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Defensive purchasing and motor-vehicle policy effectiveness

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Abstract

We present a theory of vehicle choice where utility depends on the vehicle choices made by other consumers. We use parameters from current transportation and public safety data to show that changes in motor vehicle policy may have unexpectedly large or non-existent effects on safety or fleet mix.

1 Introduction

Empirical evidence (Gayer (2004), White (2002)) suggests that drivers of sport-utility vehicles (SUVs) and light truck drivers are less likely to die in multi-vehicle collisions than drivers of traditional cars. This increased safety of driving an SUV or light truck – from a driver's perspective – is well known to consumers. There is considerable anecdotal evidence that many consumers choose to buy SUVs and light trucks because they "feel safe" driving them. This phenomenon is known as defensive purchasing. However, econometric studies also suggest that SUV drivers are more likely than car drivers to kill the occupants of other vehicles involved in multi-vehicle collisions. Thus, by purchasing an SUV or light truck, a driver improves her own expected level of safety, but increases the risk to other motorists of dying or being seriously injured in a crash. Moreover, the externality from SUV driving shows increasing returns: the greater the proportion of SUVs on the road, the greater the likelihood of their involvement in collisions, and thus the greater the externality imposed by them.

In this paper, we present a theory of vehicle choice where each consumer's utility depends not only on preferences for the quality attributes of vehicles, but also on the vehicle choices made by other consumers. We then use parameters from current transportation and public safety data to analyze the implications of changes in motor vehicle policy for the mix of vehicles on the road and public safety.

In our theoretical model, the equilibrium fleet mix depends on each consumer's beliefs about other consumers' actions. This problem has been studied in the macroeconomic literature, but to the best of our knowledge has not been applied previously to an externality problem in environmental economics. We show that in this kind of system, there are conditions under which there are either multiple equilibria, or the equilibrium is indeterminate. In our analysis, we examine how the determinacy and uniqueness of equilibria depend on the relative advantage of trucks over cars in collision with cars or with other trucks, and on the quality-adjusted cost differential between SUVs and cars.

The U.S. passenger-vehicle fleet has shifted markedly from cars to light trucks; the percentage of the registered fleet composed of light trucks has risen from about 18% in 1975 to around 35% in 2000. Studies have estimated that much of that shift was a result of fuel-economy regulation (CAFE standards) that is stricter for cars than for light trucks, yielding an implicit subsidy on light truck production. Once the subsidy shifted some purchases away from cars to light trucks, the relative safety benefit of purchasing a light truck went up, spurring a sort of automotive arms race constrained by heterogeneous preferences over types of motor vehicles.

It is likely that the shift in fleet composition has been exacerbated by the incentive for defensive purchasing. It is also likely that innovations in fuel-economy regulation or vehicle-aggressivity standards will alter the fleet mix, and that defensive purchasing can make the nature of that change difficult to predict. We use our model to examine the extent to which the arms-race effect is an important factor in the current market for motor vehicles. In particular, we focus on the impact of aggressivity standards (such as the voluntary standards recently agreed upon by the motor-vehicle industry, which would impose design alterations, such as lowered bumpers and crumple zones, to SUVs that reduce the expected damage to other vehicle involved in collisions). In contrast to many existing studies of motor vehicle policy and vehicle choice (e.g. Bento and Goulder, 2003), our model is extremely simple and has only a few parameters. Nevertheless, our study demonstrates that motor-vehicle policy analysis is likely to reach qualitatively different conclusions if one neglects to incorporate defensive purchasing into the analysis. In particular, we demonstrate that given current vehicle design, it is important to consider consumers' beliefs about vehicle safety in their vehicle choice decisions. Additionally, given the current fleet mix, defensive purchasing and the nature of the driving externality may mean that any change in motor vehicle policy has an unexpectedly large or small impact on fleet mix.

2 Background and literature review

Motor vehicle regulation has long been a topic of study by economists and policy analysts. Debate over the effects of Corporate Average Fuel Economy (CAFE) standards has raged since they were established as part of the Energy Policy and Conservation Act of 1975. Their introduction was driven by national security concerns triggered by the OPEC embargoes, and by fears that world oil reserves were dangerously close to exhaustion. Those concerns have largely faded in recent years. However, CAFE standards remain in the policy limelight because of new concerns over the contribution of mobile-source carbon emissions to climate change and to urban air pollution problems. In addition, the increased popularity of light trucks has led federal regulators and the auto industry to consider whether such vehicles should be subject to safety standards designed to reduce the damage they cause to other vehicles in multi-vehicle accidents. As we shall see, these policy problems are closely inter-related.

Separate CAFE standards have been maintained for cars and light trucks, and for domestic- and foreign-made vehicles. Light trucks are defined for the purposes of this regulatory program as any vehicle under 8500 pounds that is not a "car," including minivans, small pickup trucks, and sport-utility vehicles (SUVs). Light-truck standards were phased in several years after the standards for cars, and have been much less stringent in every year of the program. While the standard for domestic passenger cars has gone from 18 mpg in 1978 to 27.5 mpg in 1996, the standard for domestic light tracks has only ranged from 17.5 mpg in 1982 to 20.7 mpg in 1996. The harmonic mean of the certified fuel efficiency (in miles per gallon) of the vehicles sold in a given category (like domestic cars) by each manufacturer must be greater than or equal to the standards. Any manufacturer who fails this test is liable for extremely large fines.

An early set of studies attempted to ascertain the potential and actual effects of CAFE on fuel economy, vehicle-miles traveled, and fuel use. This included work by Kleit (1990), Greene (1990, 1992), Greene, Kahn, and Gibson (1999). In general, these papers found that while consumers respond to increasing fuel economy by increasing the numbers of miles that they drive, the program did increase the fuel efficiency of new cars and reduce fuel use by those vehicles. However, these studies neglected to consider light trucks. Given that such vehicles were a relatively small part of the market during the 1980s, this focus was understandable. However, the market has changed since CAFE was put in place. The ratio of new car to new light truck sales has fallen from 2.16:1 in 1986 to .93:1 in 2002 (Automotive News, 2003), and the percentage of the registered fleet composed of light trucks has risen from about 18% in 1975 to around 32% in 1995 (US DOT, 1995).

A second body of work has analyzed the effect of CAFE on new-vehicle fleet composition, making clear that these changes have hindered the ability of CAFE to improve average new-vehicle fuel efficiency. Thorpe (1997) points out that the average fuel economy of new vehicles, including light trucks, leveled out in the mid 1980s and has actually fallen since 1987. He uses a computable general equilibrium model of the industry to illustrate that this may well be because the relative vehicle prices encouraged by CAFE have stimulated several shifts in new-vehicle purchases from more to less fuel efficient vehicles, including from cars to light trucks. Yun's empirical work (1997) on national demand for new cars and trucks supports Thorpe's case, finding that CAFE has increased the demand for light trucks and decreased the demand for cars.

A third vein of research has focused on the effects of CAFE on motor-vehicle safety. Traditional work in this area rests heavily on a few key stylized "facts." First, fuel efficiency and vehicle weight have typically been viewed as strong substitutes (Crandall et al., 1986.) Second, safety analysts have emphasized that as vehicle weight rises, the risk to the vehicle's occupants of injury and death is reduced. Crandall and Graham (1989) outline the literature that has developed that school of thought, emphasizing the work of Evans (1982, 1984). Given these asserted links, Crandall and Graham (1989) conclude that CAFE will significantly raise the rate of motor-vehicle fatalities in new cars by forcing manufacturers to lower the average weight of cars.

Crandall and Graham's work, like Greene's, excludes light-trucks from the scope of the study. That exclusion, however, may have been important to their results. Godek (1997) claims that the shift toward light trucks (seemingly caused by CAFE) should work to ameliorate about 75% of any negative effect on safety of the reduction of the average weight of cars. Substitution from cars to light trucks may prevent CAFE from achieving its stated goal, but Godek takes comfort in the conclusion that at least drivers are safer for it.

Yet, is overall motor-vehicle safety really enhanced by increasing the fraction of light trucks in the fleet? The traditional view of motor vehicle safety does imply that the sheer weight of these vehicles conveys safety benefits to their occupants. However, vehicles that protect their own occupants may exert large negative safety externalities on the drivers of other vehicles. Gayer (2004) finds that, while a driver is .29-.69 times as likely to die in a given crash if she is driving a truck instead of a car driver, a light-truck driver is 1.48-2.63 times as likely to kill the opposing driver as is the driver of a car. In a related study, White (2002) finds that drivers replace cars with light trucks, an additional 3,700 crashes occur per year involving fatalities of smaller-vehicle occupants, cyclists, and pedestrians, while only 1,400 fatalities in light trucks are avoided. Some insurance companies have begun to raise liability insurance rates on SUVs and pickups precisely because they inflict unusually expensive damage on cars (and car occupants) in collisions (Bradsher, 1997). However, even if this practice becomes widespread, it is unlikely to cause owners of SUVs and pickups to internalize these costs, since features of the legal system surrounding motor-vehicle-accident liability prevent insurance companies and their clients from having to reimburse accident victims and their families for the true damages associated with an accident (Posner, 1977, p. 154.) Regulatory and physical differences between cars and light trucks cause problems for public policy and social welfare. The ability to shift into light trucks emasculates CAFE's ability to achieve its goal of improving the fuel efficiency of new vehicles in the fleet. At the same time, the presence of large numbers of light trucks on the road imposes potentially large safety externalities on the drivers of traditional cars. The externality problem provides new-vehicle buyers with an added incentive to buy light trucks instead of cars, since most drivers that happen to be in a two-vehicle accident would rather be driving the vehicle that "wins." These incentives push the fleet even further toward vehicles with high levels of air-pollution emissions per mile driven.

Recent work seeks to construct more sophisticated models to analyze the effects of automobile policies (e.g. Bento and Goulder, 2003). However, these models have not yet incorporated defensive purchasing into their frameworks. In this paper, we take a different approach to consumer choice of vehicles that focuses specifically on defensive purchasing.

3 Theoretical model

Consider a system with a unit continuum of consumers, each purchasing exactly one motor vehicle. For simplicity, we assume that there are only two types of vehicle, 'cars' and 'trucks', where both light trucks and SUVs are considered to be trucks. The two vehicle types are assumed to have different qualities based on consumer perceptions of physical attributes such as comfort and performance. We assume that trucks represent a higher quality of good than cars.

Each consumer chooses the vehicle type that maximizes their net utility of ownership, including the expected disutility of dying or being seriously injured in a motor-vehicle accident. Driving imposes an externality on all other users. Externalities are asymmetric, so that the externality cost to consumers depends both on their own choice of vehicle and on the choices of other consumers.

Define the proportion of trucks in the vehicle fleet as θ, the quality-adjusted cost of trucks as x_t, and the quality-adjusted cost of cars as x_c. We assume that as the higher quality good, trucks will have the higher cost, so that $x_t > x_c$.

Vehicle ownership and use entails the risk of accidents. In any two vehicle collision, the probability of death will depend on the type of each vehicle involved in the collision. Define P_{ij} as the disutility (the conditional probability of death in a two-car accident multiplied by the value of life) for the occupant of a vehicle of type i involved in an accident with a vehicle of type j. Note that the monetized disutility from one-car accidents is exogenous to the fleet mix and can be included, without loss of generality, in the quality-adjusted cost terms. As trucks weigh more and are more aggressively designed than cars, it is assumed that $P_{it} > P_{ic}$ and $P_{cj} > P_{tj}$ for $i, j \in \{c, t\}$. The first inequality states that for drivers of a particular vehicle type, the probability of dying is greater in a collision with a truck than with a car. The second inequality states that for a collision with a particular vehicle type, the probability of dying in two-vehicle accidents is greater for car drivers than truck drivers.

The expected disutility of owning a vehicle is thus given by $x_i + P_{it}\theta + P_{ic}(1-\theta)$, where $i \in \{c, t\}$. In order to have an equilibrium vehicle fleet with both cars and trucks, consumers must be indifferent between cars and trucks. This implies that

$$x_c + P_{ct}\theta + P_{cc}(1-\theta) = x_t + P_{tt}\theta + P_{tc}(1-\theta) \tag{1}$$

Equation (1) is an extremely simplified view of vehicle choice. In this model, we have assumed that consumers are homogeneous in their underlying preferences across vehicle types. However, the analysis for heterogeneous consumers would be broadly similar. In that case, some consumers would always prefer cars, some would always prefer trucks, and the remainder would still be faced with the decision in (1). Additionally, note that we have assumed a static system. Thus, population is constant, and any consumer deaths are exactly replaced by new consumers. Similarly, we ignore scrappage.

Rearranging (1) gives a condition for an interior solution of θ:

$$\theta = \frac{(x_t - x_c) - (P_{cc} - P_{tc})}{(P_{ct} - P_{tt}) - (P_{cc} - P_{tc})}, \qquad \theta \in (0, 1) \tag{2}$$

Define the quality-adjusted cost differential, $(x_t - x_c)$ as C. The quality-adjusted cost differential may be thought of as representing the difference in price between trucks and cars remaining once all the quality differences have been taken into account. Similarly, define the relative advantage of trucks in a collision with cars, $(P_{cc} - P_{tc})$, as X, and the relative advantage of trucks in a collision with trucks, $(P_{ct} - P_{tt})$, as Y. Then, (2) may be written compactly as

$$\theta = \frac{\frac{C}{X} - 1}{\frac{Y}{X} - 1}, \qquad \theta \in (0, 1) \tag{3}$$

Note that based on our definitions, C, X, and Y, and thus $\frac{C}{X}$ and $\frac{Y}{X}$, are all strictly positive. Based on the relative values of the three parameters C, X, and Y, the parameter space of $\{\frac{C}{X}, \frac{Y}{X}\}$ can be divided into seven regions. In each of these regions, the equilibrium mix of cars and trucks will be different.

Table 1. Stability and nature of equilibrium in the two-vehicle system.

Region	*Parameter space*	*Equilibrium type and vehicle mix*
1	$\left\{1 > \frac{C}{X} > \frac{Y}{X}\right\}$	Unique interior equilibrium, $\theta \in (0, 1)$.
2	$\left\{1 > \frac{Y}{X} \geq \frac{C}{X}\right\} \cup \left\{\frac{Y}{X} \geq 1 > \frac{C}{X}\right\}$	Corner solution with trucks only, $\theta = 1$.
3	$\left\{\frac{C}{X} \geq 1 > \frac{Y}{X}\right\} \cup \left\{\frac{C}{X} > \frac{Y}{X} \geq 1\right\}$	Corner solution with cars only, $\theta = 0$.
4	$\left\{\frac{Y}{X} > \frac{C}{X} > 1\right\}$	Multiple equilibria, $\theta \in [0, 1]$. The corner solutions $\theta = 0$ and $\theta = 1$ are stable, while interior solutions are unstable.
5	$\left\{\frac{Y}{X} = \frac{C}{X} > 1\right\}$	Multiple equilibria, $\theta \in \{0, 1\}$. Corner solution with trucks only, $\theta = 1$, is not stable, corner solution with cars only, $\theta = 0$, is stable.
6	$\left\{\frac{Y}{X} > \frac{C}{X} = 1\right\}$	Multiple equilibria, $\theta \in \{0, 1\}$. Corner solution with trucks only, $\theta = 1$, is stable, corner solution with cars only, $\theta = 0$, is not stable.
7	$\left\{\frac{Y}{X} = \frac{C}{X} = 1\right\}$	Indeterminate, $\theta \in [0, 1]$.

Proofs for the equilibrium types and stability are given in the Appendix.

Once again, note that if we had modeled consumers as heterogeneous, corner solutions would still exist. In this case, they would represent regions of parameter space for which no consumer is indifferent between cars and trucks. Interior solutions would represent regions of parameter space for which some consumers are indifferent between cars and trucks.

4 Analysis

In order to analyze possible implications of motor vehicle policy, we need to define the set of parameters P_{ij}, $i, j \in \{c, t\}$, for the current vehicle fleet mix. Two-vehicle crash statistics may be obtained from data in White (2002) and Gayer (2004). In this analysis, we ignore one-vehicle crashes, as they constitute less than one-tenth the number of two-vehicle crashes (White, 2002).

Table 2. Two-vehicle crash statistics.

Vehicle type	*Car*	*Truck*	*Total*
Car	1,864,727	1,474,022	3,338,749
Truck	1,474,022	372,198	1,944,831

Given that there are approximately 130,000,000 cars and 67,500,000 light trucks registered, we can obtain the annual crash rate of cars in two-vehicle accidents as 0.026 and of light trucks as 0.029. The numbers in Table 2 may be combined with data reported in Gayer (2004) to give approximate fatality rates by vehicles involved in collision, where values in Table 3 show the probability that a driver of vehicle type i, conditional on being involved in a collision with a vehicle type j, dies:

Table 3. Conditional fatality probabilities.

Vehicle type	$j = \text{Car}$	$j = \text{Truck}$
$i = \text{Car}$	0.0058	0.012
$i = \text{Truck}$	0.0030	0.0074

Combining the data in Table 3 with the annual crash rate and a value of statistical life of $3 million (in the middle of the range suggested by Dreyfus and Viscusi (1995)) gives the annual disutilities of each type of accident for drivers of vehicle type i involved in collisions with vehicles of type j:

Table 4. Disutilities resulting from the different types of two-vehicle collision.

Vehicle type	$j = \text{Car}$	$j = \text{Truck}$
$i = \text{Car}$	450	930
$i = \text{Truck}$	261	630

Now, for these values of P_{ij}, $\frac{Y}{X} = 1.59$. From Table 1, it is clear that current vehicle design does not fall within Region 1 of the parameter space of $\frac{Y}{X}$ and $\frac{C}{X}$. The current value of θ, the proportion of trucks on the road, is 0.34 (White, 2002). If we assume that this represents an equilbrium, we can solve for the implicit value $\frac{C}{X}$, which, assuming the same $3 million value of statistical life, is $227 annually. Hence, if the current fleet mix given by $\theta = 0.34$ is an equilbrium, then from Table 1, it must be an unstable one, as $Y = \$300$. This represents the quality-adjusted price differential between trucks and cars. With a discount rate of 5% and a vehicle life of 8 years, this corresponds to a net present value of the difference of over $1500.

Using the results from Tables 1 and 4, we can now consider the policy implications of a motor vehicle policy that reduces the aggressivity of light trucks in comparison to cars. The parameter $\frac{Y}{X}$ is a measure of the aggressivity, in collisions with cars, of light trucks when compared to cars. The current value of $\frac{Y}{X}$ is 1.58, and that of $\frac{C}{X}$ is 1.20. This means that if the relative aggressivity of trucks were lowered to 1.20, the all truck equilibrium would no longer be stable. For values of $\frac{Y}{X}$ less than 1.20, the only stable solution is an equilibrium with cars only. Thus, if defensive purchasing is important to conusmer vehicle choice, it may be possible to effect a large change in fleet mix through a relatively small change in truck aggresivity. Existing studies do not take defensive purchasing into account at all; these studies would predict no change at all from a change in truck aggressivity. A side effect of changes in truck aggressivity that reduce the proportion of trucks on the road is a reduction in motor vehicle air pollution and an increase in fleet average fuel economy.

However, it is also important to consider that small changes in parameters may not change the equilibrium fleet mix, particularly if the equilibrium is a corner solution for the distribution of preferences. We hope to explore these interactions in a dynamic setting in future research.

5 Conclusion

We present a simple theoretical model of consumers' vehicle choice when the decision includes the expected disutility of dying in a motor-vehicle accident. Because fatality risks depend both on the vehicle one drives and the vehicles everyone else drives, expected disutility depends on the fleet mix at any given time. We show that SUVs and light trucks impose a significant negative externality on car drivers. For current vehicle designs and fatality data, our analysis reveals the possibility of multiple equilibria of fleet mix. In such situations, changes in government policy may have unexpectedly large or non-existent effects on the mix of cars and SUVs in the fleet. Thus, public policy analyses need to take defensive purchasing behavior into account in order to predict correctly the effects of changes in motor vehicle regulations.

6 References

Automotive News."New Vehicle Sales by Year and by Manufacturer." NADA Industry Analysis Division, http://www.nada.org/pdf/ND_TNVD.pdf, October 2003.

Bento, Antonio M. and Lawrence H. Goulder. "An Equlibrium Model for Analyzing Automobile Fuel-Use and Pollution Policies." Working Paper, University of California at Santa Barbara, 2003.

Bradsher, Keith. "Some Insurers to Increase Rates for Large Vehicles," New York Times, October 17, 1997.

Crandall, Robert W., Howard K. Gruenspecht, Theodore E. Keeler, and Lester B. Lave. Regulating the Automobile. Washington, D.C.: The Brookings Institute, 1986.

Crandall, Robert W. and John D. Graham, "The Effects of Fuel Economy Standards on Automobile Safety," Journal of Law and Economics 32 (1989): 97-118.

Dreyfus, Mark K. and W. Kip Viscusi, "Rates of time preference and consumer valuations of automobile safety and fuel efficiency." Journal of Law and Economics 38 (1995): 79-105.

Evans, Leonard. "Driver Fatalities versus Car Mass Using a New Exposure Approach," Accident Analysis and Prevention 16 (1984): 19-36.

Evans, Leonard. Car Mass and Likelihood of Occupant Fatality. SAE Technical Paper Series 820807, 1982.

Gayer, Ted. "The Fatality Risks of Sport-Utility Vehicles, Vans, and Pickups Relative to Cars." Journal of Risk and Uncertainty 28 (2004): 103-133.

Godek, Paul E. “The Regulation of Fuel Economy and the Demand for ‘Light Trucks’,” Journal of Law and Economics 40 (1997): 495-509.

Greene, David L. “CAFE or Price? An Analysis of the Effects of Federal Fuel Economy Regulations and Gasoline Price n New Car MPG, 1978-89,” Energy Journal 11 (1990): 37-57.

Greene, David L. “Vehicle Use and Fuel Economy: How Big is the ‘Rebound Effect’?” Energy Journal 13 (1992): 117-143.

Greene, David L., Kahn, James R., and Gibson, Robert C. “Fuel Economy Rebound Effect for U.S. Household Vehicles,” Energy Journal 20 (1999): 1-31.

Hakim, Danny. “The Mini in Big Car Country,” New York Times, April 7, 2002.

Kleit, Andrew N. “The Effect of Annual Changes in Automobile Fuel Economy Standards,” Journal of Regulatory Economics 2 (1990): 151-172.

Kwoka, John E. Jr. “The Limits of Market Oriented Regulatory Techniques: The Case of Automotive Fuel Economy,” Quarterly Journal of Economics 97 (1983): 695-704.

Thorpe, Steven G. “Fuel Economy Standards, New Vehicle Sales, and Average Fuel Efficiency,” Journal of Regulatory Economics 11 (1997): 311-326.

Yun, John M. “Measuring the Unintended Effects and Costs of Fuel Economy Regulation,” Emory University mimeo, November 24, 1997.

U.S. Department of Energy (US DOE), Energy Information Administration. Emissions of Greenhouse Gases in the United States 1996, Washington, D.C., 1997.

U.S. Department of Transportation (US DOT), National Highway Traffic Safety Administration. “Registered Passenger Cars and Light Trucks,” DOT HS 808 235, Washington, D.C., 1995.

White, Michelle J. “The ‘Arms Race’ on American Roads: The Effect of Heavy Vehicles on Traffic Safety and the Failure of Liability Rules.” NBER Working Paper No. 9302, 2002.

7 Appendix

In order to demonstrate equilibrium types and stability, we introduce the following lemmas:

Lemma 1 (Existence of all-car equilibria) *Equilibria with* $\theta = 0$ *can only exist if* $\frac{C}{X} \geq 1$.

Proof: For an equilibrium in which all consumers drive cars to exist, cars must be preferred to trucks when $\theta = 0$. *From equation (1), this implies that* $x_c + P_{cc} \leq x_t + P_{tc}$. *Rearranging gives* $P_{cc} - P_{tc} \leq x_t - x_c$ *and* $X \leq C$. *Hence,* $\frac{C}{X} \geq 1.\|$

Lemma 2 (Stability of all-car equilibria) *(i) If* $\frac{C}{X} > 1$, *equilibria at* $\theta = 0$ *will be stable.*

(ii) If $\frac{C}{X} = 1$, *equilibria at* $\theta = 0$ *will be stable if* $\frac{Y}{X} \leq 1$.

Proof: (i) If $\frac{C}{X} > 1$, *then* $x_c + P_{cc} < x_t + P_{tc}$, *so no consumer has an incentive to buy a truck, and the equilibrium is stable.*

(ii) If $\frac{C}{X} = 1$, *then consumers are indifferent between trucks and cars at* $\theta = 0$. *Consider a small* $\varepsilon > 0$ *and a fleet mix* ε. *A fleet mix with more trucks than* ε *will be preferred if* $\varepsilon(P_{ct} - P_{cc}) > \varepsilon(P_{tt} - P_{tc})$. *Rearranging and eliminating* ε *gives the condition* $P_{ct} - P_{tt} > P_{cc} - P_{tc}$, *which simplifies to* $\frac{Y}{X} > 1$. *Thus, the equilibrium is unstable if* $\frac{Y}{X} > 1$ *and stable if* $\frac{Y}{X} \leq 1.\|$

Lemma 3 (Existence of all-truck equilibria) *Equilibria with* $\theta = 1$ *can only exist if* $\frac{Y}{X} \geq \frac{C}{X}$.

Proof: For an equilibrium in which all consumers drive trucks to exist, trucks must be preferred to cars when $\theta = 1$. *From equation (1), this implies that* $x_c + P_{ct} \geq x_t + P_{tt}$. *Rearranging gives* $P_{ct} - P_{tt} \geq x_t - x_c$ *and* $Y \geq C$. *Hence,* $\frac{Y}{X} \geq \frac{C}{X}.\|$

Lemma 4 (Stability of all-truck equilibria) *(i) If* $\frac{Y}{X} > \frac{C}{X}$, *equilibria at* $\theta = 1$ *will be stable.*

(ii) If $\frac{Y}{X} = \frac{C}{X}$, *equilibria at* $\theta = 1$ *will be stable if* $\frac{Y}{X} \leq 1$.

Proof: (i) If $\frac{Y}{X} > \frac{C}{X}$, then $x_c + P_{ct} > x_t + P_{tt}$, so no consumer has an incentive to buy a car, and the equilibrium is stable.

(ii) If $\frac{Y}{X} = \frac{C}{X}$, then consumers are indifferent between trucks and cars at $\theta = 1$. Consider a small $\varepsilon > 0$ and a fleet mix $(1-\varepsilon)$. A fleet mix with less trucks than $(1-\varepsilon)$ will be preferred if $-\varepsilon(P_{ct} - P_{cc}) < -\varepsilon(P_{tt} - P_{tc})$. Rearranging and eliminating ε gives the condition $P_{ct} - P_{tt} > P_{cc} - P_{tc}$, which simplifies to $\frac{Y}{X} > 1$. Thus, the equilibrium is unstable if $\frac{Y}{X} > 1$ and stable if $\frac{Y}{X} \leq 1$.$\|$

Lemma 5 (Stability of interior equilibria) *Interior equilibria will be stable if $\frac{Y}{X} \leq 1$.*

Proof: To see whether an interior equilibrium $\theta \in (0,1)$ is stable, consider small $\varepsilon > 0$ and a fleet mix $(\theta + \varepsilon)$. A fleet mix with more trucks than $\theta + \varepsilon$ will be preferred if $\varepsilon(P_{ct} - P_{cc}) > \varepsilon(P_{tt} - P_{tc})$. Rearranging and eliminating ε gives the condition $P_{ct} - P_{tt} > P_{cc} - P_{tc}$, which simplifies to $\frac{Y}{X} > 1$. Similarly, a fleet mix with less trucks than $\theta - \varepsilon$ will be preferred if $-\varepsilon(P_{ct} - P_{cc}) < -\varepsilon(P_{tt} - P_{tc})$, and this condition also simplifies to $\frac{Y}{X} > 1$. Thus, interior equilibria will be stable if $\frac{Y}{X} \leq 1$.$\|$

These lemmas and the relative values of C,X, and Y can then be used to demonstrate the existence and stability of equilibria in each of the seven parameter spaces.

Region 1. If $1 > \frac{C}{X} > \frac{Y}{X}$ then a solution to (3), $\theta \in (0,1)$ exists, so an interior equilibrium is possible. By Lemma 5, this equilibrium is stable, as $\frac{Y}{X} < 1$. By Lemmas 1 and 3, corner solutions can not exist.

Region 2. If $\frac{Y}{X} > \frac{C}{X}$ then no solution to (3) exists in $(0,1)$, and no interior equilibrium is possible. If $\frac{Y}{X} = \frac{C}{X}$, $\theta = 1$ solves (3) and no interior equilibrium is possible. By Lemma 1, no all-car equilibrium can exist. By Lemmas 3 and 4, the all-truck equilibrium exists and is stable.

Region 3. If $\frac{C}{X} \geq 1 > \frac{Y}{X}$ or $\frac{C}{X} > \frac{Y}{X} \geq 1$, then no solution to (3) exists in $(0, 1)$, and no interior equilibrium is possible. By Lemmas 1 and 2, the all-car equilibrium exists and is stable. By Lemma 3, no all-truck equilibrium exists.

Region 4. If $\frac{Y}{X} > \frac{C}{X} > 1$ then a solution to (3) exists in $(0, 1)$, so an interior equilibrium is possible. By Lemma 5, this equilibrium is unstable. By Lemmas 1 and 2, the all-car equilibrium exists and is stable. By Lemmas 3 and 4, the all-truck equilibrium exists and is stable.

Region 5. If $\frac{Y}{X} = \frac{C}{X} > 1$ then no solution to (3) exists in $(0, 1)$, so an interior equilibrium is not possible. By Lemma 3 and (3), an equilibrium with $\theta = 1$ exists, but by Lemma 4, it is not stable. By Lemmas 1 and 2, the all-car equilibrium exists and is stable.

Region 6. If $\frac{Y}{X} > \frac{C}{X} = 1$ then no solution to (3) exists in $(0, 1)$, so an interior equilibrium is not possible. By Lemma 1 and (3), an equilibrium with $\theta = 0$ exists, but by Lemma 2, it is not stable. By Lemmas 3 and 4, the all-truck equilibrium exists and is stable.

Region 7. If $\frac{Y}{X} = \frac{C}{X} = 1$, the system is indeterminate and every value of $\theta \in [0, 1]$ is an equilibrium.