E85 and Fuel Efficiency: An Empirical Analysis of 2007 EPA Test Data

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Abstract: It is well-known that ethanol has less energy per unit volume than gasoline. Differences in engine design and fuel characteristics affect the efficiency with which the chemical energy in gasoline and ethanol is converted into mechanical energy, so that the change in fuel economy may not be a linear function of energy content. This study analyzes the fuel economy tests performed by the US EPA on 2007 model year E85-compliant vehicles and finds that the average difference in fuel economy nearly mirrors the differential in energy content.

In recent years, a convergence of interests has increased attention to the role of biofuels in the global transportation infrastructure. Fears of global climate change have caused renewed interest in biofuels' abilities to reduce carbon emissions from currently existing vehicles. Energy security advocates favor solutions which reduce Western reliance on imports from politically unstable or hostile nations. Rural development advocates see the possibility of agriculturally-derived energy sources reinvigorating rural economies. These forces have resulted in policies which have incentivized the rapid expansion of US ethanol production since 2001. As the explicit and opportunity costs of these policies have grown, economists and policy-makers have begun to reassess the relevant legislative mechanisms currently in place.

One critical component of any economic analysis of ethanol as a biofuel is its reduced energy density in comparison to gasoline. According to Appendix B of Davis and Diegel, gasoline contains approximately 34.8 MJ/l (125,000 BTUs per US gallon) whereas ethanol contains 23.5 MJ/l (84,600

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BTUs/gal)—ethanol contains 32.5% less energy per unit volume.[2] Therefore, E85, a blend of 85% ethanol and 15% gasoline, has an energy content 71.95% that of gasoline. However, there are many different estimates of the actual difference in automotive fuel economy between E85 and gasoline. According to the National Ethanol Vehicle Coalition, using E85 instead of gasoline will result in a 5%-12% decrease in fuel economy. 'Conventional Wisdom' estimates a 25% penalty (Bedard, 2006). Bonnema, et al. (1999) find that going from E10 to E30 results in an average 8.83% decrease in miles per gallon. The American Coalition for Ethanol finds average fuel economy reductions for E10, E20, and E30 of 1.43%, 2.15%, and 5.08% compared to regular unleaded gasoline. The difference is potentially relevant to much ethanol research. For example, Vedenov and Wetzstein (2007) examine the optimal volumetric tax rate for ethanol fuel in the US based upon the model of Parry and Small. (2005) In these studies, a Pigouvian tax on fuels to internalize the effects of road congestion is one determinant of the second-best tax rate. In these models, congestion externalities are a function of fuel economy; the greater the differential between the distance travelled per gallon using gasoline and ethanol, the greater the differential in the optimal volumetric tax rate. Likewise, any analysis of the economics of the ethanol industry, such as Elobeid, et al. (2006), must assume that a fuel economy differential between gasoline and ethanol will lead to a differential in consumers' willingness to pay for the fuels.[3]

To this point, studies of the ethanol market have typically assumed that the differential in fuel economy is a linear function of the differential in energy content. However, energy content is not the only difference between gasoline and ethanol. Octane is a measure of a fuel's ignition characteristics. Fuels with high octane ratings are more difficult to ignite, and are therefore less prone to pre-ignite in engine combustion chambers. This allows engine designers to use higher levels of engine compression, whether natural compression or through forced induction, which more efficiently convert the chemical energy of the fuel into mechanical energy. This is exemplified in modern high-performance automobile engines, which invariably recommend premium (high octane) gasoline for optimal performance, but continue to operate, albeit with reduced performance, even with regular (standard octane) gasoline. Modern engines contain sensors which detect pre-ignition and alter the ignition characteristics to de-tune the engine, lowering the conversion efficiency. E85 has an octane rating of 101-105, compared to

[2] In fact actual energy content of gasoline and ethanol can and does vary. Depending on the precise blend of gasoline, energy content can vary by as much as 4%. The actual energy of ethanol is dependent on the denaturant used to make the ethanol unsuitable for human consumption. One typical method of denaturing ethanol is to add 5% gasoline, for example.

[3] Many consumers do not have the choice to consume 100% gasoline, as various regulators have mandated renewable fuels blends for environmental reasons. For example, in the US, all gasoline sold in the state of Minnesota is a 10% ethanol blend.

84-91 for gasoline, and this increases the potential for an internal combustion engine to operate more efficiently.

All passenger vehicles sold in the United States must undergo fuel economy certification by the United States Environmental Protection Agency (EPA) each model year. Flexible fuel vehicles (FFVs), vehicles capable of using E85, must undergo fuel economy testing for both gasoline and E85. The test results of these vehicles are the most comprehensive data available for the comparison of gasoline and E85 fuel efficiency. For the 2007 model year, 24 different models from 5 manufacturers were designated FFVs. Within these 24 models, there were 76 different drivetrain/body-style variants tested for gasoline and E85 fuel economy.

Table 1. Summary Statistics of 2007 EPA FFV Fuel Economy Tests

	City			Highway			Average		
	Gas	**E85**	**Ratio**	**Gas**	**E85**	**Ratio**	**Gas**	**E85**	**Ratio**
Mean	14.9	10.9	73.4%	19.8	14.6	73.4%	17.1	12.6	73.4%
Std. Dev.	1.87	1.83	0.025	2.96	2.28	0.024	2.3	1.83	0.021
Minimum	13.1	9.1	66.9%	16.7	12.4	67.6%	14.7	10.8	68.3%
Maximum	21.8	15.8	81.3%	31.2	23.4	81.5%	25.8	19.2	81.4%

Notes: 'City' and 'Highway' refer to the EPA fuel economy testing cycle specifications. Nominal values are EPA estimated miles travelled per gallon consumed. 'Ratio' is the ratio of E85 fuel economy to gasoline fuel economy. 'Average' is the average of 'City' and 'Highway' weighted 55% 'City' and 45% 'Highway'. N=76 total vehicles tested.

These data were used to analyze the fuel economy differences between gasoline and E85; table 1 presents these results. The mean fuel economy of E85 in city driving is 73.42% that of gasoline, with a range of 66.89% to 81.33%. In highway driving, the mean fuel economy is 73.4% that of gasoline, with a range of 67.61% to 81.53%. The EPA also produces a mean fuel economy by averaging city and highway fuel economy, with a 55% city/45% highway weighting. By this measure, the ratio of E85 to gasoline fuel economy was also 73.40%, with a range of 62.74% to 78.15%. Each of the means is statistically different from unity at ;α=.005 or better but they are not different from 71.95%, the energy content ratio of E85, at the 10% level—indicating that the use of the energy differential as the fuel efficiency differential is appropriate given the current crop of FFVs sold in the US. This result does assume that the fleet of FFVs is reasonably equally-distributed among the FFVs offered for sale, which may or may not be an accurate assumption, but given the dearth of alternative sources of data on the topic, seems reasonable.

While many question the accuracy of the EPA mileage estimates, the validity of the energy ratios depends only on the precision of the EPA test suite, not its accuracy. These mileage differentials are very similar to those found in more limited studies. Using State of Ohio Motor Pool 1996 Ford Taurus FFVs, Chandler, et al. (1998) found mileage for E85-fueled vehicles to be 25% lower than that of the same vehicles using gasoline. Bedard (2006) found reductions of 25-32% resulting from E85 use in a 2007 Chevrolet Tahoe. Roy (2005) found a 24.3% decrease in average fuel economy when using E85. Consumer Reports found a 27% decrease in average fuel economy for a 2007 Chevrolet Tahoe FFV.

Table 2: Regression of Efficiency Ratio on Vehicle Characteristics

	City Estimate	Highway Estimate
Intercept	0.4164***	0.6508
Car	0.0324***	0.0177
Compression Ratio	0.0346***	0.0054
Axle Ratio	0.0400***	0.0293**
n/v Ratio	-0.0055***	-0.0025
Regression R^2	0.3652	0.0866
Regression F Statistic	10.21***	1.68

Notes: Vehicle weight in tons. n/v ratio is the ratio of engine speed to vehicle speed at 50mph. N=76. *,**,*** indicates significance at the 10%, 5%, and 1% levels, respectively.

From the differences between the maximum and minimum fuel economy differentials in table 1, it is clear that the change in fuel economy resulting from E85 usage is not uniform among vehicles. To identify characteristics that may be systematically related to differences in the E85/gasoline fuel economy ratio, a regression of vehicle characteristics on city and highway economy change was performed. Four vehicle characteristics from the EPA dataset were included. CAR indicates whether the vehicle is considered a car (CAR=1) or truck. Trucks are typically heavier than cars, which may affect the mileage differential, and buyers of trucks may place a lower priority on fuel efficiency, decreasing the incentive for truck makers to maximize E85 efficiency. Compression ratio is the measure of the compression of the air/fuel mixture in the engine just before ignition. Higher compression ratios result in more efficient combustion, but high compression ratios can also lead to pre-ignition, where the fuel/air mixture spontaneously ignites, which can cause severe engine damage. Octane measures a fuel’s resistance to preignition, and the higher octane of E85 would be more suited to high compression engines. Axle ratio is the reduction in rotational speed from the transmission to the wheels. Higher axle ratios indicate more reduction. Axle ratios are typically thought to vary systematically with vehicle type, with large trucks having the numerically highest ratios, sacrificing fuel efficiency for torque. While CAR and axle ratio have a correlation of -0.42, they are separately identified in the regression. Finally, N/V ratio is the speed of the engine at 50mph, and is a measure of the vehicle’s gearing in its top gear.

The most striking result of table 2 is the disparity between the results of the city and highway fuel economy regressions. The each of the variables examined for effect on city fuel economy was found to be very highly significant, with the expected signs: cars with high compression-ratio engines and high overall gearing (resulting in lower engine speed for any given road speed) display the smallest differential in fuel economy between gasoline and E85. But only axle ratio was found to be significantly related to the differential in highway fuel economy, and the overall ability of these variables to explain differences among vehicles is very poor.

In formulating biofuels economic and policy analysis, an accurate estimation of the difference in fuel economy of E85 and gasoline fueled vehicles is critical. This study utilizes 2007 EPA fuel economy test data to arrive at the conclusion that in the currently offered flex fuel vehicle fleet, the average difference in fuel economy from using E85 and gasoline cannot be distinguished from the energy differences between the two fuels. These vehicles, however, exhibit a range of fuel efficiency differentials, however, so that although the average fuel economy differential cannot be statistically distinguished from the energy differential, certain vehicular characteristics are strongly associated with a smaller differential.

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