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## *ABSTRACT*

Since the early 1980s, U.S. auto makers and policy makers have resisted policies to increase automobile fuel economy, arguing in part that such increases were neither technically feasible nor economically justified. This paper analyzes such assertions for the 1992 Honda Civic hatchbacks. These new Hondas are virtually identical to the previous year's models in size, vehicle amenity, engine power, and performance, but they offer substantially increased fuel economy and improved safety. We assess the cost of improving fuel economy using actual retail prices, after correcting for differences in cosmetic features.

Our calculations show that the efficiency of the 1991 Civic DX was improved by 56% from 1991 to 1992, at a cost per conserved gallon of gasoline that is $0.77/gallon, or 30% less than the levelized gasoline price without externalities or taxes. In addition, a comparison of two other Civic models reveals that fuel economy was improved in the 1992 version at no additional cost. Virtually all of the efficiency increases described here were achieved through measures that do not affect safety or vehicle size, such as engine modifications, transmission alterations, and drag reduction.

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## I. INTRODUCTION

Since the early 1980s, U.S. auto makers and some analysts (Shin 1989) have argued that policies to increase automobile fuel economy were neither technically feasible nor economically justified. This paper applies Kenneth Boulding's first law ("Anything that exists is possible") to analyze such assertions in the case of the 1992 Honda Civic hatchbacks. These new Hondas are virtually identical to the previous year's models in size, vehicle amenity, engine power, and performance, but they offer substantially increased fuel economy and improved safety.

This paper first describes the characteristics of the 1991 and 1992 Honda Civics and demonstrates their equivalence in vehicle amenity. Second, it presents the fuel economy technologies Honda used to improve the efficiency of the Civic by more than 50%. Third, it describes the methodology for estimating the Cost of Conserved Energy (CCE) for these efficiency improvements. Fourth, the paper presents the results of our CCE calculations. The paper concludes by discussing the potential impact of gasoline taxes and "feebate" policies on both consumer and manufacturer behavior related to energy efficiency choices for these vehicles.

## II. CHARACTERISTICS OF HONDA CIVICS

### General Description

The 1992 model year Honda Civics represent a "new generation" of Civics. Honda completely redesigned the engine, body style, suspension, aerodynamics, and other major features of this model, but kept total interior space constant while improving performance. In addition, Honda added a new hatchback, the VX, to its Civic line. The VX is similar to the mid-cost Civic DX hatchback, except that the VX is optimized for fuel economy.

Table 1 presents specifications and features of the 1991 and 1992 Civic DX and VX hatchbacks (Honda 1990, Honda 1991, Leestma 1992, USAA 1991a, USAA 1991b).[1] The major difference among the 1991 Civic DX, the 1992 DX, and the 1992 VX is the improved fuel economy of the 1992 vehicles. The 1992 DX is about 13% more fuel efficient than the 1991 model, while the 1992 VX has 56% higher efficiency.[2]

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[1]For a similar but less detailed comparison of the 1991 2-door base-model Civic hatchback and the 1992 Civic CX hatchback, see Appendix B.

[2]The latter estimate is for the "49-State" VX sold in all states but California. The stricter emissions requirements in that state made Honda abandon the lean burn technology for VXs sold there, though the

The 1992 DX and VX are slightly larger than the 1991 DX, as shown by the interior and exterior dimensions listed in Table 1.[3] Additionally, the 1992 models are equipped with a driver-side airbag, resulting in improved safety over the 1991 DX. It is also noteworthy that the fuel tank of the VX is nearly two gallons, or 16%, smaller than those of the 1991 and 1992 DX. However, the improved fuel economy of the VX means that a VX owner would still have to refuel less often than an identical DX owner.

## Performance

Other than fuel economy differences, operational and performance variations among the three cars are minimal. The 1992 VX and the 1991 DX are both rated at 92 horsepower. However, maximum horsepower is achieved at 5500 rpm in the VX and at 6000 rpm in the 1991 DX. Thus, the VX engine provides slightly more power at engine speeds up to 5500 rpm, which is the range in which most drivers operate. The 1992 DX reaches a maximum horsepower of 102 at 5900 rpm. However, in comparison to the VX, the horsepower difference is likely to go unnoticed unless one drives at engine speeds greater than 5500 rpm (which few drivers ever do). The time required to go from 0 to 100 kilometers per hour (kph), or 62 mph, is also related to horsepower. There is little difference between the 1992 DX and the 1992 VX in this area: the 1992 DX takes 10.2 seconds to reach 100 kph while the 1992 VX takes 10.5 seconds.

Another important indicator of vehicle performance is torque. High torque allows quicker acceleration at low engine rpm (e.g., when accelerating from a stoplight). The 1992 DX and the VX both provide slight torque improvements over the 1991 DX. The 1992 DX supplies 98 ft-lbs at 5000 rpm, while the 1991 DX supplies 89 ft-lbs at 4500 rpm. The VX is likely to have the best "pickup" at engine speeds comparable to those commonly encountered in everyday driving, as it attains 97 ft-lbs of torque at only 4500 rpm (Keebler 1992a).

## Driveability

The comparison of features and specifications has focused on the differences between the three vehicles on paper. However, before one can conclude that the Civic hatchbacks are identical in terms of the service they provide, one must also evaluate the cars on the road. A series of drivers who test-drove the VX found that, in general, it handled well and performance was impressive. Some drivers found that they had to adjust their driving styles to take advantage of the taller gearing of the VX (Maio 1992b, Passino 1992). Taller gearing results in lower engine speeds than those typically experienced in a given gear and is reflected in the gear ratios listed in Table 1 (see Appendix A for more detailed information on gearing changes). Some drivers also noted occasional engine "stumble", or hesitation, during quick acceleration in lean burn operation (Keebler 1992b). This hesitation occurs as the engine adjusts to a lower air/fuel ratio. All but one *Automotive News* reviewer believed that this effect would not adversely influence the average driver's perception of the vehicle's performance, and the reviewer who found the stumble unacceptable was a driver who admittedly preferred high performance vehicles (Keebler

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California VX still uses the basic VTEC-E engine and the other efficiency technologies found in the 49 state VX. This compromise reduced the efficiency improvement of the California VX to about 51% relative to the 1991 DX, or to 46.9 mpg composite.

[3] The exception is cargo volume which is 3.3 cubic feet less in the 1992 models. However, passenger volume was increased by more than 4 cubic feet in the 1992 Civic hatchbacks. Thus, the total interior volume is nearly equal in the 1991 and 1992 models we evaluate.

1992a). For typical Civic drivers (who probably do not seek high power), we can conclude from these reviews that the performance and driveability of the VX is equivalent to that of the 1991 and 1992 DX.

### Comfort and Amenities

Although the primary specifications and performance of the Civic models are essentially identical, minor differences exist in the cosmetic features of the DX and VX hatchbacks. These features and their estimated costs are shown in Table 2 (Honda 1990, Honda 1991, Maio 1992a, Maio 1992b). The 1991 and 1992 DX models are both equipped with an adjustable steering column, rear cargo cover, rear windshield wiper, and bodyside molding, while the VX lacks these features but has a tachometer and lightweight alloy wheels. The cargo area cover adds utility to the DX models because it hides any cargo and makes it appear that the vehicle has a trunk. The lightweight alloy wheels on the VX are cosmetic in that they look "sportier", but they also affect fuel economy due to their lighter weight.

### Safety

The safety of the 1992 Civic models was improved significantly by the addition of a driver's side airbag in both the DX and VX. The 1991 DX does not have a driver's side airbag. The added safety provided by the airbag is reflected in reduced insurance premiums. For example, the United Services Automobile Association (USAA) Casualty Insurance Company reduces the premium for Medical Payments Coverage (MPC) by 60% relative to the 1991 DX for owners of either the 1992 DX or VX (Blackstone 1992). There is no difference in the premium for MPC for the 1992 DX and VX, which indicates that professional risk assessors of at least one major insurance company believe that the slight difference in weight of these two vehicles has a negligible affect on safety. Further, because the VX is lighter than the DX, its use imposes less risk on other vehicles. There are currently no crash test data with which to further compare the safety of these vehicles.

### Emissions

In addition to comparing the fuel economy, performance, and features of the DX and VX models, it is useful to analyze pollutant emission levels. Emissions are a particular concern in evaluating the VX because lean burn engines have been associated with higher emissions of nitrogen oxides ($NO_X$) than traditional engines due to the inability of 3-way catalysts to control $NO_X$ at high air/fuel ratios.

Table 3 presents data on emissions of hydrocarbons (HC), carbon monoxide (CO), and $NO_X$ for the 1991 DX, 1992 DX and 1992 VX models (US EPA 1991a, US EPA 1991b, US EPA 1992a, US EPA 1992b). The 4,000 mile certification results represent stabilized emission levels for new motor vehicles.[4] Changes in emissions caused by vehicle use are approximated based on testing of prototype vehicles which are driven for 50,000 miles. This testing results in "deterioration factors", which describe the amount that emissions increased during the tests as a result of catalyst degradation over time. The 50,000 mile

[4]The new vehicles are driven for 4,000 miles in order to "break them in", as emission levels for brand new, never-driven vehicles may be highly variable.

values provided in Table 3 were obtained by multiplying the 4,000 mile data by the deterioration factors provided by EPA.[5]

All vehicles easily meet emission standards.[6] However, there are some noteworthy variations in emission factors. The VX has significantly higher direct HC emissions than either the 1991 and 1992 DX models. However, the improved fuel economy of the VX will result in reduced "upstream" HC emissions from the production and handling of crude oil and products, as total fuel throughput will be reduced by reducing vehicle fuel consumption (Deluchi et al. 1992). Thus, the total amount of hydrocarbons emitted from each of the three cars is similar. The California version of the 1992 DX has higher CO emissions per mile than either the 1991 DX or the 1992 VX, which are comparable to each other in this respect.

$NO_X$ emissions for the 1992 DX are 24% lower than those of the 1991 DX. $NO_X$ emissions are higher for the 49-State VX than either DX model, as expected. However, the California VX achieves a 43% fuel economy improvement over the 1991 DX while maintaining $NO_X$ emissions that are lower than the 1991 and 1992 DX. This demonstrates that, given a regulatory mandate, $NO_X$ emissions can be reduced. However, the higher $NO_X$ levels for the 49-State VX may indicate a limitation of the present applicability of lean burn technology.

Though not shown in the table, $CO_2$ emissions vary in direct proportion to the amount of fuel used. This relationship implies that $CO_2$ emissions are somewhat lower for the 1992 DX and significantly lower for the 1992 VX than for the 1991 DX.

In summary, emissions from the 49-State version of the VX are comparable to those from the 1991 and 1992 DX with the exception of $NO_X$, which is higher in the 49-State VX, and carbon dioxide, which is lower in the more efficient vehicles. All of these automobiles meet current standards in the states in which they are sold.

### Summary

Examination of the specifications of these vehicles and actual test drives reveal that fuel economy gains were achieved with negligible impact on performance, driveability, and comfort. We can conclude from the results of this section that the cars deliver equivalent consumer utility.

## III. FUEL ECONOMY TECHNOLOGIES

As discussed above, the 1992 VX provides a 56% improvement in efficiency over the 1991 DX. This is achieved by the use of technological improvements that increase the efficiency of converting fuel energy to usable work and reduce the amount of work required to move the vehicle.

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[5] This method was used because we were unable to obtain durability testing data from cars with the same features as those used for 4,000 mile testing.

[6] Federal light-duty vehicle standards for 1992 (in grams per mile) are as follows: HC: 0.41; CO: 3.4; $NO_X$: 1.0. The California standard for $NO_X$ -- 0.4 g/mi -- is more stringent.

The technological differences responsible for the improved fuel economy in the VX include:

- lean-burn VTEC-E engine[7]
- changes in axle and gear ratios
- multi-point fuel injection
- decreased vehicle weight
- improved aerodynamic characteristics
- low rolling resistance tires
- reduced idle speed
- shift indicator light

Table 4 summarizes these fuel economy technologies and presents estimated contributions to fuel efficiency and costs (in 1992$) associated with each approach (Greene and Duleep 1992, Harrington 1992, National Research Council 1992, SRI International 1991). The primary technological improvements are described in detail in Appendix A. More details on particular technologies are available in Bleviss (1988).

The largest percentage improvements come from transmission/gearing and engine modifications. This fact is noteworthy because changing engine and transmission characteristics (keeping horsepower and torque roughly constant) does not affect safety or vehicle size. Weight reduction may have an effect on safety, depending on from where the weight is removed, but the weight changes in the VX are quite small (3-4%). While it is possible that the use of certain types of low rolling resistance tires might affect braking and cornering capabilities, we know of no "on-road" reviews of the Civic VX that compare the performance of the particular tires used on this vehicle to those used in the 1991 Civic DX.

### Capital Costs of Fuel Economy Improvements

The costs of the technologies listed above are not readily available and vary widely depending on the source of the estimate. Cost estimates are further complicated by the fact that several of the technologies may overlap. For example, the variable valve feature of the VTEC-E engine permits the use of lean burn technology and changes in drive ratio. Thus, an estimate of the cost of variable valve timing may also include the cost of lean burn technology and drive ratio changes.[8] Despite these complications, we provide estimated costs of fuel economy technologies in Table 4. The total estimated costs of these technologies range from $448 to $1084.[9]

### Applicability of Civic VX Improvements to Other Vehicles

Not all technologies used to improve the efficiency of the Civic can currently be transferred to other new cars. We focus in particular on the applicability of the lean-burn engine. For

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[7] VTEC and lean-burn are separable. Honda also uses the VTEC engine in the 1992 Civic Si, but not for lean burn. Instead, it provides a significant increase in horsepower in conjunction with a modest improvement in efficiency.

[8] For this reason, we have estimated the cost of lean burn technology to be $100 to $500.

[9] This range neglects axle and gear ratio improvement costs which were unavailable. In principle, the capital cost of axle and gear assemblies should not vary significantly as gear ratios change.

details on how other efficiency options might apply to different portions of the U.S. automobile fleet, see Ledbetter and Ross (1990).

Keebler (1992b) reports that "heavy vehicles have poor driveability when calibrated with lean-burn fuel strategies", which implies that this strategy, as currently implemented, may not be directly transferable to the larger cars in the U.S. fleet. Because of increasingly strict $NO_X$ emissions standards, lean-burn technology may not be viable in some vehicles until improved $NO_X$ catalysts are developed. According to Sanger (1991), Honda engineers believe it will be "several years . . . before they can transfer the technology to larger, less efficient engines". However, it has been reported that Honda plans to employ lean-burn technology on its larger Accord model as early as the 1994 model year (Johnson 1992). Research on this issue is proceeding elsewhere as well. Recently, a company in Massachusetts announced the development of a new lean-burn engine that combines high efficiency and low $NO_X$ emissions, for an additional cost of $100 to $200 per car (Cutter Information Corp. 1992).

## IV. METHODOLOGY

This Section describes the methodology and assumptions used for the cost-effectiveness calculations contained in Section V (below). We use actual retail prices to estimate the cost of improving fuel economy and projections of motor gasoline prices to estimate the levelized fuel price.

### Definition of Cost Effectiveness

By cost effective, we mean that the costs of investing in automobile efficiency are lower than the costs avoided by this investment. The cost of an efficiency improvement is usually assessed by calculating the *Cost of Conserved Energy* (CCE). The costs avoided by the efficiency investment include the *direct cost* of the unused fuel, and whatever *social or external costs* are associated with the consumption of gasoline that are not included in the gasoline price. Whenever the CCE is lower than the avoided direct costs plus external costs ($/gallon), we can say that an efficiency investment is cost effective.

### Cost Perspective

We adopt the perspective of the buyer of a new car who will use the vehicle over its entire lifetime. This simplifying assumption is also roughly comparable to the societal perspective without externalities (assuming that the discount rate used reflects social and not individual preferences).

### Cost of Conserved Energy

The Cost of Conserved Energy or CCE ($/gallon) is calculated using Equation (1)[10]:

$$\text{CCE (\$/gallon)} = \frac{\text{Capital Cost (\$)} \times \dfrac{d}{(1-(1+d)^{-n})}}{\text{Annual Energy Savings (gallons)}} \qquad (1)$$

[10]For more details on such calculations, see Meier et al. (1983) or Koomey et al. (1991).

where d is the discount rate, n is the lifetime of the automobile, and $\frac{d}{(1-(1+d)^{-n})}$ is equal to the Capital Recovery Factor. The numerator in the right hand side of Equation 1 is the annualized cost of the conservation or efficiency investment. Dividing annualized cost by annual energy savings yields the CCE, which is independent of, but can be compared to, the levelized price of fuel (in $/gallon).

### Consumer Choice Models

There is some controversy over the procedure that consumers actually use to choose the efficiency level of the automobiles they purchase. Greene (1983), in a review of such decision algorithms, summarizes this controversy. The main issue of contention surrounds the multifaceted nature of the purchase decision. Usually, the choice between vehicles is based on many different decision criteria, most of which are unrelated to the efficiency of the vehicle. The use of a Cost of Conserved Energy model (or equivalently, a life-cycle cost model[11]) to describe such choices is problematic in that it is a simple measure that does not address the complexity of the purchase decision.

While this issue is an important one when assessing consumer choices over a broad range of vehicle types, it does not significantly affect our analysis. We have, to a first approximation, created a comparison between vehicles that have different fuel economy but that are otherwise equivalent in terms of size, features, performance, and safety. For this reason, we believe it is appropriate to discuss choices between these vehicles as if consumers were actually using a discount rate in a CCE calculation.

### Discount Rate

The discount rate in our calculations is 7% real. This value roughly corresponds to the current cost of capital for consumers seeking an auto loan (11% to 12% with inflation). We also perform a sensitivity analysis using real discount rates of 3%, 10%, and 30%.

### Miles Driven

We use an estimate of 10,200 miles traveled per year for a typical U.S. automobile in 1988, taken from Davis and Morris (1992). The source cited by Davis and Morris is the U.S. Department of Energy's Residential Transportation Energy Consumption Survey.

### Rebound Effect

Greene (1992) suggests, after reviewing the literature, that consumers will increase their vehicle miles traveled by 0.05% to 0.15% in response to a 1% decrease in the fuel cost per mile of their vehicle. We omit this factor in calculating the CCE, because if consumers use their vehicles more, the increased mobility must be worth more to them than the increased expenditure on gasoline. Therefore, our per-unit cost-effectiveness calculation is unaffected by such rebound.

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[11]A life-cycle cost model is one in which future costs are discounted back to the present using some discount rate and are added to the capital cost of a given device. The same calculation is performed for different devices delivering the same service, and the device with the lowest life-cycle cost is chosen as the optimal one. The issue usually relevant to automobile choices is that the level of service is rarely constant between automobiles.

If one is interested in calculating *total* energy savings from a given policy affecting many such vehicles, then this correction factor must be included. We do not make such a calculation here. In any case, the correction is a small one.

### Vehicle Lifetime

We use an estimate of automobile lifetime of 13.3 years derived from a retirement curve for vehicles presented in Davis and Morris (1992). This curve applies to vehicles purchased between 1987 and 1989. We assume that the fuel economy improvement technologies used in the VX will not affect the vehicle lifetime.

### Rated Fuel Economy

Fuel economy estimates based on the EPA test procedure have been found to diverge from actual performance. This divergence was significant enough to induce EPA to reduce the sticker fuel economy relative to the test procedure values to better account for real-world driving conditions. Beginning in 1985, EPA reduced the city fuel economy estimates from the test procedure by 10% and reduced the highway estimates by 22% to calculate the fuel economy rating on the sticker.[12] This correction is important because if actual miles per gallon (mpg) is lower than the rated mpg, then using the rated mpg to calculate gasoline savings will underestimate those savings in absolute terms.

We use the city and highway fuel economy as listed on the EPA sticker for each car, which includes the above correction factors. We weight the city and highway fuel economy sticker values to estimate composite fuel economy for our cost effectiveness calculations. This weighting assumes that 55% of driving is city driving and 45% is highway driving, as specified in the Energy Policy and Conservation Act passed in 1975 (EPCA 1975).

### Consistency of Comparison

All fuel prices and capital costs are in 1992 dollars. We use a real discount rate (without inflation) to levelize the prices, and use the same real discount rate to calculate the Cost of Conserved Energy. The comparison between the initial capital expense and the levelized fuel price is therefore a consistent one.

### Fuel Prices

Average motor gasoline prices are taken from the Annual Energy Outlook (US DOE 1992), and are levelized using a 7% real discount rate (using the method from Kahn (1988)). According to the forecast, the retail price of motor gasoline will be $1.27/gallon in 1992

[12] There is some controversy over whether these corrections are sufficient to account for real-world conditions, with some analysts arguing that even higher reductions in composite mpg (20% to 30%) are justified because congestion is increasing. There is also uncertainty about whether the corrections used by EPA, which represent an average over all vehicles, give an accurate picture for the particular cars of interest in this paper. We do not address either of these issues here, but note that the first would increase the relative cost effectiveness of the cars under consideration, while the second would have an unknown effect on cost effectiveness.

and $1.61 in 2005.[13] Levelized over this period (which corresponds to the lifetime of our Honda Civic purchased in 1992), the price of gasoline is $1.40/gallon.

This price includes roughly $0.25-0.30 per gallon of state and federal gasoline taxes, which are used primarily to fund highway construction and maintenance.[14] Society does not avoid the construction and upkeep of roads if automobiles are more efficient, so a societal cost comparison should not include these costs in the avoided cost of fuel. This price also does not include the external costs associated with gasoline combustion, many of which are reduced by a more fuel efficient car.

We show comparisons with the levelized fuel price with and without taxes. The case with taxes provides an understandable reference point, and represents the situation in which avoidable external costs roughly equal the level of state and federal taxes. The case without taxes represents the situation in which external costs are assumed to be equal to zero.

### Operation and Maintenance Costs

We assume that operation and maintenance (O&M) costs for the VX are unaffected by the technologies used to achieve improved fuel economy. Thus, we assume lifetime O&M costs for the 1991 and 1992 DX models and for the 1992 VX are identical.

### Invoice Cost vs. Manufacturer's Suggested Retail Price

Invoice cost is also known as "Dealer cost". It is the average price charged to the dealer by the auto manufacturer. Manufacturer's Suggested Retail Price (MSRP) is also known as "Sticker Price", and is supposed to represent the price of the car to the consumer. In this analysis, we choose to rely on MSRP as an "official" price, but also show the invoice cost in our tables. The invoice cost and MSRP are taken from USAA (1991a, 1991b) and documents from a local Honda dealer. The invoice cost and MSRP for the 1991 DX have been adjusted to 1992 dollars, assuming 4% inflation.

The MSRP is somewhat arbitrary. Good bargainers have been known to purchase autos at or below the invoice cost. Auto manufacturers also give "volume incentives" to dealers that sell more than a target number of cars. Therefore, invoice cost and MSRP based on the sale of a single car may not actually reflect the true cost to the dealer.

### Does Retail Price Reflect True Cost?

Automobile pricing is a complicated process and the market price of a vehicle may have little to do with actual production costs. For example, anti-lock braking systems provided as an option on many cars are currently under priced on the vehicle "sticker" in order to encourage the purchase of these safety-enhancing mechanisms (Rinek 1992). Some of the redesign costs for the new Civics are probably included in the MSRP, as are any savings from the redesign. Without detailed manufacturer data, we cannot determine the extent to

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[13]The Annual Energy outlook reports fuel prices in 1990 dollars, which we have adjusted to 1992 dollars by assuming 4% inflation in each of the two intervening years.

[14]Of the current 14.1 cents/gallon federal gasoline tax, 10.1 cents are used for highways, 1.5 cents fund transit services, and 2.5 cents are devoted to budget deficit reduction per the Budget Reconciliation Act of 1990, which extends through 1995. State taxes in California are roughly 16 cents/gallon, and are comparable to those of other states.

which such cost changes are related to fuel economy improvements alone. We also cannot know whether Honda is taking a loss on the VX because it wants to gain experience with new technology in anticipation of growing demand for efficiency in a more environmentally conscious world.

We do not have access to Honda's cost data, and we cannot determine the manufacturer cost for improving the fuel economy in the Honda Civic hatchbacks. Nevertheless, we believe that the MSRP offers an approximate representation of the actual cost of improving auto fuel economy in these vehicles.

### Airbags

The 1992 Civics both have airbags, while the 1991 DX does not. Except for a minor weight penalty, airbags are unrelated to fuel economy, and their cost should not be included in our assessment of the incremental cost associated with improving the efficiency of the 1991 DX. According to Maio (1992b), the MSRP cost of an airbag is $800 in a new Honda Civic, and $1200 to replace an airbag that has been "blown" in a collision. We subtract $800 from the MSRP cost of the 1992 DX and VX to correct for this added cost.[15]

### Correction for Cosmetic Differences

The cargo cover is available as an option on the VX for $159. Costs for the other cosmetic differences shown in Table 2 can only be roughly estimated based on estimates by the parts department of a local Honda dealer.

We add the average cost of hatch cover, body side molding, and rear wiper/washer to the cost of the VX (no correction is made for the cost of the adjustable steering column, since the cost to replace the steering columns in the DX and the VX are the same). We add the midrange cost of the tachometer and half of the cost of the alloy wheels[16] to the price of the 1991 and 1992 DX.

These cosmetic differences result in an additional MSRP cost of $365 on both DX models, and $614 on the VX. By correcting for cosmetic differences and for the airbag, we have created a consistent comparison and can draw conclusions about the actual cost to improve the efficiency of the 1991 DX to the level of the 1992 VX. These corrections result in what we refer to as our "Full Correction Case", which represents our best estimate for the retail price of the fuel economy improvements in the VX as compared to the DX.

Although these cost corrections make the comparison a more consistent one, they should be viewed as approximate for three reasons:

> 1) Actual costs for these options are speculative, since the features available on the VX are not available on the DX, and vice-versa.

[15]The invoice cost for the airbag is calculated by multiplying the MSRP of the airbag times the ratio of the invoice and MSRP for the entire car. The MSRP markup thus calculated is 17%.

[16]Only half the cost of the alloy wheels is added to the DX price because some fraction of their cost is attributable to their lower weight and the rest is attributable to their "sporty" appearance. We choose half arbitrarily, since we had no way to separate these two attributes of the wheels.

2) Actual production costs for standard features may be quite different from the costs for installing such features as options after the car is manufactured.

3) Separating the cost of the alloy wheels attributable to cosmetic differences from that attributable to fuel economy is problematic.

To account for the fact that some options are not available on specific models in the showroom, we also show a comparison between the 1992 DX and the 1992 VX that only corrects for the feature that is actually an option -- the hatch cover. We refer to this case as the "As Available" comparison.

### Comparison of Estimated Technology Costs with Retail Cost Difference

When we compare the estimated costs of fuel economy technologies (Table 4) to the retail cost difference calculated after making the corrections described above, we see that the results are similar. The mean of the engineering cost estimates for the VX efficiency improvements (Table 4) is $766, while the cost difference between the 1991 DX and the 1992 VX in Table 5 (based on the "Full Correction" case) is $726. In view of the rather large range of error to be expected in such a comparison, we can conclude that the engineering costs and our retail cost calculation give roughly the same result, which gives us confidence that our calculations are of the correct approximate magnitude.

## V. COST EFFECTIVENESS OF FUEL ECONOMY TECHNOLOGIES

### Cost of Improving 1991 DX Efficiency to 1992 DX and VX Levels

In this calculation, we estimate the cost of improving fuel economy of the 1991 Honda Civic DX to the levels of the 1992 Civic DX and VX. This information can be used to determine whether the fuel economy of a particular vehicle can be improved substantially at a cost less than the cost of fuel, while keeping vehicle amenity constant and without reducing safety.

Table 5 shows the results of this calculation. The MSRP cost of an airbag ($800) has been subtracted from the cost of the 1992 Civics, which makes the 13% efficiency improvement for the 1992 DX achievable at negative net cost.[17] Engine torque also increased relative to the 1991 DX in this case. This result implies that Honda improved the fuel economy and power of this vehicle while reducing its initial cost.

After subtracting the cost of the airbag, the additional incremental cost for the VX over the 1991 DX is $477. The correction for cosmetic differences increases the incremental cost of moving from the 1991 DX to the 1992 VX by $249, giving a total incremental cost for the VX of $726. This $726 cost translates to a Cost of Conserved Energy of $0.77 per conserved gallon, which is about 45% less than the levelized price of gasoline with taxes and 30% less than the price without taxes. This CCE corresponds to a simple payback time of about 4.6 years using MSRP and including taxes in the gasoline price, and 5.9 years when taxes are omitted.

[17] For another such calculation that shows a similar result, see the comparison of the 1991 2 door base-model Civic hatchback with the 1992 CX hatchback in Appendix B.

### Cost of the Consumer's Choice: 1992 DX vs. 1992 VX

We also investigate the actual efficiency choice available to consumers on the showroom floor (1992 DX vs. 1992 VX). We show two cases: (1) the "As Available" case, which corrects only for the cost of the hatch cover in the VX, and (2) the "Full Correction" case, which uses the cost estimates for all the cosmetic differences from Table 2. Table 5 shows the results of this calculation, which indicates that the Cost of Conserved Energy relative to the 1992 DX (based on MSRP) is comparable to the levelized price of gasoline with taxes and roughly 25% to 30% higher than the levelized price of gasoline without taxes.[18] This CCE corresponds to a simple payback time of about 8 to 11 years depending on the treatment of taxes and cosmetic differences. These paybacks are long enough to make consumers think twice about spending the extra money for the VX.

### Sensitivity of Results to Discount Rate

Table 6 summarizes the effect of using 3%, 7%, and 10% real discount rates on the cost to society of employing the technologies in the 1992 VX relative to the 1991 DX. This range corresponds to that typically used in cost-benefit analyses. As expected, the Cost of Conserved Energy goes down in the 3% case and up in the 10% case relative to the case using the 7% real discount rate. Note also that the levelized gasoline price also changes (the levelization procedure is a type of present-valued average, which depends on the discount rate). With these discount rates, the CCE of the VX relative to the 1991 DX never exceeds the levelized gasoline price (with or without taxes), which indicates that our finding of cost-effectiveness for the VX compared to the 1991 DX is robust with respect to assumed discount rates. Only when the 30% real discount rate (roughly corresponding to a three-year simple payback) is applied does the CCE exceed the levelized price of fuel.

In assessing the consumer choice between the 1992 DX and the 1992 VX, we find that the 10% real discount rate pushes the CCE over the levelized fuel price with taxes by roughly 20-30%. The 3% real case produces a CCE that is roughly 10-20% lower than the levelized fuel price with taxes. The CCE ranges from 15% to 70% higher than the fuel price without taxes in the 3% real and 10% real cases, respectively. When the 30% real discount rate is applied, the CCE jumps to 2 to 3 times the price of fuel, which illustrates why consumers, many of whom do not use such paybacks in making investment choices for energy-using equipment, might not find the VX an attractive investment.

### Limitations of Cost Effectiveness Calculations

These calculations were done without accounting for external societal costs. External costs include all costs to society that are not included in the market price of gasoline, such as: increased health costs, costs arising from damage to agriculture, and costs resulting from damage to physical structures due to air pollution from automobiles; increased national security costs from consumption of imported oil; and increased environmental damage from acid rain, carbon dioxide emissions, and other pollutants. In practice, exact numerical

[18] Different consumer preferences about the worth of various accessories could change this assessment. If the consumer finds body side molding to be a frill, or is not interested in the rear wiper, this could make the VX more attractive. If the consumer finds the tachometer to be a frill and doesn't care about the sportier look of the alloy wheels, this assessment would make the 1992 DX relatively more attractive.

values for these externalities are difficult to calculate.[19] Many authors have attempted to assess these costs in monetary terms, and in general, they find that such costs are probably substantial (Bohi and Montgomery 1982, Broadman 1986, Cannon 1990, DeLuchi et al. 1987, Hall 1992, MacKenzie et al. 1992). We do not estimate these costs here, but simply note that accounting for them would improve the relative cost effectiveness of efficiency improvements compared to the consumption of gasoline alone.

## VI. POLICY IMPLICATIONS

The range of issues surrounding policies designed to affect vehicle efficiency choices are too complex to describe in detail here, and are described elsewhere (Gordon 1991, Griffin and Steele 1986). Our purpose in this section is to describe the most important policy-related conclusions emerging from our work, and to illustrate in this specific example the potential effects of gas taxes and feebates on the consumer's choice between the 1992 DX and VX models.

### Implications for Society

We have shown that improving the fuel economy of a particular vehicle (the 1991 Civic DX) was not only possible, it was cost-effective from society's perspective. The efficiency improvements in the 1992 Civic VX were achieved at a Cost of Conserved Energy that is about 45% less than the levelized cost of gasoline with taxes, and 30% less than the levelized cost of gasoline without taxes (relative to the 1991 DX). This empirical evidence indicates that, at least for small cars similar to the Civic, improvements in fuel economy can be achieved at attractive costs.

### Implications for Consumers

The 1992 Civic DX and VX deliver comparable performance, but the VX delivers higher fuel economy at a Cost of Conserved Energy that is comparable to the avoided cost of fuel. A consumer deciding between these two vehicles will have little, if any, direct economic incentive to choose the VX, although the U.S. as a whole might prefer the lower carbon dioxide emissions and reduced use of imported oil of the more efficient vehicle. According to estimates from Honda Corporation, about 5% of '92 Civic sales were VXs (Pollack 1992).

### Effects of Increased Gas Taxes and Feebates

In this section we investigate the effect of commonly discussed policy measures on the consumer's choice between the 1992 DX and VX models. We discuss only the effect of gas taxes and feebates on the life-cycle cost of the 1992 DX and VX models, and do not address the rationale for such policies. It is important to note that these policy tools have a different focus: gas taxes affect the cost of operating the car over its lifetime while feebates alter the initial cost to the consumer of purchasing the vehicle.

*Gas taxes*: Gas taxes in the range of $1 to $4 per gallon are common in Europe and Japan. Taxes that are only a fraction the size of the European taxes (e.g., an additional $0.50 per gallon) would tip the balance of cost effectiveness in favor of the VX relative to the 1992 DX for consumers who use discount rates of 3% to 10% real. Consumers who use simple

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[19] See Koomey (1990) for a discussion of the pitfalls of estimating monetary values for externalities.

payback times of about 3 years, corresponding to real discount rates of roughly 30%, would require gasoline taxes of $2 to $3 per gallon to make the VX cost competitive with the 1992 DX.

*Feebates*: This policy mechanism puts fees on inefficient cars, gives rebates to efficient cars, and uses the fees to pay for the rebates (Griffin and Steele 1986, Koomey and Rosenfeld 1990). We examine the financial impact of two currently proposed feebate strategies on the consumer's choice between the 1992 DX and VX:

> (1) The California legislature is considering a feebate program called DRIVE+, which would offer a rebate based on vehicle carbon dioxide emissions (a measure of fuel efficiency) on the order of $0.20 per gallon of gasoline or $21 per metric tonne of carbon dioxide.[20] If adopted in a state other than California, consumers buying a Civic VX would be eligible for a $160 greater rebate than the DX due to its higher fuel efficiency rating.[21]. The rebate difference within California would be lower because of the lower efficiency of the California VX.
>
> (2) The State of Maryland recently enacted feebate legislation that would adjust the vehicle titling tax based on a vehicle's fuel economy .[22] Other states are interested in adopting similar legislation. The Maryland program limits feebates to one percent of the new car sales price ($100 for the DX and $110 for the VX). However, other states are considering feebate legislation that calculates feebates based on fuel efficiency levels without limitation.
>
> If we estimate the size of feebates using the calculation methods detailed in the Maryland legislation, but without restricting their size, we find that those purchasing a new Civic VX would be eligible for an $800 rebate while a DX buyer would only receive a $200 rebate. This $600 difference in rebates is over 85% of the difference in the MSRPs of these models.

Either gas taxes or feebates may persuade consumers (and therefore manufacturers) to purchase (and produce) more efficient vehicles such as the Civic VX.

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[20] DRIVE+, as currently conceived, would also offer feebates on vehicle emissions of air pollutants. A fee or rebate depending of the car's emissions rating ("low-emission vehicle", "ultra-low-emission vehicle, etc.) in accordance with 1994 emission specifications would be added to the carbon dioxide feebate detailed above to arrive at the financial incentive or disincentive offered to the consumer. The 1993 Civic VX has been certified to meet California's transitional-low-emission vehicle standards and would be subject to a rebate based on lower emissions as well as a rebate for high efficiency (Automotive News 1992). Senator Gary Hart (D-Santa Barbara) is the sponsor of this feebate legislation–SB 431.

[21] We only considered the $CO_2$ feebate in this calculation because the emission feebate component depends on the model's emission status starting in 1994 which has not yet been determined.

[22] The State of Maryland's fuel efficiency feebate policy was passed by the legislature and signed into law by the governor in 1992. However, the federal government is currently challenging the state law based on preemption language in the federal fuel economy statute. Maryland's Attorney General maintains that the state has the right to enact the law. Further action is expected to break this deadlock in 1993.

## VII. CONCLUSIONS

Honda increased efficiency by 13% in the 1992 DX and by 56% in the 1992 Civic VX (relative to the 1991 Civic DX), with negligible impacts on performance, driveability, and comfort. The efficiency improvements in the 1992 DX (based on actual retail/MSRP prices) were captured at negative net costs. The Cost of Conserved Energy for the efficiency improvements in the 1992 Civic VX was significantly lower than the levelized price of fuel (45% less than the cost of the saved gasoline with taxes, and 30% less than the cost of the saved gasoline without taxes). These results suggest that the difficulty and cost of improving fuel economy in new compact and subcompact automobiles may be less than has been suggested by U.S. auto makers.

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## APPENDIX A: MORE DETAIL ON FUEL ECONOMY TECHNOLOGIES

This section describes in detail each of the fuel economy technologies used in the Civic VX.

### VTEC-E Engine

The Honda Variable Valve Timing and Lift Electronically Controlled (VTEC-E) engine is a 4-valve per cylinder, variable valve engine optimized for fuel economy. It is a completely different engine than that found in the 1991 and 1992 Civic DX hatchbacks. The VTEC-E engine has variable valve timing and uses lean burn technology. Additional modifications to reduce engine friction contribute further to the improved fuel economy of the VTEC-E engine.

*Variable valve timing*: Conventional engines use fixed valve timing and lift (height of intake valve) at all engine speeds. At light loads when lower power is required, fixed valve timing results in pumping losses, or efficiency losses due to the use of energy to pump air and fuel into the cylinder and push out the products of combustion. Pumping losses occur because, in order to reduce power, air and fuel input must be decreased using a throttle that produces a pressure differential between intake and exhaust valves on the engine cylinder, resulting in a loss of efficiency. Thus, closing the intake valve at light loads would reduce the pressure differential and decrease pumping losses. This is the principle on which variable valve timing operates. In the VTEC-E engine, the valve cycles are electronically controlled to promote more complete combustion at lower engine speeds, thus reducing fuel requirements. At low rpm, one of the two intake valves in each cylinder of the VTEC-E engine is nearly closed. This creates a swirling motion in the combustion chamber. The mixing and turbulence caused by this motion, combined with central placement of the spark plug, shorten combustion time and assure more complete combustion. Combustion time is also lessened by reducing the surface to volume ratio of the combustion chamber. The use of variable valve timing also enhances low speed torque, allowing gearing modifications (see below). At higher rpm, when more power output is required, both intake valves are activated simultaneously with full lift to provide power comparable to engines without variable valve timing (Honda Motor Co. Ltd 1991). Honda estimates that this feature produces a 2.5% increase in fuel economy (Harrington 1992).

*Lean burn technology*: A lean burn engine is operated with air in excess of that required for complete combustion (a high air/fuel ratio). Fuel economy increases with the addition of excess air to the combustion chamber, as more air results in more complete combustion of fuel, improves the efficiency of converting fuel energy into usable work (thermodynamic efficiency), and decreases pumping losses. The use of variable valve timing and electronic control enabled Honda to incorporate lean burn technology in the 1992 Civic VX. At low engine speeds, the VTEC-E engine can operate at air/fuel ratios as high as 25:1, compared to the stoichiometric ratio of 14.7:1 at which there is just enough air to theoretically achieve complete combustion. At low rpm, the swirl motion, discussed above, creates turbulence and results in the formation of a rich mixture (lower air/fuel ratio) that is maintained in a vortex near the spark plug, while the total air/fuel ratio in the combustion chamber remains lean. At higher speeds, the ratio decreases to approximately stoichiometric via electronic control. This return to stoichiometric conditions at high rpm resolves a problem common to lean burn systems where wide open throttle power decreases because less fuel is burned. Another problem associated with lean burn is an increase in nitrogen oxide ($NO_X$) emissions due to inability of the 3-way catalysts to control $NO_X$ at high air/fuel ratios. In order to meet more stringent $NO_X$ emission standards in California, Honda modified the VX to use exhaust gas recirculation (EGR) instead of excess air to dilute a stoichiometric air/fuel ratio. Using EGR, exhaust gases are recirculated into the combustion chamber to reduce $NO_X$ emissions by lowering combustion temperature. EGR also improves fuel economy by using energy from the waste stream. However, lean burn is more efficient than EGR. The lean burn characteristic of the VTEC engine has been estimated to account for a five to ten percent improvement in fuel economy over the 1992 DX (Harrington 1992). Although the lean burn technology is used successfully in the Civic VX, it had been largely dismissed by researchers as "speculative" prior to the release of the Civic VX and was not considered viable in larger cars due to uncertainty about the performance of nitrogen oxide catalyst technology in such applications (OTA 1991).

*Reduced engine friction:* Useful energy is lost due to friction between engine components including pistons and rings, valve train, and crankshaft. Engine friction has been reduced in the VTEC-E engine by the use of coated pistons and special low-friction piston rings. Honda estimates that reduced engine friction in the VX contributes to a 1.5% fuel economy improvement (Harrington 1992).

*Roller cam followers:* Intake and exhaust valves are operated by a camshaft in contact with a cam follower. The VTEC-E engine uses roller cam followers that reduce valve train friction by replacing the sliding contact between the roller cam and camshaft with a rolling contact. According to Honda, they increase fuel economy by approximately one percent in the VX (Harrington 1992).

### Changes in Axle or Drive Ratio

Axle or drive ratio is defined as the ratio of revolutions of the drive shaft, or transaxle, to the revolutions of the wheels. Generally, a low ratio means less engine wear and better fuel economy than a higher ratio. However, a lower ratio will also result in slower acceleration and decreased performance. The VTEC-E engine's variable valve timing enhances low-speed torque, meaning that torque is higher at lower rpm than in the standard Civic engine. This advantage allows a reduction in drive ratio without compromising performance (Honda Motor Co. Ltd 1991). The drive ratio of the VX is 16% lower than that of the 1991 DX and 20% lower than that of the 1992 DX. In general, a 10% decrease in the axle ratio can improve fuel economy by 4% (Gillis 1991).

### Changes in Gear Ratio

Automotive transmissions vary the ratio of engine speed to vehicle speed, allowing the engine to operate in the optimal speed range and the automobile to operate over a wider range of speeds. The wider, or taller, the ratio range of the gears in the transmission, the more the engine can operate over a wide range of speeds and loads without sacrificing performance. The VX operates at wider gear ratios and, thus, lower engine speeds than the 1991 and 1992 DX. This is made possible by the enhanced low-end torque resulting from the use of variable-valve timing. The combination of axle and gear ratio changes accounts for a 21% improvement in fuel economy (Harrington 1992).

### Multi-point Fuel Injection

Fuel injection systems provide more control over addition of fuel and more complete fuel atomization than carburetors. Such systems result in improved fuel economy, lower emissions, and increased power. The 1991 Civic DX is equipped with a dual-point fuel injection system using two injectors to inject fuel at essentially the same place as from a carburetor. This system has been replaced by multi-point fuel injection in the 1992 Civics. One injector is used for each cylinder (four cylinders in the case of the Civic hatchbacks) and fuel is injected upstream of the intake valves. Multi-point fuel injection allows control of the air/fuel ratio at each cylinder and results in improvements in power, fuel economy, and emissions. It is estimated to provide a 1.5% improvement in fuel economy over dual-point fuel injection (Harrington 1992).

### Weight Reduction

Lighter vehicles require less energy to overcome inertial forces. The 1992 Civic VX is about 84 pounds (4%) lighter than the 1992 DX and 64 pounds (3%) lighter than the 1991 DX due to the use of lightweight alloy wheels, a lighter engine block, and other minor modifications (Honda Motor Co. Ltd 1991). This weight reduction results in a 2.5% increase in fuel economy relative to the 1991 DX (Harrington 1992).

### Aerodynamic Improvements

Aerodynamic drag is due to the resistance of air to the movement of the vehicle. The aerodynamic characteristic of a vehicle is generally expressed as the coefficient of drag, or $C_D$. The lower the $C_D$, the less energy is required to overcome air resistance. The $C_D$ of the 1992 DX is 0.32, compared with 0.33 for the 1991 DX, while the VX has a drag coefficient of 0.31. This reduction in drag coefficient is estimated to produce a 1.5% increase in fuel economy in the VX relative to the 1991 DX (Harrington 1992).

### Low Rolling Resistance Tires

Rolling resistance results from heat generated and lost by tires as they flex. The 1992 VX is equipped with tires that have reduced surface area in contact with the road and increased stiffness, thus decreasing rolling resistance. Low rolling resistance tires improve fuel economy by an estimated 1% (Harrington 1992). We have no data on braking or cornering characteristics of these new tires compared to those used on the 1991 Civic VX.

### Reduced Idle Speed

An engine that idles at higher than average rpm will generally consume more fuel than one that idles at lower rpm. Honda has reduced idle fuel consumption by decreasing the speed at which the VTEC-E engine idles, thus improving fuel economy by 3% (Harrington 1992).

### Shift Indicator Light

Honda estimates that the shift indicator light, which alerts the driver to shift gears at the most efficient shift point, will result in a 5% fuel economy improvement. The 49-State Civic VX is equipped with a shift indicator light, while the California VX is not (Harrington 1992).

## APPENDIX B: 1991 2-DOOR HATCHBACK COMPARED TO 1992 CX

This Appendix compares the 1992 Honda Civic CX 2-door hatchback with the 1991 Honda Civic 2-door hatchback. As shown in Table B.1, these two cars are functionally identical, with the exception of an airbag and a shift indicator light in the 1992 CX, but have efficiencies that differ by 28%. The efficiency difference is mainly caused by the shift to a 5-speed transmission from a 4-speed transmission and improved aerodynamics. Table B.2 presents the estimated direct emissions for these models.

After subtracting the cost of the airbag and correcting for 4% inflation (same assumptions as Table 5 above), we find that these efficiency improvements are accomplished at approximately zero cost. The efficiency of this Civic hatchback has been improved at low or zero cost to society, while actually improving safety. This comparison adds weight to the previous calculations for the DX and VX.

**Table 1: Specifications/Features of Honda Civic Models**

| Specifications/Features | 1991 DX | 1992 DX | 1992 VX |
|---|---|---|---|
| **Fuel Economy** | | | |
| Unadjusted miles per gallon (city/hwy) | 34/39 | 39/44 | 53/61 |
| Adjusted miles per gallon (city/hwy) | 31/35 | 35/40 | 48/55 |
| Adjusted miles per gallon (composite) | 32.7 | 37.1 | 50.9 |
| **Engine, Drive Train** | | | |
| Horsepower (@ rpm) | 92 @ 6000 | 102 @ 5900 | 92 @ 5500 |
| Torque (lb-ft @ rpm) | 89 @ 4500 | 98 @ 5000 | 97 @ 4500 |
| Valve train | SOHC, 16-valve | SOHC, 16-valve | VTEC-E |
| Fuel induction | Dual-point Fuel Injection | Multi-point Fuel Injection | Multi-point Fuel Injection |
| Drive-train type | Front-wheel Drive | Front-wheel Drive | Front-wheel Drive |
| Transmission | 5-Speed Manual | 5-Speed Manual | 5-Speed Manual |
| Final drive train ratio | 3.89 | 4.06 | 3.25 |
| **Exterior Dimensions** | | | |
| Wheelbase (in) | 98.4 | 101.3 | 101.3 |
| Overall Length (in) | 157.1 | 160.2 | 160.2 |
| Overall Width (in) | 66.3 | 66.9 | 66.9 |
| Curb weight (lbs) | 2158 | 2178 | 2094 |
| Coefficient of drag | 0.33 | 0.32 | 0.31 |
| **Interior Dimensions** | | | |
| Headroom front/rear (in) | 38.2/36.6 | 38.6/36.6 | 38.6/36.6 |
| Legroom front/rear (in) | 38.6/36.6 | 42.5/30.5 | 42.5/30.5 |
| Cargo volume (cu. ft) | 16.9 | 13.3 | 13.3 |
| Passenger volume (cu. ft) | 73 | 77.2 | 77.2 |
| Fuel capacity (gal) | 11.9 | 11.9 | 10 |
| **Power features** | | | |
| Steering | no | no | no |
| Windows | no | no | no |
| **Safety features** | | | |
| Driver airbag | not available | standard | standard |
| **Cost (1992 $)** | | | |
| Invoice/dealer cost | 8171 | 8663 | 9258 |
| Manufacturers suggested retail price (MSRP) | 9563 | 10140 | 10840 |
| **Performance** | | | |
| Seconds to go from 0 to 100 kph | NA | 10.2 | 10.5 |

(1) Sources: Honda 1990, 1991; Leestma 1992; USAA 1991a, 1991b

(2) 1991 costs adjusted to 1992 $ assuming 4% inflation.

(3) Fuel economy is listed for the 49-State version of the 1992 VX. The California version has the following fuel economy: unadjusted: 49/57; adjusted: 44/51; composite: 46.9. The California version of the 1991 and 1992 DX has the same fuel economy as the 49-State versions of these cars.

(4) Unadjusted mpg is used for CAFE compliance purposes and does not include real-world corrections to the EPA test procedure. To calculate adjusted mpg that reflects real-world driving, unadjusted mpg for city driving is reduced by 10% and fo highway driving is reduced 22%. Composite mpg assumes 55% of driving is urban and 45% of driving is on the highway.

(5) Gear ratios for the 1992 DX and VX are as follows (this data was unavailable for the 1991 DX):

| Gear number | 1 | 2 | 3 | 4 | 5 | R |
|---|---|---|---|---|---|---|
| Ratio 92 DX | 3.25 | 1.761 | 1.172 | 0.909 | 0.702 | 3.153 |
| Ratio 92 VX | 3.25 | 1.761 | 1.066 | 0.852 | 0.702 | 3.153 |

**Table 2: Cosmetic Differences and Associated Costs**

| | 1991 DX | 1992 DX | 1992 VX | Cost to add feature (1992$) (2) |
|---|---|---|---|---|
| Rear wiper/washer | yes | yes | no | 300 |
| Body side molding | yes | yes | no | 150-160 |
| Tachometer | no | no | yes | 150-300 |
| Adjustable steering column | yes | yes | no | 0 (3) |
| Cargo area cover | yes | yes | no | 159 |
| Wheel type | steel covers | center caps | lightweight alloy | 240-320 (4) |
| MSRP correction added to DX (5) | | | | 365 |
| MSRP correction added to VX (5) | | | | 614 |

(1) Sources: American Honda Motor Co., Inc. 1990, 1991; Maio 1992.

(2) Figures represent estimated MSRP costs of adding the specified features. Estimates are in some cases crude because these particular items are not available as actual options (with the exception of the cargo area cover, which is available as an option on the VX).

(3) Cost to replace steering column (as a repair) = $272 for both DX and VX, according to Maio 1992b. The incremental cost therefore is 0 for tilt steering column in the DX, since there is no difference in cost to replace the column between DX and VX.

(4) Indicates cost of lightweight alloy wheels (4) above that of steel covers or center caps.

(5) To correct for differences in costs of cosmetic features, the mean cost of each option that exists on the 1991 and 1992 DX but not on the VX has been added to the cost of the VX, and the mean cost of each option that exists on the VX but not on the DX has been added to the cost of the DX. The only exception to this rule is that only half the cost of the alloy wheels has been added to the cost of the DX, because part of their benefit is to increase fuel economy, and part is cosmetic. These MSRP costs are adjusted to reflect the standard 17% markup when estimating invoice costs. See Table 5 for details on how these numbers are used in the CCE calculations.

| Table 3: Estimated direct emissions for Honda Civic hatchbacks | | | | | |
|---|---|---|---|---|---|
| | | | **Pollutant (g/mi)** | | |
| **Vehicle** | **Applicability** | ***HC*** | ***CO*** | ***NOx*** | **Comments** |
| 1991 DX | 4k mile certification data | 0.091 | 0.90 | 0.34 | 50 State |
| 1992 DX | 4k mile certification data | 0.100 | 0.96 | 0.20 | 49 State |
| | 4k mile certification data | 0.130 | 1.60 | 0.20 | CA |
| 1992 VX | 4k mile certification data | 0.152 | 0.70 | 0.54 | 49 State |
| | 4k mile certification data | 0.155 | 0.95 | 0.60 | 49 State w/SIL (1) |
| | 4k mile certification data | 0.140 | 0.90 | 0.20 | CA |
| 1991 DX | *Deterioration factors* | *1.247* | *1.260* | *1.129* | |
| 1992 DX | *Deterioration factors* | *1.243* | *1.292* | *1.453* | |
| 1992 VX | *Deterioration factors* | *1.205* | *1.268* | *1.000* | |
| 1991 DX | Estimated 50k mile emissions (2) | 0.11 | 1.1 | 0.38 | 50 State |
| 1992 DX | Estimated 50k mile emissions | 0.12 | 1.2 | 0.29 | 49 State |
| | Estimated 50k mile emissions | 0.16 | 2.1 | 0.29 | CA |
| 1992 VX | Estimated 50k mile emissions | 0.18 | 0.89 | 0.54 | 49 State |
| | Estimated 50k mile emissions | 0.19 | 1.2 | 0.60 | 49 State w/SIL |
| | Estimated 50k mile emissions | 0.17 | 1.1 | 0.20 | CA |

(1) SIL= shift indicator light
(2) Deterioration factors are multiplied by 4k mile emissions to calculate 50k mile emissions.
Deterioration factors are derived from testing of prototype vehicles by EPA.
(4) Emissions represent direct tailpipe emissions and do not include indirect emissions from the extraction, processing, and transport of fuel.
(5) Sources: American Honda Motor Co, Inc., Certification Department, 1991 EPA Test Car List, US EPA Federal Certification Test Results for 1991 Model Year, and US EPA Federal Certification Test Results for 1992 Model Year.

**Table 4: Technologies Used to Increase Fuel Economy in 1992 VX**

| Technology | Fuel Economy Improvement (%) '91 DX to '92 VX | Cost (1992 $/car) (2,3) |
|---|---|---|
| Multi-point fuel injection | 1.5 | 56-162 |
| Low rolling resistance tires | 1 | 21-22 |
| VTEC-E engine | | |
| variable valve timing | 2.5 | 108 -164 |
| lean burn | 5 -10 | 150 - 500 |
| reduced friction | 1.5 | 35-65 |
| roller cam followers | 1 | 19-54 |
| Weight reduction | 2.5 | 37 - 78 (4) |
| Aerodynamic improvements | 1.5 | 22 - 39 (5) |
| Gearing and drive ratio changes | 21 | N/A (6) |
| Reduced idle speed/rpm | 3 | N/A (6) |
| Shift indicator light | 5 | N/A (6) |
| Total | 45.5 - 50.5 (7) | 448 - 1084 |

(1) Sources: Greene and Duleep. 1992, Harrington 1992, National Research Council 1992, SRI International 1991.

(2) All costs taken from SRI International (1991) and Greene and Duleep (1992). They represent retail costs to the consumer. Greene and Duleep provide the low end of the range and SRI provides the high end estimate for all technologies with the exception of variable valve timing. Both sources used a variety of information including cost figures from vehicle manufacturers and component suppliers, and information on cost components such as production costs, fixed costs, and markups for overheads, taxes, and dealer profit.

(3) Most cost estimates adjusted from 1988 and 1990 $ based on 4.1% implicit price deflator for GNP for 1989 and assumed 4% annual deflator for 1990 to 1992.

(4) Cost estimate from Greene and Duleep based on $0.50/lb reduced (1988$). Estimate from SRI based on 5% weight reduction.

(5) Cost based on 10% aerodynamic improvement.

(6) N/A = not available.

(7) Totals based on simple addition do not add to 56% due to synergistic effects of fuel economy technologies (e.g., variable valve timing allows gearing changes and use of lean burn).

**Table 5: Cost of Conserved Gasoline for 1992 Honda Civic DX and VX Hatchbacks**

| | 91 DX | 92 DX | 92 VX | Changes in mpg, fuel use, and capital costs: *Costs Fully Corrected 91DX to 92DX* | *Costs Fully Corrected 91DX to 92VX* | *Costs As Available 92DX to 92VX* | *Costs Fully Corrected 92DX to 92VX* |
|---|---|---|---|---|---|---|---|
| *EPA mpg estimates* | | | | | | | |
| Adjusted miles/gallon (city) | 31 | 35 | 48 | *13%* | *55%* | *37%* | *37%* |
| Adjusted miles/gallon (highway) | 35 | 40 | 55 | *14%* | *57%* | *38%* | *38%* |
| Adjusted miles/gallon (EPA composite) | 32.7 | 37.1 | 50.9 | *13%* | *56%* | *37%* | *37%* |
| Fuel used (gallons/year) | 312 | 275 | 200 | -37 | -112 | -75 | -75 |
| Invoice cost (IC, in 92$) | 8171 | 8663 | 9258 | 492 | 1087 | 595 | 595 |
| MSRP cost (92$) | 9563 | 10140 | 10840 | 577 | 1277 | 700 | 700 |
| IC adjusted for airbag+cosmetic difs (92$) | 8474 | 8282 | 9084 | -192 | 610 | 727 | 802 |
| MSRP adjusted for airbag+cosmetic difs (92$) | 9928 | 9705 | 10654 | -223 | 726 | 859 | 949 |
| Annualized incremental invoice cost ($/year) | 999 | 976 | 1071 | -23 | 72 | 86 | 94 |
| Annualized incremental MSRP cost ($/year) | 1170 | 1144 | 1256 | -26 | 86 | 101 | 112 |
| CCE based on invoice cost (92 $/gallon) | | | | < 0 | 0.64 | 1.15 | 1.26 |
| *CCE based on MSRP cost (92 $/gallon)* | | | | < 0 | *0.77* | *1.36* | *1.50* |
| SPT (in years)-MSRP & gas price w/tax | | | | < 0 | 4.6 | 8.2 | 9.0 |
| SPT (in years)-MSRP & gas price w/o tax | | | | < 0 | 5.9 | 10.4 | 11.5 |
| *Other parameters* | | | | | | | |
| Real discount rate | 7% | | | | | | |
| Auto lifetime (years) | 13.3 | | | | | | |
| Capital recovery factor | 11.8% | | | | | | |
| City driving percentage | 55% | | | | | | |
| Highway driving percentage | 45% | | | | | | |
| Miles driven/year | 10200 | | | | | | |
| Invoice cost of airbag (1992 $) | 683 | | | | | | |
| MSRP cost of airbag (1992 $) | 800 | | | | | | |
| Levelized cost of gasoline w/taxes (92$/gal) | 1.40 | | | | | | |
| Levelized cost of gasoline w/o taxes (92$/gal) | 1.10 | | | | | | |

(1) 1991 DX costs adjusted to 1992$ assuming 4% inflation.
(2) Source of invoice and MSRP costs: USAA 1991a, 1991b.
(3) Automobile lifetime derived from retirement curve in Davis and Morris (1992).
(4) Composite mpg calculated assuming city and highway percentages are 55% and 45%, respectively (EPCA 1975).
(5) Annual auto mileage from Davis and Morris (1992).
(6) MSRP airbag cost from Maio 1992. Invoice cost of airbag calculated from MSRP using average markup of 17% (from total Civic costs).
(7) Levelized cost of gasoline calculated using a 7% real discount rate and the fuel price forecast contained in U.S. DOE 1992 over the period 1992-2005, based on the method from Kahn 1988. This price includes roughly $0.30/gallon of state and federal taxes.
(8) Cost of airbag subtracted from 1992 DX and VX models.
(9) Mean cost of hatch cover, body side moulding, adjustable steering column, and rear wiper/washer added to cost of VX in Full Correction case. Mean cost of tachometer and 1/2 of cost of alloy wheels added to cost of 1991 and 1992 DX. Invoice cost for options calculated from MSRP costs in Table 2 using same markup as for airbag (see note 6). In the As Available case, only the cost of the hatch cover is added to the VX, because that is the only option that can actually be purchased by a new car buyer.
(10) no rebound effect is included in cost-effectiveness calculations. See text for details
(11) SPT = simple payback time (in years), defined as incremental capital cost divided by annual energy cost savings

| Table 6: Sensitivity of Cost of Conserved Energy to Choice of Real Discount Rate | | | | | |
|---|---|---|---|---|---|
| | *Real discount rate* | *Levelized gasoline price 1992$/gal* | *Fully Corrected CCE 1992 $/gallon 91 DX vs 92 VX* | *As Available CCE 1992 $/gallon 92 DX vs 92 VX* | *Fully Corrected CCE 1992 $/gallon 92 DX vs 92 VX* |
| CCE based on invoice cost (1992 $/gallon) | 3% | 1.411 | 0.50 | 0.90 | 0.99 |
| *CCE based on MSRP cost (1992 $/gallon)* | 3% | | *0.60* | *1.06* | *1.17* |
| CCE based on invoice cost (1992 $/gallon) | 7% | 1.404 | 0.64 | 1.15 | 1.26 |
| *CCE based on MSRP cost (1992 $/gallon)* | 7% | | *0.77* | *1.36* | *1.50* |
| CCE based on invoice cost (1992 $/gallon) | 10% | 1.398 | 0.76 | 1.35 | 1.49 |
| *CCE based on MSRP cost (1992 $/gallon)* | 10% | | *0.90* | *1.60* | *1.77* |
| CCE based on invoice cost (1992 $/gallon) | 30% | 1.364 | 1.69 | 3.01 | 3.32 |
| *CCE based on MSRP cost (1992 $/gallon)* | 30% | | *2.01* | *3.56* | *3.93* |

(1) Assumptions for auto lifetime, mileage travelled, and other parameters are the same as in Table 5.
(2) Levelized cost of gasoline calculated using appropriate real discount rates and the fuel price forecast contained in U.S. DOE 1992 over the period 1992-2005, based on the method from Kahn 1988.

**Table B.1: Cost of Conserved Gasoline for 1992 Honda Civic CX Hatchbacks**

| | *1991 2 door hatchback* | *1992 CX hatchback* | **Changes** *1991 to 1992CX* |
|---|---|---|---|
| *EPA mpg estimates* | | | |
| Adjusted miles/gallon (city) | 33 | 42 | *27%* |
| Adjusted miles/gallon (highway) | 37 | 48 | *30%* |
| Adjusted miles/gallon (EPA composite) | 34.7 | 44.5 | *28%* |
| Fuel used (gallons/year) | 294 | 229 | -65 |
| *Characteristics* | | | *1992 CX rel. to 1991* |
| Horsepower | 70.0 | 70.0 | *same* |
| Transmission | 4 speed manual | 5 speed manual | + |
| Airbag | No | Yes | + |
| Engine | 4 cylinder, 1.5 liter | 4 cylinder, 1.5 liter | *same* |
| Shift indicator light | No | Yes | |
| Curb weight | 2127.0 | 2094.0 | - |
| Overall length | 157.1" | 160.2" | + |
| HC emissions (g/mi) | 0.208 | 0.112 | - |
| CO emissions (g/mi) | 1.73 | 1.52 | - |
| NOx emissions (g/mi) | 0.49 | 0.28 | - |
| Invoice cost (IC, in 92 $) | 6641 | 7290 | 649 |
| MSRP cost (92 $) | 7379 | 8100 | 721 |
| Invoice cost adjusted for airbag (92 $) | 6641 | 6570 | -71 |
| MSRP cost adjusted for airbag (92 $) | 7379 | 7300 | -79 |
| Annualized incremental invoice cost ($/year) | 783 | 774 | -8 |
| Annualized incremental MSRP cost ($/year) | 870 | 860 | -9 |
| CCE based on invoice cost (92 $/gallon) | | | < 0 |
| *CCE based on MSRP cost (92 $/gallon)* | | | < 0 |
| Simple payback time-MSRP & gas price w/tax | | | < 0 |
| Simple payback time-MSRP & gas price w/o tax | | | < 0 |
| *Other parameters* | | | |
| Real discount rate | 7% | | |
| Auto lifetime (years) | 13.3 | | |
| Capital recovery factor | 11.8% | | |
| City driving percentage | 55% | | |
| Highway driving percentage | 45% | | |
| Miles driven/year | 10200 | | |
| Invoice cost of airbag (1992 $) | 720 | | |
| MSRP cost of airbag (1992 $) | 800 | | |
| Levelized cost of gasoline w/taxes (92$/gal) | 1.40 | | |
| Levelized cost of gasoline w/o taxes (92$/gal) | 1.10 | | |

(1) Assumptions are the same as for Table 5, with the addition that there are no cosmetic differences between the 1991 hatchback and the 1992 CX hatchback.
(2) Emissions factors are estimated 50k mile values, calculated using method described in Table 3.

| Table B.2: Estimated emissions for 1991 base model Honda Civic hatchback and 1992 CX (1) | | | | | |
|---|---|---|---|---|---|
| | | **Pollutant (g/mi)** | | | |
| **Vehicle** | **Applicability** | ***HC*** | ***CO*** | ***NOx*** | **Comments** |
| 1991 Base Htchbk | 4k mile certification data | 0.208 | 1.73 | 0.49 | 50-State |
| 1992 CX | 4k mile certification data | 0.112 | 1.52 | 0.28 | 50-State w/ SIL (2) |
| | 4k mile certification data | 0.078 | 0.85 | 0.32 | 50-State |
| 1992 CX | *Deterioration factors* | *1.184* | *1.295* | *1.129* | |
| 1992 CX | Estimated 50k mile emissions (3) | 0.13 | 2.0 | 0.30 | 50-State w/SIL |
| | | 0.092 | 1.1 | 0.34 | 50-State |

(1) Emissions represent direct tailpipe emissions and do not include indirect emissions from the extraction, processing, and transport of fuel.
(2) SIL= shift indicator light
(3) Deterioration factors are multiplied by 4k mile emissions to calculate 50k mile emissions. Deterioration factors are derived from testing of prototype vehicles by EPA.
(4) Sources: American Honda Motor Co., Inc., Certification Department; 1991 EPA Test Car List; US EPA Federal Certification Test Results for 1991 Model Year; and US EPA Federal Certification Test Results for 1992 Model Year.