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The nonpecuniary costs of automobile emissions standards

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An important component of the costs of automotive air-pollution control has been nonpecuniary: a decline in vehicle performance characteristics. This regulatory impact on what the auto industry calls "drivability" has never been quantified, although there is considerable reason to believe that it has been a major component of the costs of some of the auto emissions standards of the last decade. We develop a methodology for econometric assessment of such costs, and apply it to the automobile air pollution standards of 1972–1981. We find that these costs are important. For the first standards implemented in the 1970s, they exceeded the costs of pollution control equipment installed on the car and the costs of decreased fuel efficiency. Since then, however, advances in compliance technology have allowed increases in automobile quality so that incremental costs of recent standards are much lower than previously believed.

1. Introduction

■ Since the Clean Air Act Amendments of 1970, new automobiles have had to comply with a series of increasingly stringent pollution control standards. The impact of these standards has been significant since an early 1980s car emits less than 10% of the pollutants of an uncontrolled 1967 model. Furthermore, their speed of introduction has been very rapid: the interval between standards has been short when compared with the three-year lead-time for automobile design. Such features of emissions regulation made the standards "technology forcing." That is, the standards forced manufacturers to expand their technological base, since a complying automobile had yet to be designed. In choosing compliance technologies, manufacturers faced two closely related decisions: would the technology be a breakthrough or an incremental change, and would compliance come by decreased auto quality or by increased auto costs. These decisions were linked because the breakthrough technology typically was associated with higher auto manufacturing costs, such as the installation of expensive pollution control equipment. Incremental technology usually involved other costs

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for the driver: higher maintenance costs, diminished fuel efficiency, poor acceleration, slow cold-weather starting, and so on. The pecuniary elements of these costs—the devices installed on the car, the maintenance, and the fuel efficiency—have been carefully studied.[1] Yet the nonpecuniary components—the decreases in drivability, acceleration, and cold-start performance—have never been satisfactorily quantified, although there is reason to believe that they are important.

In this article we use second-hand car prices to estimate consumers' willingness to pay to avoid the nonpecuniary disamenities associated with automobile emissions standards. We model those disamenities as an element of automobile quality, and we develop a framework for measuring the changes in product quality associated with regulatory compliance. Our framework for assessing quality change is based on changes in the cross section rate of depreciation. At any given time, older vintage cars are less valuable than newer ones with the same (nonage) quality attributes. When the newer car is of lower quality because of compliance with a more stringent emissions standard, this difference is diminished. A measure of the lower quality is obtained by comparing the cross section rate of depreciation in years when newer cars meet more stringent standards with the rate in years when both newer and older cars meet the same standards. Our method bases the estimates only on automobile models whose nonemissions characteristics remain essentially constant from one year to the next.[2]

The ratio of the prices of newer and older used cars, like any other relative price, is affected by both market forces and the relative quality of the two goods. Two kinds of market shifts in the demand for newer relative to older cars are evident in our data. The first is movements in relative prices caused by changes in income. Demand is more income elastic for newer cars than for older ones, so that an increase in income shifts the demand curves for newer and older cars disproportionately. Since the short-run supply curves of used cars are vertical, while the supply of new cars can respond to demand shifts, the relative prices are likely to change after a shock to permanent income. The second force tending to shift the relative prices of newer and older cars is the fuel price shocks of the 1970s. In this period demand for automobiles shifted rapidly between the larger and smaller car segments. A shift in demand to fuel-efficient cars changes the equilibrium cross section rate of depreciation within the small-car segment. We estimate structural demand relations from a larger system of automobile supply/demand functions. Although it is appropriate to treat the supply curves of used automobiles as vertical in the short run, new automobiles are a close substitute and are supplied with some elasticity. Our framework treats the prices and quantities of new automobiles and the prices of used ones as endogenous. Thus, the inferences drawn will be purged of shifts of the demand curve except those due to regulation.

Two previous studies have attempted to measure the nonpecuniary costs of automobile emissions controls. Dewees (1974) used a hedonic method, in which the extent to which compliance changes observable performance characteristics (horsepower) is multiplied by the estimated marginal value of those characteristics. This approach requires that the set of observable quality proxies be inclusive; cold-start performance, for example, is valuable but

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[1] See White (1982) for a very careful review of these studies, and Crandall, Keeler, and Lave (1982) for more recent work.

[2] Thus, for example, the price of a 1979 Mustang is compared with that of a nearly identical 1980 Mustang, but a 1979 Thunderbird is not compared with the redesigned 1980 Thunderbird. We used no comparisons across models. We do not attempt to measure any explicit indicators of auto quality change, such as horsepower and acceleration. Instead, we look at models in adjacent years whose engineering attributes are the same and see how their market values change. A hedonic study would, for example, see by how much emissions regulations lowered horsepower, estimate the value of horsepower, and calculate the value of the loss. We instead simply verify that the 1979 and the 1980 cars have the same engine and ignore performance criteria (e.g., horsepower) across models when we hold attributes constant. Thus, our method is inclusive: we do not require explicit measures of all of the quality variables that we believe are affected by the regulations.

not included in the analysis. Langenfeld (1983) specifies an aggregate supply/demand system for automobiles including emissions compliance as a quality variable. We discuss the relation of our results to his below.

We find that consumers' valuations of the quality differences of cars complying with different standards are of the same order of magnitude as the capital costs and fuel economy costs of those standards. Since 1973, in fact, increases in capital costs attributed to regulation have been partially offset by corresponding *increases* in quality associated with advances in emissions technology. Although some of these improvements in quality would have occurred in the absence of regulation, we believe that the quality changes we measure reflect regulation-induced technical change and, to a lesser extent, reflect the automakers' decisions to incur higher product costs to obtain higher quality.

The article is organized as follows. In Section 2 we present background information about the emission control standards and the compliance technologies. Section 3 sets out our methodology for assessing differences in automobile quality over time, and Section 4 takes up some important estimation issues. We present the empirical results in Section 5, and discuss their implications for the costs of emission controls in Section 6. Finally, Section 7 contains concluding remarks.

2. Background

■ The Clean Air Act Amendments of 1970 were the key federal legislation affecting automobile emissions control. That legislation required a 90% reduction in the level of HC (hydrocarbons) and CO (carbon monoxide) by 1975 and a similar reduction in NO_x (nitrogen oxides) by 1976. Through a combination of the reassessment of technical possibilities and industry recalcitrance, the original federal standards were modified and delayed through 1981. As a result, implementation proceeded by a collection of "interim" standards approved by regulatory bodies and legislature-approved delays in standards. Table 1 lists each new standard as it actually came into force. The "uncontrolled" row gives the average levels of emissions for uncontrolled automobiles in grams per mile.

The 1970 Act also permitted California to set its own emissions standards, which are shown on the right side of Table 1. California standards tended either to lead federal standards by one model year or to move to stricter standards in the same year.

Except in 1977, all of the new federal standards required substantial compliance tech-

TABLE 1 **Automobile Emissions Standards, 1966–1981**

	Federal			California		
Model year	HC	CO	NO_x	HC	CO	NO_x
uncontrolled	(8.7)	(87)	(4.4)	(8.7)	(87)	(4.4)
1966	none	none	none	4.3	44	none
1968	6.2	51	none	4.3	44	none
1970	4.1	34	none	4.1	44	none
1972	3.0	28	none	3.0	28	3.1
1973	3.0	28	3.1	3.0	28	3.1
1974	3.0	28	3.1	3.0	28	2.0
1975	1.5	15	3.1	.9	9	2.0
1977	1.5	15	2.0	.41	9	1.5
1980	.41	7	2.0	.39[a]	9	1.0
1981	.41	3.4	1.0	.39[a]	7	.7

All standards in gm./mi.

[a] Nonmethane hydrocarbon standard versus total hydrocarbon standard (not comparable to other hydrocarbon standards).

nology changes. Table 2 shows how the technology changed to meet the new standards. When different manufacturers complied by using different technologies, we list the more common technologies first.

In the early 1970s the automakers based their compliance technology development strategy on the catalytic converter. The catalyst seemed to promise moderate compliance costs with low risk and no major changes in powertrain technology.[3] The expected advantage of the catalyst was that it would allow compliance with much less effect on fuel economy and drivability than did the then available methods of control. Because the catalyst was not ready in time for the 1972–1973 model year automobiles, compliance with those standards was achieved with noncatalyst systems or with fuel injection. Noncatalyst systems typically involved engine detuning and axle ratio reductions, which were often augmented with air injection devices to help control CO and HC and exhaust gas recirculation to control NO_x. Dewees (1974) and White (1982) have noted that the noncatalyst technologies used to comply with the 1972 California and 1973 49-states' standards may have substantially lowered automobile quality.

Many manufacturers were able to take advantage of the catalyst technology in time for the 1974–1975 standards.[4] Thus, compliance costs for these manufacturers were mostly pecuniary in the form of expensive compliance devices rather than being reflected in lower auto quality. Other manufacturers employed less sophisticated noncatalyst systems involving air injection or exhaust gas recirculation.[5] By the 1977 model year, only about 10% of automobile models complied without a catalytic converter. Most of these models had small engines, which were easier to bring into compliance than large ones, or were low-priced cars, for which the high-cost, high-quality catalyst technology did not pay.

Manufacturer choices among compliance technologies for the 1980–1981 standards again reflected product decisions and differences in technological options. Some automakers complied with three-way catalysts in a closed-loop emissions control system that used so-

TABLE 2 **Technologies Used for Compliance**

Model Year Federal (Calif.)	Base Technology	Advanced Technology
1973 (1972)	Noncatalyst	Fuel Injection (FI)
1975 (1974)	Noncatalyst	Catalyst or FI
1977 (1977)	Noncatalyst	Catalyst or FI
1980	Catalyst	3-Way Catalyst (TWC) or Closed-Loop System (CLS) or FI
1981 (1980)	Catalyst or TWC	CLS or CLS/FI
(1981)	Catalyst or TWC	CLS or CLS/FI

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[3] The likelihood that the technology would meet the final goals of the 1970 legislation was not a crucial consideration to the automakers, since they probably expected that an unsuccessful effort, made in good faith, would result in a delay or cancellation of the final standards required by the 1970 Act. This belief was reinforced by the piecemeal delays in standards that began in 1973 and occurred in three of the next four years. It is also possible that inefficient devices may have been the result of a strategy by automakers to delay future standards (Yao, 1984) or that the automakers were concentrating on developing devices for the later, more stringent standards.

[4] The 1974 standard was the only one on which California's right to set its own standard was preempted by the EPA. It was set to force automakers to gain experience with the use of catalytic converters in California while leaving them the option of using converters on the federal models.

[5] Ford and Chrysler appear to have had poorer catalyst technology than GM in 1975. In certain instances, as with the Ford 3.3L engine in California, they chose to comply by removing products from the market. The choice of compliance technology was conditioned on available technologies as well as on marketing considerations and the timing of the engine life-cycle.

phisticated electronics to control engine functions, while others used three-way catalysts without sophisticated electronics. Many automakers met the 1980 standards merely through upgrading the traditional catalyst system. Thus, technology choice determined the split of the compliance costs between pecuniary and nonpecuniary components, with breakthrough technologies like electronic engine controls and fuel injection providing high vehicle quality at higher cost than an incremental technology such as conventional systems with larger catalysts.

3. A model to measure differences in automobile quality over time

■ Suppose that a regulatory standard is applied to durables built in year $y + 1$ but not in year y or $y - 1$. An attractive measure of consumers' willingness-to-pay to avoid quality changes from regulatory compliance can be found in the relative prices of newer and older durables. In the automobile case we select representative model cars and look at their relative prices in the used-car market. Letting the user cost of a model m, age a car at time t be $\rho^t_{m,a}$, we would like to compare

$$\frac{\rho^{y+1}_{m,2}}{\rho^{y+1}_{m,1}} \text{ with } \frac{\rho^{y+2}_{m,2}}{\rho^{y+2}_{m,1}} . \tag{1}$$

Since the number on the left is the relative price of one- and two-year-old cars meeting the same emissions standards (at time $y + 1$, no used cars meet the new standard), it serves as a benchmark. Typically, this is a number around .85—the cross section depreciation rate for late-model autos is around 15%. The number on the right is the relative price of one- and two-year-old cars when the younger car meets the new standard. It should reflect the lowered willingness-to-pay of consumers for lowered quality caused by the emissions standards. If the younger car were lower in quality (measured by willingness to pay) by ϵ percent, we would expect to see a figure of around $.85 + \epsilon$. The goal of this article is to estimate a parameter $\epsilon_{S\tau}$ for each emissions standard S and each compliance technology τ.

This calculation requires care because of three important factors.

(1) Automobiles are durable: the price of a used car is not the same as the cost to a consumer of a year of automotive services. The latter is the sum of the capital cost of owning the automobile (which depends on expectations of future prices) and the operating cost of driving it (which depends on the price of fuel, insurance, etc.).
(2) The qualities of automobiles built in different years change for reasons that have nothing to do with emissions controls. Thus, quality must be held constant.
(3) Like any other relative price, the relative price of newer and older used cars is set by demand and supply forces. To interpret the difference in relative prices as differences in willingness to pay, we must make certain we are estimating the demand curve rather than some combination of the supply and demand curves. The relative prices of newer and older vintages of any particular type of automobile may also be affected by supply and demand conditions in another segment of the automobile market.

The user cost, ρ^t_{ma} of model/age ma at time t is the sum of the operating cost, c^t_{ma}, and the capital cost, v^t_{ma}. The capital cost of owning a durable for one time period is the familiar Hall-Jorgenson formulation.[6] To calculate v^t_{ma}, we need three pieces of data: the price of

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[6] Previous studies of the demand for automobiles have treated the user cost of durable ownership in this way (Johnson, 1978; Wykoff, 1973; Hess, 1977). These studies have not, however, treated the product-differentiated nature of automobile demand, and thus are not directly applicable to the problem of quality measurement. Hedonic price analyses (Griliches, 1971; Griliches and Ohta, 1976; Crandall, Keeler, and Lave, 1982) have made quality corrections but have not attempted to embed the quality analysis in a fully specified demand system. Berndt (1982) provides a reconciliation between quality assessment and demand analysis similar to our approach. Joskow (1984) and Mannering and Winston (1985) estimate models of automobile demand similar to ours, but they do not treat regulatory compliance issues.

the durable good now, P^t_{ma}, the real interest rate r^t, and the current expectation of the real price of the durable good next period, $E_tP^{t+1}_{m,a+1}$. (Our econometric treatment of price expectations is discussed below.) Note that in the last expression both real time and the age of the durable good advance. The capital cost v of owning the durable is then

$$v^t_{ma} = P^t_{ma}(r^t + (E_tP^{t+1}_{m,a+1} - P^t_{ma})/P^t_{ma}). \tag{2}$$

Here the first term is the interest charged to the durable and the second is an expected capital loss in percentage terms. Note that we write the expected capital loss without an explicit rate of depreciation. Instead, we allow the expectation $E_tP^{t+1}_{m,a+1}$ to be less in real terms than P^t_{ma} by the amount of depreciation. The operating cost of the durable depends on its features and on prices at the time of operation. Features of the durable include such things as fuel efficiency and the type of fuel used. The operating costs of automobiles consist largely of fuel, repairs, and insurance. The prices of these inputs enter the demand equations for automobiles through c^t.

Our specification of the demand system begins at a very high level of generality; each automobile model/age combination is treated as a separate commodity. Let ρ^t be the vector of all of the ρ^t_{ma}. Similarly, let Q^t be the vector of Q^t_{ma}, the quantities of autos by model and age, including new cars. For example, one element of Q^{1978} is the number of 1976 Chevy Caprices in existence in 1978. Let every model/age car have a complete list of quality attributes Z^t_{ma} such as car size, engine displacement, and emissions compliance technology,[7] and collect these together in the vector Z^t. Then, the demand system written in inverse form is

$$\rho^t = D^{-1}(Q^t, Z^t, X^t), \tag{3}$$

where X^t are exogenous variables shifting the demand for automobiles or shifting the demand for different ages or models. The effects of regulations on quality will enter through Z^t. Clearly, this demand system is much too richly specified to be estimated, so that some restrictions must be imposed.

The quality-correction problem is approached by estimating only part of the entire demand system. In particular, our dependent variable will be the ratio that appears in (1), $\rho^t_{m,a+1}/\rho^t_{m,a}$. Our sample will consist of those model cars, m, at those time periods, t, such that the a-year-old and the $(a + 1)$-year-old cars are identical except (possibly) for emissions equipment. Although automobile price reflects the marginal consumer's valuation of the emissions control system on the automobile, the price also reflects other features of the automobile, such as styling, handling, and comfort, all of which present problems for measurement. Rather than unravelling these various attributes, we exploit the feature of the automobile market that about 70% of all automobile models remain essentially unchanged between adjacent model years and we limit our estimation to such cases. This method is similar to that employed by Cagan (1971) to measure year-to-year quality changes in automobiles.

Thus, the quality attributes, except emissions compliance, are the same for the car in the numerator and in the denominator in (1). We assume that this lets us write the demand system (3) in the form:

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[7] This is a list of quality *inputs,* such as car size, engine displacement, and emissions compliance technology, rather than of quality *outputs,* like horsepower, ride, or other measures of performance. Most research based on the hedonic model involves an input-based measure of quality on the grounds of convenience or feasibility. In the regulatory-compliance case, it is necessary to use the quality-as-inputs convention. Emissions standards and compliance technologies are necessarily inputs into the production of automotive quality, not direct measures of it. For example, suppose emissions controls worsen both observable performance variables, like horsepower, and unobservable ones, like cold-start performance. If one of the quality attributes held constant is horsepower, then the emissions effect will be underestimated.

$$\frac{\rho^t_{m,a+1}}{\rho^t_{m,a}} = f_{ma}(Q^t, X^t) \times \exp[\epsilon_{E_\tau} - \epsilon_{E'_{\tau'}}], \tag{4}$$

where the older car complies with emissions standard E using technology τ, and the younger one complies with E' using τ'. The percentage difference in automobile quality relative to an uncontrolled car that results from compliance with E using τ is ϵ_{E_τ}. Conditions under which consumers' valuations of a change in quality will be a constant ϵ_{E_τ} have been investigated by Berndt (1982). Under these conditions, relative prices within a segment of the automobile market may vary depending on the quality attributes of different models, but (4) embodies the "perfect repackaging" assumption employed by Cagan (1971) and Hall (1971).

We simplify the way in which consumers substitute across different automobiles by making an assumption about automobile market "segments": relative prices for all models within the same segment and of the same age are independent of quantities. This simply assumes that all consumers trade off cars within the segment in the same way, although they may be heterogeneous in their relative valuation of models in different segments. The separability across age-segment groups implies the existence of a quantity index Q^t_{sa}, of a very specific form,[8]

$$Q^t_{sa} = \sum_{m \in S_s} Q^t_{ma}, \tag{5}$$

where S_s is the set of models in the segment. We take all of the Q^t_{sa} and assemble them into a vector called $\{Q^t_{sa}\}$.

We assume that all models of automobiles taken together are separable in demand from all other goods, except for those goods whose prices enter c^t. This separability assumption still permits movements in the prices of complements, such as fuel, to affect the demand for automobiles by type, since they enter the system through c^t. It also allows income to affect the demand by type, since no assumption of homotheticity has been made.

The assumption of separability from other goods plus the existence of consistent segment quantity indexes implies that the demand equations can be written in the form,

$$\frac{\rho^t_{m,a+1}}{\rho^t_{m,a}} = \frac{D^{-1}_{m,a+1}(Q^t, Z^t, X^t)}{D^{-1}_{ma}(Q^t, Z^t, X^t)} = h_{sa}(\{Q^t_{sa}\}) \times \exp[\epsilon_{E_\tau} - \epsilon_{E'_{\tau'}}]. \tag{6}$$

The absence of X^t from $h(\cdot)$ reflects the separability assumption.

Our empirical specification assumes that $h_{sa}(\{Q^t_{sa}\})$ is linear in the logs:

$$\log\left(\frac{\rho^t_{m,a+1}}{\rho^t_{m,a}}\right) = \delta_{s,a} + \sum_{i=1}^{N_{segs}} \sum_{j=0}^{N_{ages}} \gamma^{ij}_{sa} \log(Q^t_{ij}) + \epsilon_{E_\tau} - \epsilon_{E'_{\tau'}} + \kappa TSS + \lambda T, \qquad m \in S_s. \tag{7}$$

The parameters $\delta_{s,a}$ are the primary determinants of the relative prices of autos in different age/segment groups. To see this, assume for the moment that all the other parameters were zero. Then automobiles of all ages in the same segment would be perfect substitutes and their relative prices would simply reflect their depreciation in quality, δ, as valued by consumers. Letting $\delta_{s,a}$ vary by segment and age permits larger and smaller cars, and newer and older ones, to depreciate at different rates. The parameters γ allow the elasticity of substitution between automobiles in different age/segment groups to differ from minus infinity. When all the elements of γ are zero, then the relative prices of automobiles of different types are fixed. Nonzero values in γ allow each individual age/segment to have a

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[8] In an aggregate discrete-choice demand setting, each consumer purchases only one item. Thus, any quantity index takes the form of the sum of quantities, since it simply represents the total number of consumers who chose a model in a given segment. This is in sharp contrast to the theory of quantity indexes for a representative consumer, where the index typically depends on values as well as on the number of units. See Fisher and Shell (1971).

downward sloping demand curve. Then shifts in exogenous variables—fuel prices, national income, or the price of the yen—will move the relative prices of automobiles.

The parameters ϵ are dummy variables for the emissions standard with which the car complies and the technology used to comply. The model is parameterized so that the ϵ associated with a later standard is interpreted as the nonpecuniary compliance costs of that standard. Compliance technology is identified by the letter immediately following the year. These technologies are indicated as follows: N for no catalyst, C for catalyst, FI for fuel-injection, CLS for cars with either closed-loop systems or fuel injection. Thus, ϵ_{73N} is a dummy variable representing compliance with the 1973 federal standards without a catalytic converter, while ϵ_{77C} is compliance with the 1977 standards using the catalyst technology. The standard depends only on the manufacturing date $(t - a)$ of the car.[9] The ϵ for pre-1973 federal standards is normalized to zero.

The parameter κ captures incremental technical change in the emissions systems of automobiles when the standards do not change. The variable TSS is a dummy that is one when both the numerator and denominator car meet the same standard and zero otherwise. That is, the quality cost of a standard E and a technology τ is $\epsilon_{E,\tau}$ in the first year the standard is in effect. Thereafter, the quality cost changes at the rate κ per year for as long as the standard is in effect. Finally, λ allows for the possibility of advance in automobile quality not captured by our attempt to use only identical models.

We estimate (7) with dependent variables for only four market segments: subcompact, compact, midsized, and full-sized. The implementation of γ we use has N_{segs} equal to five, since luxury cars are also included. We do not estimate (7) for the luxury car segment, however, because of the unusual features of that segment, such as thin markets, the presence of market power, and idiosyncratic demand. Further, although we only include three ages of cars as dependent variables, the sum j in (7) runs from zero (new cars) up to N_{ages}, which is six in this model. Thus, we use as independent variables quantities of all cars up to six years old, but we only estimate price ratios of one-, two-, and three-year-old cars. We treat all cars older than six years and in the same segment as being perfect substitutes, so that $\{Q_{sa}^{t}\}$ is a 35-vector in our empirical work.

The parameter vector just described is quite large. We reduce its dimensionality after conducting some preliminary tests, which are discussed below. As a result, our actual reported estimates involve somewhat fewer parameters than some recent treatments of the demand for automobiles. This is so since our estimating equations only consider substitution between the same model car of different vintages.

4. Estimation

■ Demand equations for automobiles that are estimated without regard for the endogeneity of price and quantity may be misspecified, in which case a simultaneity bias may be present. This bias is likely to be reflected in the assessment of emissions effects. As it happened, some increases in the stringency of emissions regulation occurred in years when the cross-section depreciation rate was "normal," while others occurred at times when some aggregate auto market shock shifted the usual relations. Thus, it is particularly important in these data to ensure that a structural demand system is being estimated when trying to draw inferences about the disamenities of emissions regulations.

The supply side of the market for durables consists of the stock of used durables and the supply curves for new ones. Partition the vector of quantities of all ages and types $\{Q_{sa}^{t}\}$ into Q_o and Q_n, old and new quantities: Q_{sa} belongs in Q_o if $a > 0$. The supply curve

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[9] EPA could grant "waivers" on individual engine lines. They did not, however, grant many waivers of the standards until 1981, when many manufacturers received waivers for the new CO standard. Before 1981, waivers were generally given only to AMC and low-volume foreign manufacturers.

for Q_o is vertical at the quantity of cars originally produced. This is a reasonable assumption for our purposes since we only consider cars that are four years old or younger, so that scrappage is not an important factor.

The supply curve for new automobiles is written in inverse form as

$$P_n^t = \Phi^{-1}(Q_n^t, X^t), \tag{8}$$

where P_n^t has the same dimension as Q_n. Here X are cost-side exogenous variables, such as wages, raw material prices, and foreign exchange rates. In estimating the demand system, we shall use these exogenous variables as instruments.

The set of equations (7), one for each model automobile, is jointly estimated by three-stage least squares. The variances of the dependent variables are assumed to be the same for all models in the same segment. The correlations between the errors in any two equations in the same segment are equal, as are the correlations between the errors in any two equations in different segments. Both new and used quantities on the right-hand side are treated as endogenous, although used quantities are treated as predetermined.[10] The instruments that affect new-car supply are current and lagged values of the interest rate, real consumption expenditures, the real price of gas, time, the yen and Deutschmark exchange rates, the wage rate in automobile manufacturing, and the price of steel. These lead to an R^2 of around .8 in the reduced-form equations for new quantities in all segments.

Expectations about the future prices of automobiles depend on such considerations as consumer expectations about future fuel prices, the state of the economy, and future emissions standards. In measuring ρ, we use as a proxy for $E_t P_{m,a+1}^{t+1}$ the actual value of $P_{m,a+1}^{t+1}$. This proxy is observed with error unless consumers have perfect foresight. Since user costs are the dependent variable, $E_t P_{m,a+1}^{t+1}$ appears only on the left-hand side in (7), so that only the projection of $P_{m,a+1}^{t+1}$ onto variables observable at time t (the instruments) enters the estimates. As a result, our estimation method implicitly imposes rational expectations in the same way as McCallum (1976). This method necessarily assumes that there is a stable forecasting equation from the instruments to future values of the relevant variables.

5. Empirical results

■ We arrived at our preferred empirical specification by deleting from (7) variables with extremely insignificant coefficients, provided the deletion did not affect the values of the remaining parameters. In our initial specification of (7) we included variables for the quantities of cars in other segments and other years, including new car quantities. Our most important departures from that unrestricted specification are some restrictions on δ (the constant term) and a radical reduction in the size of the vector γ (the coefficients of quantities). The parameters actually estimated are shown in Table 3.

☐ **Estimates of δ and γ.** In Table 3 the constant is $\delta_{4,2}$, the normal depreciation rate of a full-sized car between its second and third years. The variables *SEG1*, *SEG2*, and *SEG3* allow for different rates of depreciation across other segments, where *SEG1*, *SEG2*, and *SEG3* are dummies for subcompacts, compacts, and midsize cars, respectively. We have imposed the restriction $\delta_{1,a} = \delta_{4,a} + \delta_{SEG1}\, SEG1$, etc. *AGE* is a dummy variable that takes the value zero if we are estimating the price ratio of two- and three-year old cars and the value one when we are estimating the ratio of one- and two-year-old cars. We have imposed the restriction $\delta_{s,1} = \delta_{s,2} + \delta_{AGE}\, AGE$ for all segments. The unrestricted specification in (7) allows the rate at which $\delta_{s,a}$ increases in a to vary across s. Such an effect does not appear

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[10] This means that exogenous variables observed as of time t are not used as instruments for quantities determined at time $t - i$. Instead, only the projection of the quantities onto exogenous variables observed as of the time of their determination is used.

TABLE 3 **Parameter Estimates**

Parameter		Estimate	Standard Error
constant		−.093	.0098
δ_{AGE}		−.00541	.00674
δ_{SEG1}		.0225	.0171
δ_{SEG2}		.005	.0142
δ_{SEG3}		.018	.0111
γ_{QDIF}		−.37	.068
ϵ_{73}	Noncatalyst	−.0471	.00146
ϵ_{75N}	Noncatalyst	−.0459	.0244
ϵ_{75C}	Catalyst	−.0254	.0021
ϵ_{75FI}	Fuel Injection	.0840	.0560
ϵ_{77N}	Noncatalyst	−.0118	.0343
ϵ_{77C}	Catalyst	−.0315	.0019
ϵ_{77FI}	Fuel Injection	.1060	.0623
ϵ_{80C}	Catalyst/TWC	−.0143	.0044
ϵ_{80CLS}	CLS/FI	.0573	.489
ϵ_{81C}	Catalyst/TWC	−.0402	.0313
ϵ_{81CLS}	CLS/FI	.0274	.0026
	κ_{TSS}	.0025	.0011
	λ_{TIME}	.0016	.0051

Number of Observations = 810

to be present in the data, as the restrictions imposed here are violated only in the fourth decimal place.

The estimates of δ are as one would expect. We estimate $\delta_{4,2}$ to be about 9.3% with a very small standard error. On the basis of the prices of used cars alone, one would expect the depreciation rate of an automobile to be approximately 15%. The difference is explained by our inclusion of operating costs in the dependent variable. The ratio of the capital costs of a newer and an older car is around .85, but the operating costs are much closer, so that the average value of $\rho_{m,a+1}/\rho_{ma}$ in the sample is above .9. The coefficient for *AGE*, −.005, suggests that the relative values of two- and three-year-old cars are slightly closer than the relative values of one- and two-year-old cars, though this effect is not large enough to be significant. The coefficients of the SEG_i variables are all positive but insignificant. This suggests weakly that full-size cars depreciate at a somewhat faster rate than smaller cars. We interpret this as evidence of complementarity between full-size car segments and newness: owners of large cars on average value newness more highly than do owners of smaller cars.

The estimates of nearly all elements of the vector γ were unimportant, so that we have deleted all quantities except Q_{sa} and $Q_{s,a+1}$, and have imposed the restriction that these remaining quantities have equal and opposite coefficients. The variable *QDIF* is log $(Q^t_{sa}/Q^t_{s,a+1})$, the log relative quantities of cars in the segment that are of age a and $a + 1$. The coefficient of *QDIF* is to be interpreted as the reciprocal of the elasticity of substitution between older and younger cars in the same segment. The elasticity of substitution is thus estimated to be around −2.7. This implies that older and newer cars in the same segment are close substitutes, though the data reject the hypothesis that they are perfect substitutes—the hypothesis that the coefficient on *QDIF* is zero.

The symmetry restriction, that the quantities included have equal and opposite effects, has little impact on the other estimated parameters. The exclusion restriction that limits quantity variables to two age/segment quantities imposes separability—the relative price of younger to older subcompacts is unaffected by the compact car market, and the relative price of two- to three-year old cars is unaffected by the quantity of one-year-old cars. Though the quantities in adjacent segments have insignificant coefficients in our estimates, we do not interpret our results as indicating segment separability. Since the estimated equations include no relative prices of automobiles in different segments, we have very limited power to draw such an inference.

□ **Emissions parameters in the preferred specification.** The results of principal interest are the estimated effects of the emissions standards on the depreciation rate. In Table 3 these effects are shown in ϵ_{73} through ϵ_{81CLS}. Because the fuel economy, maintenance, and insurance effects of the various models have already been included in the relative prices, the emissions-standard-compliance technology coefficients estimate only the marginal consumer's willingness-to-pay for drivability associated with the various car models.

Compliance with the 1973 standards was associated with a quality loss of 4.7% of the total user cost of the car. Although the 1975 standards were considerably more stringent, noncatalyst technology improvements maintained drivability costs at approximately the 1973 level. Compliance by using the catalytic converter technology (ϵ_{75C}), however, *decreased* the drivability costs that had been incurred in 1973 by about half. Thus, by 1975 the quality penalty associated with emissions controls was about 2.5% for cars with catalysts.

As might be expected, compliance with the 1977 standards by using the catalytic converter (ϵ_{77C}) decreased quality relative to the 1975 catalyst cars by a small amount. But the point estimate of the quality loss owing to compliance with the 1977 standards by using noncatalyst technology is smaller than the equivalent value for the more advanced compliance system. The standard error for this estimate, however, indicates that the coefficient is estimated very imprecisely, and thus we attribute little significance to the estimate.[11]

Fuel-injection technology generated even greater gains relative to traditional technology. An interesting sidelight is that a large fraction of cars that were fuel-injected in 1975 were not fuel-injected in 1974. Thus, it appears that some manufacturers, such as Volkswagen, may have adopted fuel injection partly because the more stringent standards made the technology more attractive.

The same general pattern of the effects of emissions standards and compliance technology is repeated in the estimates for 1980 and 1981. Compliance with the old-style technology—catalytic converters—shows substantially higher costs than compliance with the newest technology—closed-loop systems and throttle-body fuel injection. In fact, closed-loop-system and fuel-injection drivability is estimated to exceed that of an uncontrolled car in both years. The 1981 standards appear to have had substantial drivability costs relative to 1980, with technology held constant. But, a great many more 1981 models used the closed-loop-system and fuel-injection technology than did 1980 models, so that the average drivability cost was lower in 1981.

Progress in refining a given technology over time is captured in *TSS*, the time-since-standard variable. The size of this parameter, κ, can best be interpreted by noting that it is about one-eighth of the difference between ϵ_{75N} and ϵ_{75C}. The importance of incremental emissions technology improvements holding technology fixed is small relative to the impact of changes in compliance technology.

The final parameter is λ, the coefficient of time. This coefficient should reflect increases in quality over time that are unrelated to emissions technology. Though too small to be of either any economic or statistical significance, this variable has not been deleted because several other parameter values change markedly when it is removed.[12] The weakness of the effect should not be interpreted as meaning that, aside from emissions-related changes, the

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[11] One plausible explanation for the unusual point estimate is that the group of cars that lack catalysts comprises mostly small Japanese cars. It is typically easier to make a lighter car comply with a given standard than to make a heavier car comply, so that the quality loss could be less for lighter cars. Our attempts (documented in the next section) to allow compliance cost to vary by type of car, however, revealed no such effect.

[12] In particular, the 1980 and 1981 standard coefficients all increase dramatically when time is removed and thus suggest that the time trend is capturing some nonemissions quality improvements. When λ is constrained to be zero, both 1981 technologies are estimated to have quality costs under 2%, and both 1980 technologies yield quality advances over 6%.

quality of automobiles has been nearly constant over time, because our method excludes quality changes that occur when models (or engines) are completely redesigned.

We conclude this section by comparing our results with those of Langenfeld (1983). He found large negative effects of compliance on quality, while we find such effects only for the 1973 standards. The crucial difference is in the way emissions standards and compliance technologies are treated in the two articles. Langenfeld enters a single variable for all the standards—e.g., the geometric mean of the three different pollutants' limits (in gm./mi.)—and uses no information on means of compliance. Thus, his specification imposes the restriction that quality costs are monotone over time as the standards grow more stringent. By including a separate dummy variable for each technology and standard, we are able to reject the monotonicity assumption.

☐ **Specification tests and robustness.** Our results about the drivability costs of emissions standards and compliance technology appear to be robust to changes in specification. The first changes in specification we considered were intended to verify that our treatment of substitution across automobiles of different types and our treatment of emissions-control technologies were adequately rich. Our specification in (7) presumes that different automobiles in the same segment are perfect substitutes. To test this we included two pieces of information about the *specific* car, above and beyond our allowance for factors that shift relative prices on a segmentwide basis. These were the weight of the car and the ratio of the older to the newer car's quantity. Neither variable's coefficient was significant, and the inclusion of these variables did not alter the estimates of the parameters for the other variables. Other variables were also tried, such as dummies for years in which the standards did not change. The coefficients of these variables were not significantly different from zero.

To test the importance of the segment definitions, we used a second set of definitions based on the weight, length, and wheelbase of the car. This had a substantial impact on the segment parameters, but changed the emissions-control parameters only in the fourth decimal place.

To assess the extent to which we are actually estimating the demand system, we undertook two tests. First, we split the sample before and after the second fuel-price crisis. Eleven parameters are common to the two subsamples: the 1977 emissions parameters and all of the nonemissions parameters. The parameters SEG_i are precisely estimated in both subsamples and show little difference. Second, we used the method of Hausman (1978) to test the endogeneity of $QDIF$. The test is based on the difference between the parameter vectors under generalized least squares (with $QDIF$ treated as exogenous) and the three-stage-least-squares estimates in Table 3. This statistic, asymptotically $\chi^2(19)$, was 87.6, quite significant. Much of the power arises because $QDIF$ has the wrong sign under generalized least squares and is apparently precisely estimated. These test results suggest that we have estimated the demand equation and that our inferences about valuation are therefore reliable.

It is often observed that automobile manufacturing technologies, including the technology of emissions compliance, vary systematically across countries. In particular, Japanese manufacturers are thought to have access to superior technology. We added a dummy variable for Japanese manufacturers interacted with all of the emissions-control technology dummies, which we interpret as a general proportional cost reduction for Japanese cars. Our point estimate of this parameter is .98, meaning that Japanese drivability costs are estimated to be 2% lower than for the general sample. Because the standard error for this estimate is .06, however, we cannot reject the hypothesis that in terms of drivability, Japanese and non-Japanese automobiles are affected similarly by the regulations and, hence, that our technology dummies adequately capture any differences.[13] Similarly, we reestimated our

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[13] We do not interpret this finding as meaning that the technology of compliance is the same in different countries, but only that any differences are captured by our technology variables. Of course, our results cannot say whether the pecuniary costs were lower in Japan.

equation allowing different parameters for different continents. The hypothesis that the parameter vectors are constant across continents could not be rejected.[14]

We also explored whether our results were sensitive to the measure of fuel economy we used in the calculation of fuel costs. The results are changed little when we use EPA highway fuel economy rates instead of city fuel economy rates.

We next relaxed the assumption that emissions compliance with a given technology has a well-defined impact on automobile quality. We allowed the emissions coefficients of the newer (automobile model in the numerator) and the older (automobile model in the denominator) cars to be different:

$$\log\left(\frac{\rho^{t}_{m,a+1}}{\rho^{t}_{m,a}}\right) = \delta_{s,a} + \sum_{i=1}^{N_{segs}} \sum_{j=0}^{N_{ages}} \gamma^{ij}_{sa} \log\,(Q^{t}_{ij}) + \eta_{E_{\tau}} - \xi_{E'_{\tau'}} + \kappa TSS + \lambda T, \quad m \in S_s. \qquad (9)$$

If the vectors η and ξ are identical, this specification is the same as (9). This hypothesis cannot be rejected,[15] even though many of the point estimates of η diverge from those of ξ by over 20%. We therefore do not reject the hypothesis of well-defined quality indexes, but we do acknowledge that imposing this restriction is crucial to the power of our estimates.

As a final test of robustness, we reestimated our specification by using data on California prices, quantities, and emissions control standards.[16] Table 4 reports our results for nonpecuniary costs of the California emissions control standards. Since our California sample size is smaller, we cannot estimate so rich a specification of the technology of compliance as we used with the federal data set.[17] In particular, we dropped the 1981 compliance dummy and one of the 1980 technology dummies because we did not have enough 1982–1983 prices to obtain adequate estimates of them. The 1975 noncatalyst dummy was dropped since almost all 1975 California cars had catalysts.

TABLE 4 Parameter Estimates for California

Parameter	Estimate	Standard Error
constant	−.095	.0486
δ_{AGE}	−.00508	.0323
δ_{SEG1}	.0518	.0838
δ_{SEG2}	.0197	.0740
δ_{SEG3}	.0081	.0493
γ_{QDIF}	−.135	.040
ϵ_{72}	−.104	.103
ϵ_{74}	−.090	.0838
ϵ_{75C}	.019	.0087
ϵ_{75FI}	.0027	.160
ϵ_{77N}	−.0431	.1343
ϵ_{77C}	.092	.0772
ϵ_{80}	.1458	.1114

Number of Observations = 317

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[14] The likelihood ratio statistic, asymptotically $\chi^2(38)$, was 21.5, while the critical value for a 5% test is 53.4.

[15] The likelihood ratio statistic, asymptotically $\chi^2(9)$, was 4.85, compared with a critical value of 16.9.

[16] It is tempting to compare the effects of the California emissions program with the effects of the federal program on the quality of automobiles, since the California standards generally lead the federal standards by one or two years. A direct comparison is not possible, however, because of differences in the value Californians place on drivability. Cold-weather starts, for example, are valueless in California.

[17] Each observation requires the collection of four used-car market prices: those of the car in the numerator and the car in the denominator in two adjacent years. As a result, those technologies used by less than 5% of the cars of a given vintage are often represented by only one or two car lines in the sample. In this case we aggregate them into a more common technology. Thus, Table 4 does not show any 1975 standard compliance without catalytic converters.

Our interpretation of the California results is that they are roughly consistent with the federal results. Compliance with the early standards entailed large drivability penalties, but technology used to comply with the later standards seems to have actually enhanced automobile quality. (The large quality increase estimated by ϵ_{80} for California should be compared with the quality increase estimated by federal ϵ_{80CLS} since most of the California models had closed-loop emissions control systems in 1980.) The magnitudes of the California point estimates, and their corresponding standard errors are, however, much larger than those in the regression on national data.

Finally, our sample selection procedures might cause difficulties if automobile models leave our sample for reasons connected with emissions compliance. There are two potential problems here. Since we use only physically unchanging models, and since engines and transmissions are important determinants of emissions, some models may be excluded because their engines or transmissions were changed to comply with a new standard. This problem does not appear to be important. Although the fraction of all auto models that are in our sample is strongly decreasing over time, there is no tendency for models to be disproportionately excluded for powertrain changes in emissions-standard years. Similarly, some models may have been withdrawn from the market because they could not cheaply comply with a new standard; the Volkswagen Beetle is often mentioned in this regard. This effect also appears to be unimportant. There is no systematic tendency for models to be withdrawn in emissions-standard years.

6. The costs of emissions controls

■ In this section, we combine our estimates of the value of emissions-control-related quality changes with White's (1982) estimates of the pecuniary costs of emissions controls to derive estimates of the overall per car compliance costs.

The drivability cost for each standard is displayed in Table 5. The second column of the table gives the fraction of automobile units sold in each model year that complied with each of the three possible technologies: noncatalyst, catalyst, and closed-loop or fuel injection. The third column gives the implied cost to drivers in constant (1981) dollars. This is followed by a 5% confidence interval for these costs. The only nonintuitive result here is that almost half of the decline in drivability costs from the 1977 to the 1981 standard occurs in 1980. We had expected a larger 1981 effect and smaller 1980 effect because of the rapid increase in the use of advanced technologies in 1981. This may simply be a statistical artifact: the incremental costs of the 1980 standards have a confidence interval over $300 wide, while the sum of those incremental costs (the incremental cost of getting to 1981 standards from 1977 ones) has a confidence interval less than $80 wide.

TABLE 5 **Drivability Costs by Year (1981 $)**

			Confidence Interval	
Model Years	Quantity Weights	Cum. Costs	Lower-Bound	Upper-Bound
1968 (base)		(0.)		
1973	1, 0, 0	$864	806	901
1974	1, 0, 0	$817	771	863
1975	.169, .807, .024	$487	426	548
1976	.162, .817, .021	$455	391	519
1977	.108, .853, .039	$479	325	633
1978	.084, .880, .036	$441	323	558
1979	.081, .896, .022	$431	330	532
1980	0, .944, .046	$196	42	350
1981	0, .310, .690	−$131	−155	−107

Our estimates of ϵ imply a percentage decrease of willingness-to-pay for emission-controlled cars, so that ϵ times the present value of the capital plus operating costs of the car yields the lifetime disamenity costs of the emissions controls. We calculate the capital plus present discounted operating cost of the car following DOT's *Costs of Owning and Operating an Automobile.* Like White, we use the historical prices (in 1981 dollars) of gasoline, insurance, and maintenance in calculating operating costs. In those years where more than one control technology was used, we calculated a weighted-average willingness-to-pay, using the ϵ's for the different technologies.[18] The imprecision with which the parameters are estimated is reflected in broad confidence intervals for the monetary value of the drivability penalty. It is clear, however, that the size of the drivability penalty has been steadily decreasing over time.

Table 6 combines our drivability cost estimates with the capital, fuel economy, and maintenance costs estimated by White (1982) to give a full picture of the impact of emissions controls on the consumer.[19]

In the absence of measures of quality change, the cost of complying with each standard appears to increase with each succeeding standard, except for the introduction of the catalytic converter in 1975. Adding in the effect on quality, we get a somewhat different picture. First, the total costs of the 1973 standards are nearly doubled (to $1,815) by inclusion of the nonpecuniary component. Second, the importance of the catalytic converter as a technological breakthrough is enhanced. If we restrict attention to the pecuniary component only, the extra capital cost of $110 to meet the 1975 standards saves $420 in fuel and maintenance, for a net gain of $310. Drivability cost savings in that year come to a further $380 and thus more than double the estimated importance of the catalytic converter. For these first two standards, then, our estimates reinforce and amplify the inference that would be drawn from the pecuniary costs alone.

After 1975 inclusion of the nonpecuniary component changes the implication considerably. From 1975 to 1981 both capital costs and fuel and maintenance costs increase. Total pecuniary cost rises from $640 to $1,400. Over the same time period, the drivability component falls from $485 to −$130. Thus, the increase in pecuniary costs of $760 was accompanied by increased automobile quality worth $615. Nearly all of the costs of additional

TABLE 6 Estimated Per-Car Compliance Costs (1981 $)

	Type of Costs			
Model Year	Capital Costs	Fuel & Maintenance	Drivability	Total
1968	30	0.	0.	30
1973	125	825	865	1815
1975	235	405	485	1125
1977	185	515	480	1180
1981	600	800	−130	1270

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[18] The zero weights for fuel-injection vehicles before 1975 do not imply that no cars in the sample were using fuel-injection systems in those years. Since there are very few (under 1% of unit sales), however, and since none of them passes our tests for inclusion in the actual estimation, we cannot estimate a parameter for their relative valuation.

[19] White's estimates are the present value, over the service life of the car, of the costs of compliance equipment added to the car, the costs of decreased fuel efficiency, and the costs of increased maintenance. For example, the 1977 model year standards of 1.5 gpm HC, 15 gpm CO, and 2.0 gpm NO_x were estimated to cost consumers $700 over the 1968 model year standards, not including drivability costs. Our 1973 and 1975 capital cost figures come from estimates in the National Academy of Sciences and National Academy of Engineering (1974) report on the costs of emissions control.

emissions equipment on automobiles over this time could be accounted for as the costs of increased automobile quality worth $615, not as regulatory compliance expense.

Our interpretation of these results is that there are two opposing forces affecting costs over this time period. The first is the increasing stringency of the emissions-control regulations over time. The second is the technological progress in compliance. Adding drivability to capital and fuel economy costs underlines the importance of considering both forces. Induced technical change is the primary reason the cost of compliance has appeared to decrease over time despite new stricter standards, at least through 1979.[20] Much of this change resulted from the development and refinement of the catalytic converter technology and should have been foreseen by both the regulators and the automakers. It does, however, appear that the 1980 and 1981 standards might be pressing the converter technology to its limits and might, therefore, involve substantially increased costs. Without the benefit of the exogenously developed microprocessor technology, these latter standards would have been much more expensive.

7. Conclusion

■ We have estimated consumers' valuations of the drivability, cold-start, and other performance disadvantages associated with automobile emissions controls. In the case of the 1973 standards set by the EPA, these nonpecuniary compliance costs were as large as the manufacturer's costs plus the foregone fuel economy. We doubt that owners of 1973 model-year automobiles will dispute the size of our estimates: those cars performed poorly, in large part because of emissions controls' using an inadequate technology. Since 1973, however, the rate of technological progress in mobile-source pollution control, as reflected in improved automobile performance, was rapid. Although a portion of this rapid rate of technological progress might have occurred in the absence of emissions standards, most of the improvement seems related to emissions technology. These improvements apply not only to the period immediately following 1973—when inadequate, incremental technologies were replaced with the breakthrough catalytic converter technology—but also to later periods, through the application of sophisticated microelectronics to engine control and to "smart" catalytic converters.

Over this same time period, emissions standards have grown steadily tighter. As a result, two opposing forces affect the costs of compliance over time: stricter regulations increase compliance costs, while improvements in technology decrease the costs of compliance. When the nonpecuniary as well as the pecuniary costs are taken into account, we find that technological advance offset the increasing stringency in most time periods. Thus, the incremental cost of emissions compliance associated with each new standard was smaller than previously thought.

Initial regulations that are overambitious or are implemented in a myopic fashion would be likely to create a pattern of costs that starts very high and falls as cost-effective technology replaces stop-gap technology. This is the pattern of costs we observe for automobile emissions regulation in the United States. Given the large decreases in incremental costs from 1973 to 1975, it appears that the pace of innovation forced by ambitious early

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[20] The entire quality change, of course, is not attributable solely to technological change. Some portion of the quality change is a result of cost-quality tradeoffs made by the manufacturer and of the rate of diffusion of technology across manufacturers. In the short run, drivability costs are also affected by another type of cost/quality tradeoff: the *ex ante* decision to develop one or more technologies that appear to offer the best tradeoff between manufacturing costs and quality. A large fraction of the quality differences that we estimate among the various technologies represents the transition costs of technology related to development decisions and diffusion of technology.

standards increased society's overall costs from mobile-source emissions control substantially. It also appears that the incremental social costs of the more recent standards is less than currently perceived. This criticism of the EPA and the Congress uses 20–20 hindsight: we now know that costs associated with the early standards were underestimated while those associated with later standards were overestimated. But, the auto emissions experience is consistent with the view that qualitative evidence tends to be ignored in favor of quantitative evidence in the regulatory process.[21]

Most of the debate on emissions control in the 1970s centered on pecuniary cost estimates. The importance of nonpecuniary costs remained largely unnoticed in final decisionmaking. After 1974 the private interests of automobile manufacturers were to provide the EPA with accurate pecuniary cost estimates. These estimates, however, counted the costs of increases in product quality in regulatory compliance costs and omitted the important complicated calculation of the value of improved drivability to consumers.

Appendix

■ **Description of the database.** The database is composed of observations on individual automobile models in the U.S. market for model years 1968 to 1981, including used car prices from 1965 to 1983. All U.S. and import models are included, except sports, specialty, and related models. Information is taken from the Automotive News' *Annual Market Data Book, Ward's Automotive Yearbook,* EPA mileage guides, the National Market Report's *Red Book* of used car prices, the *Los Angeles Times,* and the *Federal Register.* The data for each model car include interior and exterior dimensions, powertrain specifications, emissions control technology, fuel economy, standard equipment, new and used prices, bodystyle and engine availability and prices, quantity, segment, and product cycle information.

All of the engineering specifications are taken for the bodystyle considered most common for each model. In general, subcompacts and compacts are represented by two- or three-door bodystyles, while larger models are represented by four-door bodystyles. Different entries are not made for different trimlines or bodystyles of the same model. The quantity used is the aggregate of the total quantity produced over all bodystyles and trimlines, not just the quantity of the model used for the specifications. Quantity is model year production for domestic cars, and a moving average of the most recent two years' sales for imports, with weights (.75, .25) because import car sales are reported in calendar rather than model-year sales. The product cycle variables keep track of major ("new" or "reskinned") and minor ("freshened") changes to the body and trim of each model.

These data allowed us to screen out the observations in which models changed substantially from one year to the next. If the engineering specifications were different or if the car was new or freshened, we did not use the data in our estimation.

The engine chosen was the most common or, if that was not known, the base engine. When more than one trimline was offered, the base trimline was the one included. Prices were those for the specific engine, trimline, and bodystyle represented in the specifications.

The database allowed for about 30 emission control equipment categories which were taken from EPA test-car lists, filings of the California Air Resources Board, and the *Federal Register.* The categories were relatively broad, making distinctions between engines with or without air injection and exhaust gas recirculation, for example, but not making a distinction between throttle-body fuel injection and standard fuel injection.

Our database contains used price series appropriate for California and federal models. The 49-states (federal)

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[21] Government incentives are complicated because of the diversity of objectives and the influence various governmental actors have in the regulatory process. Mayhew (1974), for instance, suggests that the reelection incentive motivates legislators towards credit-claiming rather than towards concern for the long-term success of policy. Given this premise, aggressive technology-forcing may make political sense, even when it makes no economic sense. Even if one is more sanguine about the motivations of our legislators or the wisdom of the electorate, high-cost regulatory programs might still arise. A public-interest-motivated politician may decide to build inertia into the legislation to counter the usual weakening of the policy over time. Legislation created under these premises may result in large transition costs to protect the overall mission of the regulation. Further, concern for transition costs may not be incentive-compatible with the incentives of either the firm or the government. When government standards are less stringent, the pace of technological change is reduced because the automakers have less incentive to innovate. With stringent standards the pace quickens, but transition costs, in the form of increasingly inefficient research and cost-ineffective technology, may increase disproportionately.

used-car prices are based on prices as quoted in the *Red Book* for the middle region of the United States, which were adjusted to reflect a constant definition of standard equipment within segments. California prices were gathered by the authors from newspaper advertisements. (The *Red Book* California version in fact uses Midwest prices as well.)

Segment definition follows the usual auto industry practice and is based in large part on the lists in the Automotive News' *Annual Market Data Book.* We include automobiles in four segments in this study, although our database also includes luxury models. Over time, some nameplates move from one segment to another. We permit such shifts only when the model actually is changed physically.

The operating cost includes the costs of insurance and maintenance as well as that of the capital costs and fuel economy. Insurance and maintenance are taken from the DOT's *Costs of Owning and Operating an Automobile,* which appears about every three years. For years not included in the report interpolations were made. Costs were smoothed to avoid the lumpiness associated with scheduled replacement of tires, engines, and other large items. Fuel economy is the city mileage given in the EPA *Mileage Guide* for the appropriate model and engine and location (California or 49-states). For years earlier than 1974, the first year in which these data are available, we used 1974 mileage figures for 1973 and earlier cars. The accuracy of this extrapolation is unimportant, since the cost of gasoline in 1973 and earlier years was quite small. Fuel cost is calculated by multiplying average miles driven per year for a car of a certain age by the model's EPA city fuel economy. Insurance and maintenance are from the DOT publication, *The Cost of Owning and Operating an Automobile* (various years), which provides these numbers at a segment/age level of aggregation. Some smoothing is done to these numbers to avoid the lumpiness problem caused by scheduled replacement of tires, brakes, batteries, and other large cost items.

The interest rate used in calculation of the capital cost of owning an automobile is the bank interest rate on new car loans from the *Statistical Abstract of the U.S.*

The instruments for new car quantities are the real price of gasoline (CPI component for gasoline divided by the CPI), the rate of change in the real price of gas, the nominal U.S./Japanese exchange rate, the nominal U.S./German exchange rate, and the nominal UAW wage. The wage rate is from *Auto News;* all others are from the *Statistical Abstract.*

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