

**An Internal Fuel Efficiency Credit Market Mechanism
for Meeting the CAFE Standard : Internalizing a Regulation Caused Externality**

Charles R. Plott

Gabriel Katz

California Institute of Technology

December 2007

Abstract

This paper uses an experimental testbed methodology to analyze an internal market for Fuel Efficiency Credits (FEC) that might be used to enable a vehicle manufacturer to meet the CAFE standards most profitably while operating as a decentralized decision-maker. The CAFE standard creates an externality between otherwise decentralized organizations within the company. The main issue addressed is whether a special market architecture in which decisions are made by decentralized divisions subject to a system-wide CAFE standard regulation is profit-maximizing from an integrated company point of view given the CAFÉ constraint. Our results indicate that high aggregate efficiency levels are attained through this market institution, and that the manufacturer's performance, as measured by vehicle production, profits and fuel-efficiency, is substantially enhanced over a benchmark process of scaling back to the CAFÉ standard from unconstrained output. The decentralized decision-making process is consistent with the CAFE standard regulation. The theoretical framework and the experimental methods used in the paper can be modified and adapted to account for additional complexities, such as allowing for fuel efficiency credit trading between firms.

1. Introduction

The Corporate Average Fuel Efficiency standard (CAFE) for passenger cars and light duty trucks was enacted by Congress in 1975 with the aim of improving vehicle fuel efficiency in a period of high oil prices. In short, the CAFE regulation requires each car manufacturer to meet a standard for the sales-weighted fuel economy for the entire fleet of vehicles sold in the USA in each model year; fuel economy, measured in miles per gallon (mpg), is defined as the average mileage traveled by a vehicle per gallon of gasoline or equivalent amount of other fuel.¹ While the original goal of the program was for every seller of automobiles in the US to achieve a minimum sales-weighted average fuel efficiency of 27.5 Miles per Gallon by 1985, a bill increasing the standard to 35 MPG by 2020 recently passed.

Although previous research has analyzed the environmental effects of the CAFE regulation and its aggregate impact on vehicle production and fuel prices (Mayo and Mathis, 1988; Greene, 1990; Goldberg, 1998), few studies have examined its implications from the perspective of a profit-maximizing vehicle manufacturer. The focus of this paper is to analyze methods that might be used to enable a vehicle manufacturer to meet the CAFE standards most profitably while operating as a decentralized decision-making entity. The manufacturing firm is assumed to be a decentralized organization with independent divisions motivated by maximizing division profits and subject to a system-wide CAFE standard regulation. The divisions control the number of vehicles produced, and the efficiency characteristics of those vehicles, which, in turn determine vehicle cost and market

¹ A detailed discussion of the CAFE standard regulation exceeds the purposes of this paper. An excellent overview can be found in Crandall (1985, 1990).

demand. For the purposes of the exercise studied here, both vehicle cost and market demand are known for given vehicle characteristics and production levels.

Several relevant questions regarding the operation of such a decentralized decision-making process consistent with the CAFE standard regulation arise. Do the decisions of decentralized profit centers lead to profit-maximizing outcomes from an integrated company point of view? What are the effects of this market institution on the firm's total production and its composition? What are the effects of the CAFE standard in terms of the manufacturer's overall fuel efficiency?

In order to address these questions, we use an experimental strategy to analyze the functioning of an internal market for Fuel Efficiency Credits (FEC) in which organized trading and FCE pricing between the different divisions of the manufacturing firm occurs. Divisions producing fuel efficient vehicles produce FEC as a joint product with vehicle production; the FEC produced can be sold at the prices that emerge from the internal FEC market, and revenues from FEC sales contribute to the FEC producing division profits. In contrast, divisions producing fuel inefficient vehicles must acquire FEC with each vehicle produced; the FEC are purchased from those divisions that produce FEC, and the prices paid are determined by the internal competitive market. The cost of FEC is a cost of production to the division that must purchase them and thus reduces division profits. The objective is to create a process that leads independent divisions within the vehicle-manufacturer to the same profit maximizing position for the firm as a collective, as would be the case if an "all knowing" centralized decision-maker made all decisions for all divisions.

The remainder of the paper is organized as follows. Section 2 briefly reviews the theory underlying the operation of an internal Fuel Efficiency Credit (FEC) market mechanism for meeting the CAFE standard. Section 3 presents the experimental procedures and design implemented to examine the performance of this market institution and its implications in terms of the

manufacturing firm's production, profits and total fuel economy. Section 4 discusses the main empirical results of the experiments from two perspectives. The first is a type of proof of principle. Does the system do what it is supposed to do? The second is a check on the internal consistency of the design. Does it do it consistently with the principles at the foundations of the design? Section 5 concludes.

2. The Mechanism Architecture

We analyze a market exchange process in which “fuel economy” permits (FEC) are traded between different divisions of a vehicle-manufacturing firm in an open market at a price P . Let $M_{i,r}$ be the number of FEC held by division i , $i=1,\dots,n$, which produces vehicle type r , $r=1,\dots,R$, with a miles per gallon performance (mpg) equal to α_r . The CAFE standard regulation requires that the average miles per gallon (mpg) value of the cars sold by the manufacturer must not be above a certain value K . In the context of the mechanism (the market exchange process) under analysis, assume that, as a form of internal regulation, for all divisions i , types of vehicle r , and production $q_{i,r}$, it must be the case that:

$$M_{i,r} \geq (K - \alpha_r) q_{i,r} \quad (1).$$

Thus:

- if $\alpha_r > K$, division i can create and sell permits in the internal FEC market up to the magnitude for which (1) is satisfied – where the constraint allows negative holding-;
- if $\alpha_r < K$, division i must buy FEC to produce vehicles.

Note that, given the constraint that the net supply of permits among the manufacturer's divisions must be zero we have the equation:

$$\sum_i \sum_r M_{i,r} = 0 . \quad (2),$$

Substituting in (1) and assuming equality yields:

$$\begin{aligned} \sum_i \sum_r (K - \alpha_r) q_{i,r} &= 0 \\ K \sum_i \sum_r q_{i,r} - \sum_i \sum_r \alpha_r q_{i,r} &= 0 \end{aligned}$$

which satisfies the CAFE regulation standard that

$$K \geq \frac{\sum_i \sum_r \alpha_r q_{i,r}}{\sum_i \sum_r q_{i,r}} \quad (3).$$

Thus, we see that constraints enforced by the mechanism guarantee that the CAFÉ regulation must be satisfied as a technical guarantee. Notice that this is done in the absence of an overall, centralized accounting and balancing of production levels.

3. Mechanism Theoretical Behavior

The analysis is contained in two sections. First the equilibrium behavior is analyzed for the case in which the fuel efficiency levels of all types of vehicles is fixed. Thus, the problem with which the system is confronted is to determine the optimal level of production for each vehicle. The second section analyzes the case in which each division produces only one type of vehicle but the fuel efficiency level of that vehicle can be adjusted within the technical and cost parameters.

3.1 Fixed Fuel Efficiency Levels

Our attention now turns to models of behavior. In this setting, and assuming that all divisions have an initial endowment of 0 FEC, division i 's profit maximization problem is then given by:

$$\max_{q_{i,r}} V_{i,r}(q_{i,r}) - P M_{i,r} \quad (4),$$

where $V_{i,r}$ is the profitability of vehicle of type r produced by division i , and P , $M_{i,r}$ and $q_{i,r}$ were defined above. Under competitive conditions, profit maximization takes place when

$$\frac{\partial V_{i,r}}{\partial q_{i,r}} - P(K - \alpha_r) = 0 \quad (5)$$

which implies

$$\frac{\frac{\partial V_{i,r}}{\partial q_{i,r}}}{(K - \alpha_r)} = P \quad (6).$$

The behavioral equations 5 and 6, together with the system balancing equation (1) and (2) define an equilibrium for the firm. It follows from (6) that the value of the marginal output is negative at the optimum for those vehicle producers with mpg over K . This means that they are producing vehicles beyond what would be profitable under no CAFE constraint. The incentive to do so is created by the profits due to FEC sales to other divisions.

The equilibrium of the system is the profit maximizing optimum of the firm subject to the CAFÉ constraint given the fuel efficiencies of the individual vehicles produced. If the technology is fixed in the sense that the efficiency levels of the vehicles produced by the different divisions are fixed then the levels of production will be coordinated to achieve a system profit maximum. That is, for a fixed efficiency levels of individual vehicles the equilibrium of the decentralized market exchange

process determined by (5)-(6) satisfies the optimal conditions of the solution to the vehicle-manufacturer's centralized profit maximization problem:

$$\begin{aligned} & \max \sum_i \sum_r V_{i,r}(q_{i,r}) \\ & \text{subject to:} \\ & \lambda_r : Q_r - \sum_i q_{i,r}, \\ & \lambda_g : \sum_r \alpha_r Q_r - K \sum_r Q_r, \end{aligned}$$

where Q_r is the total production of vehicles of type r by all divisions. The Lagrange multipliers λ_r , $r = 1, \dots, R$, are the marginal value of producing an additional car of type r . The multiplier λ_g , on the other hand, is a measure of the implicit marginal system benefit of increasing the CAFE regulation standard K ; actually, it is the marginal system benefit of increasing z , where $z = \sum_r \alpha_r Q_r - K \sum_r Q_r$.

The Lagrangian problem – assuming K and z constant - is thus:

$$\max_{\substack{q_{i,r}, i=1,\dots,n; r=1,\dots,R \\ Q_r, \lambda_r, r=1,\dots,R \\ \lambda_g}} H = \sum_i \sum_r V_{i,r}(q_{i,r}) + \sum_r \lambda_r \left(Q_r - \sum_i q_{i,r} \right) + \lambda_g \left(\sum_r \alpha_r Q_r - K \sum_r Q_r - z \right) \quad (7)$$

with first order conditions – assuming that the constraints are satisfied – given by:

$$\frac{\partial V_{i,r}}{\partial q_{i,r}} = \lambda_r \quad (8)$$

$$\lambda_r + \lambda_g (\alpha_r - K) = 0 \quad (9)$$

so that

$$\lambda_g = \frac{\frac{\partial V_{i,r}}{\partial q_{i,r}}}{(K - \alpha_r)} \quad (10).$$

It follows from (5)-(6) and (8)-(10) that the equilibrium of the decentralized market exchange process satisfies the conditions of the centralized (mathematical) optimum; in addition, the CAFE regulation standard is also satisfied, with the marginal cost of the CAFE constraint properly identified in $P = \lambda_g$.

3.2 Variable Fuel Efficiency Levels

The model has even more powerful predictions that include the case in which divisions can change the efficiency levels of their vehicles in response to market incentives. That is, if the different division can change mpg of the vehicles they produce, an additional equation becomes important to describe their behavior: the mpg parameter becomes part of the valuation function for vehicles of type r , since it influences both demand and cost. Hence, an additional equation is added to the First-Order Optimization Condition for vehicle producers:

$$\frac{\partial V_{i,r}}{\partial \alpha_r} = P \frac{\partial M_{i,r}}{\partial \alpha_r} \quad (11).$$

Equation (11) implies that the value of the marginal change of mpg is balanced against the change of revenue from FEC sales or change of cost of FEC purchases that will result from the technological change. Therefore, if division i sees a profit that would result from a mpg change, it will make the change as guided by the price of FEC.

Thus the behavioral model of decentralized division choices become profit maximizing for the firm operating under CAFÉ constraints. Theoretically this takes place without centralized decision making other than the creation and enforcement of the rules of the process. The technologies and market conditions faced by the individual divisions need not be known by the centralized

administration of the firm. Yet, each division acting in its own interest leads to the optimum fuel efficiency of individual vehicles and the optimum production of each from the centralized firm point of view.

4. Experimental Procedures and Design

We use an experimental methodology to explore the mechanism described in Section 2. We will ask two different types of questions. (1) Does the mechanism perform as desired? That is, is it the case that the aggregate, profit producing predictions hold? (2) Does the mechanism behave according the principles used to design it? That is, does the mechanism do what it does for understandable reasons? Basically, the strategy to test whether individuals' system behavior and individual behavior are consistent with the implications of the theoretical model presented in Section 2 and to assess the impact of the market exchange process on the firm's aggregate production, profits, and fuel economy. In the next subsections, we describe the procedures and the experimental design implemented in our empirical analysis.

4.1 Experimental Procedures

The subjects in the experiments were students recruited from Caltech by a general request for people to put themselves in a database if they were interested in participating in experiments. The day before the experiment, invitations were sent via e-mail recruiting subjects from that database. A total of 73 students participated in 8 experimental sessions, with 10 participants per session (some students participated in more than one session). Several of the students had prior experience with economics experiments in general, and few subjects also had prior experience with market experiments in particular.

Experiments were computer-based, conducted in Caltech's EEPS Lab; a screenshot of the software used in the experiment and the computer guide provided to the subjects is presented in Appendix I.² Upon entering the lab, participants were randomly assigned a seat in front of a computer, an identification number corresponding to a particular manufacturing division, and were given a set of instructions. The instructions described the general setting of the market environment, the tasks to be performed by the subject and the payment schemes, and included examples of how to perform the computations required to make the relevant decisions. In addition, each participant was given a series of tables with redemption values obtained from the production of the different types of vehicle available to him; information regarding the different mpg values was private. A sample of the instructions is presented in Appendix II.

Each experimental session consisted of four fifteen-minute periods, preceded by a fifteen minute practice period for which subjects did not receive payment. During each period, asks and bids for FEC were recorded in an open book, and transactions were conducted in an open market, with information on prices and quantities traded publicly observed. At the end of each period, subjects were given 5 minutes to record their earnings and the trades they had made in the FEC market. At the end of the session they were asked to compute their total earnings and submit the final amount to the experimenters; the calculations were verified by the experimenters, based on the computer logs. Subjects were paid in class credits, and they earned between \$10 and \$60 for a two-hour experiment, depending on their performance, with most subjects earning close to an average of \$40.

4.2 Experimental Design

Two different experimental designs were implemented:

² The software used is an adaptation of Caltech's Marketscape program. It is capable of supporting multiple markets and multiple production technologies.

A) Fixed MPG: each subject was assigned a predetermined mpg value and was not allowed to change it during the experiment. Subjects had to decide their optimal production level given their mpg constraints, taking into account profits from the sales of vehicles and sales/purchases of FEC in the FEC market.

B) Variable MPG: each subject was provided four possible levels of mpg. The choice of mpg influenced vehicle sale profitability. In the first period of the experiment, subjects were assigned a predetermined mpg value as in design A and had to choose only the production level. In the second and later periods, subjects had to choose both the efficiency level of the vehicle – defined by the mpg value - and the production level.

Three experiments of design A and five experiments of design B were conducted. In both experimental designs, the CAFE mpg requirement – the value of K , in Section 2 - was set to 20. In experiments in which design A was implemented, 4 subjects were assigned mpg values higher than 20 – i.e., they produced fuel-efficient vehicles and were thus sellers of FCE -, 5 subjects were assigned mpg values lower than 20 – they produced fuel-inefficient vehicles and were buyers of FCE -, and one agent was assigned mpg of 20. In experiments in which design B was implemented, 5 subjects were sellers of mpg and 5 subjects were buyers of FCE in equilibrium. Subjects' profits are determined as follows:

FEC buyers:

Profit = Value received from vehicles produced - cost of FEC for the production of vehicles

FEC sellers:

$\text{Profit} = \text{Value received from vehicles produced} + \text{revenue received from the sale of FEC}$

where, as mentioned in the introduction, both vehicle cost and market demand are known for given vehicle characteristics and production levels.

Subjects' values were generated according to the following formula, which is the the experimental equivalent of a net profit function before any internal tax or transfer price for a vehicle:

$$\text{Total Value} = 100s \times Q_s - \frac{5s}{2} Q_s^2 \quad (12)$$

$$\text{Marginal (unit Value)} = 100s - 5s \times Q_s$$

where: s can be interpreted as the size or the weight of a vehicle type r and Q_s is the number of unites produced of vehicle of size s . Let $Y_s = (\alpha_s - K)$ denote the mpg value of a vehicle of size s in excess of the CAFE mpg requirement, where, as mentioned above, we set $K = 20 = \frac{40}{s}$, so that

$\alpha_s = \frac{40}{s} + Y_s$. Then, denoting by z the Lagrangian multiplier, we have:

$$\sum_s \left[s \left(100 - \frac{5}{2} Q_s \right) Q_s - s^{1/4} \times 3.125 \times Y_s^2 \right] + z \sum_s \left(\frac{40}{s} + Y_s \right) Q_s - 20 \sum_s Q_s \quad (13)$$

with F.O.C

$$s (100 - 5 Q_s) - [s^{1/4} \times 3.125 \times Y_s^2] + z \left(\frac{40}{s} + Y_s - 20 \right) = 0 \quad (14)$$

and
$$-[s^{1/4} \times 3.125 \times 2 Y_s] Q_s + z Q_s = 0 \quad (15).$$

From equation (14), the equilibrium FEC price is z times the difference between the mpg of a vehicle of size s and 20; from equation (15), $z = [s^{1/4} \times 3.125 \times 2 Y_s]$, which is additional cost per vehicle due to a marginal increase in fuel economy.

The parameters of both experimental designs are summarized in Tables 1 and 2; the set of redemption values for each of the mpg values available for experimental subjects is presented in Appendix III.

Table 1 - Parameters of Experimental Design A

Subject ID	MPG	Equilibrium production of vehicles	FEC bought (sold) in equilibrium
1	26.7	43	(287)
2	2.7	13	242
3	4.6	10	167
4	22.9	28	81
5	4.4	11	171
6	4.1	12	183
7	26.7	43	(287)
8	4.2	11	179
9	26.7	43	(287)

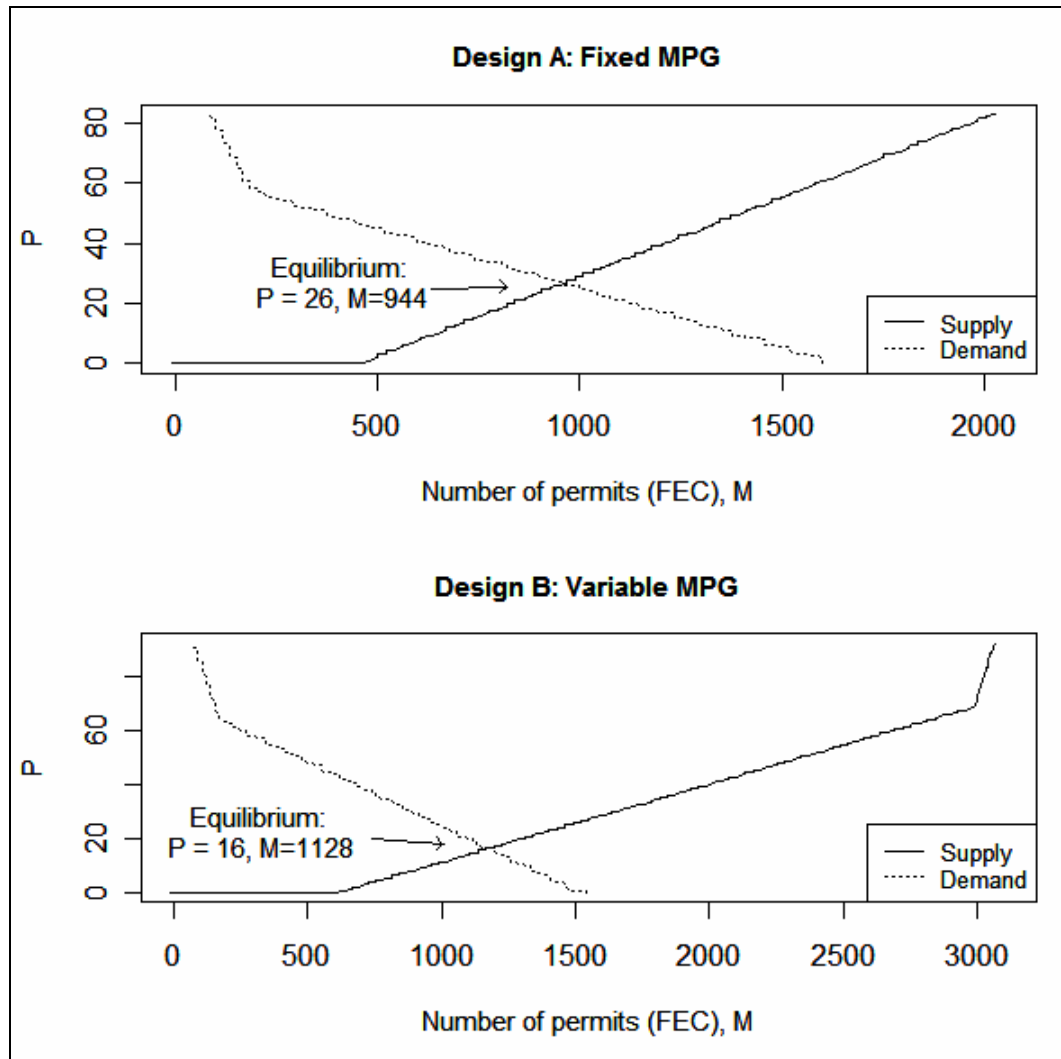
10	20.0	20	0
----	------	----	---

Table 2 - Parameters of Experimental Design B

Subject ID	Original MPG	Alternative MPG choices			Equilibrium MPG	Equilibrium production of vehicles	FEC bought (sold) in equilibrium
1	26.7	27.9	28.9	29.9	28.9	36	(317)
2	2.7	2.9	3.9	4.9	3.9	17	267
3	4.6	5.0	6.0	7.0	6.0	15	208
4	22.9	24.0	25.0	26.9	25.0	27	(133)
5	4.4	4.9	5.9	6.9	5.9	15	211
6	4.1	4.5	5.5	6.5	5.5	15	222
7	26.7	27.9	28.9	29.9	28.9	36	(317)
8	4.2	4.6	5.6	6.6	5.6	15	218
9	26.7	27.9	28.9	29.9	28.9	36	(317)
10	20.0	21.1	22.1	23.1	22.1	22	(44)

Figure 1 below presents the equilibrium in FEC market resulting from the demand and supply of FEC induced by the parameters in the two experimental designs.³

Figure 1: Equilibrium in the FEC market for the two experimental designs



Given the parameters and the resulting equilibria for each experimental design, Table 3 compares the system-wide production, profit and fuel-efficiency levels under three alternative

³ In the case of Design B, Figure 1 illustrates the equilibrium in the FEC market for periods 2 – 4, in which subjects choose both the fuel-efficiency and the production levels of the vehicles; the equilibrium for period 1 is the same as under Design A.

baseline scenarios : a) The centralized (mathematical) optimum subject to CAFE constraint; b) the equilibrium that would exist if no CAFE regulations exist; c) a natural administrative response to CAFE: leaving untouched the production of vehicles that have mpg above CAFE and proportionally scaling back the production of all vehicles with mpg less than CAFE until the overall CAFE standard is met. For both experimental designs, the aggregate production and fuel-efficiency levels under the mathematical optimum subject to the CAFE constraint are higher than in the scenario with no CAFE constraint, and it the centralized solution also leads to higher production and profit levels than the administrative response.

Table 3 – Comparison of production, profit and fuel-efficiency levels:

Alternative baseline scenarios

	Centralized optimum	No CAFE regulation	Administrative response (proportional rescaling)
Design A – Fixed mpg			
Production (number of vehicles)	234	200	128
Profits (experiment money)	42,473	60,250	33,483
Fuel-efficiency (mpg)	20.11	14.29	20.07
Design B – Variable mpg			
Production	233	200	142

(number of vehicles)			
Profits (experiment money)	48,992	60,250	40,612
Fuel-efficiency (mpg)	20.03	14.29	21.71

5. Empirical results

The results are divided into three parts. The first part overviews our main findings about prices and quantities traded in the FEC market. The second part reports the subject's vehicle-production and the system efficiency levels attained under both experimental designs. Finally, the third part presents the aggregate results regarding the firm's production, profits from vehicles produced and average fuel-efficiency and compares them to the results obtained under the alternative baseline scenarios described in Table 3.

5.1 Prices and quantities traded in the FEC market

Figures 2 and 3 plot the time-series of the trade prices in the FEC market for all experiments under Designs A and B, respectively. As is clear from the figures, trade prices exhibit considerable variability, particularly under the variable mpg design (Design B). Note, however, that prices tend to converge to the equilibrium level as time goes on. This pattern is evident in Figure 2: under the fixed mpg design, the initial trades take place at relatively high prices, but convergence towards the equilibrium is observed at the end of virtually every period. In the case of the variable mpg design, the "learning" process takes considerably more time due to the complexities induced by the

different mpg choices available for each subject and the fact that subjects shift from an initial period in which the mpg values are given (Period 1) to choosing both the fuel-efficiency and the production levels of the vehicles they produce. Nonetheless, despite the difficulties involved in Design B, Figure 3 indicates that trade prices also tend to converge to the equilibrium levels as subjects' performance improves with experience; averaged over the entire experiment, trade prices tend to be relatively close to the equilibrium price, and in fact the average of Period-4 trade prices for all experiments under Design B 17.85, quite near to the equilibrium level of 16 represented in Figure 1.

Figure 2 – Trade prices in the FEC market

Design A: Fixed mpg

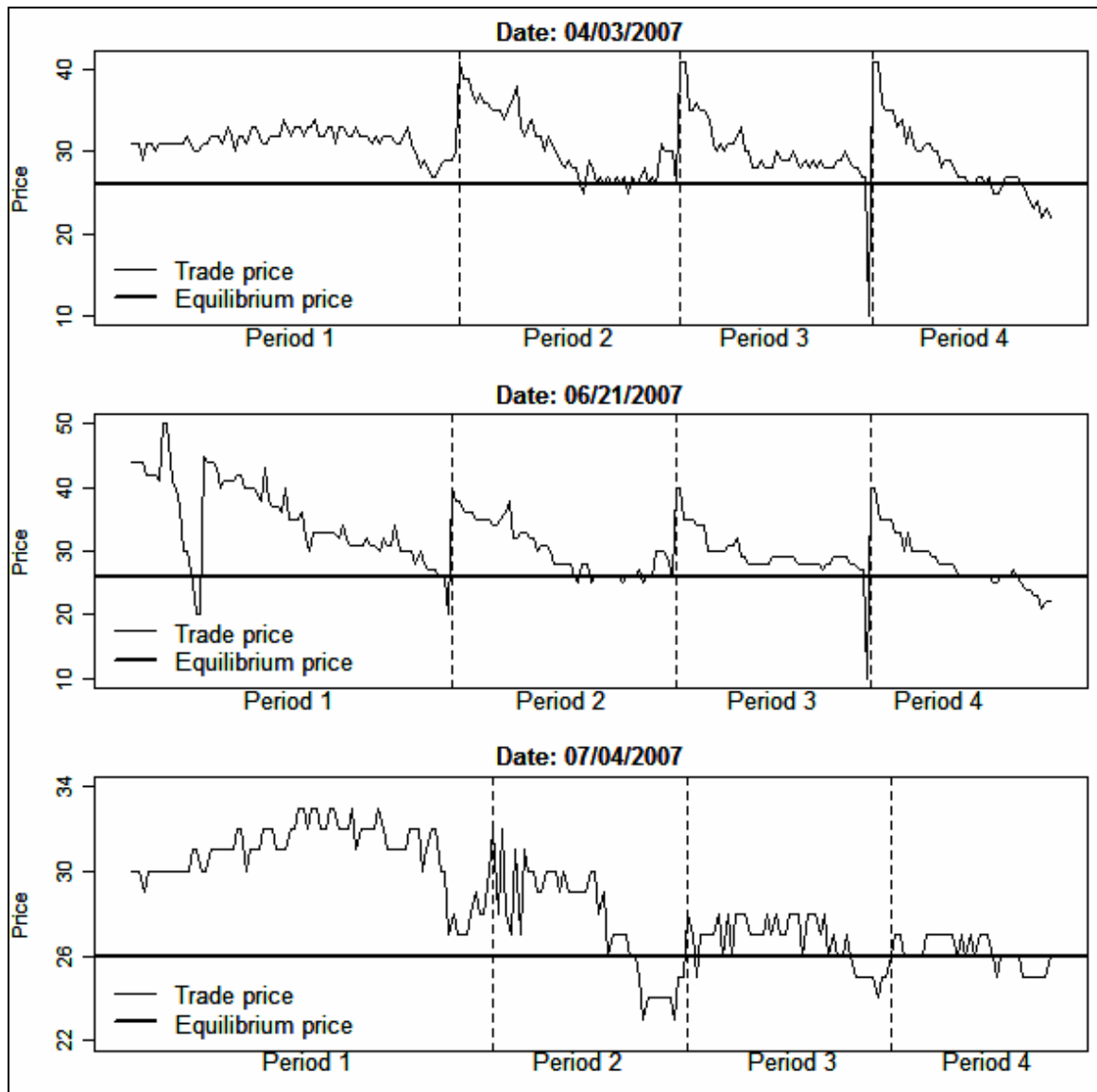
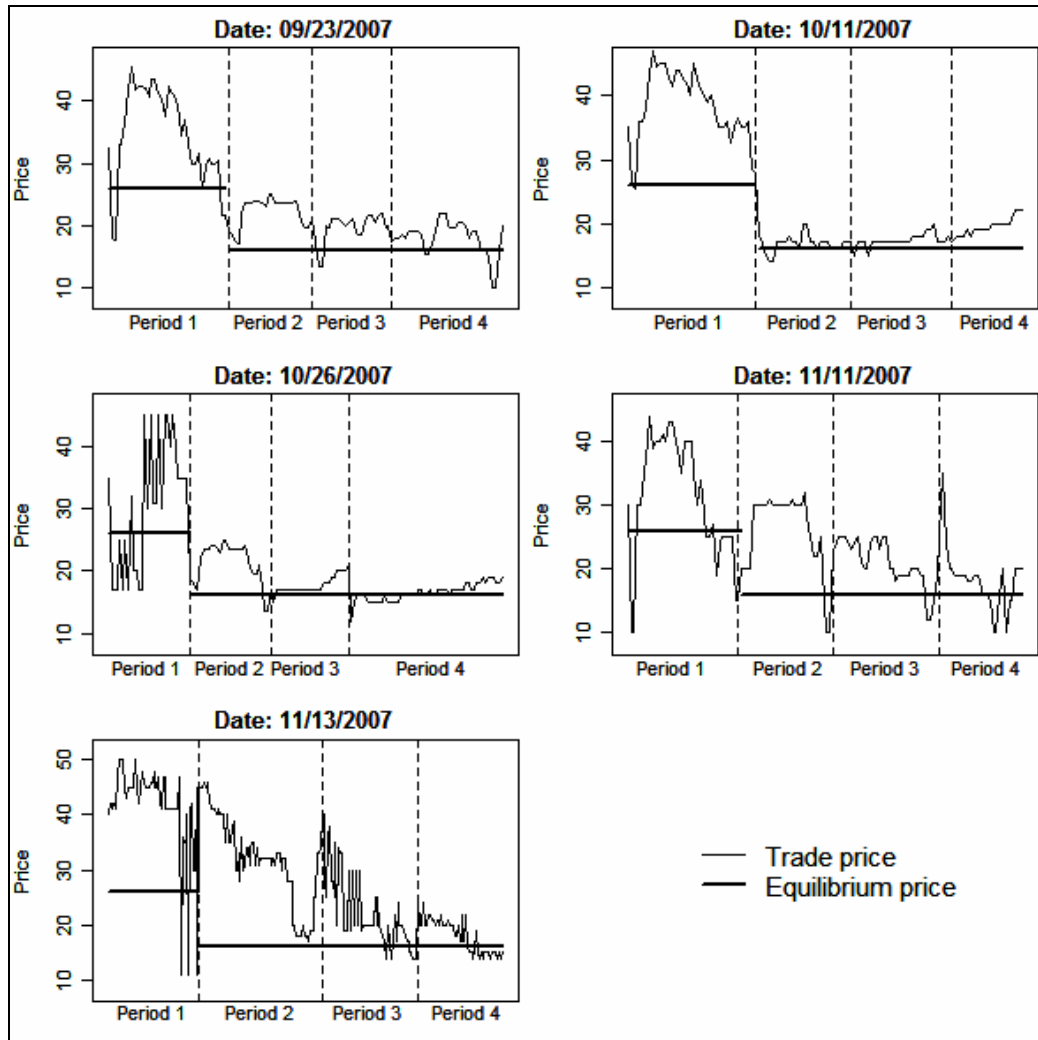


Figure 3 – Trade prices in the FEC market

Design B: Variable mpg



It is interesting to note that convergence towards the equilibrium-level price under the variable mpg design tends to occur despite the fact that subjects do not necessarily choose the optimal mpg value for the vehicles they produce. Figure 4 plots the choice of mpg values for each subject under Design B, discriminated by period. As seen in the Figure, there is wide variation in the pattern and timing of choices among divisions and experiments. For some divisions and experiments, mpg choices “overshoot” and then pullback, indicating that the market is guiding the divisions through disequilibria towards the optimum; in some other cases, subjects fail to choose the fuel-efficiency level of their vehicles in accordance with the theoretical predictions.

Figure 4 – Choice of mpg value, Design B

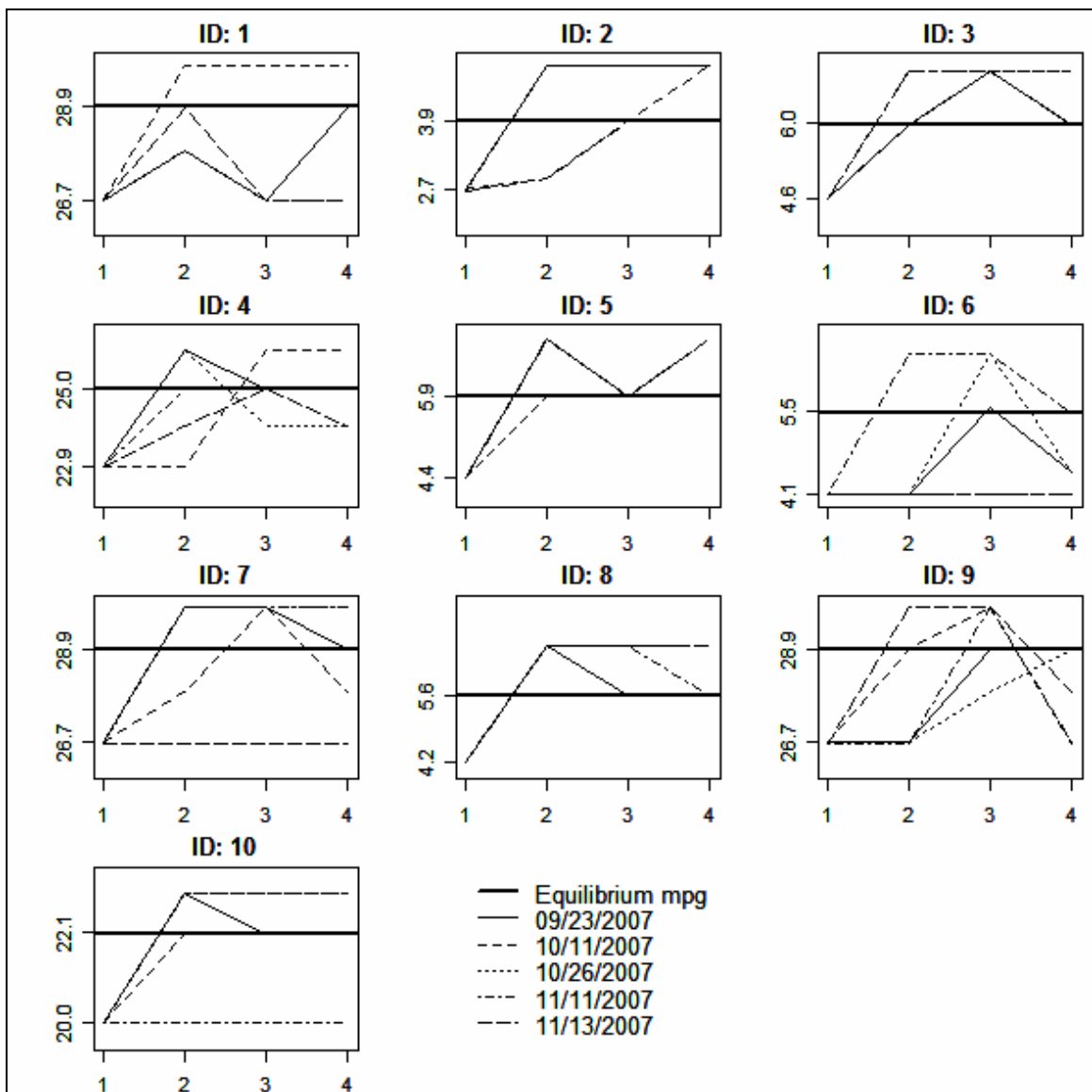


Table 4 presents the average FEC traded in each round of every experiment under Designs A and B, as percentage of the equilibrium quantities reported in Figure 1. In virtually all of the experiments, the average volume of FEC actually traded in the market is around or above 90% of the equilibrium volume, though, again, variability is much higher under Design B. In the fixed mpg

design, quantities traded as a percentage of the equilibrium volume tend to increase rapidly during the first rounds of the experiments. The pattern of trades is less clear in the variable mpg design: in some experiments (e.g., 09/23/2007 and 11/13/2007) trading is very high during the first period and tends to stabilize as time goes on, while in others (e.g., 11/11/2007) trades show substantial fluctuations over periods.

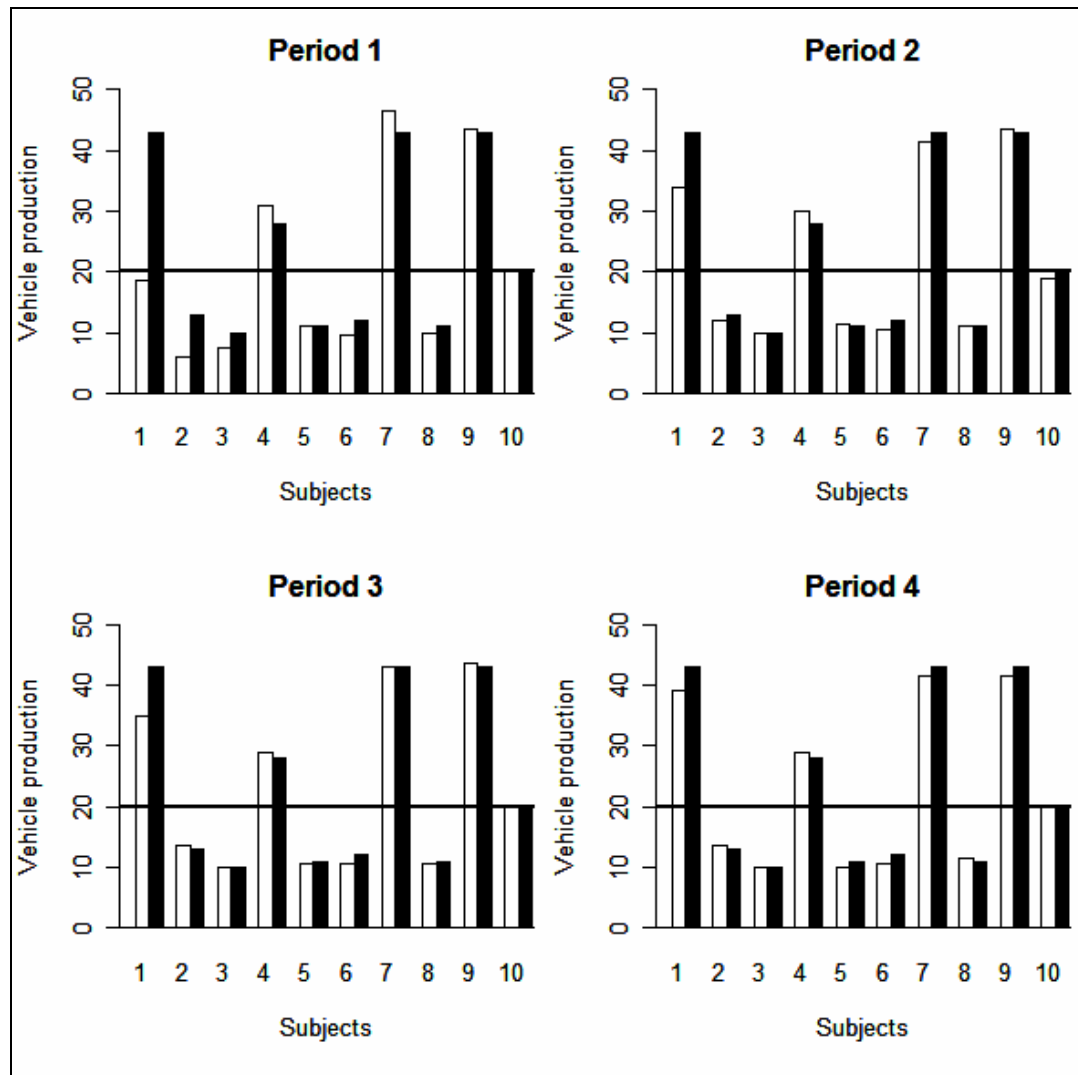
Table 4 – FEC traded, as percentage of equilibrium quantities

	Period 1	Period 2	Period 3	Period 4	All periods [*]
Design A – Fixed mpg					
04/03/2007	88.77	96.08	90.15	95.02	92.51 (3.59)
06/21/2007	83.58	99.79	98.83	95.23	94.36 (7.45)
07/04/2007	88.61	92.01	92.49	94.44	91.89 (2.43)
Design B – Variable mpg					
09/23/2007	105.97	85.49	97.31	91.00	94.94 (7.62)
10/11/2007	90.43	87.59	93.35	92.11	90.87 (2.49)
10/26/2007	91.37	92.45	91.47	86.52	90.45 (2.67)
11/11/2007	95.87	80.76	103.28	77.75	89.41 (12.18)
11/13/2007	113.98	88.12	95.30	89.89	96.82 (11.84)

^{*} Sample standard deviations reported in parenthesis.

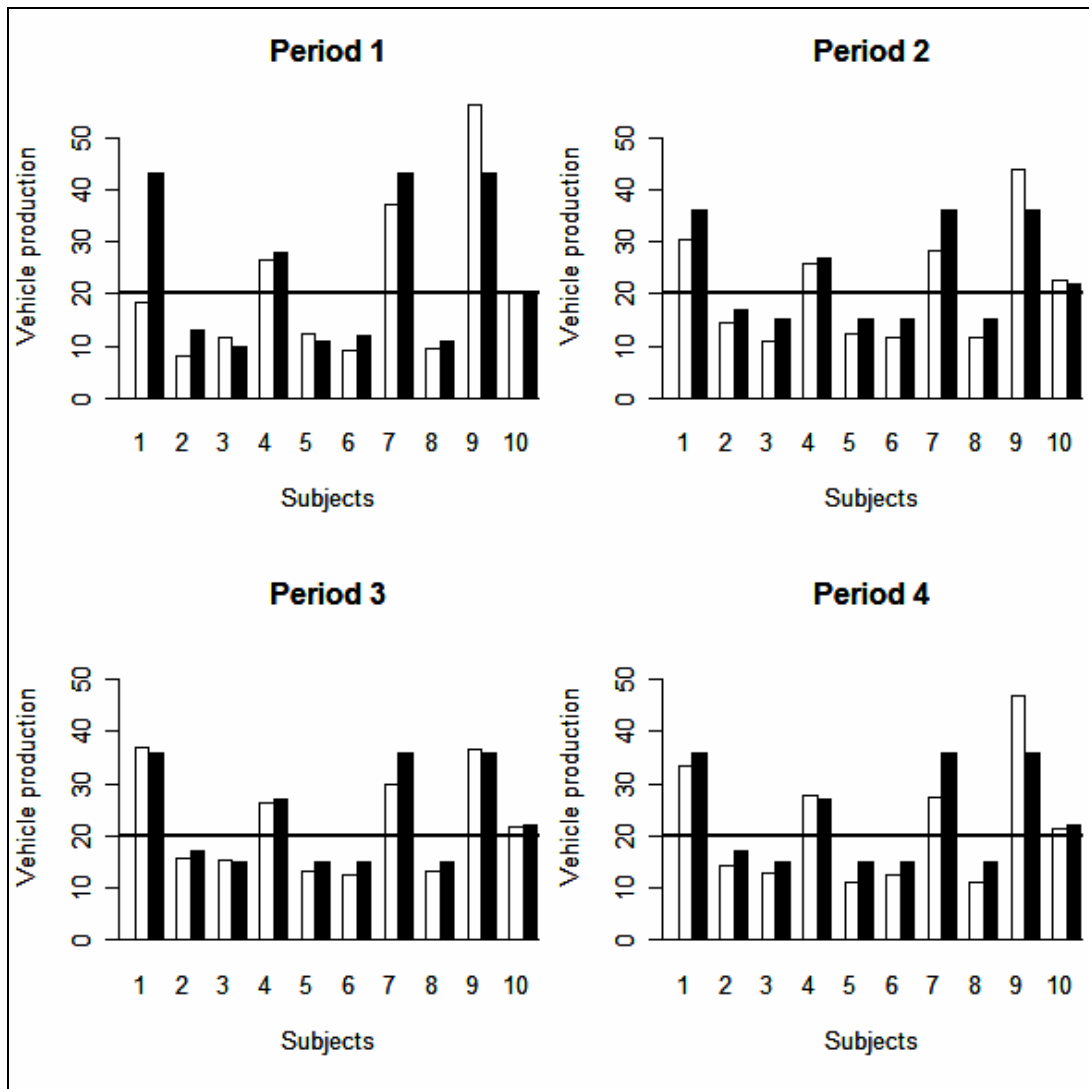
The higher volatility of prices and quantities traded in the FEC market under Design B is reflected in subjects' individual production levels. Figures 5 and 6 reflect average production levels by division and period under both experimental designs.

Figure 5 – Production by division and period, Design A



Note: White bars represent experiment output and black bars represent the equilibrium production. The horizontal line indicates the equilibrium production without the CAFE standard regulation.

Figure 6 – Production by division and period, Design B



Note: White bars represent experiment output and black bars represent the equilibrium production. The horizontal line indicates the equilibrium production without the CAFE standard regulation.

The results in Figures 5 and 6 indicate that convergence towards vehicle-production equilibrium levels tends to occur faster and more smoothly under Design A. Under Design B, there is more disparity between divisions and, in particular, some of the divisions producing fuel-efficient vehicles tend to produce more than the equilibrium quantity in response to high FEC prices. Nonetheless, even in the variable mpg design, production levels tend to approach the equilibrium as

the number of periods increase, again suggesting that subjects' and system's performance tends to increase with experience.

In order to explore this issue further, we run a Poisson regression for the absolute value of the difference between the equilibrium and the experimental output as dependent variable. The predictors included in the model are: *Period*; *Price*, measured as between the average trade prices in the FEC market during the period; *Design B*, a dummy variable for the variable-mpg design; and *Fuel Efficiency, measured in miles-per-gallon*. The latter variable was coded in two different ways: i) as a dichotomous variable taking the value of 1 for efficient divisions – i.e., those with mpg values over 20 – and 0 for inefficient divisions (Specification 1); and ii) on an eight point-scale, in ascending order according to each division's mpg value (Specification 2). The results of both specifications, reported in Table 5, are in line with our expectations: the differences between the experimental and the equilibrium output decline with the number of periods, and they are larger for high fuel-efficiency divisions and for the variable-mpg design. Our results imply that, *ceteris paribus*, the differences under the variable mpg design are 2.2 units higher across subjects than under the fixed mpg design, and that, for a given design, the differences are 2.4 units larger for fuel-efficient divisions. In contrast, the average trade price in the FEC market has no impact on the dependent variable after controlling for the other regressors; the reason for this is that, as seen in Figures 2 and 3, trade prices tend to decline uniformly with the number of periods.⁴

Table 5 – Estimates of the Poisson regression
(standard deviations in parenthesis)

⁴ The results remain virtually identical if *Price* is defined as the difference between the average trade price in each period and the equilibrium price.

	Specification 1	Specification 2
Intercept	1.69 ^{***} (0.48)	0.78 (0.5)
Period	-0.38 ^{***} (0.07)	-0.38 ^{***} (0.07)
Price	-0.01 (0.01)	-0.01 (0.01)
Design B	0.79 ^{***} (0.11)	0.79 ^{***} (0.11)
Fuel Efficiency		
Dummy	0.89 ^{***} (0.09)	
Scale		0.24 ^{***} (0.02)
Null Deviance	882.21	882.21
Residual Deviance	675.42	606.31
AIC	1014	945.2
N	320	320

Significance levels: ^{***} 0.01, ^{**} 0.05, ^{*} 0.1.

5.2 Efficiency levels

In line with the definition of experimental market efficiency first developed by Plott and Smith (1978), we measure efficiency levels as the ratio between the actual profits obtained from vehicles produced to the maximum possible profits subject to the CAFE constraint. Table 6 reports the

efficiency levels attained in the three experiments conducted under Design A and the five experiments conducted under Design B.

Table 6 – Efficiency levels per period, Designs A and B

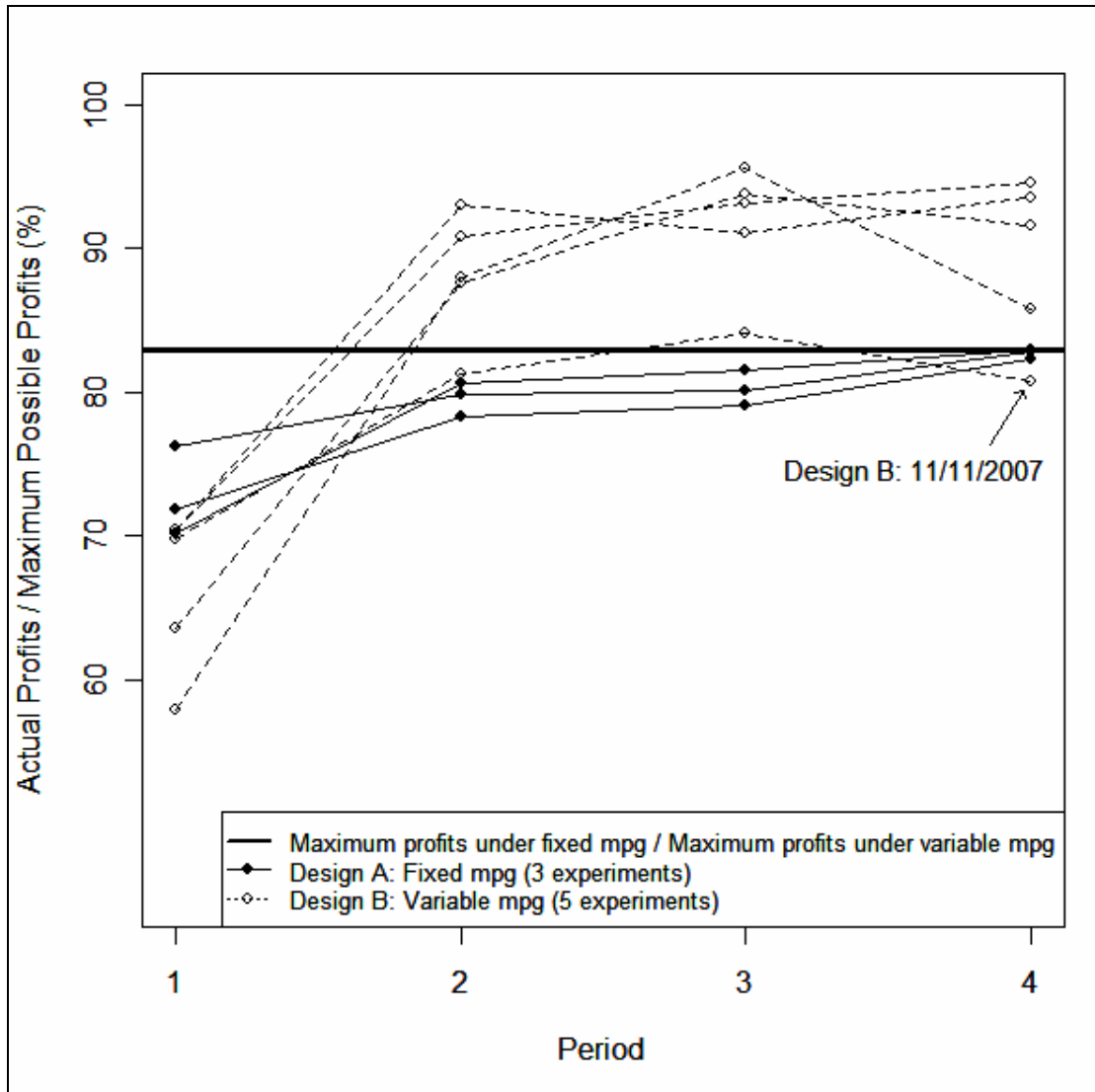
Experiment	Efficiency levels (%)			
	Period 1	Period 2	Period 3	Period 4
Design A – Fixed mpg				
04/03/2007	86.60	94.31	95.23	99.11
06/21/2007	91.86	96.17	96.48	99.79
07/04/2007	84.54	97.16	98.19	99.87
Design B – Variable mpg				
09/23/2007	91.17	92.95	91.06	93.47
10/11/2007	69.87	87.91	95.62	85.78
10/26/2007	84.9	90.8	93.1	94.5
11/11/2007	84.15	81.29	84.09	80.73
11/13/2007	76.57	87.64	93.71	91.61

Again, efficiency levels under both experimental designs tend to increase over the periods. However, some interesting differences emerge between both experimental designs, illustrating the higher complexity of the variable mpg design from the perspective of subjects' decision-making process. For Design A, efficiency levels increase almost uniformly with the number of periods and

become close to the maximum possible under such constraint, indicating that that the choice of vehicle production levels approaches the optimum. On the other hand, efficiency levels under Design B also tend to increase with the number of periods, illustrating that the choice of vehicle moves in the optimum direction and the vehicle production levels given mpg choice are also moving the direction of greatest profitability as the number of periods increase. However, efficiency is much more variable both across periods and experiments than under Design A; moreover, for one of the sessions (11/11/2007), some subjects failed to understand the total impact on profits of changing mpg, and thus did not adjust their mpg choice in the direction implied by the theoretical model.

Figure 7 allows us to contrast the relative efficiency attained under both experimental designs, comparing the efficiency levels in experiments with fixed and variable mpg to a baseline level determined by the maximum possible profitability with mpg fixed divided by maximum possible potential profits if the mpg is not fixed.

Figure 7 – Relative efficiency levels under Designs A and B



The evidence presented in Figure 7 reveals that substantive efficiency gains result not only from better coordinated output levels, but also from changing the mpg values in those experiments in which the mpg was allowed to be determined endogenously. Also, note that in the session conducted on 11/11/2007, the failure of some subjects to adjust their mpg choice led to relative efficiency levels that are close to those attained under Design A. Nonetheless, we cannot reject the null hypothesis that the relative efficiency levels under Design B are higher than under Design A:

the p-value of the Wilcoxon Mann-Whitney test for the null hypothesis $\text{Relative Efficiency}_A - \text{Relative Efficiency}_B \leq 0$ is 0.982, and 0.991 when stratified by period.

5.3 Aggregate Scenario Comparisons

In this section we compare the experimental results regarding the vehicle-manufacturer's production, profit from vehicle production and average fuel-efficiency levels with those obtained under three baseline scenarios described in Section 3. Table 7 presents the results for both experimental designs, where the experimental outcomes are averaged over all periods and experiments.

Despite the fact that, as reported in Section 4.1, individual subjects often failed to behave optimally in line with the theoretical model, the comparison of the results reported in Table 7 with those in Table 3 shows that the experimental outcomes under Designs A and B are relatively close to the centralized (mathematical) optimum subject to the CAFE standard regulation. Hence, the system-wide results seem to be quite robust to miscalculations and poor performance of individual agents. Moreover, production and average fuel-efficiency levels of the vehicles produced are on average higher than in the scenario with no CAFE constraint, and the decentralized decision-making process also leads to higher production and profits than those obtained using proportional rescaling (administrative response).

**Table 7 – System-wide production, profit and fuel-efficiency levels
under designs A and B***

	Design A	Design B
Production (number of vehicles)	221 (22.41)	220 (19.43)
Profits (experiment money)	40,706 (2,167.37)	43,201 (5,401.57)
Fuel-efficiency (mpg)	20.08 (0.42)	19.56 (1.43)

*Sample standard deviations reported in parenthesis.

6. Discussin and Conclusions

This paper analyzes methods that can be used to enable a vehicle manufacturer to meet the CAFE standards most profitably while operating as a decentralized decision-maker. Specifically, we examine the functioning of an internal market for Fuel Efficiency Credits (FEC) in which organized trading and FCE pricing between the different divisions of the manufacturing firm occurs, and use an experimental strategy in order to assess the effect of this market institution on the firm’s production, profits and overall fuel-efficiency. The theory supporting the market architecture implemented is consistent with the basic principles of economics, based on operational concepts, and supported by “proof of principle” experiments. The experimental evidence presented in Section

5 suggests that high efficiency levels are attained, relatively easy adaptation and learning on the part of subjects is observed, and that the results are robust to miscalculations and poor performance of individual agents. The vehicle-manufacturer's performance, as measured by vehicle production, and profits, is substantially enhanced through the decentralized decision-making process that is consistent with the CAFE standard regulation, compared to alternative administrative responses available in the absence of an internal market for FEC.

The technology used for the experiments in this paper can be modified to account for additional complexities or adapted to address other issues or policy proposals concerning the automobile industry. For instance, Ellerman, Jacoby and Zimmerman (2006) consider the problem of integrating the CAFE program with a cap-and-trade system aimed at mitigating greenhouse gas emissions using some form of tradable instrument related to vehicle characteristics, such as fuel economy. The theoretical framework and the experimental strategy implemented in this paper can be easily extended to study this possibility. In addition, the theory underlying our work supports a natural generalization of regulatory policy to the case in which fuel efficiency credit trading between firms is allowed. In this context, there would be a single FEC traded in an open market among firms, with production and use being essentially analogous as in this paper. In the simplest case of a two-firm example, the implication would be as if firm A contracted with firm B for the production of vehicles; the vehicles produced by firm B would not be used in applying the CAFE standard to firm B but the vehicles would be used when applying the CAFE standard to firm A. We leave these possible extensions of our work for further research.

Appendix I – Computer Screen Guide

FEC market

The screenshot shows a web-based interface for the FEC market. At the top, it displays 'MARKET SUMMARY ID: 124', the date 'Sat Mar 3 10:28:18 2007', and 'Period 11' with a '-1' in a box. A 'RELOAD CURRENT DATA' link is in the top right. Below this is a table with columns: 'Your Best Buy Market', 'Best Sell Offer', 'Last Offer', 'My Trade Offers', and 'My Trades Graph History'. The first row shows 'FEC 20.3' with bid and ask prices of '-@-' and '-@-'. To the right is an 'Order Form' with radio buttons for 'Buy' and 'Sell', a 'Market' dropdown set to 'FEC', input fields for 'Units', 'Price', and 'Time to Expire' (set to '0'), and 'Order' and 'Clear' buttons. At the bottom left, it says 'Your francs on hand is: 200000'. At the bottom right, there are links for 'Home', 'Instructions and Help', 'Inventory', 'Payoff Summary', 'Production Announcements', and 'LOGOUT'. Callout boxes provide instructions for each of these elements.

Indicate if you want to buy or sell FECs

Press **RELOAD** to actualize your screen each time you change any input

Summary information about the market

Indicate the quantity you want to buy or sell

Indicate the price you want to pay or receive for **each** FEC

Press to put your order in the market. Otherwise, press clear

Press to see your production plan

Time remaining to make transactions

Production screen

Production

Allocation of MPG and Units.
Information accurate as of Sat Mar 3 11:18:54 2007

		Allocation Planner				
	Current Allocation	Proposed Allocation		Change	New Total	
Total fec	1.06581410364015e-14				1.07	
Available fec	20.3			-2.89	23.2	Available fec
Committed fec	-20.3				23.2	Committed fec
MPG choice	22.9	22.9			22.9	MPG
Vehicle commitment	7	8			8	Units
Redemption value	980			105	1085	Redempti value
				-36.99		Ratio

FECs not used in the production of vehicles (e.g., available for sale, if positive, or required to buy, if negative)

Your current MPG

Input new MPG choice

Your current vehicle production

Input new vehicle production

Press to calculate the changes with the new production plan

Press if you accept the changes; otherwise, press clear

Change in Redemption Value / Change in FECs.

FECs used in production of vehicles

Calculate-->

Clear----->

Change Allocation

Inventory screen

Inventory Page

Information accurate as of Sat Mar 3 11:48:42 2007

Cash and Unit Holdings

earnings	0	
fec	20.3	← Current inventories
francs	200000	
mpg	22.9	← Current MPG
units	7	

Defaults (your inventory will reset to this at the end of each period)

fec	0	
francs	200000	← Inventories at the beginning of each period
units	0	

Appendix II – Instructions

You are about to participate in a special market process that will consist of a number of independent periods or “days”. If you follow the instructions carefully and make good decisions, you may earn a considerable amount of money. You will be paid in EC 11 credits at the end of the experiment. The currency used in the experiment is called francs, but your credits will be computed in US Dollars, at an exchange rate of _____

Please do not talk or in any way communicate with other participants. If you have a question or problem, please raise your hand and one of the experimenters will come to you.

You will find attached a payoff sheet that will describe the value to you of your decisions, a key to the functions used on the computer and a record of earnings sheet.

GENERAL INSTRUCTIONS

In this experiment you are placed in a position of a vehicle manufacturer who operates under specific economic and regulatory constraints.

Each period, the value to you of producing “vehicle” units are contained in your **redemption value table** found attached to these instructions. Think of **redemption values** as the amount of profit you can make each period from the sale of the units you produce that period.

When producing your vehicles, you will deal with a regulation called “Corporate Average Fuel Economy” (CAFE). This means that your decisions will be closely aligned with a special market for fuel efficiency credits (FEC).

The impact of the regulation depends on the fuel efficiency of your vehicle, measured in miles per gallon (mpg). The mpg of your vehicle determines what you must do or what you are able to do in the FEC market. You will be originally assigned a certain mpg that you will find on your redemption value table and in your computer screen.

- If the mpg of your vehicle is **BELOW** 20, then you are required to deposit FEC with each vehicle you produce. If you do not have the FEC required by the amount that you want to produce, then you must buy them on the FEC market. For each vehicle you produce you will need FEC equal to 20 minus the mpg of your vehicle.
- If the mpg of your vehicle is **ABOVE** 20, then you receive new FEC with each additional vehicle produced. The FEC you receive can then be sold in the FEC market for profit. For each vehicle you produce you will receive FEC equal to the mpg of your vehicle minus 20.
- If you buy FEC you spend francs and if you sell FEC you receive francs. You are given a loan of 200,000 francs each period. This loan must be repaid at the end of the experiment.

▪ **PROFIT DETERMINATION, REDEMPTION VALUE TABLES AND EARNINGS**

The information regarding the redemption values and the FEC requirements from the production of vehicles is given in your Redemption Value Table. Consider the following two cases:

CASE ONE: The mpg of your vehicle is BELOW 20.

If the mpg of your vehicle is **BELOW** 20 then your profit is:

Profit = **Value received from vehicles produced – cost of FEC for the production of the vehicles.**

EXAMPLE 1) **Your mpg is below 20, so you must buy and use FEC with each vehicle unit produced.** Suppose your Redemption Value Table is like Table 1, and you have produced 4 units and have an MPG of 2.67.

Column (C), labeled “unit redemption value”, gives you the INCREMENTAL redemption value for each unit produced (e.g., 1200 francs for the 4th unit produce and 1125 for the 5th unit).

Column (D), labeled “total of redemption values”, gives the SUM of the INCREMENTAL redemption values of the units you produce (e.g. 5250 francs if you produce 4 units and 6375 if 5).

Column (E), labeled “FEC REQUIRED per unit”, indicates the number of FCEs you need to buy for each vehicle you produce: 17.33.

Column (G) gives you the redemption value per FEC obtained per unit of vehicle produced.

Table 1 – Redemption values

(A) Unit	(B) Your MPG	(C) Unit (incremental) redemption value	(D) Total of redemption values	(E) FEC REQUIRED per unit: 20 - (B)	(F) Total FEC REQUIRED: (E)*(A)	(G) Redemption value per FEC REQUIRED by unit produced: (C) / (E)
1	2.67	1425	1425	20-2.67=17.33	17.33 *1=17.33	1425/17.33 = 82.23
2	2.67	1350	2775	20-2.67=17.33	17.33 * 2 =34.66	1350/17.33 = 77.90
3	2.67	1275	4050	20-2.67=17.33	17.33 * 3 = 51.99	1275/17.33 = 73.57
4	2.67	1200	5250	20-2.67=17.33	17.33 * 4 =69.32	1200/17.33 = 69.24
5	2.67	1125	6375	20-2.67=17.33	86.65	1125 / 17.33 =64.92
...	2.67	20-2.67=17.33
20	2.67	0	14250	20-2.67=17.33	346.6	0/17.33 = 0
21	2.67	-75	14175	20-2.67=17.33	363.93	-75 / 17/33 = -4.33
...

So long as you pay less for the FEC needed to produce an incremental unit than the incremental redemption value for the unit, the unit is profitable for you. Notice that the INCREMENTAL redemption values are positive up to several units and then can become negative. **If the required FEC for the unit are acquired at a per unit price below the figure in column (G), then the FEC purchase together with the unit production is profitable.**

CASE TWO: The mpg of your vehicle is ABOVE 20.

If the MPG of your vehicle is **ABOVE** 20 then your profit is:

$$\text{Profit} = \text{Value received from vehicles produced} + \text{revenue received from the sale of FEC}$$

EXAMPLE 2) Your vehicle mpg is above 20, so you obtain FEC along with each vehicle unit produced. You can sell the FEC you obtain. Suppose your redemption value table is like Table 2, and you have produced 4 units and have an mpg of 22.9.

Column (C), labeled “unit redemption value”, gives you the INCREMENTAL redemption value for each unit produced (e.g., -8.75 francs for the 4th unit produce and -17.5 for the 5th unit). It is as if you are producing the vehicles at a loss (not including possible sale of the FEC obtained)

Column (D), labeled “total of redemption values”, gives the SUM of the INCREMENTAL redemption values of the units you produce (e.g. 315 francs if you produce 4 units and 297.5 if 5).

Column (E), labeled “FEC OBTAINED per unit”, indicates the number of FEC you obtain from each incremental vehicle you produce: 2.9.

Column (F), labeled Total FEC OBTAINED is the sum of all or the FEC obtained from all incremental units.

Column (G) gives you the redemption value per FEC obtained per unit of vehicle produced.

. Table 2 – Redemption values

(A) Unit	(B) Your MPG	(C) Unit (incremental) redemption value	(D) Total of redemption values	(E) FEC OBTAINED per incremental unit: (B) - 20	(F) Total FEC OBTAINED (E)*(A)	(G) Redemption value per FEC OBTAINED by unit produced: (C) / (E)
1	22.9	166.25	166.25	22.9-20=2.9	2.9 *1=2.9	166.25/2.9 = 57.33
2	22.9	157.5	323.75	22.9-20=2.9	2.9 * 2 =5.8	157.5/2.9 = 54.31
3	22.9	0	323.75	22.9-20=2.9	2.9 * 3 = 8.7	0/2.9 = 0
4	22.9	-8.75	315	22.9-20=2.9	2.4 * 4 =11.6	-8.75/2.9 = -3.02
5	22.9	-17.5	297.5	22.9-20=2.9	2.9 * 5 =14.5	-17.5/2.9 = -6.03
6	22.9	-26.25	271.25	22.9-20=2.9	2.9*6=17.4	26.25/2.9 = -9.05
...
10	22.9	-61.25	57.15	22.9-20=2.9	2.9*10=29	-61.25/2.9 = -21.12
11	22.9	-70	-12.85	22.9-20=2.9	2.9 * 11=31.9	-70/2.9 = -24.14
...

The fact that the incremental redemption values are negative means that producing the unit will reduce your profit unless the loss from production is offset by the gain in revenue from the sale of FEC. Column (G) will help you in making this calculation. It can be viewed as the cost to you of obtaining incremental FEC. For example if you are producing 4 vehicles, the additional FEC you obtain from producing the 5th vehicle will cost you 6.03 per FEC obtained. **If the prices received for the FEC obtained by the production of the unit are on average below the figure in column (G) then the production together with the sale of the FEC is profitable.**

CHANGING YOUR MPG PERFORMANCE:

In the first period of the experiment, you will have to produce vehicles with the mpg value that is originally assigned to you. In the following periods, you can choose to change the mpg of the vehicles you produce. Changing your mpg will affect the values you will receive for the vehicles produced and the FEC you will sell or buy in the FEC market. You can choose the mpg of the vehicles you produce at any time during these periods, but will have to produce only one type of car –defined by its mpg - in each period. In order to choose your desired mpg level, you are given a payoff sheet for different possible mpg values.

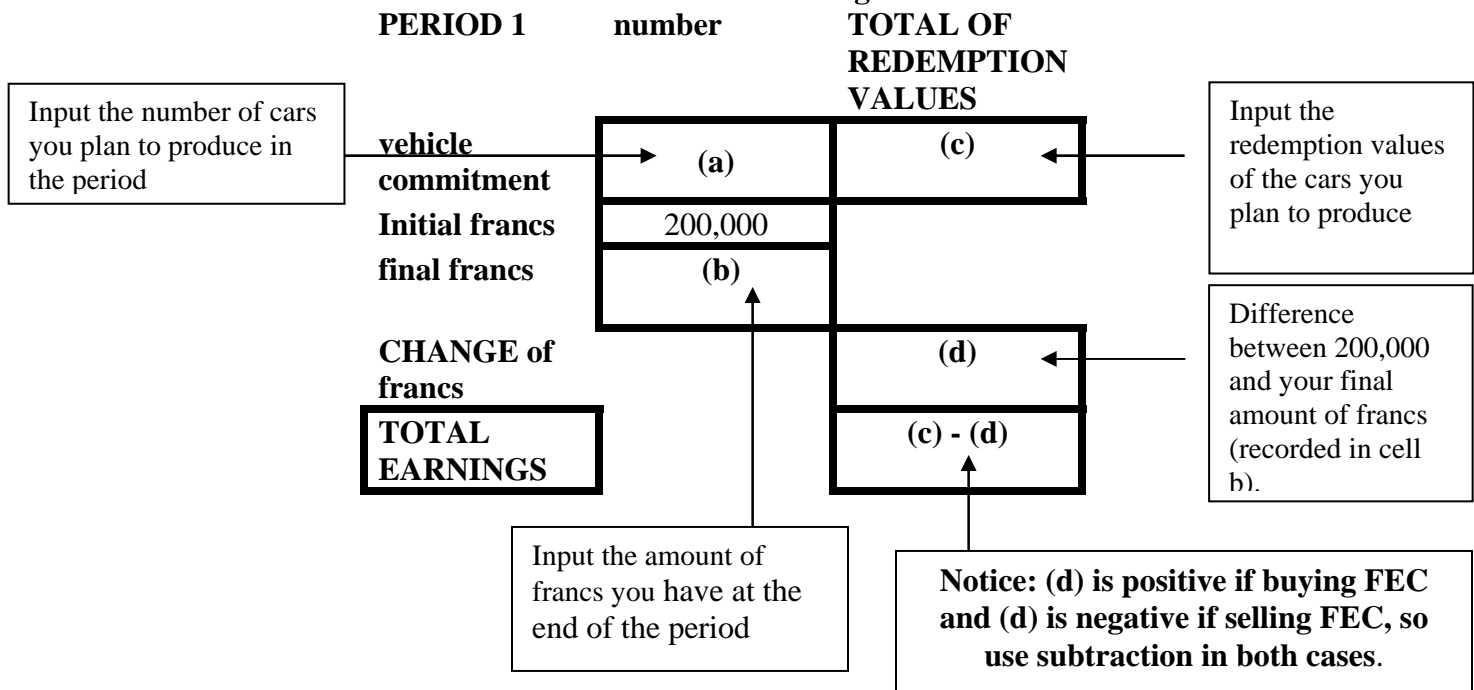
Unit (incremental) and total redemption values for alternative mpg performances								
Units produced	Your current mpg		Alternative mpg values					
	mpg=26.7		Mpg=27.87		mpg=28.87		mpg=29.87	
	UNIT	TOTAL	UNIT	TOTAL	UNIT	TOTAL	UNIT	TOTAL
1	146	146	141	141	130	130	112	112
2	139	285	134	275	123	253	105	217
3	131	416	126	402	115	368	97	314
4	124	540	119	521	108	476	90	404
...

Earnings record sheet

Your earnings during the periods are the differences between the redemption values you receive for units and the costs or receipts that you derive from the FEC market. The record sheet will help you compute your earnings each period. Your end of period earnings are calculated using the total redemption value of the vehicles produced and subtracting (adding) the value of your purchases (sales) of FEC.

RECORD YOUR EARNINGS AFTER EACH ROUND OF THE EXPERIMENT. Your end of period earnings will be listed in the **PAYOFF SUMMARY** screen of your computer.

Table 3 - Record of earnings sheet



Appendix III – Redemption values tables

ID: 1, 7, 9

Total Value and Unit (marginal) Value of Different Vehicles									
Units	MPG=26.67		MPG=27.87		MPG=28.87		MPG=29.87		
	Total value	UNIT	TOTAL	UNIT	TOTAL	UNIT	TOTAL	UNIT	
1	146	146	141	141	130	130	112	112	
2	285	139	275	134	253	123	217	105	
3	416	131	402	126	368	115	314	97	
4	540	124	521	119	476	108	404	90	
5	656	116	632	111	576	100	486	82	
6	765	109	736	104	668	93	560	75	
7	866	101	833	96	753	85	627	67	
8	960	94	922	89	831	78	687	60	
9	1046	86	1003	81	901	70	739	52	
10	1125	79	1077	74	964	63	784	45	
11	1196	71	1144	66	1019	55	821	37	
12	1260	64	1203	59	1067	48	851	30	
13	1316	56	1254	51	1107	40	873	22	
14	1365	49	1298	44	1139	33	887	15	
15	1406	41	1334	36	1164	25	894	7	
16	1440	34	1363	29	1182	18	894	0	
17	1466	26	1385	21	1192	10	886	-8	
18	1485	19	1399	14	1195	3	871	-15	
19	1496	11	1405	6	1190	-5	848	-23	
20	1500	4	1404	-1	1178	-12	818	-30	
21	1496	-4	1396	-9	1158	-20	780	-38	
22	1485	-11	1380	-16	1130	-27	734	-45	
23	1466	-19	1356	-24	1095	-35	681	-53	
24	1440	-26	1325	-31	1053	-42	621	-60	
25	1406	-34	1286	-39	1003	-50	553	-68	
26	1365	-41	1240	-46	946	-57	478	-75	
27	1316	-49	1187	-54	881	-65	395	-83	
28	1260	-56	1126	-61	809	-72	305	-90	
29	1196	-64	1057	-69	729	-80	207	-98	
30	1125	-71	981	-76	641	-87	101	-105	
31	1046	-79	898	-84	546	-95	-12	-113	
32	960	-86	807	-91	444	-102	-132	-120	
33	866	-94	708	-99	334	-110	-260	-128	
34	765	-101	602	-106	217	-117	-395	-135	
35	656	-109	489	-114	92	-125	-538	-143	
36	540	-116	368	-121	-40	-132	-688	-150	
37	416	-124	239	-129	-180	-140	-846	-158	
38	285	-131	103	-136	-328	-147	-1012	-165	
39	146	-139	-41	-144	-482	-155	-1185	-173	
40	0	-146	-192	-151	-645	-162	-1365	-180	
41	-154	-154	-350	-159	-815	-170	-1553	-188	
42	-315	-161	-516	-166	-992	-177	-1748	-195	
43	-484	-169	-690	-174	-1177	-185	-1951	-203	
44	-660	-176	-871	-181	-1369	-192	-2161	-210	
45	-844	-184	-1059	-189	-1569	-200	-2379	-218	

ID: 2

Total Value and Unit (marginal) Value of Different Vehicles								
Units	MPG=2.67		MPG=2.91		MPG=3.91		MPG=4.91	
	TOTAL	UNIT	TOTAL	UNIT	TOTAL	UNIT	TOTAL	UNIT
1	1463	1463	1462	1462	1453	1453	1432	1432
2	2850	1388	2849	1387	2832	1378	2790	1357
3	4163	1313	4161	1312	4135	1303	4072	1282
4	5400	1238	5399	1237	5363	1228	5280	1207
5	6563	1163	6561	1162	6517	1153	6412	1132
6	7650	1088	7648	1087	7595	1078	7470	1057
7	8663	1013	8660	1012	8598	1003	8452	982
8	9600	938	9597	937	9527	928	9360	907
9	10463	863	10459	862	10380	853	10192	832
10	11250	788	11247	787	11159	778	10950	757
11	11963	713	11959	712	11862	703	11632	682
12	12600	638	12596	637	12490	628	12240	607
13	13163	563	13158	562	13044	553	12772	532
14	13650	488	13645	487	13522	478	13230	457
15	14063	413	14057	412	13925	403	13612	382
16	14400	338	14394	337	14254	328	13919	307
17	14663	263	14657	262	14507	253	14152	232
18	14850	188	14844	187	14685	178	14309	157
19	14963	113	14956	112	14789	103	14392	82
20	15000	38	14993	37	14817	28	14399	7
21	14963	-38	14955	-38	14770	-47	14332	-68
22	14850	-113	14842	-113	14649	-122	14189	-143
23	14663	-188	14655	-188	14452	-197	13972	-218
24	14400	-263	14392	-263	14181	-272	13679	-293
25	14063	-338	14054	-338	13834	-347	13312	-368
26	13650	-413	13641	-413	13412	-422	12869	-443
27	13163	-488	13153	-488	12916	-497	12352	-518
28	12600	-563	12590	-563	12344	-572	11759	-593
29	11963	-638	11953	-638	11697	-647	11092	-668
30	11250	-713	11240	-713	10976	-722	10349	-743
31	10463	-788	10452	-788	10179	-797	9531	-818
32	9600	-863	9589	-863	9307	-872	8639	-893
33	8663	-938	8651	-938	8361	-947	7671	-968
34	7650	-1013	7638	-1013	7339	-1022	6629	-1043
35	6563	-1088	6550	-1088	6242	-1097	5511	-1118
36	5400	-1163	5388	-1163	5071	-1172	4319	-1193
37	4163	-1238	4150	-1238	3824	-1247	3051	-1268
38	2850	-1313	2837	-1313	2503	-1322	1709	-1343
39	1463	-1388	1449	-1388	1106	-1397	291	-1418
40	0	-1463	-14	-1463	-366	-1472	-1201	-1493
41	-1538	-1538	-1552	-1538	-1912	-1547	-2769	-1568
42	-3150	-1613	-3164	-1613	-3534	-1622	-4411	-1643
43	-4838	-1688	-4852	-1688	-5231	-1697	-6129	-1718
44	-6600	-1763	-6615	-1763	-7002	-1772	-7921	-1793
45	-8438	-1838	-8453	-1838	-8849	-1847	-9789	-1868

ID: 3

Total Value and Unit (marginal) Value of Different Vehicles

Units	MPG=4.57		MPG=4.99		MPG=5.99		MPG=6.99	
	TOTAL	UNIT	TOTAL	UNIT	TOTAL	UNIT	TOTAL	UNIT
1	853	853	852	852	842	842	822	822
2	1663	809	1661	808	1640	798	1600	778
3	2428	766	2425	765	2394	754	2334	734
4	3150	722	3146	721	3105	711	3025	691
5	3828	678	3823	677	3772	667	3671	647
6	4463	634	4457	633	4395	623	4275	603
7	5053	591	5046	590	4974	579	4834	559
8	5600	547	5592	546	5510	536	5349	516
9	6103	503	6095	502	6001	492	5821	472
10	6563	459	6553	458	6450	448	6249	428
11	6978	416	6968	415	6854	404	6634	384
12	7350	372	7339	371	7214	361	6974	341
13	7678	328	7666	327	7531	317	7271	297
14	7963	284	7949	283	7804	273	7524	253
15	8203	241	8189	240	8034	229	7733	209
16	8400	197	8385	196	8219	186	7899	166
17	8553	153	8537	152	8361	142	8021	122
18	8663	109	8645	108	8459	98	8099	78
19	8728	66	8710	65	8514	54	8133	34
20	8750	22	8731	21	8524	11	8123	-9
21	8728	-22	8708	-23	8491	-33	8070	-53
22	8663	-66	8642	-67	8414	-77	7973	-97
23	8553	-109	8531	-110	8293	-121	7833	-141
24	8400	-153	8377	-154	8129	-164	7648	-184
25	8203	-197	8179	-198	7921	-208	7420	-228
26	7963	-241	7938	-242	7669	-252	7148	-272
27	7678	-284	7653	-285	7373	-296	6832	-316
28	7350	-328	7323	-329	7034	-339	6473	-359
29	6978	-372	6951	-373	6651	-383	6070	-403
30	6563	-416	6534	-417	6224	-427	5623	-447
31	6103	-459	6074	-460	5753	-471	5132	-491
32	5600	-503	5570	-504	5239	-514	4597	-534
33	5053	-547	5022	-548	4680	-558	4019	-578
34	4463	-591	4430	-592	4078	-602	3397	-622
35	3828	-634	3795	-635	3433	-646	2732	-666
36	3150	-678	3116	-679	2743	-689	2022	-709
37	2428	-722	2393	-723	2010	-733	1269	-753
38	1663	-766	1626	-767	1233	-777	472	-797
39	853	-809	816	-810	413	-821	-369	-841
40	0	-853	-38	-854	-452	-864	-1253	-884
41	-897	-897	-936	-898	-1360	-908	-2181	-928
42	-1838	-941	-1877	-942	-2312	-952	-3153	-972
43	-2822	-984	-2863	-985	-3308	-996	-4169	-1016
44	-3850	-1028	-3892	-1029	-4347	-1039	-5228	-1059
45	-4922	-1072	-4965	-1073	-5430	-1083	-6332	-1103

ID: 4

Total Value and Unit (marginal) Value of Different Vehicles

Units	MPG=22.86		MPG=23.98		MPG=24.98		MPG=25.98	
	TOTAL	UNIT	TOTAL	UNIT	TOTAL	UNIT	TOTAL	UNIT
1	171	171	166	166	154	154	136	136
2	333	162	323	157	300	146	262	127
3	486	153	472	149	437	137	381	118
4	630	144	612	140	565	128	490	109
5	766	136	743	131	685	119	591	101
6	893	127	865	122	796	111	682	92
7	1011	118	979	114	898	102	766	83
8	1120	109	1084	105	991	93	840	74
9	1221	101	1180	96	1075	84	906	66
10	1313	92	1267	87	1151	76	962	57
11	1396	83	1346	79	1218	67	1011	48
12	1470	74	1416	70	1276	58	1050	39
13	1536	66	1477	61	1326	49	1081	31
14	1593	57	1529	52	1366	41	1102	22
15	1641	48	1573	44	1398	32	1116	13
16	1680	39	1608	35	1421	23	1120	4
17	1711	31	1634	26	1436	14	1116	-4
18	1733	22	1651	17	1442	6	1102	-13
19	1746	13	1660	9	1439	-3	1081	-22
20	1750	4	1660	0	1427	-12	1050	-31
21	1746	-4	1651	-9	1406	-21	1011	-39
22	1733	-13	1633	-18	1377	-29	962	-48
23	1711	-22	1607	-26	1339	-38	906	-57
24	1680	-31	1572	-35	1292	-47	840	-66
25	1641	-39	1528	-44	1237	-56	766	-74
26	1593	-48	1475	-53	1172	-64	682	-83
27	1536	-57	1414	-61	1099	-73	591	-92
28	1470	-66	1344	-70	1018	-82	490	-101
29	1396	-74	1265	-79	927	-91	381	-109
30	1313	-83	1177	-88	828	-99	262	-118
31	1221	-92	1081	-96	720	-108	136	-127
32	1120	-101	976	-105	603	-117	0	-136
33	1011	-109	862	-114	477	-126	-144	-144
34	893	-118	739	-123	343	-134	-298	-153
35	766	-127	608	-131	200	-143	-459	-162
36	630	-136	468	-140	48	-152	-630	-171
37	486	-144	319	-149	-112	-161	-809	-179
38	333	-153	161	-158	-282	-169	-998	-188
39	171	-162	-5	-166	-460	-178	-1194	-197
40	0	-171	-180	-175	-646	-187	-1400	-206
41	-179	-179	-364	-184	-842	-196	-1614	-214
42	-368	-188	-557	-193	-1046	-204	-1838	-223
43	-564	-197	-758	-201	-1259	-213	-2069	-232
44	-770	-206	-968	-210	-1481	-222	-2310	-241
45	-984	-214	-1187	-219	-1712	-231	-2559	-249

ID: 5

Total Value and Unit (marginal) Value of Different Vehicles

Units	MPG=4.44		MPG=4.85		MPG=5.85		MPG = 6.85	
	TOTAL	UNIT	TOTAL	UNIT	TOTAL	UNIT	TOTAL	UNIT
1	878	878	877	877	867	867	846	846
2	1710	833	1708	832	1688	822	1647	801
3	2498	788	2495	787	2465	777	2403	756
4	3240	743	3236	742	3197	732	3114	711
5	3938	698	3933	697	3884	687	3780	666
6	4590	653	4585	652	4525	642	4401	621
7	5198	608	5191	607	5122	597	4977	576
8	5760	563	5753	562	5674	552	5509	531
9	6278	518	6269	517	6181	507	5995	486
10	6750	473	6741	472	6642	462	6436	441
11	7178	428	7167	427	7059	417	6832	396
12	7560	383	7549	382	7431	372	7183	351
13	7898	338	7886	337	7758	327	7489	306
14	8190	293	8177	292	8039	282	7750	261
15	8438	248	8424	247	8276	237	7966	216
16	8640	203	8625	202	8468	192	8137	171
17	8798	158	8782	157	8615	147	8263	126
18	8910	113	8894	112	8716	102	8344	81
19	8978	68	8960	67	8773	57	8380	36
20	9000	23	8982	22	8785	12	8371	-9
21	8978	-23	8958	-23	8752	-33	8317	-54
22	8910	-68	8890	-68	8673	-78	8218	-99
23	8798	-113	8777	-113	8550	-123	8074	-144
24	8640	-158	8618	-158	8382	-168	7886	-189
25	8438	-203	8415	-203	8168	-213	7652	-234
26	8190	-248	8166	-248	7910	-258	7373	-279
27	7898	-293	7873	-293	7607	-303	7049	-324
28	7560	-338	7535	-338	7259	-348	6680	-369
29	7178	-383	7151	-383	6865	-393	6266	-414
30	6750	-428	6723	-428	6427	-438	5807	-459
31	6278	-473	6249	-473	5944	-483	5303	-504
32	5760	-518	5731	-518	5416	-528	4754	-549
33	5198	-563	5167	-563	4842	-573	4160	-594
34	4590	-608	4559	-608	4224	-618	3521	-639
35	3938	-653	3906	-653	3561	-663	2837	-684
36	3240	-698	3207	-698	2853	-708	2108	-729
37	2498	-743	2464	-743	2099	-753	1334	-774
38	1710	-788	1675	-788	1301	-798	515	-819
39	878	-833	842	-833	458	-843	-349	-864
40	0	-878	-36	-878	-430	-888	-1257	-909
41	-923	-923	-960	-923	-1364	-933	-2211	-954
42	-1890	-968	-1928	-968	-2342	-978	-3210	-999
43	-2903	-1013	-2942	-1013	-3365	-1023	-4254	-1044
44	-3960	-1058	-4000	-1058	-4433	-1068	-5343	-1089
45	-5063	-1103	-5103	-1103	-5547	-1113	-6477	-1134

ID: 6

Total Value and Unit (marginal) Value of Different Vehicles								
Units	MPG=4.10		MPG=4.47		MPG=5.47		MPG=6.47	
	TOTAL	UNIT	TOTAL	UNIT	TOTAL	UNIT	TOTAL	UNIT
1	951	951	950	950	940	940	920	920
2	1853	902	1851	901	1832	891	1790	871
3	2706	853	2703	852	2674	843	2613	822
4	3510	804	3507	804	3468	794	3386	773
5	4266	756	4262	755	4213	745	4111	725
6	4973	707	4968	706	4910	696	4786	676
7	5631	658	5625	657	5557	648	5414	627
8	6240	609	6234	609	6156	599	5992	578
9	6801	561	6794	560	6706	550	6521	530
10	7313	512	7305	511	7208	501	7002	481
11	7776	463	7767	462	7660	453	7434	432
12	8190	414	8181	414	8064	404	7818	383
13	8556	366	8546	365	8420	355	8152	335
14	8873	317	8862	316	8726	306	8438	286
15	9141	268	9129	267	8984	258	8675	237
16	9360	219	9348	219	9192	209	8864	188
17	9531	171	9518	170	9353	160	9003	140
18	9653	122	9639	121	9464	111	9094	91
19	9726	73	9711	72	9527	63	9136	42
20	9750	24	9735	24	9541	14	9130	-7
21	9726	-24	9710	-25	9506	-35	9074	-55
22	9653	-73	9636	-74	9422	-84	8970	-104
23	9531	-122	9513	-123	9290	-132	8817	-153
24	9360	-171	9342	-171	9109	-181	8616	-202
25	9141	-219	9122	-220	8879	-230	8365	-250
26	8873	-268	8853	-269	8600	-279	8066	-299
27	8556	-317	8535	-318	8273	-327	7718	-348
28	8190	-366	8169	-366	7897	-376	7322	-397
29	7776	-414	7754	-415	7472	-425	6876	-445
30	7313	-463	7290	-464	6998	-474	6382	-494
31	6801	-512	6777	-513	6476	-522	5839	-543
32	6240	-561	6216	-561	5905	-571	5247	-592
33	5631	-609	5606	-610	5285	-620	4607	-640
34	4973	-658	4947	-659	4617	-669	3918	-689
35	4266	-707	4239	-708	3899	-717	3180	-738
36	3510	-756	3483	-756	3133	-766	2393	-787
37	2706	-804	2678	-805	2318	-815	1558	-835
38	1853	-853	1824	-854	1455	-864	674	-884
39	951	-902	921	-903	542	-912	-259	-933
40	0	-951	-30	-951	-419	-961	-1241	-982
41	-999	-999	-1030	-1000	-1429	-1010	-2271	-1030
42	-2048	-1048	-2079	-1049	-2487	-1059	-3350	-1079
43	-3144	-1097	-3177	-1098	-3595	-1107	-4478	-1128
44	-4290	-1146	-4323	-1146	-4751	-1156	-5655	-1177
45	-5484	-1194	-5518	-1195	-5956	-1205	-6880	-1225

ID: 8

Total Value and Unit (marginal) Value of Different Vehicles								
Units	MPG=4.21		MPG=4.59		MPG=5.59		MPG=6.59	
	TOTAL	UNIT	TOTAL	UNIT	TOTAL	UNIT	TOTAL	UNIT
1	926	948	925	925	916	916	895	895
2	1805	879	1803	878	1784	868	1743	848
3	2636	831	2634	830	2605	821	2543	800
4	3420	784	3417	783	3378	773	3296	753
5	4156	736	4152	735	4104	726	4001	705
6	4845	689	4840	688	4782	678	4659	658
7	5486	641	5481	640	5413	631	5269	610
8	6080	594	6074	593	5996	583	5831	563
9	6626	546	6619	545	6532	536	6347	515
10	7125	499	7117	498	7021	488	6814	468
11	7576	451	7568	450	7461	441	7235	420
12	7980	404	7970	403	7855	393	7607	373
13	8336	356	8326	355	8200	346	7932	325
14	8645	309	8634	308	8499	298	8210	278
15	8906	261	8894	260	8750	251	8440	230
16	9120	214	9107	213	8953	203	8623	183
17	9286	166	9273	165	9109	156	8758	135
18	9405	119	9391	118	9217	108	8846	88
19	9476	71	9461	70	9278	61	8886	40
20	9500	24	9484	23	9291	13	8879	-7
21	9476	-24	9460	-25	9257	-34	8824	-55
22	9405	-71	9388	-72	9175	-82	8722	-102
23	9286	-119	9268	-120	9046	-129	8572	-150
24	9120	-166	9101	-167	8869	-177	8374	-197
25	8906	-214	8886	-215	8645	-224	8130	-245
26	8645	-261	8624	-262	8373	-272	7837	-292
27	8336	-309	8315	-310	8054	-319	7497	-340
28	7980	-356	7958	-357	7688	-367	7110	-387
29	7576	-404	7553	-405	7273	-414	6675	-435
30	7125	-451	7101	-452	6812	-462	6193	-482
31	6626	-499	6602	-500	6302	-509	5663	-530
32	6080	-546	6055	-547	5746	-557	5086	-577
33	5486	-594	5460	-595	5142	-604	4461	-625
34	4845	-641	4818	-642	4490	-652	3789	-672
35	4156	-689	4129	-690	3791	-699	3069	-720
36	3420	-736	3391	-737	3044	-747	2302	-767
37	2636	-784	2607	-785	2250	-794	1487	-815
38	1805	-831	1775	-832	1408	-842	625	-862
39	926	-879	895	-880	519	-889	-285	-910
40	0	-926	-32	-927	-418	-937	-1243	-957
41	-974	-974	-1006	-975	-1402	-984	-2247	-1005
42	-1995	-1021	-2028	-1022	-2434	-1032	-3300	-1052
43	-3064	-1069	-3098	-1070	-3513	-1079	-4400	-1100
44	-4180	-1116	-4215	-1117	-4640	-1127	-5547	-1147
45	-5344	-1164	-5379	-1165	-5814	-1174	-6742	-1195

ID: 10

Total Value and Unit (marginal) Value of Different Vehicles											
Units	MPG=20			MPG=21.05			MPG=22.05			MPG=23.05	
	TOTAL	UNIT		TOTAL	UNIT		TOTAL	UNIT		TOTAL	UNIT
1	195	195		191	191		179	179		160	160
2	380	185		372	181		349	169		311	150
3	555	175		544	171		508	159		451	140
4	720	165		705	161		658	149		582	130
5	875	155		856	151		797	139		702	120
6	1020	145		997	141		927	129		813	110
7	1155	135		1129	131		1046	119		913	100
8	1280	125		1250	121		1156	109		1003	90
9	1395	115		1361	111		1255	99		1084	80
10	1500	105		1462	101		1344	89		1154	70
11	1595	95		1554	91		1424	79		1215	60
12	1680	85		1635	81		1493	69		1265	50
13	1755	75		1706	71		1553	59		1306	40
14	1820	65		1767	61		1602	49		1336	30
15	1875	55		1819	51		1642	39		1357	20
16	1920	45		1860	41		1671	29		1367	10
17	1955	35		1891	31		1691	19		1367	0
18	1980	25		1912	21		1700	9		1358	-10
19	1995	15		1924	11		1699	-1		1338	-20
20	2000	5		1925	1		1689	-11		1309	-30
21	1995	-5		1916	-9		1668	-21		1269	-40
22	1980	-15		1897	-19		1638	-31		1220	-50
23	1955	-25		1868	-29		1597	-41		1160	-60
24	1920	-35		1830	-39		1547	-51		1090	-70
25	1875	-45		1781	-49		1486	-61		1011	-80
26	1820	-55		1722	-59		1416	-71		921	-90
27	1755	-65		1653	-69		1335	-81		822	-100
28	1680	-75		1575	-79		1244	-91		712	-110
29	1595	-85		1486	-89		1144	-101		593	-120
30	1500	-95		1387	-99		1033	-111		463	-130
31	1395	-105		1278	-109		913	-121		323	-140
32	1280	-115		1160	-119		782	-131		174	-150
33	1155	-125		1031	-129		642	-141		14	-160
34	1020	-135		892	-139		491	-151		-155	-170
35	875	-145		743	-149		331	-161		-335	-180
36	720	-155		585	-159		160	-171		-524	-190
37	555	-165		416	-169		-20	-181		-724	-200
38	380	-175		237	-179		-211	-191		-933	-210
39	195	-185		48	-189		-412	-201		-1153	-220
40	0	-195		-150	-199		-622	-211		-1383	-230
41	-205	-205		-359	-209		-843	-221		-1622	-240
42	-420	-215		-578	-219		-1073	-231		-1872	-250
43	-645	-225		-807	-229		-1314	-241		-2131	-260
44	-880	-235		-1046	-239		-1564	-251		-2401	-270
45	-1125	-245		-1294	-249		-1825	-261		-2680	-280

References

- Crandall, R.W. 1985. "Why Should We Regulate Fuel Economy at All?" *Brookings Review*, 3(3), 3-7.
- Crandall, R.W. 1990. "The Changing Rationale for Motor Vehicle Fuel-Economy Regulation". *Regulation*, 13(3), 10-13.
- Ellerman, A.D., H.D. Jacoby, D. Henry and M.B. Zimmerman, Martin B. 2006. "Bringing Transportation into a CO2 Cap-and-Trade Regime".
- Goldberg, Pinelopi K. 1998. "The Effects of the Corporate Average Fuel Efficiency Standards in the US". *Journal of Industrial Economics*, 46(1), 1-33.
- Greene, D.L. 1990. "CAFE or Price? An Analysis of the Effects of Federal Fuel Economy Regulations and Gasoline Price on New Car MPG, 1978-89". *Energy Journal*, 11(3), 37-57.
- Mayo, J. and J. Mathis. 1988. "The Effectiveness of Mandatory Fuel Efficiency Standards in Reducing the Demand for Gasoline". *Applied Economics*, 20(2), 211-19.
- Plott, C. R. and V. Smith. 1978. "An Experimental Examination of Two Exchange Institutions". *The Review of Economic Studies*, 45(1), 133-53.