Greening transportation fleets: Insights from a two-stage game theoretic model

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Abstract

The greening of organizational transportation fleets, especially trucks and automobiles, has gained increasing attention by companies in a variety of industrial sectors. The reasons for this concern and attention are due to regulatory and competitive pressures, but also increasing costs of fossil-fuels. Surprisingly, the amount of research and modeling for fleet management overall has been rather limited, with the focus on managing green vehicle investments virtually non-existent. In this study, we develop a two-stage game theoretic model that helps evaluate, from both policy and organizational perspectives, the implications of greening of transportation fleets. Various parameters are evaluated including factors such as innovations in green vehicle technology, levels of service differences, cost of fuel, adjusting tax policy, regulatory compliance requirements, and adaptation costs. This evaluation provides practical insights into actions that could be considered by regulators and organizations to encourage environmental investments.

1. Introduction

Within organizations, transportation and distribution activities are major contributors to environmental degradation and resource consumption. The emissions from transportation vehicles and related organizational activities contribute to air emissions that can cause local (smog), regional (acid rain), and global (climate change) environmental implications (Calef and Goble, 2007; Orsato and Wells, 2007). In addition, energy resource consumption from transportation activities by organizations in logistics and transportation industries result in some of their largest operational expenses. Most of these deliveries and logistics activities utilize energy produced by petroleum that is a very volatile commodity whose available inventory as a natural resource is rapidly depleting (Bakhtiari, 2004; Jeffers, 1978; Meng and Bentley, 2008). As environmental concerns are increasingly attracting attention from the public, a widespread adoption of a clean-technology for delivery vehicles has been of critical importance for the practitioners in this industry.

Many alternative energy-based vehicle designs, compared to traditional internal combustion engines, exist including full electric vehicles (MacCready, 2004), hydrogen/fuel cell vehicles (Lovins and Cramer, 2004; Sperling and Ogden, 2004), internal combustion/electric hybrids (Demirdoven and Deutch, 2004), biofuels (Rostrup-Nielsen, 2005), and compressed natural gas (MacLean and Lave, 2003). Each of these technologies has their strengths and weaknesses on various dimensions such as operational performance, environmental, and economic dimensions.
Recent significant developments in consideration and adoption of alternative energy vehicles, especially electric/internal combustion engine hybrids, have started to occur among companies in a wide variety of companies and industries. Some examples include logistics and delivery services such as UPS (Gallagher, 2007) and FedEx (Birchall, 2006); retail giant Wal-Mart (Birchall, 2006); telecommunications and utilities such as AT&T (Energy Resource, 2008) and Verizon (Wireless News, 2008); large and small beverage companies such as Coca-Cola (Cioletti, 2008), Pepsi (Deierlein, 2007) and VinLux Fine Wine (Mele, 2008); and even companies within the forestry (Fleet Equipment, 2007) and banking industries (Carr, 2007). Even though some of these companies have trucking and transportation fleets that number in the tens of thousands, most are only considering to adopt or adopting dozens of vehicles. Thus, there is ample room to grow in the adoption of these vehicles, but careful competitive, strategic and operational considerations must be made. Also, guidance, support and encouragement from policy makers and regulators may provide different environmental contexts for the adoption of these types of vehicles.

In this paper, we will investigate how external policies and internal organizational decisions play a role in these environmentally oriented investment decisions, such as greening transportation fleets for organizations, using a two stage game theoretical framework. The specific problem we consider in this paper focuses on determination of the level of hybrid or alternative energy delivery fleet for a logistics and transportation company. We construct a model of self-selection with heterogeneous consumers who value the firm’s delivery service along two dimensions: the quality of delivery service and the relative reduction in emissions (a proxy for environmental performance). In this framework firms choose the adoption level and the percentage of their fleet that should be ‘green’, in the first stage, and the optimal level of price in the second stage. We consider an asymmetry between the firms by initially crediting high quality delivery service for one firm when compared to a competing firm with a focus on their formation choice of their fleet. This high-low delivery service quality difference is treated as an exogeneity; this situation not only reflects the fact that firms generally have different market shares in equilibrium, but it is also useful for investigation of insightful propositions which cannot be drawn from a symmetrical model.

The main contribution of this study is an in-depth examination of the role of strategic interactions between firms in terms green technology adoption. The optimal adoption rate for each firm depends on the balance between the benefits (increase in demand and reduction in fuel cost and government penalties) and the cost (increase in adaptation cost). An increase in adaptation rate also has two important countervailing strategic effects on competitiveness in pricing at stage two: The first product differentiation effect will enlarge the gap between the adaptation rate, which reduces price competition at stage two; the second cost reduction effect will increase price competition.

After presenting the model and solving for equilibrium conditions, we provide some exemplary and illustrative results of the effects of the change in important organizational and policy parameters. These parameter scenario analyses provide additional insights for organizational and regulatory policy issues, which can then be used for evaluation and justification of alternative decisions facing investments in environmentally oriented transportation technology, specifically alternative energy transportation vehicles and/or technology. We conclude with an overview summary and possible extensions to this work.

### 2. Regulatory and organizational evaluation of environmental innovation

To exemplify some of the nuances of environmentally-oriented organizational decisions for transportation fleet management let us consider the case of FedEx, one of the leading organizations in developing and adopting an alternative energy, hybrid transportation fleet. Environmental Defense and FedEx had been collaborating to source a new generation of delivery trucks since 2000, which was expected to bring a huge improvement in fuel efficiency and pollution emission. As a reasonable course of this collaboration, FedEx joined forces with manufacturers to develop the necessary technology for its trucks and purchased a number of clean, relatively energy efficient trucks, known as hybrid delivery fleet. The multiple partnerships involved technological supporting groups, like Eaton Corporation (transmission technology) and Freightliner (chassis technology). Environmental Defense estimated that for every 10,000 conventional FedEx delivery trucks, which cause serious environmental and health damages through diesel exhaust, replaced by cleaner hybrids, pollution reduction of 2000 tons per year would occur. Moreover, diesel fuel usage would be reduced by 6.5 million gallons per year bringing significant benefits to the organization, according to the estimate. A study prepared for the Texas Council on Environmental Technology (TCET) estimated that the future price of diesel electric hybrid trucks would be 30% higher than that of the conventional ones if the production reaches to the mature stage, while the maintenance cost would be 10% lower through electric power supplements. These estimated results occurred even before the costs of petroleum more than doubled in more recent years.

The decision for adoption of these types of alternative energy and hybrid vehicles may bring improved environmental performance for the benefit of society. But it is expected that this adoption contributes to additional financial burdens for organizations, in some areas, on initial investment, operational, and maintenance costs, especially over a short time span.

An organizational justification issue now arises based on these tradeoffs. What benefit could be accrued for organizations where they would be willing to adopt a short-term cost burden from this environmentally oriented investment strategy of greening their transportation fleets? This is where organizations need to make the ‘business case’ for these types of investment. Making the business case for environmentally sound practices is not always a trivial decision (Presley and Sarkis, 1994; Presley et al., 2007). The business case involves both operational and strategic costs and benefits that need to be

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integrated into an evaluation. The difficulty with environmental issues and concerns are the many possible scenarios, both competitively and regulatory based that can effect the organization’s decisions.

There are at least two broadly-defined alternative ways of approaching this problem; one is related to issues of responding to governmental and regulatory behavior on environmental issues, and the other is concerning the firm’s long run, competitive perspective. Regulators are consistently under pressure by their constituencies to introduce frameworks and policies for reducing the level of the environmental damage caused by organizational production processes, products and activities. The policy frameworks may include a variety of instruments but can generally be grouped to include ‘carrots’, as well as ‘sticks’ (Meyer, 1999; Kassinis and Vafeas, 2006). That is, governmental regulators could provide subsidies for R&D projects designed for a reduction of the pollution level, or give tax and price incentives for a spread of emission-free equipment and facilities (Frondel et al., 2008), the carrot approach. Regulators may also specify a standard for a maximum level of environmental damage or tax a firm that contributes to these negative externalities, the stick approach. For example, in California, policymakers used a “technology-forcing approach,” setting ambitious goals such as zero emission vehicles, established strict deadlines and issued penalties for non-compliance. In France similar regulations, albeit more flexibly oriented, were also introduced to increase the use of hybrid and low-emission vehicles (Calef and Goble, 2007). These behaviors of governments will generally impose certain responses from a firm related to their own internal environmental issues and policies.

The second possible way of evaluating and addressing the issue of organizational investment in green technologies such as environmentally oriented vehicles, may come from consideration of a firm’s long run competitive stance (Berchicci and King, 2007; Rugman and Verbeke, 1998; Sarkis and Cordeiro, 2009). A firm may pursue investments regardless of whether there is short term loss, which usually occurs because of other competitive reasons that may not be easily quantifiable such as an environmentally-friendly public image as a very important asset for success in its future businesses (Konar and Cohen, 2001). The benefits of a good public image may come through various sources like a firm’s savings in advertisement cost, relatively high willingness to pay for its products from the consumers, and productivity increases from a higher morale of workers (Lyon and Maxwell, 2008; Mahenc, 2008; Miles and Covins, 2000). Given the cost and benefit of adopting an environment-friendly new technology or new equipment, we might ask what will happen to the optimal level of adoption if there is a change in the circumstances in which a firm is doing business. For instance, how would the optimal level of adoption change if governments move towards ‘carrots’ rather than ‘sticks’? Which would be more effective for increasing the optimal level, an R&D subsidy or price subsidy on new equipment? These and other issues have been of concern, but have not really been fully considered in the research literature, especially with respect to the issue of organizational investment in greening their transportation fleets. Also, even though the recognition of the importance of operations research tools to environmental management problems has some history (e.g. Allett, 1986; Jeffers, 1978; Lenihan, 1986; Somerville, 1986; Sarkis and Cordeiro, 2009), the visibility and application of these tools has been relatively limited (Midgley and Reynolds, 2001). The applications to specific organizational investments and adoption of practices, especially within a transportation investment perspective, are virtually non-existent. We begin to address this issue and gaps in the research with the models and experimentation in this paper.


For our model development we initially consider a duopoly model with vertical differentiated products (Mussa and Rosen, 1978). In this duopoly game two firms (A and B) offer transportation logistics, distribution, and delivery service to potential customers. Their services are differentiated with respect to the quality of delivery service (i.e., delivery time, reliability, customer service, etc) and environmentally-friendly deliveries (which require new investment in transportation equipment) (i.e., reduction in the relative ratio of emissions). In this paper, we assume a fixed quality of delivery service $\gamma_j$ ($j = A, B$) since our focus will be on decisions facing a firm’s greening of its transportation fleet. The delivery fleet of each firm, initially, consists of $T$ traditional trucks (i.e., diesel powered trucks) which emit pollutant $\Theta$ per truck (we assume that each delivery requires one truck). Therefore, the level of total emissions equals $\Theta \cdot T$. Each firm is assumed to have an option to replace its old trucks with environment-friendly trucks (i.e., hybrid or green trucks) with improved fuel efficiency and environmental performance, lessened emissions. If firm $j$ adopts the new greener trucks, the new formation of its fleet becomes $T = O_j + N_j$ where the number of old trucks and new trucks are denoted by $O_j$ and $N_j$ respectively. This replacement decision carries a trade-off in the sense that each replacement improves fuel efficiency and environmental performance at the expenses of new procurement cost and infrastructure requirement. Therefore, the delivery firms choose their optimal numbers of new trucks carefully balancing these factors.

We now introduce the aspect of improved environmental performance into our model. Compared to the level of per-truck emissions of the old truck $\Theta$, the green truck is assumed to reduce its emission level by $x \cdot \Theta$ where the parameter $x$ captures the technological efficiency of reducing emissions with $x \in [0, 1]$.

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3 They analyzed the optimal choice of quality and price of a monopoly in a quality-differentiated product spectrum and compared it to the competitive market outcome. The model of vertical differentiation within a duopoly setting was first developed by Gabszewicz and Thisse (1979, 1980) and Shaked and Sutton (1982, 1983). The main focus of these models was the optimal strategic choice of qualities for competing producers in a two-stage game framework: the quality choices of the firms were followed by price competition at the second stage. Our primary interest in this paper is in explaining how environmentally oriented investment decisions affect firms’ optimal choice of quality and price and thus the degree of competition. To the best of our knowledge, greening transportation fleets in the duopoly framework with vertical differentiated products has not been analyzed.
Given the choice of an adoption level of the new greener trucks \((N_j)\), the level of total emission is equal to \(\Theta_0 + (1 - \alpha)\Theta N_j\), which becomes \(\Theta(T - N_j) + (1 - \alpha)\Theta N_j\). For computational convenience, we assume that the ratio of new greener trucks \(\left(\frac{N_j}{N} = n_j\right)\) with \(T\) normalized to 1 as a choice variable in the first stage of the game. We assume that the government (local or national) regulatory policy requires that firms deliver items in an environment-friendly to comply the maximum level of emissions, denoted by \(\Theta\). For notational simplicity, we define the relative measure of the level of emissions by \(\theta = \Theta / \Theta\), with \(\theta \in [1, \infty)\). Note here that with this definition, a tougher government regulation would imply \(\Theta \downarrow \Rightarrow \theta \uparrow\), and a more lax governmental regulation would dictate \(\Theta \uparrow \Rightarrow \theta \downarrow\).

In the framework of vertical differentiation it is assumed that customers are heterogeneous in their marginal benefit of delivery service and environmental expectations, which is denoted by \(\nu\). For example, \(\nu\) can be a measure of a marginal impact on its public image when it uses more environmentally efficient delivery service. The differentiation in customer expectations from an environmental expectations perspective is well studied in the green marketing literature (Ginsberg and Bloom, 2004). Consumers have been studied and grouped into those that are extremely environmentally conscious ‘true-blue’ greens to those that are apathetic or ‘grouses’ or ‘basic browns’ (Doane, 2005). Organizational environmental sensitivity of organizations will drive industrial markets and is also dependent on various stakeholder pressures that they may face from their customers, their supply chains, and regulatory forces (Zhu and Sarkis, 2006). Given these practical industrial situations and market differences, we assume there is a population of customers whose total number is equal to \(m\) and that each customer \(i\) buys at most one unit service from delivery firms. For simplicity, we assume that a uniform distribution of customer types and their marginal benefits is given by \(\nu_i \sim U[0,1]\). We assume that some consumers, which include industrial customers, will appreciate a firm’s endeavors to contribute to cleaner air and other environmental benefits of greener vehicles. Thus, consumer’s expected valuation with respect to environmental performance is given by \(\nu \cdot n_j\), and hence \(s_j = \gamma_j + \nu \cdot n_j\), where \(s_j\) denotes the sum of the quality of delivery service and the relative reduction in emissions. Using this setup, the net utility for a customer with \(\nu_i\) can be represented as (1):

\[
u_i \equiv \mathcal{S} + s_j \nu_i - p_j = \mathcal{S} + \left[\gamma_j + \nu \cdot n_j\right] \nu_i - p_j
\]

for a given price \(p_j\) and a formation of the delivery fleet \((O_j, N_j)\) with \(j = \{A, B\}\). Here we assume that an organization’s decision to lower pollution emissions related to its delivery service by employing greener trucks is recognized and acknowledged by consumers exactly to the extent it lowers these emissions by adopting a greener transportation fleet. In this paper, note that the emission reduction is a voluntary activity since each firm is assumed to be endowed with a minimum quality level of delivery service \(s\), large enough to cover the market.\(^4\)

Adoption of green technology also affects fuel efficiency and the cost structure associated with vehicle investment, operation and maintenance. We begin by defining the marginal cost of delivery by firm \(j\) as \(c\) per delivery, which can be reduced by \(\delta \cdot c\) when adopting \(n_j\) new greener trucks, or greening the organization’s transportation fleet, primarily from fuel cost savings. Therefore, the total energy fuel cost becomes \(C(n_j, q_j) = c(1 - n_j) + (1 - \delta)cn_j = c(1 - \delta n_j)q_j\), where \(q_j\) denotes firm \(j\)’s demand for its delivery service which will be derived explicitly in stage two. Adopting a new technology, however, will increase other costs. The procurement cost of new hybrid trucks, due to newer technology development costs and lessened infrastructure, will be higher than traditional trucks (Chan, 2002). Also there are adaptation costs for workers, retraining for the new technologies in the trucks, and facilities and infrastructure to support the new technology. A firm is assumed to pay \(\mu\) more per new greener truck (annually calculated) which measures an extra cost a firm should pay in excess of comparable traditional trucks. Also the green trucks with new technology will incur maintenance and infrastructure costs (adaptation costs) to ensure green trucks operate properly, which is assumed to be an increasing convex function of the rate of adoption. This cost may be defined as \(l(n_j) = \mu n_j\), where \(\omega\) captures the marginal impact of the adaptation costs. These adaptation costs are assumed to have quadratic growth rates due to increasingly greater risks associated with complete adaptation of a technology that may not succeed. In addition, there may be step function growth in costs as increased capacity requirements may cause a significant in-house investment when a critical mass of vehicles are purchased, a quadratic function (maintaining a continuous relationship) would model this costs structure more effectively than a linear function.\(^5\)

Finally, we introduce a government or regulatory penalty cost to make environmental regulation compliance binding for a firm’s decisions. Note that when \(\theta < \frac{1}{T^2}\), the emission level of a new greener truck passes a set of governmental regulations: \(\frac{T}{2} < \frac{T}{2} \Rightarrow \frac{\Theta}{\Theta} \leq \frac{\Theta}{\Theta}\) and the total pollution level is \(\Theta(\Theta - \Theta)O_j\). On the other hand, when green technology is not efficient enough to meet the regulations with \(\theta \geq \frac{1}{T^2}\) the total emission level becomes \((\Theta - \Theta)O_j + (1 - \alpha)\theta \Theta \Theta)N_j\). Therefore, the penalty cost may exhibit two different cases depending on the values of parameters as shown in expression (2).

\[
F(n_j, q_j) = \begin{cases} 
\tau[(\theta - 1)(1 - n_j) + ((1 - \alpha)(\theta - 1)n_j] \cdot q_j = \tau[(\theta - 1 - \alpha n_j) \cdot q_j & \text{if } \theta \geq \frac{1}{T^2} \\
\tau[(\theta - 1)(1 - n_j) + ((1 - \alpha)(\theta - 1)n_j] \cdot q_j = \tau[(\theta - 1)(1 - n_j)] \cdot q_j & \text{if } \theta < \frac{1}{T^2}
\end{cases}
\]


\(^5\) The adaptation cost can be viewed in a similar context as the cost of quality development in the literature on vertical quality differentiation. Most of the analysis in this area has modelled quadratic investment cost for existence and uniqueness of equilibrium and see, for example, Motta, 1993; Herguera et al., 2000).
where \( \tau \) is the marginal rate of tax charged on the relative level of pollution emissions. Combining all of these costs, we derive the total cost function (3).

\[
TC(n_j, q_j) = C(n_j, q_j) + F(n_j, q_j) + I(n_j)
\]

(3)

4. Solving for equilibrium in the two-stage game

To help solve the adoption problem we consider a two-stage game with the following stages:

**Stage one**: Each delivery service firm (A and B) chooses \( n_j \) for its formation of the green transportation fleet \( (O_j, N_j) \) to improve fuel efficiency and environmental performance.

**Stage two**: Each firm chooses its price \( (p_j) \) to maximize its profit.

Using specifications for consumer preference, green technology, cost functions and government regulations, each firm’s objective is to maximize its profit with respect to its decision variables in each stage. Profit functions of each firm are shown to be concave for the decision variables, thus the first-order conditions are used throughout to characterize the optimality of the decision variables. To find the Subgame Perfect Nash equilibrium (SPNE), we begin with period two. Fig. 1 summarizes the computational steps and parameters for the two-stage game.

4.1. Stage two: price competition with given adoption rate

In stage two, with given quality levels \((s_A, s_B)\), which is determined by \((n_A, n_B)\) in stage one, the two firms \((A \text{ and } B)\) compete for customers in terms of pricing. Even though there are pricing expectations, it is assumed that due to competitive reasons the environmental performance expectations are at a minimal level or higher in this green environment competitive market. When customers make their purchase decision, they choose the option that yields the highest net utility. We consider the case of \( s_A = s_B \), without loss of generality, where firm \( A \) is competing primarily on maintaining higher environmental performance/image than its competitors and firm \( B \) will have the option to further improve its environmental performance or further compete on pricing. In this case, a customer’s optimal choice between products or companies for a given price and environmental performance level can be divided as follows:

\[
\begin{align*}
\frac{p_A - p_B}{\sigma(n_A - n_B) + (\gamma_A - \gamma_B)} & \leq \nu \quad \text{purchase product from Firm A} \\
\nu < \frac{p_A - p_B}{\sigma(n_A - n_B) + (\gamma_A - \gamma_B)} & \quad \text{purchase product from Firm B}
\end{align*}
\]

Thus, for a given price and environmental performance level, there will be a customer with environmental performance expectations denoted by \( \nu \) that is indifferent between buying a transportation or logistics service from firm \( A \) and \( B \) if \( \xi = [\gamma_A + \sigma(n_A)]\nu - p_A = [\gamma_B + \sigma(n_B)]\nu - p_B \).

This feature of the self-selection choice of customers between companies is shown in Fig. 2.

Each firm’s product demand then can be described as

\[
q_A = m(1 - \nu) = m \left( 1 - \frac{(p_A - p_B)}{\sigma(n_A - n_B) + (\gamma_A - \gamma_B)} \right) \quad \text{and} \quad q_B = m\nu = m\frac{(p_A - p_B)}{\sigma(n_A - n_B) + (\gamma_A - \gamma_B)}.
\]

(4)

Given the cost function described above, each firm determines the price of delivery service by taking into account the adaptation rates determined in stage one and the competition from the other firm. Firm \( j \) maximizes its profit by

\[
\max_{p_j} \pi_j = p_j q_j - C(n_j, q_j) - F(n_j, q_j) - I(n_j).
\]

(5)

From the concavity of the objective functions, we determine the best response functions from the simultaneous solution of the first-order conditions for \( p_j \). By solving each team’s profit maximization problem, we derive the best response, price \( (p^r) \) and market share \((q^r)\) as functions of \((n_A, n_B)^6\):

\[
p_A(n_A, n_B) = \begin{cases} 
\frac{1}{2} \left[ 3(c + (\theta - 1)\tau) - 2(\delta c + \sigma(\tau - 1))n_A - (\delta c + 2\sigma(1 + 2\tau))n_B + 2(\gamma_A - \gamma_B) \right] & \text{if } \theta \leq \frac{1}{1-2}, \\
\frac{1}{2} \left[ 3(c + (\theta - 1)\tau) - 2(\delta c + \sigma(\tau - 1))n_A - (\delta c + 2\sigma(1 + 2\tau))n_B + 2(\gamma_A - \gamma_B) \right] & \text{if } \theta \geq \frac{1}{1-2},
\end{cases}
\]

(6a)

\[
p_B(n_A, n_B) = \begin{cases} 
\frac{1}{2} \left[ 3(c + (\theta - 1)\tau) - (\delta c + \sigma(\tau - 1))n_A - (2\delta c + \sigma(1 + 2\tau))n_B + (\gamma_A - \gamma_B) \right] & \text{if } \theta \leq \frac{1}{1-2}, \\
\frac{1}{2} \left[ 3(c + (\theta - 1)\tau) + (\delta c + \sigma(1 + \theta))n_A - (2\delta c + \sigma(1 + 2\tau))n_B + (\gamma_A - \gamma_B) \right] & \text{if } \theta \geq \frac{1}{1-2},
\end{cases}
\]

(6b)

\(^6\) For profit function (5) to be concave in \( p_j \), it should satisfy the conditions \( \frac{\partial^2 \pi_j}{\partial p_j^2} < 0 \). It can be easily shown that we have \( \frac{\partial^2 \pi_j}{\partial p_j^2} = -2m/\sigma(n_A - n_B) + (\gamma_A - \gamma_B) < 0 \).
Parameters:
c: unit fuel cost
m: population of consumers
α: environmental performance
γ: firm j’s delivery service quality
δ: fuel efficiency
θ: government regulation on the relative level of emissions
μ, ω: the adaptation cost
τ: penalty rate

Firm j’s choice variables:
nj: green technology adoption rate
pj: price for delivery service

Other variables:
πj: profit function of firm j
qj: market share of firm j

Stage One: competition for adoption of green technology
The first order conditions:
\[ \frac{\partial \pi_j}{\partial n_j} = 0 \]
\[ \frac{\partial \pi_j}{\partial \alpha} = 0 \]

The equilibrium values:
\[ (n_j^*, \alpha^*, \gamma_j^*, \delta, \theta, \mu, \tau, \omega) \]

Stage Two: price competition given \((n_j, n_p)\)
The first order conditions:
\[ \frac{\partial \pi_j}{\partial p_j} = 0 \]
\[ \frac{\partial \pi_j}{\partial \gamma_j} = 0 \]

The best responses:
\[ p_j^*(n_j, n_p) \]
\[ p_j^*(n_j^*, n_p^*) \]
We have \( q_j^*(n_j, n_p) \) and \( \pi_j^*(n_j, n_p) \).

Comparative Statics (numerical simulations)
Measure response of the equilibrium values \((p_j^*, p_j, n_j^*, n_j^*)\) to a marginal change in parameters 
\((c, m, \alpha, \gamma_j, \delta, \theta, \mu, \tau, \omega)\)

By backward induction

Fig. 1. Computational steps and parameters for the two-stage game.

Fig. 2. Customer’s quality choice/perception ranges and utility values.
Thus we set \( \theta \geq \frac{1}{1 - \gamma} \), and
\[
q_A(n_A, n_B) = \begin{cases} 
\frac{m(c + 2\theta(1 + \tau) + 2\theta|\gamma - \gamma_B|)}{2(m(n_A - n_B) + |\gamma - \gamma_B|)} & \text{if } \theta \geq \frac{1}{1 - \gamma}, \\
\frac{m(c + 2\theta + 2\theta|\gamma - \gamma_B|)}{2(m(n_A - n_B) + |\gamma - \gamma_B|)} & \text{if } \theta \leq \frac{1}{1 - \gamma},
\end{cases}
\]
and
\[
q_B(n_A, n_B) = \begin{cases} 
\frac{m(c + 2\theta(1 - \tau) + 2\theta|\gamma - \gamma_B|)}{2(m(n_A - n_B) + |\gamma - \gamma_B|)} & \text{if } \theta \geq \frac{1}{1 - \gamma}, \\
\frac{m(c + 2\theta + 2\theta|\gamma - \gamma_B|)}{2(m(n_A - n_B) + |\gamma - \gamma_B|)} & \text{if } \theta \leq \frac{1}{1 - \gamma},
\end{cases}
\]

The corresponding best response profits are as follows:
\[
\pi_A^*(n_A, n_B) = \begin{cases} 
\frac{m(c + 2\theta(1 + \tau) + 2\theta|\gamma - \gamma_B|)}{2(m(n_A - n_B) + |\gamma - \gamma_B|)} - \mu n_A - \omega n_A^2 & \text{if } \theta \geq \frac{1}{1 - \gamma}, \\
\frac{m(c + 2\theta + 2\theta|\gamma - \gamma_B|)}{2(m(n_A - n_B) + |\gamma - \gamma_B|)} - \mu n_A - \omega n_A^2 & \text{if } \theta \leq \frac{1}{1 - \gamma},
\end{cases}
\]
and
\[
\pi_B^*(n_A, n_B) = \begin{cases} 
\frac{m(c + 2\theta(1 - \tau) + 2\theta|\gamma - \gamma_B|)}{2(m(n_A - n_B) + |\gamma - \gamma_B|)} - \mu n_B - \omega n_B^2 & \text{if } \theta \geq \frac{1}{1 - \gamma}, \\
\frac{m(c + 2\theta + 2\theta|\gamma - \gamma_B|)}{2(m(n_A - n_B) + |\gamma - \gamma_B|)} - \mu n_B - \omega n_B^2 & \text{if } \theta \leq \frac{1}{1 - \gamma}.
\end{cases}
\]

With the covered market assumption we focus on the case where the both firms have positive market share when 
\(-m\frac{c + 2\theta + 2\theta|\gamma - \gamma_B|}{2(m(n_A - n_B) + |\gamma - \gamma_B|)} < (n_A - n_B) < m\frac{c + 2\theta + 2\theta|\gamma - \gamma_B|}{2(m(n_A - n_B) + |\gamma - \gamma_B|)}
which means that the quality gap in terms of adapting green technology is not too small [big] so that one firm dominates the other.

4.2. Stage one: choice of environment-friendly quality investment and quality level

At stage one, we now turn to firm \( j \)’s optimal choice on its transportation fleet formation. The objective is to simply maximize equation with respect to \( n_j \), which yields the following necessary first-order conditions:
\[
\frac{dn_j^*}{dn_j} = \begin{cases} 
\frac{1}{2}(4\omega^2 + 4\theta^2)(1 + \tau) - 9\mu - 12\omega n_A & \text{if } \theta \geq \frac{1}{1 - \gamma}, \\
-\frac{\omega^2(1 - \delta n_A)^2 + 2\theta(1 - \delta n_A)(1 - n_A)}{2(m(n_A - n_B) + |\gamma - \gamma_B|)} = 0 & \text{if } \theta \leq \frac{1}{1 - \gamma},
\end{cases}
\]
and
\[
\frac{dn_j^*}{dn_j} = \begin{cases} 
\frac{1}{2}(4\omega^2 + 4\theta^2) - 9\mu - 12\omega n_B & \text{if } \theta \geq \frac{1}{1 - \gamma}, \\
\frac{\omega^2(1 - \delta n_B)^2 + 2\theta(1 - \delta n_B)(1 - n_B)}{2(m(n_A - n_B) + |\gamma - \gamma_B|)} = 0 & \text{if } \theta \leq \frac{1}{1 - \gamma},
\end{cases}
\]

The optimal adaptation rates of green fleet are determined by strategic interactions between the two firms specified by Eqs. (9a) and (9b). By solving these equations simultaneously the closed form solutions are presented in appendix. The optimal adaptation rate can then be used to compute the price, demand, and profits.

5. Empirical investigation and discussion

To understand the decision mechanism of the firms and the results from the equilibrium of this game, we execute some numerical analyses using a simulation method. In this empirical analysis, we compare the effects on the decision variables (adoption level of new greener trucks by firms \( A \) and \( B \), \( n_A, n_B \)) and profit \( P_A, P_B \) of the exogenous parameters, \( \alpha \) (a marginal increase in environmental performance), \( c \) (unit fuel cost), \( \delta \) (factor of marginal increase in fuel efficiency), \( \tau \) (marginal increase of government regulation on the relative level of emissions), \( \mu \) (new technology procurement cost), \( \gamma_A, \gamma_B \) (the quality gap between firms’ delivery services), and \( \tau \) (marginal tax rate on pollution emissions).

In this two stage duopoly game, it is important for a meaningful simulation to have an interior solution as a benchmark case. At first, we approach this task by approximating some of the parameter values to those of the real world (see Lane and Macleod, 2002). We choose who compare the environmental and fuel efficiency evaluation between a Toyota Prius and Corolla). Thus we set \( \alpha = .15 (\alpha = .3) \) and \( \delta = .1 \). Other parameters like \( c, \tau, \gamma_A, \gamma_B \) are initially set to 1 without loss of generality.

7 We realize that there may be a difference for larger vehicles and trucks, but based on available data and analyses from existing commercial vehicles, our ranges are reasonable for the purpose of our initial analyses. Clearly, variations on these parameters can be completed in future studies.
market share (interestingly, will benefit both firms, leading to higher profits. But the first mover will tend to get a slightly larger sales or

\[ \frac{p_A}{p_B} > 0 \text{, } \frac{q_A}{q_B} > 0 \]

('+' represents direct relationship between increase in row element and intersecting column element, a '-' represents an inverse relationship, '0' means no relationship).

Since \( n_1 \) is assumed to be less than 1 (it is expressed as a relative ratio to \( T \)), the optimal value of \( n_1 \) is more sensitive to \( \mu \), rather than \( \omega \). It was also sensitive to \( m \) (the total population of consumers). We initially fixed \( m \) first, then found \( \omega \) and \( \mu \), for an interior solution satisfying \( 0 < n_1 < 1 \), where \( n_A > n_B \). A relatively stable initial equilibrium solution\(^8\) was provided by \( \omega = 300, \mu = 5 \).

After finding a reasonable numerical instance of an equilibrium solution, we completed a simulation that is stable around this local equilibrium. The results were relatively robust and stable. Since we are more interested in the direction of the changes of decision variables affected by a change in exogenous parameters, we completed a simulation centering on this initial equilibrium as a benchmark. The following simulation results show equilibrium changes from this initial equilibrium, given changes in a specific parameter concerned. By this method, we could derive some insightful observations concerning key policy and organizational decision issues.

5.1. Basic results

We initially frame the competitive situation with firm \( A \) producing a qualitatively better product and service and adopting higher levels of green technology, and thus we identify it as the first mover. By the same token, let's call firm \( B \) the late comer or laggard. Table 1 summarizes the results.

<table>
<thead>
<tr>
<th>Increase in</th>
<th>Cases</th>
<th>( n_A )</th>
<th>( n_B )</th>
<th>( p_A )</th>
<th>( p_B )</th>
<th>( q_A )</th>
<th>( q_B )</th>
<th>( \pi_A )</th>
<th>( \pi_B )</th>
<th>( n_A + n_B )</th>
<th>( n_A/n_B )</th>
<th>( p_A/p_B )</th>
<th>( q_A/q_B )</th>
<th>( \pi_A/\pi_B )</th>
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<tr>
<td>( x )</td>
<td>( \theta \geq 1/(1-x) )</td>
<td>(+)</td>
<td>(+)</td>
<td>(-)</td>
<td>(-)</td>
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<td>( \theta \leq 1/(1-x) )</td>
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<tr>
<td>( c )</td>
<td>( \theta \geq 1/(1-x) )</td>
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<td>( \theta \leq 1/(1-x) )</td>
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<tr>
<td>( \theta \leq 1/(1-x) )</td>
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</tr>
<tr>
<td>( \tau )</td>
<td>( \theta \geq 1/(1-x) )</td>
<td>(+)</td>
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<tr>
<td>( \theta \leq 1/(1-x) )</td>
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</tr>
</tbody>
</table>

\(^8\) To determine well-behaved interior solutions without discontinuous jumps or kinks in the optimal price and \( n \), we find these values of parameters after a large number of calculations.

5.1.1. Result 1 (the effect of the improvement in green technology)

Our first situation is to focus on the efficiency of the green technology (\( x \)) through improved engines, motors, drive trains, battery power, or even weight of vehicle with fewer emissions. Let us assume that the technology may improve and reduces pollution emission at greater rates. As seen in Table 2 we increase the value of \( x \) from .125 to .35. When \( \theta \leq 1/(1-x) \), the first mover firm \( A \) in this case will increase the adoption rate \((n_A^*)\), while the laggard, firm \( B \) will slightly decrease it \((n_B^*)\). But in total, this change will induce more adoption in the industry (i.e., \( n_A + n_B \) increases). Both firms will tend to set higher prices \((p_A^* \text{ and } p_B^*)\), but the price competition will be less intense, as firm \( A \) becomes more aggressive in raising its price. This result, interestingly, will benefit both firms, leading to higher profits. But the first mover will tend to get a slightly larger sales or market share \((q_A^*)\) and become the larger beneficiary of the improved environmental efficiencies. This is an interesting case in the sense that with improved green technology, both firms will gain by widening environmental performance \((n_A^*/n_B^*)\) and price differences. Of course, as prices go up, customers will ultimately have to pay. The intuition behind this is follows. The product differentiation effect dominates the cost reduction effect. On the other hand, we observe the opposite happens when \( \theta \geq 1/(1-x) \) with dominant cost reduction effect increases price competition.

5.1.2. Result 2 (the effect of fuel cost)

As energy cost (i.e., gas prices) increases, both firms will increase their adoption rates of greener transportation fleets by making a larger percentage of their vehicles greener. Yet, the late comer firm \( B \) will be more aggressive in its adoption, see Table 3. Hence, the relative ratio of adoption rate \((n_A^*/n_B^*)\) will decrease. Both firms would set higher prices, but the price competition becomes more intense, since the late comer will increase their price faster. Nonetheless, the first mover will
ultimately gain since its market share and profit will be larger. Clearly, economic forces will play a much larger role in getting organizations to adopt these greener vehicles.

5.1.3. Result 3 (the effect of energy efficiency improvement)

As the new greener truck becomes more efficient in energy usage (i.e., higher $\delta$) both firms will increase their adoption rate, as shown in Table 4. The price gap lowers since firm $A$ will decrease its price at a faster rate. Both companies will tend to decrease their prices. As price competition in the market increases, firm $A$ will ultimately gain market, while firm $B$ will lose market share. Major winners in this scenario are customers who will gain through improved prices and price competition. As a result, cost savings are passed on to them.
5.1.4. Result 4 (the effect of tougher regulatory policy on emission levels)

As the regulators ratchet up standards, lowering levels of emissions, (i.e., higher $\theta$), both firms would increase the adoption level (Table 5, $n_1$ and $n_2$). Firm A, the environmental leading first mover firm, adopts at a faster rate as emissions regulations tighten. The prices charged customers will tend to increase for both companies ($p_A$ and $p_B$). Firm A will charge higher prices at an increasing rate, as seen in the increase in the price gap ($p_A/p_B$). Interestingly, the market will further differentiate on environmental performance, causing firm A to ultimately gain with higher market share and profit.

5.1.5. Result 5 (the effect of initial quality difference in service)

We now consider what happens when operational quality differences in terms of delivery and service occur between the two firms (i.e., larger $\gamma_A - \gamma_B$). As the difference in quality increases (see Table 6), Firm B, the laggard in adoption of green vehicles, becomes more aggressive in adopting the green vehicles, increasing its percentage of green vehicles in its transportation fleet, other things being equal. Firm A, the first mover and the firm providing better quality service, will actually lower the adoption rate as the initial difference in quality becomes larger. This result decreases the gap between the two firms adoption of the new greener trucks. Interestingly, the overall adoption rate of the green vehicles ($n_A + n_B$) does not change for both firms. Prices for both firms will increase, but the effect of initial quality differences and investments made in them will dominate as firm A will increase price faster than firm B, resulting in a wider price gap. Both firms will benefit by this change (profits will increase), but the late comer will benefit more since it gets a slightly higher market share ($q_A/q_B$) and faster increase in profit ($\pi_A/\pi_B$). This is a case where a shift in operations strategy to a quality oriented competition may benefit both firms, while it hurts customers through higher prices. We also note that Firm A, as a leading firm in environmental areas, tends to invest less in an environmentally sound transportation fleet as this shift to quality competition increases. The lagging company Firm B shifts to an environmental focus, realizing that it cannot compete as effectively on operational and quality measures. Firm A will lose some of its market share to Firm B within this situation.

5.1.6. Result 6 (the effect of adaptation costs)

As the expected adaptation costs increase (i.e., larger $\omega_1$), both firms will decrease the adoption of new technology, but the first mover, Firm A will decrease at a faster rate (see Table 7). Prices will go up, but the price gap will become slightly wider since firm A will be faster in setting higher prices. Firm B will ultimately gain a larger market share and higher profit, i.e., as the cost of adoption due to adaptation costs for supporting systems becomes higher, the first mover advantage backfires.

5.1.7. Result 7 (the effect of marginal tax rate on pollution emission)

As the government charges more penalties on a firm's violation of emission standards, both firms will increase greening their transportation fleets (Table 8). In this situation the late comer will complete this greening at a faster rate. Prices set by both firms will tend to increase but the price gap will lessen as firm B's price increases at a higher rate. The intensified price competition will be beneficial to firm A as their environmental leadership position will allow them acquire more market share and higher profit. In this scenario, all other factors being equal, Firm B, the laggard company will lose. The first mover definitely will be at an advantage.

5.2. Discussion of results

5.2.1. Policy and organizational implication 1: Pollution standards vs. taxation

To improve the environmental quality, the government can use two different policies. One is to tighten the pollution standards, and the other is to tax the violation more severely. Essentially, this approach is based on either command-and-control

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Table 5
Numerical analysis with respect to a marginal increase on government regulation on the relative level of emissions ($\theta$) (with $m = 1000, x = 1, c = 1, \gamma_A = 2, \gamma_B = 1, k = 1, \mu = 5, \omega = 300, \tau = 1$).

<table>
<thead>
<tr>
<th>$\theta$</th>
<th>$n_1$</th>
<th>$n_2$</th>
<th>$p_A$</th>
<th>$p_B$</th>
<th>$q_A$</th>
<th>$q_B$</th>
<th>$\pi_A$</th>
<th>$\pi_B$</th>
<th>$n_A + n_B$</th>
<th>$p_A/p_B$</th>
<th>$q_A/q_B$</th>
<th>$\pi_A/\pi_B$</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>0.140</td>
<td>0.010</td>
<td>1.666</td>
<td>1.332</td>
<td>670.963</td>
<td>329.037</td>
<td>449.464</td>
<td>109.602</td>
<td>0.150</td>
<td>14.447</td>
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<td>2.039</td>
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<td>1.1</td>
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<td>1.747</td>
<td>1.419</td>
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<td>453.385</td>
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<td>0.267</td>
<td>5.236</td>
<td>1.231</td>
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<td>1.843</td>
<td>1.516</td>
<td>680.954</td>
<td>319.046</td>
<td>455.266</td>
<td>103.313</td>
<td>0.294</td>
<td>5.202</td>
<td>1.215</td>
<td>2.134</td>
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<td>0.049</td>
<td>1.941</td>
<td>1.615</td>
<td>682.599</td>
<td>317.401</td>
<td>457.143</td>
<td>102.583</td>
<td>0.311</td>
<td>5.380</td>
<td>1.202</td>
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</tr>
<tr>
<td>1.4</td>
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<td>0.050</td>
<td>2.039</td>
<td>1.714</td>
<td>684.327</td>
<td>315.673</td>
<td>458.248</td>
<td>101.828</td>
<td>0.328</td>
<td>5.556</td>
<td>1.190</td>
<td>2.168</td>
</tr>
<tr>
<td>1.5</td>
<td>0.293</td>
<td>0.051</td>
<td>2.138</td>
<td>1.812</td>
<td>686.135</td>
<td>313.865</td>
<td>460.609</td>
<td>101.047</td>
<td>0.344</td>
<td>5.732</td>
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<td>0.052</td>
<td>2.236</td>
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<td>311.976</td>
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<td>310.010</td>
<td>464.828</td>
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<td>97.692</td>
<td>0.411</td>
<td>6.438</td>
<td>1.146</td>
<td>2.270</td>
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</table>

* Numbers with bold represent the optimal values under inefficient green technology (i.e., $\theta > 1/(1 - \alpha)$).
or market based mechanism approaches. In this two stage quality-price competition model, both policies will help to increase the adoption rate of green technology by increasing the percentage of new greener trucks adopted for an organizational delivery fleet. These policies also increase the prices for the organizational services (and hence are detrimental to customers). But, some differences do exist. First, with tighter regulatory standards, the first mover organization will move faster, increasing adoption rates for greener transportation fleets at higher rates. More severe tax regulations will cause faster adoption rates for environmentally-friendly fleets for the late comer in adoption. In other words, a tighter regulation on standards will induce more response from the first mover in adoption rate, while a strengthened tax regulation will influence the late comer more sensitively. The implication for policy makers is relatively clear here, if they wish to get organizations that have lagged in their implementation of green vehicles, then taxing emissions may provide a more effective adoption strategy.

Table 6
Numerical analysis with respect to a marginal increase on the quality gap between firms' delivery services (γ₁ - γ₂).

<table>
<thead>
<tr>
<th>γ₁ - γ₂</th>
<th>nₐ₁</th>
<th>nₐ₂</th>
<th>pₐ₁</th>
<th>pₐ₂</th>
<th>q₁</th>
<th>q₂</th>
<th>π₁</th>
<th>π₂</th>
<th>nₐ₁ + nₐ₂</th>
<th>nₐ₁/nₐ₂</th>
<th>pₐ₁/pₐ₂</th>
<th>q₁/q₂</th>
<th>π₁/π₂</th>
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<td>A. Inefficient green technology (i.e., θ ≥ 1/(1-x)) with m = 1000</td>
<td>0.15</td>
<td>0.47248</td>
<td>0.419444</td>
<td>6.52841</td>
<td>0.12</td>
<td>1/50</td>
<td>1/50</td>
<td>1/50</td>
<td>1/50</td>
<td>1/50</td>
<td>1/50</td>
<td>1/50</td>
<td>1/50</td>
</tr>
<tr>
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<td>0.53673</td>
<td>0.0557149</td>
<td>1.9297</td>
<td>1.60663</td>
<td>695.239</td>
<td>304.761</td>
<td>470.88</td>
<td>97.2483</td>
<td>0.419444</td>
<td>6.52841</td>
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<td>1/50</td>
<td>1/50</td>
</tr>
<tr>
<td>0.5</td>
<td>0.3577</td>
<td>0.0617242</td>
<td>3.26206</td>
<td>2.27192</td>
<td>687.186</td>
<td>323.814</td>
<td>375.89</td>
<td>319.168</td>
<td>0.419444</td>
<td>5.79547</td>
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<td>2.08819</td>
<td>2.45448</td>
</tr>
<tr>
<td>B. Efficient green technology (i.e., θ ≤ 1/(1-x)) with m = 1000</td>
<td>0.15</td>
<td>0.47248</td>
<td>0.419444</td>
<td>6.52841</td>
<td>0.12</td>
<td>1/50</td>
<td>1/50</td>
<td>1/50</td>
<td>1/50</td>
<td>1/50</td>
<td>1/50</td>
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<tr>
<td>0.2</td>
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<td>0.12</td>
<td>1/50</td>
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<td>1.43581</td>
<td>2.08819</td>
<td>2.45448</td>
</tr>
</tbody>
</table>

* Numbers with bold represent the optimal values under inefficient green technology (i.e., θ > 1/(1-x)).

Table 7
Numerical analysis with respect to a marginal increase on the adoption cost (ω).

<table>
<thead>
<tr>
<th>ω</th>
<th>nₐ₁</th>
<th>nₐ₂</th>
<th>pₐ₁</th>
<th>pₐ₂</th>
<th>q₁</th>
<th>q₂</th>
<th>π₁</th>
<th>π₂</th>
<th>nₐ₁ + nₐ₂</th>
<th>nₐ₁/nₐ₂</th>
<th>pₐ₁/pₐ₂</th>
<th>q₁/q₂</th>
<th>π₁/π₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Inefficient green technology (i.e., θ ≥ 1/(1-x)) with m = 1000</td>
<td>0.15</td>
<td>0.47248</td>
<td>0.419444</td>
<td>6.52841</td>
<td>0.12</td>
<td>1/50</td>
<td>1/50</td>
<td>1/50</td>
<td>1/50</td>
<td>1/50</td>
<td>1/50</td>
<td>1/50</td>
<td>1/50</td>
</tr>
<tr>
<td>0.2</td>
<td>0.53673</td>
<td>0.0557149</td>
<td>1.9297</td>
<td>1.60663</td>
<td>695.239</td>
<td>304.761</td>
<td>470.88</td>
<td>97.2483</td>
<td>0.419444</td>
<td>6.52841</td>
<td>0.12</td>
<td>1/50</td>
<td>1/50</td>
</tr>
<tr>
<td>0.5</td>
<td>0.3577</td>
<td>0.0617242</td>
<td>3.26206</td>
<td>2.27192</td>
<td>687.186</td>
<td>323.814</td>
<td>375.89</td>
<td>319.168</td>
<td>0.419444</td>
<td>5.79547</td>
<td>1.43581</td>
<td>2.08819</td>
<td>2.45448</td>
</tr>
<tr>
<td>B. Efficient green technology (i.e., θ ≤ 1/(1-x)) with m = 1000</td>
<td>0.15</td>
<td>0.47248</td>
<td>0.419444</td>
<td>6.52841</td>
<td>0.12</td>
<td>1/50</td>
<td>1/50</td>
<td>1/50</td>
<td>1/50</td>
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<td>319.168</td>
<td>0.419444</td>
<td>5.79547</td>
<td>1.43581</td>
<td>2.08819</td>
<td>2.45448</td>
</tr>
</tbody>
</table>

* Numbers with bold represent the optimal values under inefficient green technology (i.e., θ > 1/(1-x)).

Table 8
Numerical analysis with respect to a marginal increase in penalty or tax rate (τ).

<table>
<thead>
<tr>
<th>τ</th>
<th>nₐ₁</th>
<th>nₐ₂</th>
<th>pₐ₁</th>
<th>pₐ₂</th>
<th>q₁</th>
<th>q₂</th>
<th>π₁</th>
<th>π₂</th>
<th>nₐ₁ + nₐ₂</th>
<th>nₐ₁/nₐ₂</th>
<th>pₐ₁/pₐ₂</th>
<th>q₁/q₂</th>
<th>π₁/π₂</th>
</tr>
</thead>
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<td>0.419444</td>
<td>6.52841</td>
<td>0.12</td>
<td>1/50</td>
<td>1/50</td>
<td>1/50</td>
<td>1/50</td>
<td>1/50</td>
<td>1/50</td>
<td>1/50</td>
<td>1/50</td>
</tr>
<tr>
<td>0.2</td>
<td>0.53673</td>
<td>0.0557149</td>
<td>1.9297</td>
<td>1.60663</td>
<td>695.239</td>
<td>304.761</td>
<td>470.88</td>
<td>97.2483</td>
<td>0.419444</td>
<td>6.52841</td>
<td>0.12</td>
<td>1/50</td>
<td>1/50</td>
</tr>
<tr>
<td>0.5</td>
<td>0.3577</td>
<td>0.0617242</td>
<td>3.26206</td>
<td>2.27192</td>
<td>687.186</td>
<td>323.814</td>
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<td>0.419444</td>
<td>5.79547</td>
<td>1.43581</td>
<td>2.08819</td>
<td>2.45448</td>
</tr>
<tr>
<td>B. Efficient green technology (i.e., θ ≤ 1/(1-x)) with m = 1000</td>
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<td>0.47248</td>
<td>0.419444</td>
<td>6.52841</td>
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</tr>
</tbody>
</table>

* Numbers with bold represent the optimal values under inefficient green technology (i.e., θ > 1/(1-x)).
Another issue here is that more restrictive regulatory standards will induce relatively faster increases in firm A’s price leading to a widened price gap. Tax regulation will drive firm B, the follower organization to raise prices more quickly resulting in a more intense price competition. Combined, both measures will induce higher adoption of green technology, but a tighter standards regulation will be more effective in this model setting. An organizational implication here is which policy the firm should support. In both regulatory cases, firm B tends to lose market share and profitability relative to firm A. But, using our ranges and scales, firm B’s market share \(q_B\) is decreasing at a faster rate under the more strict command and control policy (about a 5% difference), than under the penalties and taxes policies (about a 2% difference). In this situation, firm B, given that they will inevitably face one of these policies, may wish to lobby regulators for a tax on emissions rather than making more strict regulatory standards.

In summary, standards regulation is more effective for inducing greener fleets within industry, but can cause increased prices and widening the price gap. This means that there is greater differentiation in environmental strategy (environmentally-friendly fleet adoption) and price differences become more prevalent with lesser competition in price.

5.2.2. Policy implication 2: Direct cost subsidy vs. R&D subsidy

Governments can also provide some “carrots” rather than “sticks”. Here we compare two different methods of subsidizing the industry. First, the government may subsidize R&D endeavors leading to an increase in the efficiency of the technologies needed for green vehicles. In our model, this may be interpreted as an exogenous increase in \(z\). Second, governments may provide direct subsidies lightening the burden of the adjustment costs for an adoption. This effect may be reasoned through an exogenous decrease in \(\phi\) or \(\mu\) in our model. As already mentioned, direct subsidy on the adaptation cost will bring more adoption in both firms with larger rate of response in greening their transportation fleet from the first mover, firm A. Prices in this situation will be lowered by both firms. This is a larger drop in the price of firm A, with price competition becoming more intense. This situation will benefit firm A and cause firm B to be at a disadvantage. The effects of an R&D subsidy are more impressive in the sense that both firms benefit. The first mover will definitely respond positively, increasing both adoption rate and price, while the late comer does not respond favorably in this exercise; firm B will have a slightly lower the adoption rate, but will increase its price. In this situation firm B will choose a strategy to widen the environmental quality-price difference, to garner extra profit. This situation is good for firms, but bad for customers who seek lower prices; in this framework, a direct subsidy for adaptation will be more beneficial to customers since it will lower the price of the final product and service, while the R&D subsidy ultimately will push prices upward, though it will benefit firms. In sum, direct subsidies will be more effective for greening transportation fleets, and more beneficial to customers since it will lower the final price. Consumer advocate groups may wish to lobby for direct subsidies instead of R&D subsidies, where they can get better service, better environmental performance, and solid service.

6. Conclusion

Environmental concern is increasingly gaining weight in every industry throughout the world. One of the major areas that industry causes substantial environmental burden is in its transportation and logistics activities. A major factor in transportation and delivery environmental implications is the characteristics of the transportation fleets for organizations. Many organizations in a wide variety of industries have recognized that planning and managing their transportation fleets requires consideration of their environmental burden. Thus, there is an increasing awareness of and responses to the importance of greener vehicle technology and a few meaningful changes are in progress.

Firms are not playing competitive games in a vacuum and they are constantly under significant competitive pressures. For a meaningful understanding of this interaction and the resulting equilibrium behavior of firms, we analyzed the situation with the help of a quality-price two stage game theoretic model developed and used in economics literature. By applying the widely acknowledged solution concept of the model, we derived numerous insightful results. First, R&D subsidy, or investment, for basic technology development may be beneficial to organizations by increase firm profits, but it may occur at the expense of customers with higher prices charged. Of course these customers will benefit from improved environmental results from greener transportation fleets. Second, energy price shocks will help to induce a better response from the industry as a whole for an adoption of greener transportation technology. The resulting intensified price competition will put organizational late comers at a disadvantage. Third, as the energy saving aspect of alternative fuel and energy technologies becomes clearer, late comers will be more aggressive in adoption, leading to intensified price competition. This situation also will benefit customers through lowered final prices. Fourth, as the regulators become stricter in environmental regulations, overall industry will adopt greater amounts of greener vehicle technologies. Customers in this situation will face higher prices. The first mover will reap the gain from this government intervention in both cases, raising standards regulations will lead to more quality competition, while tax regulation is likely to induce more price competition. Fifth, subsidizing directly for adaptations costs related to the adoption of greener technology might induce better results in the sense that it will induce more adoption and lowered prices than R&D subsidies. Sixth, a wider initial quality difference in services and products will induce a greater response from late comer firms, which may be a larger percentage of firms overall, and be better for firms since it reduces price competition but with a general increase in prices.

These results are generated based on an initial equilibrium calculation we found with specific parameter values, which were presupposed outside the model. Therefore, there might be a problem of ‘status quo bias’ in the sense that the simula-
tion results are dependent on the initial equilibrium we selected. Additional sensitivity analysis varying parameters is required to detect further nuances. For example, the uniform distribution for demand may be simplistic. Accepted consumer market distributions need to be developed and may be different for various markets. Actual 'willingness' to pay also is an issue, even though some consumers (individual or industrial consumers) say that they will pay a green premium, the actual practice is that a smaller percentage tend to do so. In addition, a potential research direction is to expand the study to a three-stage game framework which would include the government's decision at the upper-level. An important parametric and model adjustment is to consider government regulatory implications for fleet size level considerations. Under evolving regulatory regimes, new policies focusing on emissions footprints of organizations can make a difference in selection of fleet environmental technology. For example, with the advent of "carbon trading" in some regions of the world, organizations may see fit to reduce their greenhouse gas emissions by reducing overall transportation fleet emissions. In this situation the organization's fleet size plays a greater role in the game theory model.

Overall, with the current model the qualitative results and insights from our current simulation show the capabilities of the game theoretic model here to provide some very robust analysis. Intuitively, we can safely state that the analysis does make sense.

Appendix A

The closed form solution of the optimal level of a green fleet is to solve Eqs. (9a) and (9b) simultaneously when \( \theta \geq \frac{1}{m^2} \). We first add Eqs. (9a) and (9b) so that we derive the following relationship of the overall adoption rate, \( A \):

\[
n_A' = A - \frac{2cm^4 \cdot dm - 2cmx + 2m(1 + 2m)}{6E^2} X
\]

By substituting \( \gamma = \gamma_A - \gamma_B \) into Eq. (9a) we have

\[
B - Xn_A - \frac{\Delta}{(\gamma + E(n_A - n_B))^2} = 0
\]

where \( B = c^2m^2 + 4cmx^2\theta + 4m^2x^2\theta^2 - 9x\theta + 2cmx^2\theta + 4mx^2\theta^2 + m^2x^2\theta^2 + \theta^2 \), \( X = -18x\theta + \Delta = m\gamma^2(\theta + x\theta)^2 \), and \( E = x\theta \).

When we solve Eqs. (A1) and (A2) together, we have the optimal level of the green fleet such as

\[
n_A' = A - \frac{1}{6E^2} X \left[ 2E(-BE + (\gamma + 2AE)X) + \frac{(E^2(2BE + (\gamma + 2AE)X)^2)}{\phi^{1/3}} + \phi^{1/3} \right]
\]

and

\[
n_B' = \frac{1}{6E^2} X \left[ 2E(-BE + (\gamma + 2AE)X) + \frac{(E^2(2BE + (\gamma + 2AE)X)^2)}{\phi^{1/3}} + \phi^{1/3} \right],
\]

where

\[
\phi = -8B^2E^4 + 12B^2E^5(-\gamma + AE)X + 27\Delta E^4X^2 - 6B^4(-\gamma + AE)^2X^2 - \gamma^2E^4X^3 + 3A^2E^4X^3 - 3A^2\gamma E^4X^3 + A^2E^4X^3 + 3\gamma X^3
\]

\[
\times \left[ \frac{\Delta E^2X^2}{-16B^3E^3 + 24B^3E^2(-\gamma + AE)X} \right]
\]

\[
\times \left[ \frac{X^2(27\Delta E - 2(-\gamma - AE)X)}{-12BE(-\gamma - AE)^2X^2 + X^2[27\Delta E - 2(-\gamma - AE)X]} \right]
\]

We first add Eqs. (9a) and (9b) when \( \theta \leq \frac{1}{m^2} \) so that we derive the following relationship of the overall adoption rate, \( I \), such that

\[
n_A' = I - n_B' \]

By substituting \( \gamma = \gamma_A - \gamma_B \) into Eq. (9a) we have

\[
H - Xn_A - \frac{1}{(\gamma + E(n_A - n_B))^2} = 0
\]

where \( H = c^2m^4 + 4cmx^2\theta + 4m^2x^2\theta^2 - 9x\theta + 2cm\theta + 2cm^2\theta^2 + m\theta^2 + m\theta^2\theta^2 \), \( X = -18x\theta \), \( I = m(c\gamma + \gamma(\theta - 1)^2) \), and \( E = x\theta \).

When we solve Eqs. (A3) and (A4) together, we have the optimal level for a green fleet:

\[
n_A' = I - \frac{1}{6E^2} X \left[ 2E(-BE + (\gamma + 2I)E)X + \frac{(E^2(2BE + (\gamma - I)E)X)^2)}{\theta^{1/3}} + \theta^{1/3} \right]
\]
\[
\hat{n} = \frac{1}{6E\mathcal{X}} \left( 2E(-\mathcal{E} + (\gamma + 2IE)X) + \frac{(E^2(2EH + (\gamma - IE)X)^2)}{\hat{\vartheta}^{1/3}} + \hat{\vartheta}^{1/3} \right),
\]

where
\[
\hat{\vartheta} = -\gamma E^3X^3 - E^3(2H - IG)X^3 - 3\gamma E^2X(-2H + IG)X^2 + 3E^2X^2(9\gamma + \gamma^2(-2H + IG)) + 3\sqrt{3}
\]
\[
\times \sqrt{E^2(2H)^2(2\gamma)^2X^2 + 2E^2(2H - IG)X^3 + 6\gamma E^2X(-2H + IG)X^2 - 3EX^2(9\gamma + \gamma^2(-4H + 2IG))).
\]

References


Birchall, J., 2006. Giants of the road in drive to be green wal-mart follows Fedex in turning to hybrid power for its fleet. The Financial Times 19 (July), 19.


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