Differences Between EPA-Test and In-Use Fuel Economy: Are the Correction Factors Correct?

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A vehicle's in-use or on-the-road fuel economy often differs substantially from the estimates developed by the U.S. Environmental Protection Agency (EPA) as part of its emissions certification program. As a result, the certification values are routinely adjusted by a set of correction factors so that the resulting estimates will better reflect in-use experience. Data from the Residential Transportation Energy Consumption Survey conducted by the Energy Information Administration of the U.S. Department of Energy were used to investigate how well the correction factors replicated the shortfall experience of all household vehicles on the road in 1985. Results indicate that the shortfall is larger than the EPA correction factors, and light trucks are experiencing significantly larger shortfalls than automobiles.

The 1970 amendments to the Clean Air Act established a Federal Test Procedure (FTP) to determine the exhaust hydrocarbon and carbon monoxide emissions of new light-duty vehicles over a prescribed driving cycle. The test procedure, both originally and as modified in 1975, is run on a chassis dynamometer and is based on a transient cycle representative of driving patterns in Los Angeles (the LA-4 cycle) in the early 1970s. Since 1973, fuel economy has also been calculated from the quantity and composition of the exhaust gas produced (*1*). Three fuel-economy ratings are derived from the FTP. Urban fuel economy is calculated from one portion of the FTP, highway fuel economy is calculated from another, and a composite fuel economy rating is computed as the harmonic mean (55 percent urban and 45 percent highway) of the two.

Since the late 1970s, the difference, or shortfall, between the EPA test and in-use fuel economy has been recognized by the motoring public and documented in various panel surveys (*2–4*). Whereas shortfalls varied by the year, make, and model of vehicle, it nevertheless became clear that a general pattern existed, and some type of adjustment was needed to maintain consumer confidence in the validity of the EPA estimates on new car labels and in the *Gas Mileage Guide*. Thus, in 1985, EPA officially acknowledged the shortfall and adopted a set of across-the-board correction factors based on earlier panel survey results for various model years and vehicle nameplates (*5*). These correction factors reduced urban fuel economy estimates by 10 percent, highway fuel economy estimates by 22 percent, and composite fuel economy estimates by 15 percent for all new vehicles. Since 1985, only the adjusted values have been reported in the *Gas Mileage Guide* published annually by EPA and the Department of Energy (DOE) (*1*).

The correction factors are intended to account for physical differences between real-world conditions and dynamometer tests like those performed by EPA. These differences include such random variables as driver behavior, maintenance practices, tire inflation, vehicle loads, weight distribution, type and condition of road surfaces, weather conditions, altitude, accessory loads, and variability within the test procedure itself. Weight distribution affects how well the rolling resistance of two tires on the dynamometer rolls can approximate that of four tires on the road. Generally speaking, these differences cannot be eliminated by revising the test procedure.

METHODOLOGY

Since the correction factors are based on surveys of in-use fuel economy conducted in the late 1970s and early 1980s, two questions arise:

1. Are shortfalls stable over time?
2. Do shortfalls vary for particular vehicles or groups of vehicles?

The answers to these questions have very different implications. If the random variables responsible for shortfalls are stable over time, we can continue to use the original correction factors to forecast fuel consumption. However, if underlying variables are changing in some systematic way, or if different vehicles are experiencing disproportionate shortfalls, development of vehicle- or size-specific factors may be advisable, along with periodic reexamination and revision of correction factors.

DATA

Two data sets were merged to investigate the above questions: the 1985 Residential Transportation Energy Consumption Survey (RTECS) and the Oak Ridge National Laboratory (ORNL) MPG and Market Shares data base (*6–9*). The 1985 RTECS is the most recent large-scale survey of in-use vehicle fuel economy. It contains fuel purchase diaries on 8,401 vehicles in 3,981 households and documents approximately 15,000

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fuel purchases during the survey year. Because of its size and representativeness, the file can be used to estimate travel, fuel consumption, and fuel economy for all household vehicles or particular subgroups of vehicles. Subgroups may be defined on the basis of population characteristics (e.g., residential location or income) or vehicle characteristics (e.g., nameplate, size class, model year, or import versus domestic origin).

ORNL's MPG and Market Shares data base is a PC file documenting new light-duty vehicle sales since model year 1976. Organized by nameplate and vehicle characteristics (e.g., curb weight, wheelbase, engine displacement, interior volume, engine/transmission type, EPA size class, and EPA-test fuel economy), it may be sales-weighted by various classifications. For this analysis, EPA size class and sales-weighted fuel economy values were retrieved from the MPG and Market Shares file for nameplates contained on the RTECS file. A merged file was then created consisting of the original RTECS household and vehicle data, along with the EPA size class and fuel economy codes obtained from the MPG and Market Shares data base.

Of the 8,401 vehicles in the RTECS data base, 6,028 (71.8 percent) are of model year (MY) 1976 or newer. Of these, 4,428 (73.5 percent) were matched to vehicle records in the ORNL MPG and Market Shares data base. Because of miscodes on the RTECS file, some matches were achieved by manually correcting obviously incorrect vehicle type codes (e.g., a 1979 Chevrolet Nova with a vehicle type code of motor home).

RESULTS

As shown in Figure 1, automobiles from the RTECS sample that were matched to MPG and Market Shares data had a fleet average EPA-test fuel economy of 24.9 mpg; light trucks had an EPA-test fuel economy of 20.8 mpg. By contrast, on-the-road experience (as measured by the RTECS fuel purchase diaries) was only 20.2 mpg for automobiles and 16.6 mpg for light trucks. The resulting gap or shortfall of 18.7 percent for automobiles and 20.1 percent for light trucks (shown in Figure 2) is significantly larger than EPA's 15 percent adjustment factor. Transport Canada has also obtained larger shortfalls. As shown in Figure 2, Transport Canada's estimates range from 9.3 to 22.5 percent for 1979–1986 MY automobiles (*10*).

Note that the last set of bars in Figure 1 is estimated by FHWA and applies to all vehicles (household and nonhousehold for all model years) that were in operation in 1985 (*11*). These values are approximately 10 percent lower than the RTECS on-road values for automobiles and 20 percent lower than the RTECs on-road values for trucks. Like RTECS, the FHWA values are computed from fuel sales and vehicle-miles traveled (VMT) and are therefore weighted by relative use. Unlike RTECS, however, FHWA's underlying fuel sales and VMT data include pre-1976 vehicles (which were not matched to the MPG and Market Shares file), commercial and government vehicles, small quantities of fuel used by other kinds of vehicles (e.g., lawn and garden equipment, pleasure boats, or other recreational vehicles), and heavier classes of light trucks (i.e., two-axle, four-tire trucks with gross weights above 10,000 lb).

Shortfall Variability over Time

Although more data are needed for definitive conclusions, shortfalls appear to be rising over time. The 18.7 percent shortfall (3.7 percentage points above the EPA estimate) obtained for automobiles is consistent with findings by Patterson and Westbrook, who project that the shortfall will rise to 29.7 percent by 2010 (*12*). The forces behind their projection—population and driving shifts, long-term trends in urban traffic congestion, and highway speeds—are clearly stronger today than in the late 1970s and early 1980s when the EPA adjustment factors were developed.

1. Population and driving shifts: In 1968, 52 percent of the VMT by automobiles occurred in urban areas (*11*). By 1991,

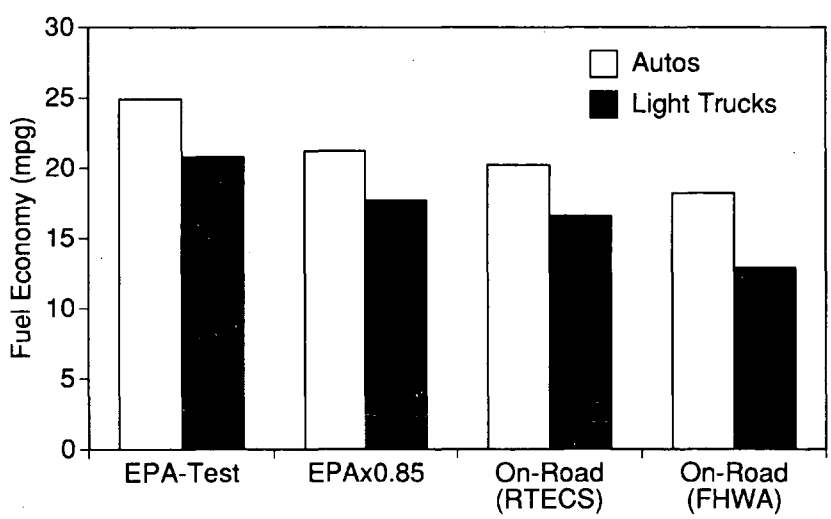

FIGURE 1 EPA-rated versus on-the-road fuel economy of automobiles and light trucks (1985 fleet average).

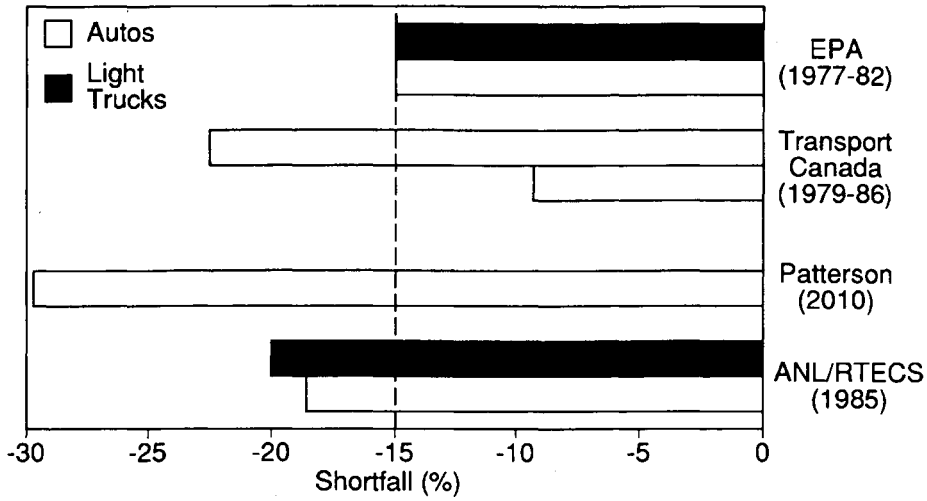

FIGURE 2 Estimates of fuel economy shortfall.

that figure had risen to 62.5 percent (*13*). As the U.S. Bureau of the Census classifies additional localities as "urbanized" or adds outlying areas to existing "urbanized areas," the share of urban vehicle-miles may be expected to grow still further. However, EPA makes no allowance for this continuing shift in the formula used to compute the composite fuel economy rating (which has assumed 55 percent urban and 45 percent rural driving since its inception). Patterson and Westbrook estimate a 0.2 percent increase in shortfall for every 1 percent increase in urban share (*12*). This alone could account for 1.6 of the 3.7 points of additional shortfall found in our analysis.

2. Traffic congestion: Roadway supply is measured in terms of lane miles, computed as road mileage times the number of traffic lanes. Traffic is measured in terms of vehicle miles, computed as the volume of traffic on a particular road segment times the length of that segment. Between 1975 and 1987, the supply of urban roadway rose 14.6 percent, while urban traffic rose 57.4 percent (*13*). As a result, the throughput, or traffic load, on urban roadways increased 38.9 percent (from 1.13×10^6 to 1.57×10^6 vehicle-miles/lane-mile). Whereas not all of this additional load produced congestion, it may be considered a reasonable upper bound. If all our observed shortfall were attributed to population shifts, congestion, and increased highway speeds (see below), the increase in urban congestion would account for 1.2 of the 3.7 points of additional shortfall.

3. Highway speeds: Between 1976 and 1991, the percentage of traffic exceeding 55 mph rose from 69 to 75.5 percent on rural Interstate highways and from 57 to 69.8 percent on urban Interstate highways (*11,13*). Most of these increases occurred in the higher speed range (i.e., vehicles traveling above 65 mph rose from 5 to 18 percent for urban Interstate traffic and from 10 to 20.9 percent for rural Interstate traffic). McGill has documented a 0.2 percentage point decline in fuel economy for every 1-mph increase in speed between 55 and 60 mph and a 0.35 to 0.4 percentage point decline in fuel economy for every 1-mph increase in speed between 60 and 66 mph (*14*). Patterson and Westbrook have estimated that increased highway speed accounts for 0.8 percentage points of additional shortfall (*12*).

Because the RTECS file is cross sectional, it can provide indications but no definitive proof of a rising trend in shortfalls. The file can be used to determine whether shortfalls are greater for vehicles that are driven fewer annual miles but not for vehicles with specific duty cycles. Presumably, low-utilization vehicles have a greater proportion of travel on short trips, without a fully warmed engine, or under congested conditions. All things being equal, either of these characteristics would tend to increase shortfalls. To test this hypothesis, the file was sorted into five mileage categories: under 5,000, 5,000 to 9,999, 10,000 to 14,999, 15,000 to 19,999, and 20,000 and over. Shortfalls were then computed and compared with the EPA correction factor. Differences between actual shortfalls and the EPA correction factor were insignificant for automobiles and light trucks driven 15,000 mi/year or more. For automobiles and light trucks driven fewer annual miles, the differences were highly significant (prob $|t| < 0.001$). Although it is indirect, the finding that shortfalls decline with increasing vehicle utilization provides further evidence that congestion and urban travel are behind much of the increasing trend in shortfalls.

Shortfall Variability Across Different Vehicles or Groups of Vehicles

Vehicle Type and Size

In the absence of major differences in materials composition or technology, fuel economy is inversely related to vehicle mass or size. In other words, for vehicles of comparable technology, the heavier the vehicle, the fewer miles it can travel on a gallon of fuel. For example, in Table 1 RTECS or on-road fuel economy drops from an average of 22.8 to 17.8 mpg and then to 15.2 mpg for small, mid-sized, and large automobiles, respectively.

The relationship between shortfall and vehicle size is less clear-cut. From an engineering perspective, one should expect little or no variation by vehicle type or size class. Our results confirm that shortfalls appear to be stable across size classes,

TABLE 1 EPA Test Versus On-the-Road Fuel Economy and Percentage Shortfall or Gap by Vehicle Type, Size Class, Model Year, and Origin

	Domestic Vehicles			Imported Vehicles			All Vehicles		
Vehicle Type, Size Class and Model Year (MY)[a]	RTECS (mpg)	EPA (mpg)	Gap (%)	RTECS (mpg)	EPA (mpg)	Gap (%)	RTECS (mpg)	EPA (mpg)	Gap (%)
Auto	18.6	23.2	-19.8[c]	26.1	30.9	-15.6	20.2	24.9	-18.7[c]
1983-1985 MY	21.2	26.6	-20.2	27.1	32.6	-17.1	22.7	28.1	-19.4[c]
1978-82 MY	18.3	22.8	-19.8	26.1	30.4	-14.1	20.1	24.5	-18.2[c]
Pre-1978 MY	14.6	18.0	-18.8	22.6	27.2	-17.1	15.7	19.3	-18.4[c]
Small	20.7	26.1	-20.9[c]	26.1	31.0	-15.6	22.8	28.0	-18.6[c]
1983-1985 MY	23.9	30.4	-21.4[c]	27.1	32.7	-17.1[c]	25.3	31.4	-19.5
1978-82 MY	20.9	26.4	-20.9[c]	26.1	30.4	-14.2	23.2	28.2	-17.6
Pre-1978 MY	15.7	19.5	-19.6[c]	22.6	27.3	-17.1	17.1	21.1	-19.0
Mid-Size	17.8	22.1	-19.5[c]	[b]	[b]	[b]	17.8	22.1	-19.5[c]
1983-1985 MY	20.2	24.9	-19.1[c]	[b]	[b]	[b]	20.1	24.9	-19.2
1978-82 MY	17.3	21.5	-19.8[c]	[b]	[b]	[b]	17.3	21.5	-19.6
Pre-1978 MY	13.2	16.4	-19.3[c]	[b]	[b]	[b]	13.3	16.4	-19.0
Large	15.2	18.3	-16.9	[b]	[b]	[b]	15.2	18.3	-16.9
1983-1985 MY	16.9	20.8	-18.8	[b]	[b]	[b]	16.8	20.7	-18.9
1978-82 MY	14.9	17.7	-15.6	[b]	[b]	[b]	14.9	17.7	-15.6
Pre-1978 MY	13.3	15.8	-15.9	[b]	[b]	[b]	13.5	16.0	-16.0
Lt. Truck & Van	15.9	19.8	-19.5[c]	20.2	26.1	-22.4[c]	16.6	20.8	-20.1[c]
1983-1985 MY	17.3	21.1	-18.1[c]	20.5	26.7	-23.0[c]	17.8	22.1	-19.2[c]
1978-82 MY	14.8	18.6	-20.3[c]	19.7	25.4	-22.5	15.6	19.7	-20.7[c]
Pre-1978 MY	13.3	17.5	-24.3	20.9	24.7	-15.5	13.9	18.1	-23.2[c]
Compact	19.7	25.1	-21.4[c]	19.8	26.1	-23.9[c]	19.7	25.4	-22.1
1983-1985 MY	19.4	24.7	-21.6[c]	20.0	26.8	-25.7[c]	19.5	25.2	-22.5
1978-82 MY	20.7	26.2	-20.9[c]	19.7	25.4	-22.5	20.3	25.9	-21.5
Pre-1978 MY	21.1	25.7	-18.0	20.6	25.8	-20.3	20.8	25.8	-19.3
Standard	13.7	16.6	-17.8[c]	21.3	26.1	-18.3	14.3	17.3	-17.9[c]
1983-1985 MY	14.8	16.8	-12.0	21.3	26.4	-19.2	15.9	18.4	-13.7
1978-82 MY	13.1	16.4	-19.9[c]	[b]	[b]	[b]	13.1	16.4	-19.9
Pre-1978 MY	12.8	17.1	-24.8[c]	[b]	[b]	[b]	13.2	17.3	-23.9

[a]Ages correspond to: 0 to 3 yrs, 4 to 8 yrs, and over 8 yrs.
[b]N < 10.
[c]Prob ltl <0.01.

but not across vehicle types. As was shown in Figure 2, a 20.1 percent shortfall was observed for light trucks and vans, compared with 18.7 percent for automobiles in the RTECS sample. The difference in shortfall between automobiles and trucks was statistically significant (prob $|t| < 0.0001$; $N = 3{,}770$ automobiles, 579 trucks). Furthermore, shortfalls for both automobiles and light trucks were significantly greater than the EPA adjustment factor. When desegregated by size class, shortfalls were also significant for all but large automobiles.

Large automobiles account for a decreasing share of light-duty vehicles and the fuel consumed by them. Thus, their relatively smaller shortfall may be another factor behind the trend toward increasing fleet-average shortfalls.

Vehicle Age

For the most part, automobile and truck shortfalls did not rise with increasing age. Standard (i.e., full-sized) trucks were a key exception (Table 1), rising from 13.7 percent for vehicles under 3 years old to 24.8 percent for vehicles more than 8 years old. This suggests that differences in duty cycle and maintenance practices may account for at least some of the additional shortfall. Quite likely, a greater proportion of older trucks are in off-road operation (e.g., on farms, at construction sites, or in mining) or improperly maintained, either of which could significantly degrade fuel economy. Since the average age of the vehicle fleet has been rising and trucks are accounting for an increasing share of light-duty vehicles, the factors responsible for the relatively greater shortfall of older trucks may become increasingly relevant to predicting trends in the shortfalls of all light-duty vehicles.

Note that variations in shortfall by vehicle age were not significant when vehicles were also categorized by annual mileage. This is to be expected, since mileage or vehicle utilization is highly correlated with age (Figure 3).

Vehicle Origin

Another factor affecting shortfalls was vehicle origin. Domestic automobiles had an average shortfall of 19.8 percent, whereas imported automobiles had an average shortfall of 15.6 percent. For light trucks, the reverse was true: domestic trucks had a 19.5 percent average shortfall, whereas imported trucks had a 22.4 percent average shortfall. For all but im-

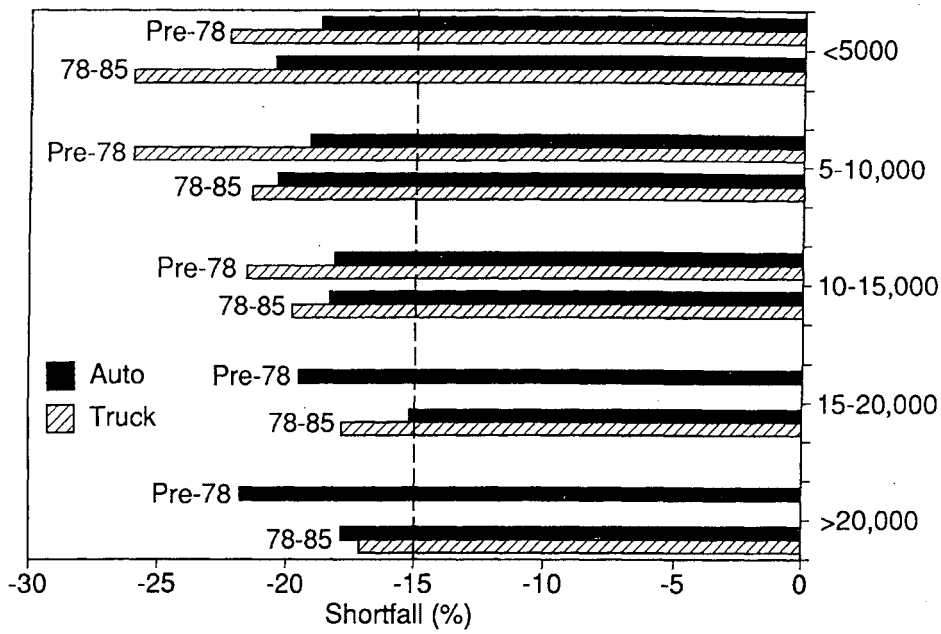

FIGURE 3 Fuel economy shortfall by vehicle type, vintage group, and annual mileage.

ported automobiles, shortfalls were statistically significant. For small domestic automobiles and standard trucks, shortfalls tended to decline with age. Imports exhibited no such pattern. Import shortfalls were also less likely to vary by annual mileage (Table 2).

Vehicle Nameplate

Results indicate that shortfalls exceed the EPA correction factor for all vehicle types, most sizes, both domestic and foreign makes, and for all except high levels of utilization. On an aggregate level, shortfalls are relatively stable. Are they equally stable on a desegregate level? To answer this question, the RTECS file was searched by nameplate. Sample size limitations precluded the investigation of model years within those nameplates (however, since all RTECS-matched vehicles were post-1976, the effect of model year should have been somewhat reduced). The largest discrete samples were obtained for Olds Cutlass (N = 230), Chevy Chevette (N = 122), Chevy Malibu (N = 101), and Buick Regal (N = 96). The resulting EPA-test, EPA-corrected (test × 0.85), and RTECS fuel economy values are shown in Figure 4. Again, shortfalls generally exceeded the EPA correction factor (Cutlass, prob $|t| < 0.0001$; Chevette, prob $|t| < 0.01$; Malibu, prob $|t| < 0.05$; Regal, prob $|t| < 0.1$).

IMPLICATIONS

In 1990, the total shortfall obtained from this analysis (i.e., 18.7 percent for automobiles and 20.1 percent for light trucks)

TABLE 2 EPA Test Versus On-the-Road Fuel Economy and Percentage Shortfall or Gap by Vehicle Origin and Annual Mileage

	Domestic Vehicles			Imported Vehicles			All Vehicles		
Size Class and Annual Mileage	RTECS (mpg)	EPA (mpg)	Gap (%)	RTECS (mpg)	EPA (mpg)	Gap (%)	RTECS (mpg)	EPA (mpg)	Gap (%)
Auto									
<5,000	18.1	23.2	-21.9[a]	24.9	30.2	-17.6	19.4	24.6	-20.9[a]
5,000-9,999	17.7	22.5	-21.2[a]	24.9	30.1	-17.2	19.2	24.0	-20.2[a]
10,000-14,999	18.7	23.3	-19.6[a]	26.1	31.0	-15.8	20.6	25.3	-18.5[a]
15,000-19,999	20.1	24.1	-16.6	28.8	32.4	-11.2	21.9	25.8	-15.2
20,000+	21.4	24.4	-12.5	29.4	33.1	-10.9	23.6	26.8	-12.0
Lt. Truck & Van									
<5,000	14.3	20.0	-28.7[a]	20.8	26.1	-20.3[a]	15.1	20.7	-27.4[a]
5,000-9,999	14.9	19.2	-22.4[a]	20.1	26.6	-24.6[a]	15.8	20.5	-22.9[a]
10,000-14,999	16.6	20.2	-18.1[a]	21.1	26.0	-19.1	17.4	21.3	-18.3[a]
15,000-19,999	17.7	20.4	-13.2	22.7	26.0	[b]	18.6	21.4	-13.1
20,000+	18.0	19.1	-5.8	15.1	25.0	[b]	17.6	19.8	-11.0

[a]Prob $|t| < 0.01$.
[b]N < 10.

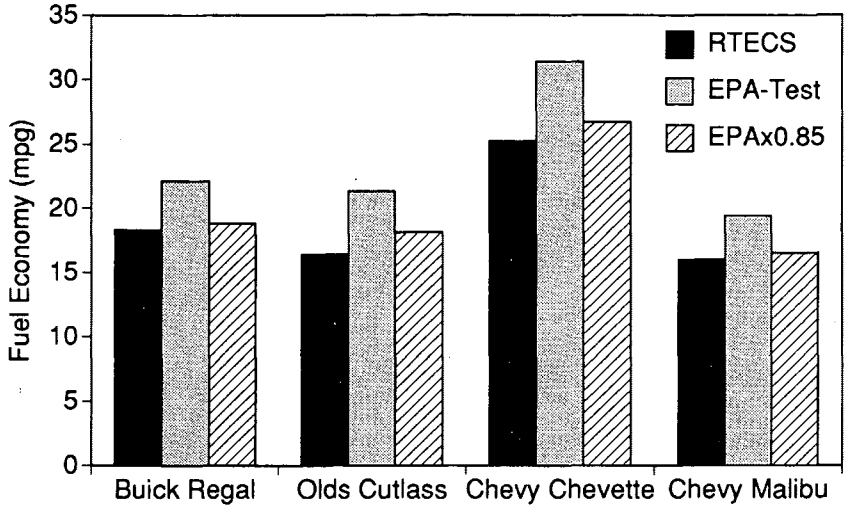

FIGURE 4 EPA-rated versus on-road fuel economy of four popular vehicle nameplates.

increased fuel consumption in the transportation sector by 2.3 quads, whereas that portion of the shortfall in excess of EPA's 15 percent estimate (i.e., 3.7 percent for automobiles and 5.1 percent for light trucks) increased consumption by 0.6 quads. Given the relationships discussed above, 55.5 percent of the current excess shortfall (0.3 quads) may be because of traffic congestion and speeding (either or both of which could be improved through more effective traffic control methods, transportation demand management strategies, congestion pricing, and speed enforcement programs). Even the remaining 44.5 percent of "excess" shortfall (0.3 quads) may be amenable to government intervention through improved control over land use, more effective transportation demand management (especially mode shift strategies), and more aggressive development policies (e.g., graduated taxes on new development to encourage densification and reduce urban sprawl). Because shortfalls are increasing over time, potential fuel savings could easily triple by 2010.

As discussed above, population and driving shifts, traffic congestion, and highway speeds are the primary factors behind increasing shortfalls. They are also key factors affecting vehicle emissions. Thus, it is quite likely that actual emission rates (as well as the degradation factors assumed in such models as MOBILE5) are larger than test values. The EPA is currently investigating this issue as part of its review of the FTP. Preliminary results from that effort indicate that the FTP simulates a more conservative cycle than is typical of most urban driving. In other words, vehicles in actual traffic tend to experience more extreme conditions (harder accelerations and decelerations and more time at idle and highway speed) than in the FTP, thereby increasing tail pipe emissions and fuel use (*15*).

CONCLUSIONS

This analysis compared EPA-test and on-the-road fuel economy for five vehicle-size classes for two types of vehicles and for four popular vehicle nameplates. Results indicate that (*a*) the shortfall or gap between the two measures of fuel economy is growing, (*b*) light trucks have a significantly larger shortfall than automobiles, (*c*) low-utilization vehicles experience much greater shortfalls than high-utilization vehicles, (*d*) domestic automobiles have a larger shortfall than imported automobiles, and (*e*) imported light trucks have a larger shortfall than domestic light trucks. For modeling and analytical purposes, EPA's 15 percent adjustment factor should be revised upward, and separate factors should be developed for automobiles and light trucks. For policy purposes, actions are less clear. However, programs to reduce shortfalls or to prevent their further growth present major conservation opportunities. Since the bulk of all shortfalls may be attributable to the driving cycle, the scope for reducing shortfalls may be limited to improving traffic flow, enforcing speed limits, increasing cold engine efficiency, and revising the FTP (see the preceding).

Beyond this, shortfalls provide a key policy perspective. At present levels, shortfalls effectively mask actual fuel use. This suggests that strategies like gas guzzler taxes are too coarse (as well as too temporally removed from fuel use) to provide the necessary incentive to conserve fuel. Since the true measure of fuel consumption is fuel purchased, these findings suggest that policies to reduce consumption are best levied at the pump.

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