

Fuel Economy: From Niche to Status-Quo Manufacturing

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ABSTRACT

Whether society chooses energy security or climate change as its motivation, the level of United States motor gasoline consumption and its current growth rate must change drastically. Models for calculating light duty vehicle's fuel economy incorporate many vehicle-based parameters: 20 to 200 with some being proprietary and challenging for policy makers to acquire or use. This paper describes a MatLab-based simulation model, MINPAR, which uses the three critical vehicle-based parameters: mass, engine size, and transmission characteristic. It is used to model over one thousand 1986 and 2004 United States offered vehicles from the EPA Test Car list (cars and light trucks) and four hundred 2004 Japanese offered vehicles' fuel economy (FE). Offered vehicles consist of vehicle models and their different configurations. Status-quo vehicles are defined as offered vehicles modeled well with MINPAR by comparing modeled to measured fuel economies. Status-quo vehicles are modeled accurately and represent over 95% sales. Niche vehicles are defined using an easily understood and interpreted percent error methodology. Physically-defined niche vehicle configurations mirror economic realities of niche markets (5% of total final sales market). By separating the high FE versus extreme power niche vehicle designs, a pattern emerges between (1) US 1986 versus 2004 and (2) US 2004 versus Japan 2004. Through Japanese policy, five of the top ten vehicle sellers in Japan are high fuel economic Kei vehicles. Whether the United States can accomplish anything similar or whether the Reformed CAFE policies open the door to create a next generation loophole in terms of alternative fuel or plug-in hybrid/electric vehicles is discussed.

1. INTRODUCTION

The legal tensions surrounding automobile manufacturing and the regulation of fuel economy and vehicle-based greenhouse gas emissions can be summarized in terms of status-quo manufacturing versus niche manufacturing. The discrepancy between expert testimonies yields the basic policy flaw that complicates our understanding of fuel economy. Fuel economy is usually simple: mass of vehicle, energy source type/size (typically, IC engine displacement in liters), and power management design either for power capability or energy efficiency. This article discusses the decisions made in the 1970s using a physics-based model of fuel economy to differentiate status-quo versus niche vehicle designs. The goal is to discuss how to make the niche vehicle designs of today the status-quo vehicles of tomorrow.

1 A. CAFE – Building on History

Why do we need to understand both the status-quo and niche technology vehicle designs? This answer rests on two issues. First, our need to make today's niche high fuel economy vehicles the status-quo vehicles of tomorrow and second, the necessity to quickly and decisively increase today's status-quo vehicles with policies which promote decreasing mass and/or engine size or optimizations of fuel economy instead of power.

In the late 1970s, the oil crisis forced Congress to create the Corporate Average Fuel Economy (CAFE) regulation. Considering Figure 1, one could ask: did CAFE work?

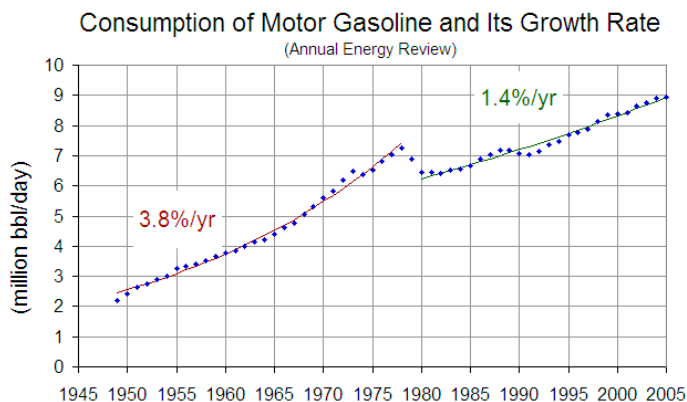


Figure 1. US motor gasoline consumption before and after oil crisis [14, 16].

Yes and no [4]. During the major 1973 oil embargo, oil consumption decreased because of extreme shortages. With CAFE implementation in 1978, motor gasoline consumption significantly decreased. Since 1980, CAFE has kept the motor gasoline consumption growth rate much lower than pre-CAFE even though prices fluctuated greatly.

This could only be accomplished through either a reduction in the number of vehicles, a reduction in the number of vehicle miles driven (VMT), or an increase in the number of miles per gallon (fuel economy: FE); unless society changed the energy source for vehicles – which it did not. The main mechanism chosen was increasing fuel economy (mi/gal) or decreasing fuel intensity (gal/100mi).

Immediately after 1978, the vehicle designs which quickly decreased fuel intensity (gal/100mi) included decreasing the mass and engine size of new cars (see Figure 2).

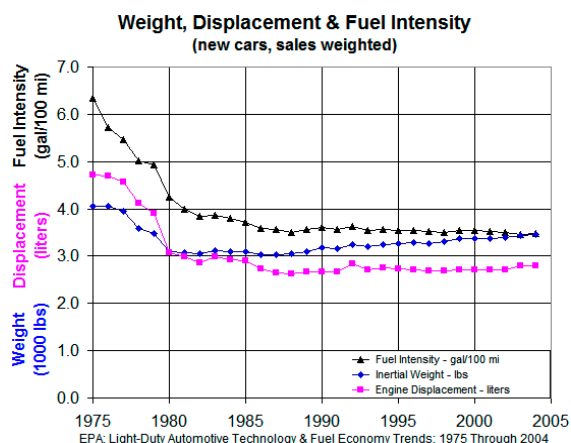


Figure 2. US manufacturing response to CAFÉ [12, 17].

However, from 1990 to 2004, *nothing* further was done to significantly decrease the fuel intensity of new cars. Furthermore, light trucks have become a larger percentage of light duty sales. This paper describes, investigates and presents the pathway to manufacturing status-quo (SQ) vehicles which increase fuel economy for light duty vehicles (cars and light trucks).

1B. Policy-Based Methodology

After 1980, essentially all heavy cars above 4000 pounds were dropped from production. In the 1990s and early 2000s, the light truck policy loophole allowed heavy vehicles back on the road as sports utility vehicles. Throughout the entire time, manufactures offered high FE vehicles, but these vehicles only stayed within niche markets and most were soon dropped from production.

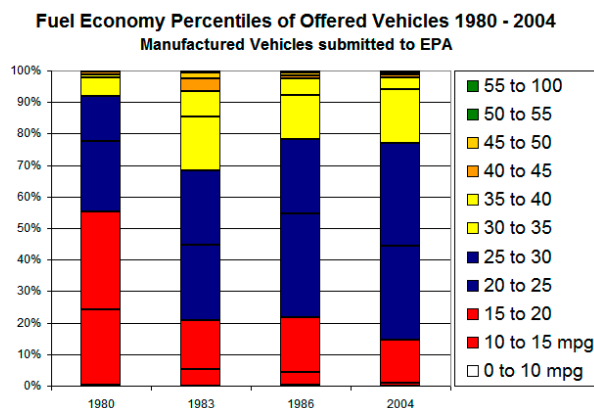


Figure 3. Percentage of all offered vehicles within various combined fuel economy ranges for three selected years from 1980 to 2004 [10, 11].

As can be seen in Figure 3, there has always been 30 to 60+ mpg vehicles offered in the United States markets, but these vehicles never became part of the status-quo market or more than 5% of total sales [12]. Understanding the pathways from niche to status-quo manufacturing designs requires defining a status-quo vehicle physically in a manner that mirrors economic reality (see Figure 4).

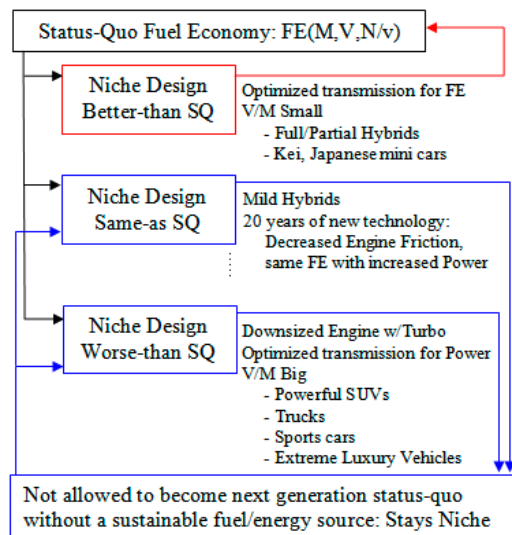


Figure 4. Three Pathways from Niche Vehicles to Status-Quo Vehicles.

The three physical variables used to calculate a vehicle's status-quo fuel economy are mass (M), engine size (V), and transmission engine-to-ground speed ratio in final gear (N/v) [1, 7, 8]. Sustainability, in terms of decreasing the motor gasoline consumed, requires (a) that the niche fuel efficient vehicles of today become the status-quo vehicles of tomorrow, (b) that the status-quo vehicles of today increase fuel efficiency by decreasing mass and/or engine size as well as choosing fuel economy over performance and/or (c) that an alternative fuel is utilized.

This paper uses a Mat-Lab based simulation model to define status-quo and niche vehicle designs for 2004 and 1986¹. These two years are then compared and contrasted in terms of differences of high and low fuel economy vehicle configurations. Finally, 433 Japanese vehicle designs are compared to 813 US vehicle designs in terms of weight, engine size, and engine size-to-weight characteristics. The goal is two-fold. The first goal is to highlight the automotive high fuel economy niche vehicle designs of today and discuss how to make them the status-quo of tomorrow. The second goal is to highlight how to design the status-quo vehicles for increased fuel economy.

2. MINPAR SIMULATION

As stated earlier, this MatLab-based minimum parameter model utilizes only three dominant variables for fuel economy of status-quo manufactured vehicles: M , V , and N/v in final gear [1, 7, 8].

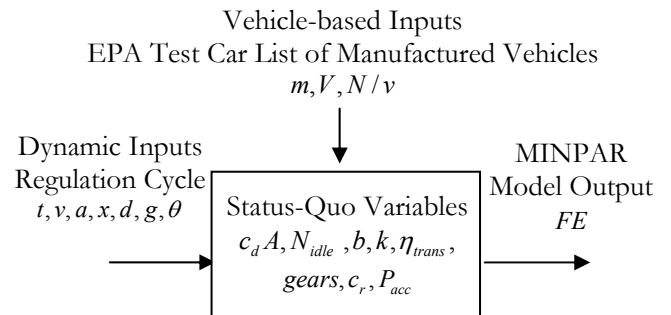


Figure 5. All 1986 and 2004 US vehicles were modeled using MINPAR with the two regulatory cycles, EPA Test Car List, and status-quo variables.

In Figure 5, there are three variable groups. The first variable group is vehicle-based inputs: M , V , and N/v in final gear [1]. The second group is dynamic inputs of the regulation cycle. The third group consists of status-quo variables for a specific year of offered vehicles. Each simulated fuel economy from MINPAR was compared to the measured fuel economy from EPA [7].

In a given year, the status-quo variables are easily estimated either based on (1) the fleet designs or (2) correlations of the vehicle's mass, engine displacement, or transmission ratio in final gear. Moreover, for a given year, the dominant vehicle-based variables are used to distinguish the status-quo from the niche vehicles. As has been said for twenty years, the manufacturing choice continues to be FE or power (e.g. 0 to 60 mph performance time versus miles/gallon) [3, 5].

2A. Status-quo Versus Niche in 2004 [10]

Using the MINPAR simulation model for 2004 vehicles, 92% of status-quo manufactured vehicles were modeled successfully while 8% were not². What is presented in this investigation is the absolute value of the percent error.

$$\%Error = \frac{MINPAR - EPA}{EPA}$$

This allows for easy graphing of results and immediate interpretation and critique of status-quo versus niche designs.

¹ Status-quo could be defined in terms of sales, but in this paper it is defined as the ability of each vehicle to be modeled physically. It turns out that these physically-based defined status-quo vehicles make up over 95% sales in United States. Other models are compared to MINPAR in the appendix.

² Repeats within EPA's test car list were deleted.

In Figure 6, the dotted lines yield the cutoff differentiating between status-quo and niche vehicles. Furthermore, the status-quo manufactured vehicles represent 95% of the final market sales. This accomplishes the desired goal to mirror the economic reality of niche markets.

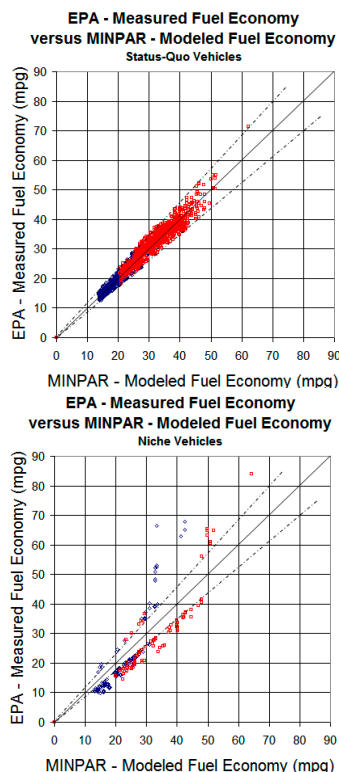


Figure 6. All 2004 US vehicles were modeled both for the urban (blue) and highway (red) driving cycle³.

In Figure 6, both plots together contain 813 different vehicle configurations for 1626 data points (one data point for city FE and one data point for highway FE). The left plot, status-quo results, contains 1491 data points. The right plot, niche results, consists of 135 data points. After reviewing the 2004 data, a set niche groups were identified and are discussed in Section 3.

Given the three vehicle parameters, some designs were better-than status-quo fuel economy (above the dotted line) while other designs were worse-than status-quo fuel economy (below the dotted line). This distinction opened the door to physically discuss the pathways niche technology offers. Even though technology is touted as a way to improve fuel economy, many niche designs are not offered to consumers for this purpose.

³ There were 1626 data points with 813 highway and 813 city fuel economies. There were 78 highway and 57 city outliers and only 37 vehicles with both.

2B. Status-quo Versus Niche in 1986 [11]

Using the same logic as in section 2A, but applied to 1986 vehicles, a different pattern of niche vehicles emerges (see Figure 7).

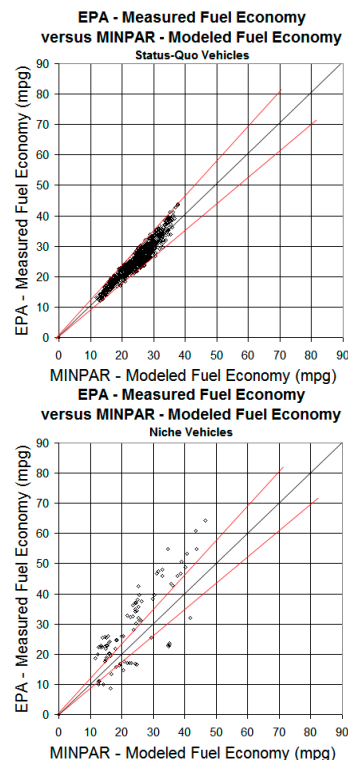


Figure 7. All 1986 US vehicles were modeled both for the combined driving cycle (55% city and 45% highway)⁴.

After reviewing the 1986 data, a set of niche groups were identified and are discussed in Section 3. Again there are niche vehicle designs which are better-than status-quo and worse-than status-quo fuel economy designs.

One result is that there are more vehicle configurations in the better-than status-quo high FE category in 1986 than in 2004. For example, the following vehicle models give a snapshot of the configurations for status-quo and the configurations for better-than status-quo FE.

⁴ There were 889 data points for the combined driving cycle. There were 86 outliers.

Vehicle Model	Year	Total Configurations	Configurations with High FE
Ford 150	1986	23	6
	2004	10	0
Toyota Camry	1986	5	2
	2004	5	0
VW – Jetta	1986	5	1
	2004	3	0

Table 1. Comparing 1986 versus 2004 vehicle configurations for status-quo FE versus configuration for better-than status-quo FE (high FE configurations)

In Table 1, the 1986 Ford 150 sent 23 vehicle configurations to EPA with 17 configurations in the status-quo FE regime and 6 configurations in the better-than status-quo high FE regime. Whereas in 2004, all ten configurations were in the status-quo FE regime and none were in the better-than status-quo regime. In the next section, this result is further discussed.

3. NICHE DESIGNS IN 1986 VERSUS 2004

Both in 1986 and in 2004, there were vehicles designed for niche markets. In 2004 and 1986, the author identified six distinctively designed niche vehicle groups. In 2004, the outliers of MINPAR make up only 5% of sales, i.e. mirroring the economic reality of niche markets.

Throughout the article, the niche vehicles' fuel economies are graphed to illustrate whether the niche design was better than a status-quo design (above red line), worse than a status-quo design (below red line), or status-quo designs (between the red lines).

3A. Niche Technology for FE in 1986 versus 2004

During the 1980s, the United States widely debated diesel technology. The same manufacturers produced and continued to sell diesels to the European markets, but not to the United States markets. Now the new technology is hybridization. This section compares and contrasts these two technologies in 1986 versus 2004.

In 1986, there were a variety of vehicle models which had configurations with a diesel engine option. As can be seen in Figure 8, in 2004, there were no diesel vehicles without turbo charging.

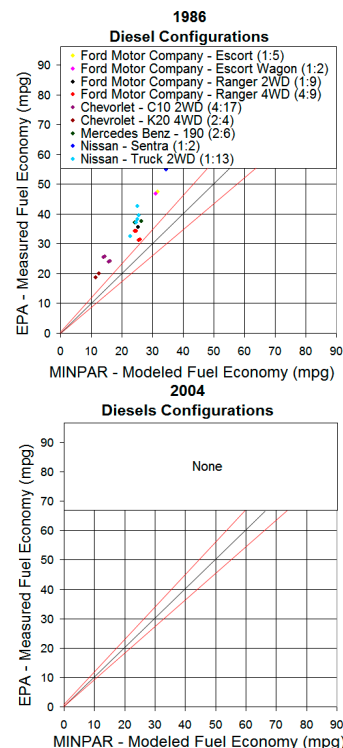


Figure 8. Comparing 1986 versus 2004 diesel vehicle configurations without turbocharging.

However, diesels with turbocharging change the picture.

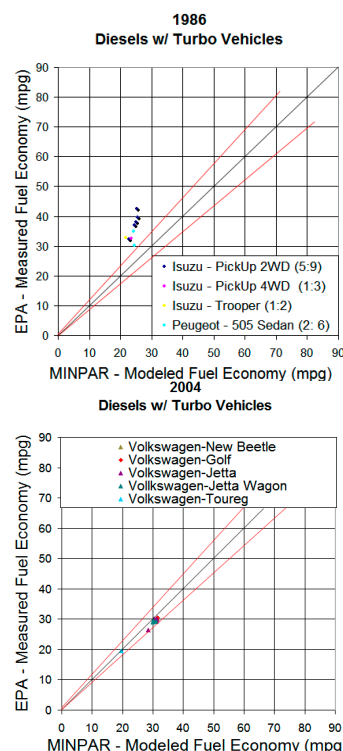


Figure 9. Comparing 1986 versus 2004 diesel vehicle configurations with turbocharging.