{68} and D_{80}. We also include D_{73} because the 1973 timeframe was so turbulent in the history of the automobile (with the first oil price shock and the first binding auto emission controls). The results are reported in the "Fleet" column of Table 5. The coefficients retain their significance when the dummies are entered jointly, and the dummy for 1973 is insignificant.

Table 6 is analogous to Table 3. The "Fleet" column of table 6 gives each regressor's contribution to life expectancy as the regressor varies over its sample-period range, fixing the other regressors at their sample means. For example, as unemployment less trend varies from -2.1 to 3.1, life expectancy falls by approximately 0.2 years.

Table 5. Disembodied Year Effects

	Fleet	Buick	Chevy
α	3.76 (.095)	3.39 (.092)	4.09 (.128)
β	7.18 (.132)	7.32 (.142)	7.31 (.164)
γ	3.67 (1.37)	-2.54 (1.58)	9.77 (1.85)
HHI_{year}	-.909 (.152)	-.524 (.166)	-.651 (.189)
$HHI_{vin(avg)}$	-.146 (.165)	-.036 (.174)	-.090 (.184)
vin	-.0021 (.0027)	.001 (.0001)	-.005 (.001)
U	-.0054 (.0027)	-.0061 (.003)	-.003 (.004)
D_{68}	-.053 (.013)	-.035 (.012)	-.087 (.016)
D_{73}	-.001 (.005)	.030 (.010)	-.006 (.014)
D_{80}	.103 (.011)	.102 (.011)	.117 (.014)
R^2	.924	.931	.900

Table 6. Contribution of regressors to Life Expectancy

	Fleet	Buick	Chevy
α			
β			
γ			
HHI_{year}	-1.7*	-0.8*	-1.4*
$HHI_{vin(avg)}$	-0.2	0	0
vin	-0.6	0.8*	-1.5*
U	-0.2*	-0.4*	-0.1
D_{68}	-0.4*	-0.4*	-1*
D_{73}	0	.4	0
D_{80}	1.1*	1.1*	1.4*
R^2			

*denotes significant at 5% level

28 When we include both D_{79} and D_{80}, both coefficients decrease to about 0.04; they are both significant, but their standard errors are about double those in table 4. We interpret this to mean that the data cannot tell whether the break occurred in 1979 or 1980.

In this regression, we find a disembodied effect similar to what we started with (equation (b) in Table 2); the erosion of industry concentration has led to approximately a 1.7 year disembodied increase in life expectancy. On the other hand, the embodied effect (built-in durability) is statistically insignificant and very small. In addition, the linear vin effect is small and of perverse sign. The dummy coefficients show that pre-68 cars did poorly after 1968 and pre-1980 cars did well after 1980. The dummy for 1973 is insignificant, and the business cycle effect is small and of perverse sign.

Why might the years 1968 and 1980 stand out? Although the first significant safety standards became effective on January 1, 1968, Crandall and co-authors estimate the full cost of these standards at only $138 per car. The more important information from this portion of the time series is that there is no significant change in mortality during the early 1970s (except that which is explained by the other regressors). Increasingly stringent emissions and other standards do not appear to have reduced mortality for grandfather cars in the aftermath of the 1973 energy crisis.

It seems likely that the D_{68} coefficient reflects a spurious movement in HHI immediately after 1968. HHI fell from just over 3000 in 1968 to approximately 2500 in 1969 and 1970, and then recovered to about 2800 in the mid-1970s. This drop is due almost entirely to a decline in sales by General Motors from 4.2 million autos (54.7 percent of the market) in 1967 to 3.3 million autos (46.3 percent) in 1970. Sales partially recovered to 4.7 million (53.6 percent) in 1971. In other words, the HHI-measured concentration declined (temporarily) in 1969 and 1970 because GM, the industry leader, had a couple of bad years. Given the estimated HHI_y coefficient, mortality of pre-'68 cars "should" have fallen just after 1968 but did not.

Reduced grandfather mortality after 1980 may be due to the Voluntary Export Restraints (VER) entered into with Japan. With this agreement, the "effective" HHI was likely considerably higher than the calculated HHI, since Japan and Detroit were effectively precluded from competing for market share.[29] As many observers have noted, Detroit evidently took advantage of the VER to raise the price of its new cars.[30]

Aside from 1968 and 1980, there is no evidence of embodied effects which left transitional legacies with older vintages. Most significantly, the dramatic fuel-economy improvements of the late 1970s did not result in the large predicted die-off of old gas guzzlers. One possibility, of course, is that these fuel-efficiency improvements just offset some negative embodied changes.

Vintage Vintages

Next we look for the effect of embodied changes not in the grandfathers but in the new cars themselves. We estimate the fleet regression of Table 5 separately with a vintage dummy

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29 Of course, the VER, as price effect, should have reduced scrappage of new cars as well. We do not have the data to study this, as the sample period ends in 1991 when these cars are still quite young and not likely to die.

30 Winston and Associates (1987) estimate that VER raised the prices of 1984 domestic cars by 8.0 percent. According to table 1, this price increase is too small to have generated an almost-one-year increase in lifetimes.

for each vintage from 1950 through 1985 (we omit D_{73}, which was small and insignificant). Inclusion of the vintage dummy has virtually no effect on the remaining coefficients. Figure 9 illustrates the vintage dummy coefficients which are statistically significant, converted into their contribution to life expectancy and correcting for the other regressors. For example, the coefficient for vintage 1950 implies that 1950-cars had a life expectancy 0.44 years greater than other vintages.

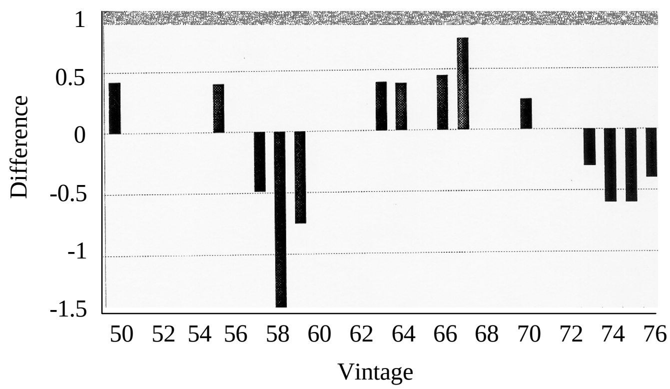

Figure 9. Unexplained longevity

Source: See text

Cars of vintage 1958 survived almost 1.5 years less than otherwise similar cars. Cars built in the early 1970s also do poorly, likely due to the rapid onset of regulations which forced Detroit to build less well-engineered cars in the early '70s (as argued by Crandall and co-authors).[31]

Specific Models

Particularly in the case of these specific-year embodied effects, it seems prudent to examine separate automobile models. For example, energy-price shocks may have differentially affected large and small cars. Because we do not have pre-1976 data on specific models, we work with automobile makes. We report results for 1962 Buicks and Chevrolets,

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[31] We are unable to estimate precise coefficients for vintages later than the late '70s as we increasingly lose data on the older cars (the part of the age distribution in which high or low mortality most starkly reveals itself). Thus the lack of significant coefficients from the 1980s conveys little information about the inherent durability of these vintages.

chosen because they are near opposite ends of the price distribution and because Buicks prior to the energy crises tended to be larger and less fuel efficient than Chevrolets (see Table 7).[32]

Table 7. Characteristics of 1962 Models

	Horsepower	Wheelbase	Price	Weight
Chevy*	80-170	110-119	1800-2450	2250-3500
Buick	155-325	112-126	2475-3450	2700-4319

Data for 1962 models from Kelley Blue Book
Price is 1962 (November-December) used-car price for 1962 model.
*Excludes Corvette

We proceed in the same manner as with the fleet. We first estimate (9) separately for each year from 1951-1989; the pattern (not reproduced here) is virtually identical to that for the fleet. Next we estimate (9) separately for Chevys and Buicks, including D_{68}, D_{73}, and D_{80}. The results appear in the "Buick" and "Chevy" columns of tables 5 and 6. For both makes, the disembodied HHI effect is large and significant; the embodied effect is small and insignificant. For Buicks, life expectancy grows linearly with vintage (by .8 years), suggesting a steady improvement in inherent durability. But for Chevys, life expectancy declines by .75 years as vintage goes from 1948 to 1990. For both makes, unemployment has a perverse sign, pre-'67 cars did badly after 1967, and pre-'80 cars did well after 1980. Interestingly, we find that pre-'73 Buicks did well after 1973; whatever happened in 1973 added about .35 years to the life expectancy of old Buicks. It certainly does not appear that the energy crisis caused consumers to retire their old Buicks after 1973.

Figure 10 shows the cross-section life expectancies of both Chevys and Buicks from 1960[33] through 1990. From 1960 through 1967, Chevys lived approximately a year longer than Buicks. Over the next 15 years Buick generally outlived Chevys, though in most years the difference was less than ¼ year. Beginning in the mid-1980s, Buicks began to outlive Chevys by as much as half a year.

This pattern, on its face, is odd. As we have seen, Buicks in 1962 were about 50 percent more expensive than Chevys; this should have caused Buicks to outlive Chevys by about 2 years.[34] We believe that the market-power/parts-pricing model discussed earlier offers the explanation for the mortality pattern displayed in Figure 10. During the 1960s the market for high-end cars was less competitive than that for low-end cars, with the result that

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[32] We estimated similar regressions for Fords, Mercurys, Chryslers, and Oldsmobiles, with very similar results (not reported). We also attempted to estimate the regression for imports, but the poor quality of the data prior to 1975 made this impossible.

[33] 1960 is the first year for which life expectancies can be constructed solely from post-war vintage cars.

[34] When we examine other makes, the pattern is quite similar. Until the late 1960s, more expensive makes died substantially younger than cheaper makes; in more recent years there has been little mortality difference between cheap and expensive makes.

the parts-price markup was also higher on high-end cars. The early deaths of Buicks in the 1960s were brought about by the market-power-induced markup on parts. Since then, the mortality patterns of Buicks and Chevys have converged because the competitive environment for Buicks converged to that of Chevys.

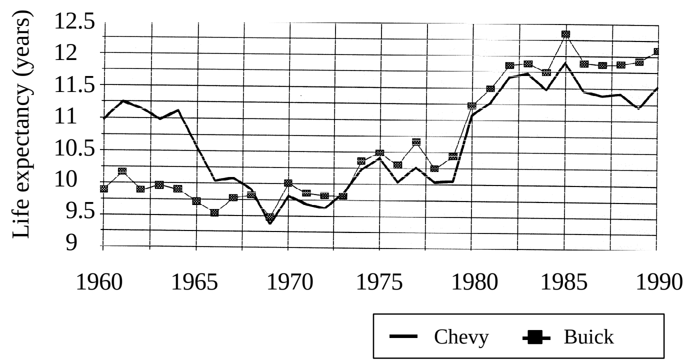

Figure 10. Life expectancy by year
Source: See text

VIII. JAPANESE CARS

There is a widely held popular perception that beginning in the early- to mid-1970s, Japanese manufacturers began to flood the domestic U.S. auto market with fuel efficient and durable cars, and that with a long and reluctant lag, American manufacturers began to match the Japanese. Our explanation, focusing on the effect of competition on maintenance-part prices, gives a prominent role to Japanese cars and the competitive pressure they imposed on the domestic industry. But it does not give a large role to increased inherent durability, either forced by Japanese manufacturers or for any other reason. Here we take a more explicit look at Japanese cars.

The superior-Japanese-cars explanation is inconsistent with the direction and timing of events. Japanese cars became a major part of the auto market in the mid-70s (see Figure 11). Through the transitional effect discussed above, this should have led to retirement of older domestic autos. From Figure 6, however, the mid-70s saw a steady improvement in survival rates of older domestics.

Evidence on the superior maintenance characteristics of Japanese cars comes from Crandall and co-authors who tabulate *Consumer Reports* readers' surveys on frequency of repair. Throughout the 1970s and 1980s, these tabulations show that the frequency-of-repair record for Japanese cars is consistently much better than for domestics. However, they note that the data are far from ideal in that the sample is self-selected and the criterion is subjective. We circumvent both problems by comparing survival rates of Japanese and American cars for various vintages beginning in the late 1960s.

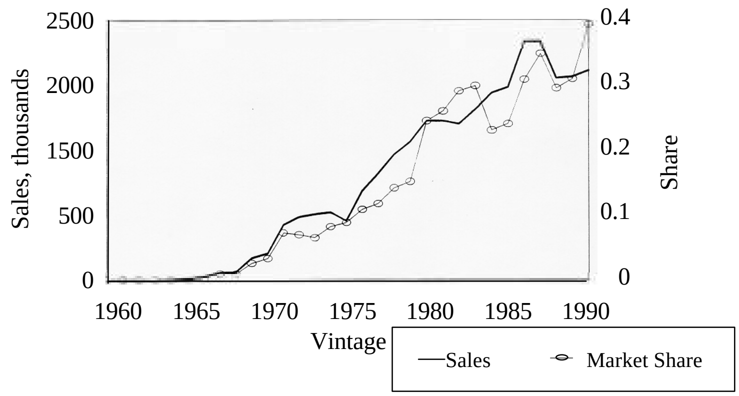

Figure 11. Japanese share of the U.S. auto market

Source: Automobile Facts and Figures (various issues).

The three panels in Figure 12 show the death rates by age for Japanese and domestic vintages. For 1968 vintages, beginning at age 6, Japanese auto death rates are significantly below those of domestic autos. For vintage 1971, Japanese and domestic auto death rates are virtually identical until age 9, after which Japanese cars do substantially better.[35] By the 1977 vintage there is essentially no difference.

The only support for superior durability of Japanese cars comes from the very small vintages which were imported well before the surge years of Japanese cars. Surprisingly, for vintages beyond the early '70s, Japanese and domestic cars look indistinguishable. The popular hypothesis, that Japanese cars during the boom years were more durable than American cars and that American manufacturers finally caught up in the late '80s, finds no support in the data.

[35] Though Japanese '71s had higher survival rates after age 9, the boost came too late to have a very large effect; 26.9 percent of Japanese '71s survived to age 15, compared with 21.5 percent of domestics.

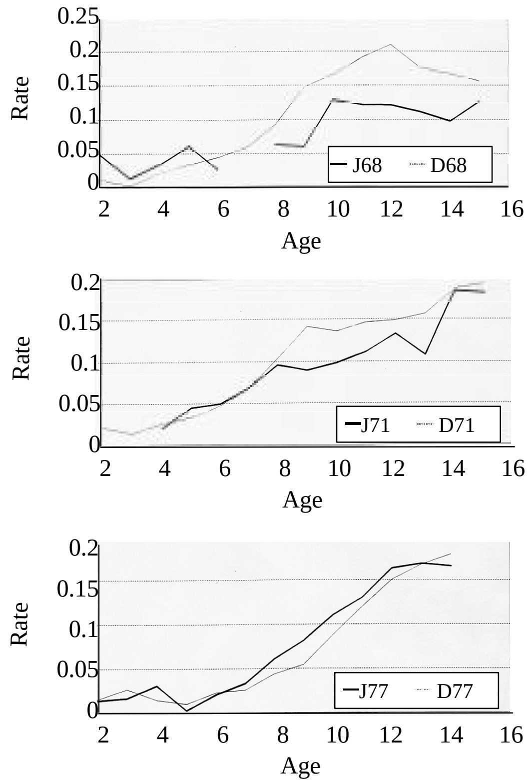

Figure 12. Japanese and domestic auto death rates, by vintage

Source: See text

IX. CONCLUSION

Given the timing of changes in auto death rates, we conclude that essentially none of the massive increase in automobile longevity over the past 25 years can be attributed to improvements in the inherent durability of cars. The rise in lifetimes was driven by some force external to the new cars themselves.

The strong correlation of mortality rates with the Hirschman-Herfindahl index of industry concentration leads us to believe that much of the longevity increase was induced by competition, and we find that the most plausible mechanism through which competition would raise lifetimes is through an erosion of repair-and-replacement parts prices. A simple model of auto scrappage enables us to determine that roughly a 50 percent decline in parts prices would be sufficient to explain the recent decline in auto mortality. This magnitude coincides closely with the roughly 60 percent decline in the cost of maintenance per mile for 2-year-old cars, as estimated by Runzheimer International. Finally, there is some evidence that the Voluntary Export Restrictions with Japan increased car longevity in the early 1980s. But there is no evidence of a retirement of fuel-inefficient cars in the aftermath of either oil shock.

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