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Tradable fuel economy credits: Competition and oligopoly

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ABSTRACT

Corporate average fuel economy (CAFE) regulations specify minimum standards for fuel efficiency that vehicle manufacturers must meet independently. We design a system of tradeable fuel economy credits that allows trading across vehicle classes and manufacturers with and without considering market power in the credit market. We perform numerical simulations to measure the potential cost savings from moving from the current CAFE system to one with stricter standards, but that allows vehicle manufacturers various levels of increased flexibility. We find that the ability for each manufacturer to average credits between its cars and trucks provides a large percentage of the potential savings. As expected, the greatest savings come from the greatest flexibility in the credit system. Market power lowers the potential cost savings to the industry as a whole, but only modestly. Loss in efficiency from market power does not eliminate the gains from credit trading.

1. Introduction

1.1. Fuel economy standard policy context

Corporate average fuel economy (CAFE) standards established by the US Energy Policy and Conservation Act of 1975 (PL94-163) specify minimum fleet average standards for fuel efficiency that US light-duty vehicle (car and light-truck) manufacturers must meet. Light-duty vehicles produced 59% of transportation CO_2 emissions in 2003 [35] and consume 36% of the oil used in the US [4].

In this paper, we investigate the potential economic cost savings from the implementation of a system of tradable fuel economy credits coupled with higher fuel economy standards. Additionally, we model the theoretical and empirical impacts of oligopolistic behavior in the market for fuel economy credits. Important to the magnitude of the cost of fuel economy improvements are the attitudes of consumers towards fuel savings. We examine alternative assumptions and estimate the impacts on costs. Omitted from our analysis are potential non-market benefits such as reductions in US GHG emissions and energy security benefits.

The effectiveness of CAFE standards in raising the light-duty vehicle fleet's fuel efficiency, and other effects of CAFE regulations, have been discussed in a large body of literature. It was debated whether the improvements in average fuel

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efficiency realized from 1978 (the first year that the CAFE standards went into effect) through 1987 were attained at a reasonable economic cost and whether the CAFE regulations induced undesirable changes in vehicles that could lower their safety [3,11,12,27].

Thorpe [32] found that the CAFE standards have led to a shift toward larger, more luxurious models in the imported Asian fleet and may have led to a decrease in the fleet's average fuel efficiency. In addition, the CAFE standards themselves, by being less restrictive for trucks than for cars, likely had the effect of encouraging the shift in market share from cars to light-duty trucks. The light-duty truck share of new vehicle sales grew from 9.8% in 1979 to 42.1% in 1997 [9,22]. Parry et al. [28] examine the social welfare of raising CAFE standards taking into consideration existing externalities. They find that higher CAFE standards can produce anything from moderate welfare gains to substantial welfare losses, depending on how consumers value fuel economy technologies and their opportunity costs.

In 2002, the National Research Council's comprehensive review of the effectiveness and impact of CAFE standards concluded that while the CAFE program has clearly increased fuel economy, certain aspects of the CAFE program have not functioned as intended. These include indirect consumer and safety costs, a breakdown in the distinctions between foreign and domestic fleets, and between minivans, SUVs and cars in the calculation of fuel economy standards, and the artificial creation of fuel economy credits for multi-fuel vehicles.[1] Moreover, the National Research Council concluded that technologies exist that, if applied to light-duty vehicles, would significantly reduce fuel consumption within 15 years (Finding 5).

The availability of improved technologies for fuel economy alone is not sufficient to encourage their widespread adoption. The National Research Council concluded that raising the CAFE standard would reduce future fuel consumption, but that other policies could accomplish this same end at lower cost and greater flexibility. The National Research Council concluded (Finding 11): "Changing the current CAFE system to one featuring tradable fuel economy credits and a cap on the price of these credits appears to be particularly attractive. It would provide incentives for all manufacturers, including those that exceed the fuel economy targets, to continually increase fuel economy, while allowing manufacturers flexibility to meet consumer preferences."[2]

1.2. Current CAFE regulations and standards

The Energy Independence and Security Act (EISA) of 2007 increases the Corporate Automotive Fuel Efficiency (CAFE) standards of the US light-duty vehicle fleet from the 2007 (combined) level of about 25 miles/gal (MPG) to the maximum feasible average to attain 35 MPG by 2020 – a 40% increase. In addition, starting in 2011, the CAFE program will include the large Sport Utility Vehicles that were previously exempt from CAFE requirements.[3]

The CAFE standard applies to all manufacturers, m, and is defined as the sales-weighted harmonic average fuel economy, measured in miles/gal. EISA changes the form of the standard from a uniform standard to one based on the sales-weighted footprint (wheel base times track width). There are separate standards E^*_{vo} for each vehicle class v (passenger car or light-truck) and origin of manufacturing for cars, o (domestic or foreign).[4] Thus, S_{mvi} are manufacturer m's sales in vehicle class v, all models I. The form of the harmonic average standard is given as follows[5]:

$$E^*_v \le \frac{S_{mv}}{\sum_i S_{mvi}/E_{mv}} \quad \text{where } S_{mv} = \sum_i S_{mvi} \tag{1}$$

If a manufacturer does not meet the standard, it is liable for a civil penalty of \$5.50 for each 0.1 mile/gal (or \$55/MPG) its fleet average falls below the standard, multiplied by the number of vehicles it sold in a given model year in each fleet. Credits are earned when a manufacturer more than attains the standard in any model year. These credits may be carried forward (banked) or carried back (borrowed) for 5 years on a rolling basis. As shown by Rubin and Kling [30] in the context of phasing in stricter standards for new vehicles for criteria emissions, a credit system can realize cost savings when firms are allowed to borrow and banking credits even if they do not trade. EISA reforms the CAFE system to allow manufacturers to average credits across vehicle types (cars and light-trucks) up to certain maximum increments (Section 104 (g)). Credit trading among manufacturers is also authorized with limitations (Section 104 (f)).

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[1] The majority of members of the Committee on the Effectiveness and Impact of CAFE standards found that down-weighting and down-sizing, in part due to CAFE standards, increased traffic fatalities. Dissenting minority committee members, including David Greene, concluded that the statistical evidence for such safety effects is not conclusive.

[2] Similar views are also expressed by the National Commission on Energy Policy [20] and the Pew Center on Global Climate Change [29].

[3] There are additional other specific rules and guidelines given in the final rule. NHTSA estimates that expanding the truck category will add an additional 240,000 vehicles into the CAFE program in 2011.

[4] For simplicity we do not separate foreign and domestic car fleets.

[5] The footprint target,

$$E_v = \frac{1}{1/a + (1/b + 1/a)(e^{(x-c)/d}/(1+e^{(x-c)d}))}$$

where a, b, c, and d are parameters representing, respectively, maximum and minimum fuel economy targets, footprint values and rates of change targets. See NHTSA [26].

1.2.1. Level of current standards and proposed regulations

The current level of fuel economy standard for passenger cars is 27.5 MPG and for light-trucks, the standard is 22.5 MPG for model year (MY) 2008 (Federal Register, 49 CFR Part 533), rising to 24 MPG by MY 2011. Draft regulations promulgated by NHTSA give a phase-in schedule of increased fuel economy standards for cars and light-trucks through 2015 on the way towards EISA's 2020 goal of a fleet average standard of 35 MPG [26]. The proposed 2015 standard is 35.7 MPG and 28.6 for cars and light-trucks, respectively, for a combined estimated sales-weighted average of 31.6 MPG.

In their report, the National Research Council determined that the cost-effective average fuel economy could be increased by 12% for subcompact automobiles, up to 27% for large passenger cars and between 25% and 42% for light-duty trucks (depending on size) over the next 15 years [21]. Cost-effective technologies mean combinations of existing and emerging technologies that would result in fuel economy improvements sufficient to cover the purchase price increases they would require holding size, weight, and vehicle performance characteristics constant.

Given these benchmarks, and EISA, we examine the impact from a 40% improvement by 2020. Because the (draft) footprint standards for EISA are only available through 2015, with the 2016–2020 parameters not yet determined, we use uniform, not footprint, standards currently in place for cars and light-trucks.[6] A 40% improvement implies targets of 38.5 and 29.0 MPG, for cars and light-trucks, respectively, and a combined light-duty fleet average of 33.8. Note that these targets are relative to the 2003 base year fuel economy standards (using the MY light-truck share of 48.9%) not the base year fleet fuel economy level actually attained [23].

2. Market model of producer behavior and the demand for fuel economy

2.1. Supply of fuel economy

We develop a model to evaluate the impact of fuel economy credit trading on the net cost of new vehicles. We formulate the objective from the perspective of a vehicle manufacturer, which maximizes the net private value to consumers of vehicle fuel efficiency plus the revenues from fuel economy credits sold (or purchased) for each vehicle type. The net value of fuel efficiency is the consumer's valuation of vehicle-lifetime fuel savings minus the increase in vehicle cost due to fuel economy technology. Thus, we are not evaluating the social welfare effects of fuel economy standards, but rather the impact on net vehicle costs, as valued by consumers.

Consumers are heterogenous with differing discount rates and annual vehicle miles of travel. Consumers use their vehicles differently, demand different rates of return, and have different preferences for fuel economy versus other vehicle attributes. To some extent, the differences among manufacturers' current fleet fuel economy levels can be explained by the different market segments they serve.

One approach to valuing fuel economy that we use follows from manufacturers' statements regarding apparent consumer behavior, that is that consumers consider only the (un-discounted) first 3 years of fuel savings. In general, this implies that consumers place less than half as much value on fuel savings as compared with the full lifetime discounted value.[7] In theory, failing to account for real future fuel savings would represent a market failure, in the sense that consumers's choices ex ante do not maximize utility ex post. That is, if forced to buy more fuel-efficient cars than they ordinarily would, consumers would be better off.[8] A second approach, discussed in more detail below, assumes that any increase in fuel economy must have positive marginal costs, regardless of the bottom-up technology costs and pay-back potentials.

Other researchers like Parry et al. [28] have taken a different approach, one that looks at maximizing social welfare of a representative agent taking into consideration existing externalities (carbon emissions, oil dependency, accidents, and congestion) and preexisting fuel taxes. They find that raising CAFE could cause significant welfare losses largely (though not exclusively) by lowering the cost per mile driven and exacerbating mileage-related external costs such as congestion, accidents and local pollution. While driving-related externalities may be important, they are better addressed directly with other policy tools than through fuel economy regulation.[9] As such, we assume such other policies are available to correct these externalities, and we focus solely on the direct effects of fuel economy regulation.

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[6] For model years 2008–2010, light-truck manufacturers have the option of unreformed (uniform standards) or reformed (footprint standards) [25].

[7] The social, as opposed to consumer, perspective values fuel savings over the discounted, full-expected life of the vehicle and would also include externalities such as greenhouse gas emissions, criterial air pollutants and any induced (rebound) impacts from increased driving such as additional accidents, deaths and congestion.

[8] One open question is the extent to which first purchasers of vehicles consider the market value of fuel economy in the used vehicle market, and, to what extent the used vehicle market accurately values fuel economy (i.e., is there a market for lemons problem)?

[9] Consider for example the congestion charging system of the City of London (UK). This congestion charging scheme levies a £8 daily charge for vehicles entering or parking within the city center during peak hours. The Department for Transport estimates that congestion has been reduced by 30%, the number of vehicles entering the zone has been reduced by 18%, air pollution from road traffic in the form of NO_x and particulates have been reduced by 12% and green house gas emissions by 19% since the program took effect in February 2003 [33, p. 1, 34, p. 4].

Table 1
Credit trading scenarios.

Scenario name	Credit trading among firms	Credit trading among vehicle classes	Scenario descriptions
Base (no trading)	No	No	Firms must independently meet separate standards for cars and trucks
Between-class averaging	No	Yes	Firms trade credits across vehicle classes (but not among firms)
Within-class trading (between firms)	Yes	No	Credits trade among firms but in separate car and truck markets
Firm and class trading	Yes	Yes	Firms can trade credits in a single market

2.2. Market power in tradable credits

There are only 15 vehicle manufacturers to whom the fuel economy regulations apply. The top five firms (General Motors, Chrysler, Ford, Toyota, and Honda) accounted for 82% of total US sales in 2003 and 84% in MY2004. Moreover, certain fundamentals of the automobile market are not likely to change. Given the economies of scale of automobile production, further consolidation seems more likely than an increase in the number of firms. Given the structure of the CAFE market where credits apply at the manufacturer level, it seems almost inescapable that the market *in tradable credits* will be imperfectly competitive: an oligopoly versus an oligopsony with a competitive fringe.

Manufacturers could use technology to cross-subsidize particular makes and models to alter their distribution of vehicle sales. This is the issue explored by Austin and Dinan [2] and Goldberg [7] who assume oligopoly power in vehicle markets. Goldberg finds that CAFE regulations can have substantial changes on the composition of vehicle fleets but does not consider CAFE credit trading. Austin and Dinan do examine CAFE trading, but assume a perfectly competitive market for credits. Greene [13], while not considering mix shifts among manufacturers, finds that pricing strategies for any given manufacturer are an expensive means to increase its corporate average MPG in comparison to technological and design changes or paying the CAFE fine. We generally take sales mix as unchanged, but in our sensitivity analysis we examine how a mix shift towards Japanese vehicle manufacturers could affect the cost of CAFE compliance.

The issue of market power in tradable credit markets has been subject to extensive theoretical and empirical research that includes Hahn [14], Sartzetakis [31], Ellerman and Decaux [5], Misiolek and Elder [19], Malueg [17], Innes et al. [16], Westskog [36], and Godby [8]. In these papers, either dominant buyers (monopsony or oligopsony) or sellers (monopoly or oligopoly) may be able to exert market power in the credit market or use their market power in the credit market to gain power in the product market.

In the context of GHG emission credits, Westskog [36], extends Hahn's [14] model to a group of nations as acting as Cournot players with a competitive fringe. The Cournot players act as leaders deciding how many credits to buy or sell given the other Cournot countries' sales or purchases of credits and given the response function of the followers. The competitive fringe acts as followers who choose the optimal amount of credits to sell or buy given the market price of credits resulting from the first move of the leaders.

2.3. Defining CAFE credits

With tradable CAFE credits, the total number of credits is determined based on a performance standard set by the NHTSA and the number and sales mix of vehicles chosen by manufacturers. Because the CAFE constraint applies to a harmonic average of MPGs, the exposition is much clearer and the analysis is simplified when the standard is written in terms of fuel intensity (gallons per 100 miles, or GPHM) rather than fuel economy (miles/gal). Written in fuel intensity G_{mvi} with the standard (maximum fuel intensity) for vehicle class v denoted by G_v^*, the CAFE regulatory constraint on each manufacturer m is linear[10]:

$$G_{mv} \equiv \sum_i \frac{S_{mvi}}{S_{mv}} G_{mvi} \leq G_v^* \tag{2}$$

The market that will emerge, if credit trading is allowed, is a market for fuel-use credits. Credit quantities will be in units of vehicle-GPHM and credit prices will have units of \$/veh-GPHM. In order to explore the potential cost savings from allowing more regulatory flexibility by credit trading we examine four possible credit trading scenarios (see Table 1). These scenarios reflect increasing amounts of flexibility, starting from the base case that does not allow any credit trading by manufacturers consistent with current CAFE regulations.

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[10] In this equation and elsewhere, we suppress the model index I when referring to the sum over all vehicle models I in class v for manufacturer m, with the understanding that $S_{mv} \equiv \sum_i S_{mvi}$. We also write $G_{jv}^* = G_v^*$, since all manufacturers face the same fuel intensity (performance) standards.

2.4. Private market model: perfect competition

Formally, the manufacturer is assumed to maximize (on behalf of the consumer) the net present value (NPV) of future fuel savings per vehicle minus the incremental cost per vehicle of fuel economy technology. Following the lead of Ahmad and Greene [1] we simplify by assuming that each vehicle design is essentially fixed except for its fuel intensity. If the initial level of fuel intensity is G^0_{mvi}, and the fractional change in fuel intensity is X_{mvi}, then the firm m objective for each model I in class v can be written as a linear expression for fuel savings minus a quadratic function for fuel economy technology cost:

$$\begin{aligned} NPV(X_{mvi}) &= K_v[G^0_{mvi} - G^0_{mvi}(1.0 + X_{mvi})] - [b_{mvi}X_{mvi} + c_{mvi}X^2_{mvi}] \\ &= -K_v G^0_{mvi}X_{mvi} - [b_{mvi}X_{mvi} + c_{mvi}X^2_{mvi}] \end{aligned} \tag{3}$$

where parameter K_v is the estimated present value of fuel savings over the lifetime of a typical vehicle in class v for a unit-change in fuel intensity (the units of K_v are ($/veh)/GPHM)).[11]

The number of credits produced (number sold net of purchases) Z_{mv} by a manufacturer m is equal to the credit allowance minus the credit demand.[12] That is, the difference between the fuel intensity standard G^*_v and the achieved average fuel intensity of its new vehicle fleet G_{mv} times the total number of vehicles it produced, $S_{mv} = \sum_i S_{mvi}$ in class v. Let P_v be the price of a fuel use credit for vehicle type v denominated in units of dollars per vehicle-gallons per 100 miles ($/veh-GPHM). That is, P_v is the price per vehicle of relaxing the fuel economy constraint by 1 gal/100 miles of travel. The competitive manufacturers' problem is

$$\begin{aligned} &\underset{X_{mvi}, Z_{mv}}{\text{Max}} \quad \sum_i NPV(X_{mvi})S_{mvi} + P_v Z_{mv} \\ &\text{s.t.} \quad Z_{mv} = S_{mv}G^*_v - \sum_i S_{mvi}G^0_{mvi}(1 + X_{mvi}) \end{aligned} \tag{4}$$

Under credit trading, each manufacturer m produces a set of vehicles indexed by I that are in regulated class v, adjusting their fuel intensities to maximize the net value of fuel use reductions *plus* the revenues from fuel use credits sold (or purchased) in credit market v. Note that each credit market v, that is each group of vehicle models, classes and manufacturers that may pool and exchange credits, will have its own credit price P_v.[13]

To solve for the outcomes for all manufacturers, the set of problems for each firm as stated above must be supplemented by overall market constraints on credit balances that determine credits prices with associated complementary slackness conditions. Consider class trading where manufacturers can trade credit in separate markets for each vehicle class v (other cases follow analogously). The first order conditions for this problem yield, for manufacturers behaving competitively in the credit market, the following:

$$\frac{\partial NPV_{mv}}{\partial X_{mvi}} = P_v G^0_{mvi} \quad \forall\, m, v, i \tag{5}$$

The left-hand side of (5) is interpreted as the marginal net present value per vehicle of a change in fuel use of a particular manufacturer's vehicle model. This must be equal to the price of a credit for fuel use weighted by the base fuel use for that model. We expect that at the optimum dNPV/dX will be positive: the CAFE constraint is binding and relaxing fuel intensity yields greater avoided technology costs than increased fuel costs. Vehicle production (S_{mvi}) drops out of the optimality condition because both the marginal value of fuel intensity and the marginal cost of credits are proportional to vehicle production. For a competitive manufacturer, the credit price will equal the marginal cost of producing a credit. Thus,

$$P_v = \left(\frac{\partial NPV_{mvi}}{\partial X_{mvi}}\right) \Big/ G^0_{mvi} = -\left(\frac{\partial S_{mvi}NPV_{mvi}}{\partial X_{mvi}}\right) \Big/ \left(\frac{\partial Z_{mvi}}{\partial X_{mvi}}\right) = -\left(\frac{\partial S_{mvi}NPV_{mvi}}{\partial Z_{mvi}}\right) \quad \forall m, v, i \tag{6}$$

Stated another way, we see that at the optimum, each competitive manufacturer adjusts the fuel intensity of its models I to balance the marginal cost of producing another credit with the credit price. If the aggregate fuel intensity constraint over the whole tradeable credit market is non-binding, the credit price will fall to zero. Manufacturers will then alter their fuel intensity until their marginal net benefit is zero.

In summary, with a competitive market for fuel economy credits it is optimal for manufacturers to sell or buy credits as long as the market price is higher or lower than their own marginal cost of providing any given level of net fuel economy benefit. In competitive equilibrium, marginal net fuel economy benefits are equalized across all manufacturers.

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[11] Fuel intensity varies for each model I in class v. In our simulations, we assume that the cost of changing fuel intensity is the same for each model, i.e., $b_{mvi} = b_{mv}$ and $c_{mvi} = c_{mv}$.

[12] We use the sign convention that when $Z_{mvi} > 0$ net credit production is positive.

[13] An additional condition is an overall market clearing constraint $P_{mv}\sum_{mv} Z_{mv} = 0$. This simply requires that the price of permits be greater than or equal to zero or there are excess credits in the sense that the constraints are not binding.

2.5. *Private market model with market power in credits*

2.5.1. *Cournot–Nash strategy for cafe credits*

In models of imperfect competition and credit trading, it is typical for the market price of credits to be a function of the difference between the total allotment of credits, exogenously set by a regulator, and those used by the dominant firm [14,16,36]. With fuel use credits, however, the allotment of credits is not fixed. Rather, the total number of credits is determined based on a performance standard set by the NHTSA, and the fuel economy and number of vehicles sold by each vehicle manufacturer. The price of credits will, nonetheless, be a function of the level of net credit sales Z_{kv} (sales less purchases) by the dominant firms k.

We partition the set of manufacturers M into a subset of oligopolists, M_o, and a subset of competitive ("fringe") firms, M_F. Following the approach of Westskog [36], we let each Cournot oligopolist player $j \in M_O \subset M$ take as given the net supply Z_{kv} of fuel economy credits by other Cournot players (for $k \neq j$) and recognize the competitive firms' price-taking behavior. The price-taking behavior of the competitive fringe implies that the market price of credits is a function $P(Z_O)$ of the total net supply of credits by oligopolistic firms Z_O.

The profit-maximizing problem for a non-competitive firm j is to determine the change X_{jvi} in fuel intensity for each of its models I of class v, and its supply of fuel economy credits Z_{jv} to maximize vehicle value plus credit sales revenue:

$$\begin{aligned} &\underset{X_{jvi},Z_{jv}}{\text{Max}} \quad \sum_i [NPV(X_{jvi})S_{jvi} + P_v Z_{jv}] \\ &\text{s.t.} \quad P_v = P_v\left(Z_{jv} + \sum_{k\neq j} Z_{kv}\right) \quad \forall v; \quad \forall j \in M_O \\ &Z_{jv} = \sum_i S_{jvi}[G_v^* - G_{jvi}^0(1 + X_{jvi})] \end{aligned} \tag{7}$$

Assuming vehicle production quantities S_{jvi} (and therefor shares) are fixed, the Lagrangian first order conditions yield the non-competitive analog to (6)

$$\frac{\partial NPV_{jv}/\partial X_{jvi}}{G_{jvi}^0} = \left[P_v + \frac{\partial P_v}{\partial Z_{jv}} Z_{jv}\right] \quad \forall j, v, i \tag{8}$$

The left-hand side of (8) can be interpreted as the marginal net present *economic* value of a fuel intensity credit for a manufacturer j's vehicle class v. That is, it is the marginal economic value of a fractional change in fuel intensity of any model in class v ($\mathrm{d}NPV_j/\mathrm{d}X_{jvi}$) divided by the marginal number of credits needed per unit-change in fuel intensity ($\mathrm{d}Z_{jv}/\mathrm{d}X_{jvi} = G_{jvi}^0$). For a net credit seller, $Z_{jv} > 0$; this marginal value of a credit must be equal to the marginal revenue from selling an additional fuel use credit. Since $[P_v + (\partial P_v/\partial Z_{jv})Z_{jv}] < P_v$ for credit sales from a firm with market power, this means that there is less incentive to decrease the fuel intensity of a manufacturer's fleet of vehicles (and thereby earn credit revenues) compared with a competitive credit market. For net credit buyers, $Z_{jv} < 0$; the opposite result obtains for price, $[P_v + (\partial P_v/\partial Z_{jv})Z_{jv}] > P_v$. Here, vehicle manufacturers face higher marginal cost of fuel use credits than under a competitive market and thereby purchase fewer fuel use credits. Thus, market power in the fuel use credit market causes both oligopolistic buyers and sellers to produce and consume fewer fuel intensity credits compared with the competitive market situation.

2.5.2. *Implementation of the Cournot–Nash solution*

We implement the Cournot–Nash solution extending the approach of Westskog [36]. In her model, there is a residual demand for credits from competitive fringe firms, $f \in M_F \subset M$, that take credit prices as given. With this distinction between the sets of fringe firms M_F and Cournot oligopoly firms M_O, the total fringe net supply of credits is

$$Z_{Fv}(P_v) = \sum_{f\in M_F} Z_{fv}(P_v) \quad \text{where } P_v = P_v(Z_{Fv}) \tag{9}$$

From (6), we know that a competitive fringe firm f will change fuel intensity until the marginal net cost of generating a credit is equal to the credit price. Taking the derivative of the net benefit function per vehicle, we get the fringe firm's inverse supply curve for credits

$$P_v(Z_{fv}) = -[K_v G_{fvi}^0 + b_{fv} + 2c_{fv}X_{fvi}]/G_{fvi}^0 \tag{10}$$

where K_v represents the effective discounted vehicle-lifetime value of fuel use of vehicle class v. Parameters b and c represent a quadratically increasing cost of fuel technology as fuel intensity is reduced via adding more efficient vehicle technologies. Solving for X_{fv} yields fringe firm f's optimal fuel intensity change (percentage increase) for model I and class v, as a function of credit price:

$$X_{fvi}(P_v) = -\frac{b_{fv} + [K_v + P_v]G_{fvi}^0}{2c_{fv}} \tag{11}$$

Then, using our expression for the net supply of credits (4) we can solve for each fringe firm f's supply for credits Z_{fv} for vehicles of class v in terms of the credit price set via the Cournot firms. Summing over the individual fringe firms and vehicle classes yields an aggregate supply for credits from the fringe:

$$Z_{fv}(P_v) = \sum_{f \in M_F} Z_{fv}(P_v) = \sum_{f \in M_F} \left[G_v^* S_{fv} - \sum_i G_{fvi}^0 S_{fvi} \left[1 - \frac{b_{fv} + [K_v + P_v] G_{fvi}^0}{2c_{fv}} \right] \right] \tag{12}$$

In the oligopoly-with-competitive fringe model, each oligopolistic firm j anticipates the effect of its production on total supply, and thereby on market price. Oligopolistic firms know the credit supply response of the fringe, Z_F, and take the other Cournot players' net supplies of credits as fixed such that $dZ_{Fv}/\partial Z_{jv} = -1$. Using this assumption and the permit price response $\partial P_v/\partial Z_{Fv}$ implied by the aggregate fringe supply curve (13) in the oligopolists' first order conditions for profit maximization, (8), we get the following necessary condition for each oligopolist:

$$-\frac{[K_v G_{jvi}^0 + b_{jv} + 2c_{jv} X_{jv}]}{G_{jvi}^0} + \left[\frac{1}{\sum_{f \in M_F} \sum_i ((G_{fvi}^0)^2 S_{fvi}/2c_{fv})} Z_{jv} \right] = P_v \quad \forall v, j \in O \tag{13}$$

This establishes the optimal behavior of Cournot oligopolists with respect to price.

Thus, a Nash solution to the Cournot oligopoly problem is to satisfy simultaneously the equations in (14) and (11) by equating all of the left-hand sides to one another, and the credit balance equation $\sum_{m \in M} Z_{mv} \geq 0$. Additionally, we impose the complementary slackness conditions to address the cases in which the credit price collapses to zero.

3. Model parameterization

3.1. Parameterization for fuel savings

We need to estimate the parameter K_v that represents the consumer's present discounted value of fuel economy of vehicle class v based on avoided fuel costs. As discussed earlier, we consider the assumption that consumers value fuel economy only on the basis of fuel savings gained over the first 3 years of ownership. Clearly, consumers do not know what future fuel prices will be. We model consumers as having static expectations over fuel prices. That is, consumers will assume that the future price of fuel will be the same as the current price at the time of vehicle purchase. We use the Energy Information Administration's 2012 reference case 2012 forecast price of \$1.51 and "high B" forecast of 1.84 cents/gal [6]. The price of fuel P is unaffected by choices about vehicle fuel economy, and average vehicle economy for the fleet of new vehicles.

We make the additional assumption that the utilization of each vehicle (vehicle miles traveled per year) M is fixed for each vehicle class, regardless of choice of fuel economy. If vehicle owners drive more with a higher fuel efficiency vehicle, or attach value to the greater driving range of a more efficient vehicle, then we are underestimating the value of fuel economy purchased. Given these estimates we are now able to estimate K_v as the discounted lifetime fuel cost per unit fuel intensity, i.e. the product of annual miles driven, M_v, the expected fuel price P, and the discounted vehicle-lifetime D_v in years taking into account the decline-rate of use and consumer discounting, where $K_v = M_v P D_v$.[14]

Only the monetary costs and benefits of fuel economy will be considered since fuel economy technologies are assumed hedonically neutral. That is, except for their impacts on fuel economy and vehicle price, they do not enter a consumer's purchase decision or affect a consumer's satisfaction with a vehicle. Thus, our base case cost curves do not include diesel and hybrid technology. While this may understate the fuel economy technology available, the NAS technologies are nearly invisible to the consumer. This is not necessarily true for diesels and hybrids. These technologies may penetrate the market in different ways in terms of consumer tradeoffs. Diesel and hybrid technologies can be added to the NAS list, but they will be disruptive to the other technologies on this list. Changes in the hedonic value due to changes in vehicle attributes are difficult to predict and measure.

3.2. Fuel intensity cost curves

We use data for MY 2003 vehicles sold in the United States, obtained from the National Highway Traffic Safety Administration (NHTSA) Manufacturer's Fuel Economy Reports. These give us vehicle manufacturers' sales and fuel economy by vehicle class (8 cars and 7 trucks) and country of origin (foreign or domestic). Not all manufacturers have product offerings in all vehicle-type categories. Moreover, examination of the weight and horsepower, and fuel economy data also confirm that manufacturers' product offerings differ somewhat even within vehicle size/class categories. For example, the average fuel economy of a compact car from BMW is lower than that of Ford.

The National Research Council presents low and high retail equivalent price estimates for a low and high range of incremental fuel intensity improvements (i.e., decreasing fuel intensity per mile) by individual technologies for 4 cars and 6

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[14] Note that we divide the number of miles through by 0.85 to discount test-value MPG numbers to reflect real-world performance (e.g., [15]). Although there is evidence that the shortfall for trucks may be larger than that for passenger cars [18], the average shortfall of 15% implied by EPA official correction factors is used here for both vehicle types.

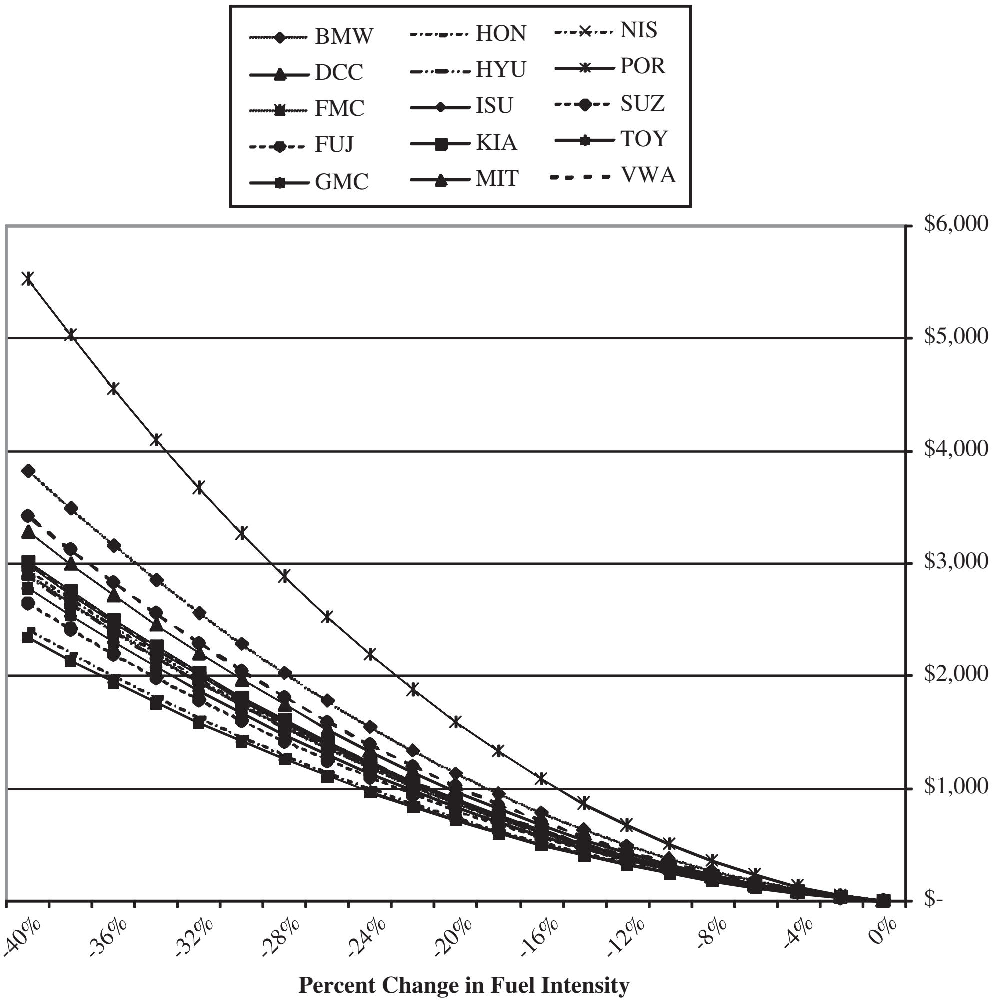

Fig. 1. Fuel consumption cost curves by manufacturer (average cost case).

truck classes [21].[15] In particular, we use National Research Council's "emerging" (path 3) technologies. Except for camless valve actuation and variable compression ratio technologies, the rest of the technologies either are implemented on some vehicles now or are capable of being implemented in the time frame of the National Research Council's analysis. This assumption is conservative because it does not include diesel or hybrid technology.

We use the National Research Council's high and low retail costs with low and high efficiency gains to generate low, average and high retail costs of decreasing fuel intensity that encompass the full range of cost and performance uncertainty. Before mathematical functions are fitted to the data, the technologies are sequenced to ensure they are implemented in order of increasing marginal cost, in accordance with economic theory. Engineering knowledge and judgment is also employed to ensure that combinations of technologies do not violate technological feasibility. The technology cost curves we develop, therefore, represent an aggregate description of the industry's ability to supply fuel economy, rather than a technical plan for improving the fuel economy of a particular vehicle. This generates low, average and high cost curves for NRC's 4 car and 6 truck classes.

A review of the technology cost literature indicated that two-parameter quadratic curves (15) fit data from all studies reasonably well [10]

$$P(X) = bX + cX^2 \tag{14}$$

$P(x)$ is the retail price (cost) increase to the percentage decreases in gallons per 100 miles over a base level, G^o , and b and c are parameters to be estimated. By construction, the curves pass through the origin (0% improvement has $0 cost). The parameter estimates are intended to be curve fits and not statistical estimations. The important point is that the fitted

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[15] For cars and trucks these include: subcompact, compact, midsized, large, (trucks) SUV-Small, SUV-Mid, SUV-Large, Minivan, Pickup-Small, and Pickup-Large. In order to reconcile the different classification systems between NHTSA and NRC, we do not include the NHTSA 2-seater car or cargo van categories (since the NRC data are not likely to be representative of these vehicle classes). We also combine a few of the NHTSA categories to match the smaller number NRC's classifications, e.g., the NHTSA mini-compact and subcompact categories are mapped to the NRC's subcompact car class, and so forth.

curves accurately reflect the rate of increase in retail price for a percent decrease in fuel intensity for the full range of fuel economy improvements being considered. The two-parameter quadratic functions fit the data very well, with adjusted R^2 values exceeding 0.98 in all instances.[16]

We generate manufacturer-specific cost curves by weighing the estimated coefficients for each size-class by manufacturer-specific sales-weighted fuel intensities. For example, to generate a particular vehicle manufacturer's cost curve for cars, we combine the sales-weighted average of the parameters for the 4 size classes of cars produced by that manufacturer and the fuel intensity of that manufacturer. For cars, we show estimates for the average case in Fig. 1.

4. Results

4.1. Cost savings from trading with perfect competition

In order to explore the potential cost savings of greater regulatory flexibility from credit trading we examine the 4 possible credit trading scenarios shown in Table 1. Moreover, we explore savings with and without varying degrees of market power in the credit market: from perfect competition to the case where the five largest firms each act as independent oligopolists. Of particular policy concern is whether market power erodes potential savings from increased flexibility. We pursue this issue further by examining hypothetical changes to the sales shares of Japanese and US manufacturers. To test the sensitivity of our parameter assumptions we also examine each of these cases assuming low and high valuation of fuel economy by consumers, base and high projections of gasoline prices, and low, medium, and high costs and effectiveness of the fuel economy technology.

Importantly, we also fundamentally re-considered our (net) cost curves, derived from the NRC's bottom-up technology assessment and the consumer valuation of vehicle-lifetime fuel savings. This is because for some scenarios, the cost of additional fuel economy technology is less than the valuation of anticipated fuel savings, i.e., there is an estimated net consumer gain to increasing fuel economy. We consider three possible explanations for this apparent suboptimality of initial fuel economy: under-estimation of the costs of fuel economy technology by the NRC; systematic market failure in the market for fuel economy technology; or because the observed level of fuel economy technology in the market place reflects tradeoffs with vehicle performance or other consumer-relevant attributes missing from our model.

Austin and Dinan [2] attribute the negative net costs of fuel saving technologies to the opportunity cost of enhanced vehicle performance, weight or other energy-consuming amenities. They address this by removing some technologies (the same as identified by the NRC) that are freely adopted in unconstrained evaluations of their model; this raises their estimates of the marginal costs of fuel economy. To evaluate the impact of this latter possibility, we re-parameterize the net cost curves by imposing the assumption that *any* decrease in fuel intensity *must* have a positive cost. We do this by adjusting the marginal consumer-valuation of fuel economy to set the first derivative of the net benefit function (3) equal to 0 at the starting point $X_{mv}=0$ (no increase in fuel economy), e.g., $\partial NPV/\partial X_{mv}|_{X_{mv}=0} = -K_v G^0_{mv} - b_{mv} = 0$. This re-calibrates (and lowers) the value of fuel economy K_v based on the observed current fuel intensity of each manufacturer. We take this re-calibrated valuation of fuel economy as our base case in the cost scenarios that follow.[17] We break out our results into 3 tables: vehicle manufacturers's costs, consumer's fuel savings, and net costs.

Table 2 reports the cost-incremental retail technology costs per vehicle – on average to manufacturers under a number of different technology costs and fuel price assumptions for a decrease in fuel intensity of 40% by 2020. Table 3 presents the average fuel savings per vehicle and Table 4 presents the net costs (technology costs less fuel savings). In all tables, columns 1–4 show the net costs under our base case assumption, re-benchmarked costs curves, regarding consumer valuation of fuel economy. For average technology costs and base fuel prices (column 1, Table 2), we estimate the *average* technology costs of increasing the CAFE standards 40% is $432. Given the construction of our cost curves and the market shares of the vehicle manufacturers, we find that "class averaging" (allowing vehicle manufacturers to trade fuel economy credits across their vehicle classes) lowers that costs 8% to $398; class trading among manufacturers where manufacturers can sell or buy credits with other manufacturers in separate car and truck markets provides 7% savings. The highest level of regulatory flexibility, firm and vehicle class trading yields the greatest savings, 12%. This holds true for all cases and scenarios.

In our base case (average NRC technology costs, EIA base fuel costs, and with our re-benchmarked net-cost curves), we estimate that the average net cost from increasing fuel efficiency 40% is $271 per vehicle. Net costs are technology costs less fuel savings. Allowing each manufacturer to average between truck and car classes reduces this cost to $252 (8% savings). Full class and firm trading of fuel economy credits lower this further to $231 per vehicle (15% savings).

As shown in data columns 2–3 (low and high technology costs) the absolute and percentage saving depends substantially on the particular scenario under examination. If in fact the NRC's low estimates of technology costs are correct (column 2), even with our re-benchmarked net-cost curves, then increasing CAFE standards by 40% yields a net gain to consumers of about $30 per vehicle without trading. We find an estimated net gain for consumers in this case (though there are still costs borne by

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[16] For a few of the low cost, high decrease in fuel intensity cases we dropped outlier data points at the high end to improve the fit of the curves for smaller changes in fuel intensity.

[17] We differ from the current regulatory situation by assuming that each manufacturer complies with the CAFE regulations rather than falling short and paying the fines noted earlier. Historically, only BMW, Porsche and the manufacturers of a few other specialty high-performance cars actually have paid fines rather than meet the standard [24].

Table 2
Average manufacturers' costs per vehicle from increasing CAFE 40%, and percent savings from trading.

Scenario name	Base case Re-benchmark value of fuel economy	Variant Low cost of fuel economy technology	Variant High cost of fuel economy technology	Variant High future gasoline prices	Variant Original cost curves, 3-year payback, average cost of fuel economy technology
No-trading cost	$432	$147	$1,185	$434	$450
Between-class averaging	$398	$137	$1,080	$400	$406
	−8%	−7%	−9%	−8%	−10%
Within-class trading-competitive	$401	$129	$1,121	$401	$415
	−7%	−12%	−5%	−8%	−8%
Firm and class trading-competitive	$378	$126	$1,039	$378	$380
	−12%	−15%	−12%	−13%	−16%
Firm and class trading-non-competitive	$379	$124	$1,041	$379	$379
	−12%	−16%	−12%	−13%	−16%

Percent change in cost is relative to the no-trade case for each variant.

Table 3
Average fuel savings per vehicle from increasing cafe 40%, and percent savings from trading.

Scenario name	Base case Re-benchmark value of fuel economy	Variant Low cost of fuel economy technology	Variant High cost of fuel economy technology	Variant High future gasoline prices	Variant Original cost curves, 3-year payback, average cost of fuel economy technology
No-trading cost	$161	$179	$159	$245	$406
Between-class averaging	$148	$172	$140	$231	$402
	−8.%	−4%	−12%	−6%	−1%
Within-class trading-competitive	$160	$170	$159	$240	$396
	−1%	−5%	−1%	−2%	−2%
Firm and class trading-competitive	$148	$167	$139	$228	$392
	−8%	−6%	−12%	−7%	−3%
Firm and class trading-non-competitive	$146	$163	$138	$227	$390
	−9%	−9%	−13%	−7%	−4%

Percent change in cost is relative to the no-trade case for each variant.

Table 4
Average net value per vehicle from increasing CAFE 40%, and percent savings from trading.

Scenario name	Base case Re-benchmark value of fuel economy	Variant Low cost of fuel economy technology	Variant High cost of fuel economy technology	Variant High future gasoline prices	Variant Original cost curves, 3-year payback, average cost of fuel economy technology
No-trading cost	−$271	$32	−$1,026	−$189	−$44
Between-class averaging	−$251	$35	−$940	−$169	−$4
	8%	11%	8%	11%	90%
Within-class trading-competitive	$241	$41	$962	−$161	−$19
	11%	29%	6%	15%	56%
Firm and class trading-competitive	−$231	$42	−$900	$150	$12
	15%	31%	12%	21%	−128%
Firm and class trading-non-competitive	-233	$40	-$904	$152	$11
	14%	25%	12%	20%	−124%

Percent change in cost is relative to the no-trade case for each variant.

manufacturers, e.g., Table 2) because the curves for consumer valuation of fuel savings are re-benchmarked to imply efficiency at the initial fuel economy levels assuming *average* technology costs. Similarly, if the technology costs in fact turn out to be on the high side, the net costs turn out to be large. We estimate the average net cost to be $1000 per vehicle. Given these large technology costs, the value of credit trading is increased in absolute magnitude (though not percentage); class and firm trading can reduce net costs by about $125 per vehicle. As anticipated, higher gasoline prices (column 4 in Tables 2–4) lower the net costs to consumers of increased efficiency standards. The costs to manufacturers are largely unchanged.

In general, however, the same pattern of savings across the trading systems remains: class averaging provides substantial savings and increased trading flexibility increases the savings. Also clear is that the cost savings from fuel economy credit trading are potentially quite substantial for the industry as a whole. Even an average savings of $25 per vehicle, given annual sales of 16 million units, represent $400 million in annual savings.

The fact that a significant portion of the total potential savings is gained from class averaging within firms is of particular importance for the possible impact of non-competitive behavior. This portion of savings will not be affected by the possible oligopolistic or oligopsonistic withholding of credit trades from the market in order to drive credit prices up or down. Note that adding the percentage savings from class averaging within firms to the savings from within-class trading between firms yields a greater level of savings than complete flexibility (allowing both types of trading). The regulatory flexibility of class averaging and class trading are, to some extent, substitutes. However, the magnitude of the substitution effect does not appear great.

Beyond the uncertainty in the actual costs of fuel technology and future gasoline prices, the net cost of increasing efficiency standards depends strongly on how consumers value the lifetime discounted fuel savings. Columns 5 of Table 3 shows the impact of assuming that in the market for vehicle fuel efficiency consumers are willing to pay for technology that pays back in 3 years. That is, they are only attentive to the first 3 years of fuel savings. Given EIA reference case gasoline prices this yields a fuel savings value of roughly $400 per vehicle, depending on the case. The value of fuel savings is similar across the various flexibility cases because the increased average fuel efficiency improvement attained is the same. In this case, the net cost (technology less fuel savings) goes from positive to slightly negative (e.g., positive $12) depending on the level of flexibility of the credit trading system. If the consumers valued the full lifetime (15 years) discounted at 12%, the average value of fuel savings would be approximately $1300 (not shown in table). In this case (full lifetime value of fuel economy), the average costs of fuel economy technology would be less than the value of fuel savings.

4.2. *Cost savings from trading: imperfect competition*

As discussed earlier, given the large proportion of vehicles produced by the 5 largest manufacturers, the effect of market power on the price and availability of fuel economy credits needs to be examined explicitly. The bottom rows of Tables 2–4 show the technology costs and fuel savings when the big five each act as independent Cournot oligopolists given firm and class trading of credits. (This is the same trading flexibility case as shown immediately above in the tables.) As is seen, the average net costs savings from firm and class trading decline modestly. This is, in part, because imperfect competition does not affect the gains from class averaging (i.e., each vehicle manufacturer internally trading car and truck CAFE credits), which, given our data, generates a large percentage of the savings from the no-trading baseline. As before, the cost savings shown are on average for all manufacturers jointly. Now especially, since we examine the impact of market power, the gains to individual manufacturers from credit trading will vary. Individualized firm impacts are examined later.

One possible impact of raising the CAFE standard suggested in the literature is induced sales mix changes that might favor foreign vehicle manufacturers. Given our model that focuses on the credit market, we are not able to endogenously estimate the magnitude of a policy-induced change in sales mix. Instead we explore the implications on the cost savings from credit trading with perfect competition and with oligopoly power if the Japanese vehicle manufacturers were to gain market share at the expense of domestic manufacturers. We do this by reallocating vehicle sales by manufacturer and type (car and truck) proportionally to their 2003 sales, but assuming that Japanese (Honda and Toyota) and US vehicle manufacturers (General Motors, Ford, Chrysler) have equal market shares. Thus, in 2003, the big five had a 75% market share of cars with a domestic–Japanese split of 46–26%. We proportionally reallocate vehicles to give domestic and Japanese manufacturers each a 37% market share. For trucks we reallocate the 2003 joint share of 90% (75% domestic, 16% Japanese) to 45–45% equal shares. We leave sales of fringe firms unaffected.

The result of this hypothetical alternative sales mix is to lower the absolute cost of attaining the higher fuel efficiency standard by about $40 per vehicle on average depending on the degree of credit flexibility. This follows from our cost curves that show that it is relatively less costly for Japanese, compared with the domestic vehicle manufacturers, to decrease the fuel intensity of their vehicles. Imperfect competition in the credit market with this mix shift imposes about the same losses as before. Thus, if Japanese vehicles make up a larger percentage of the vehicle fleet, the average cost of attaining higher efficiency standards will decrease.

4.3. *Firm compliance costs*

What matters from an individual firm's perspective is its own cost of compliance, not the average cost. Apart from technology costs and consumers' perceptions of the value of future cost savings, these costs are determined from the degree of regulatory flexibility available and from the possible effects of non-competitive behavior in the market place.

In Fig. 2, we show the net costs (technology costs, fuel savings) per manufacturer including the impact of credit purchases and sales (depending on manufacturer) for our base case results. This figure captures the estimated average net cost of compliance to a 40% increase in CAFE standards given the base case cost assumptions and no restrictions on credit trading (Table 4, column 1). For all manufacturers we see that allowing vehicle manufacturers to average and trade fuel economy credits lowers the cost of compliance. As is seen in this figure, the magnitude of savings can be quite substantial for some manufacturers, less so for others. Importantly, for all manufacturers, both net sellers and net buyers, oligopolistic behavior by the big five manufacturers does not substantially diminish the savings from being able to trade fuel economy credits. The largest beneficiary is estimated to be Honda, which, after net credit sales, has a negative compliance cost. This benefit is somewhat diminished from the oligopsony behavior of credit purchasers Ford and General Motors.

Besides lowering the potential gains from credit trading, market power also affects the price of credits. Using the base case assumptions, with credit trading across classes and manufacturers, yields the following credit prices for different scenarios of imperfect competition. These include assuming that all firms act perfectly competitively (PC), and the following groups act as Cournot oligopolists: Honda and Toyota (H&T), Ford, GM, Chrysler (US 3), and Honda, Toyota, Ford, GM and Chrysler (All 5) (Fig. 3).

As is seen, credit prices rise, reflecting tightening standards. As expected, credit prices are slightly below the competitive level when the net buyers ("US 3") act non-competitively, and slightly above the non-competitive price when the net sellers ("H&T") act non-competitively. The largest divergence occurs when the big five sellers each act as independent oligopolists.

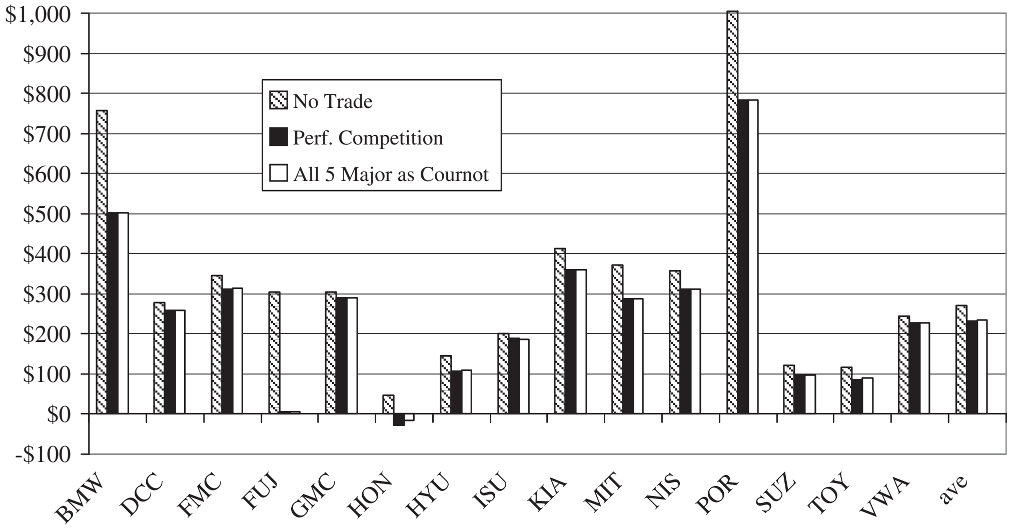

Fig. 2. Net present cost per vehicle (including technology costs, fuel savings and net credit sales), base case, full trading (the value for Porsche is $2,024).

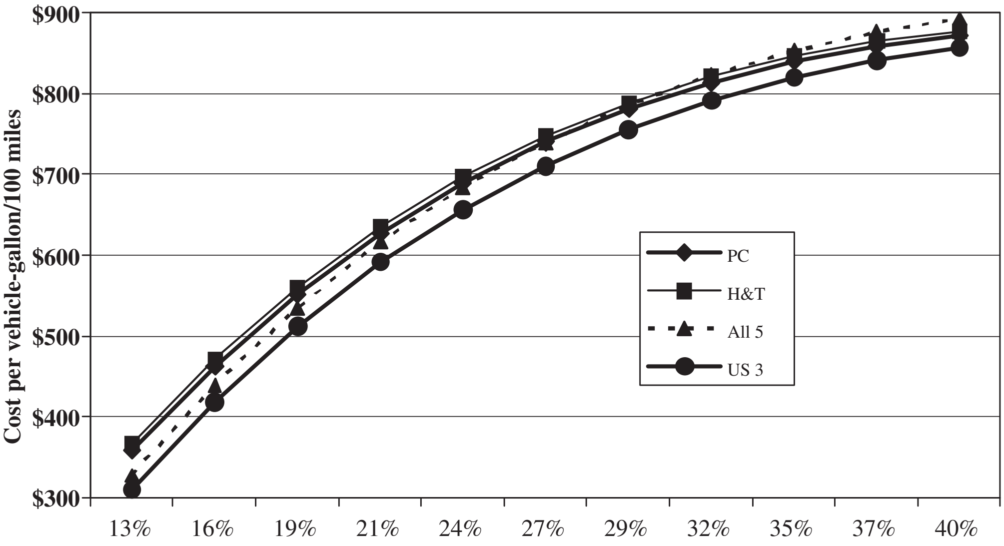

Fig. 3. Credit prices for different levels of imperfect competition-full trading.

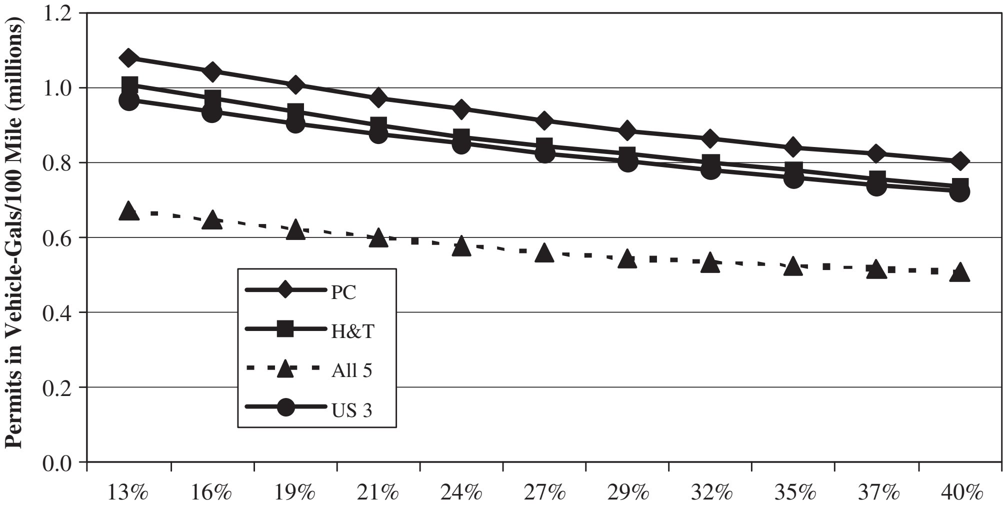

Fig. 4. Credit volume by levels of competition, base case, full trading.

While the market price for credits could be higher or lower under oligopoly versus oligopsony trading than under perfect competition, depending on the relative market power of buyers and sellers, theory tells us the net effect of non-competitive supplier and demander behavior is always to reduce trade volumes. This is because both non-competitive buyers and sellers reduce their market transactions to limit their anticipated adverse effects on the market price of credits. This phenomenon is seen in Fig. 4. Here in the most extensive case of market power we explore, all 5 major manufacturers behaving non-competitively, the credit volume drops about 37% compared with the perfectly competitive benchmark.

5. Final comments

Depending on the case, the net cost of tightened fuel economy standards to the industry as a whole may be quite large or small. This uncertainty reflects the large range of possible costs of fuel economy technology, uncertain future gasoline prices, and ambiguity regarding how consumers value future fuel economy savings. The results in this paper show how the net costs also depend on the flexibility of the standards, and the degree to which a tradable credit market is affected by non-competitive behavior. Resolving uncertainty over the engineering costs of increasing fuel economy at the firm and industry levels and improving our understanding of consumers' valuation of fuel economy are clearly needed.

We find the potential savings from averaging and trading credits to be significant: in the range of 7–16% depending on the scenario and the degree of credit trading flexibility. When fuel economy improvements are expensive, the gain from being able to average and trade credits is particularly valuable – on the order of $100 per vehicle on average. For many of the scenarios, the ability of each manufacturer to average credits between its car and truck classes provides a large percentage of the potential savings available. As expected, the greatest savings come from the greatest flexibility, when manufacturers are able to average and trade fuel economy credits.

Given the high concentration of vehicle sales by the five largest firms, we explicitly examined the potential impact of market power in the credit markets. We modeled the largest firms as Cournot oligopolists facing a competitive fringe. The theoretical effect of imperfect competition on fuel economy credit price (compared with a perfect competition benchmark) is ambiguous since firms with market power are both sellers and buyers. Our numerical simulations show that there are small changes in the price of credits when all five of the largest firms act as oligopolists, and seek a Cournot–Nash equilibrium. However, both sellers and buyers of credits have an incentive to reduce their net credit transactions in order to influence the credit price. We find that the volume of credit sales can be up to 37% less compared with the perfectly competitive benchmark.

As expected, the existence of permit market power did lower the potential cost savings from permit trading to the industry as a whole. However, we estimate the magnitude of the potential losses in efficiency from the market power to be small when considering the industry as a whole. Since some firms are net sellers and some net buyers, individual firms experienced greater gains or losses from trading when taking market power into consideration than did the industry as a whole. Under the Cournot–Nash treatment, permit suppliers Honda and Toyota are slightly worse off if all 5 Majors act non-competitively, and permit buyers are essentially unchanged. Importantly, every firm was still better off from credit trading with imperfect competition than they were with our no-trading baseline. Imperfect competition in credits does not appear to eliminate all the gains from trading at the firm level and has relatively modest impacts on the industry as a whole.

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