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A Market Analysis on Green Production Lines Penetrating into Original Equipment Manufacturers (OEMs)

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Abstract: Fierce market competition has been big obstacle in the growth process of sustainable/green production industry. Sustainable production lines often come into play by penetrating into traditional Original Equipment Manufacturers (OEMs). This is due to the high setup cost and opportunity risks. In this study, we look into the scenario when traditional Original Equipment Manufacturers (OEMs) introduce green production lines into their production systems. We want to address the questions whether and how the green production lines can survive in the market competitions. Analyses are conducted between ordinary and green production sectors which produce a similar type of product with different materials and techniques. A game theoretic model is formulated to analyze the competition in the market. Sensitivity analyses and numerical examples can provide suggestions to assist policy makers, government, company executives and consumers to make better and rational decisions.

Keywords: Market Competition, Original Equipment Manufacturers, Green Production, Game Theory Model, Sustainability.

1. Introduction

As the global awareness and concerns about the environment issues increase, many governments, regulatory organizations and business leaders have begun to call on the manufacturing and business community to play a leading role in the process of moving the global economy toward sustainability. At the same time, people from both academia and industry start to realize that there exists an intrinsic business value in the sustainability practices. However, fierce market competition and price sensitivity have been big obstacles in the development and growth of sustainable/green production industry. Therefore, green production lines are often initiated by penetrating into traditional Original Equipment Manufacturers (OEMs). This is due to the high setup cost and the embedded opportunity risks.

The concept of "sustainability" was first introduced in the Brundtland Report of the UN World Commission on Environment and Development in 1987 [WCED, 1987]. "Sustainability" is defined as "meeting the needs of the present without compromising the ability for the future generations to meet their needs." This definition includes environmental, economic, and social goals, in which it claims that long-term environmental protection requires appropriate economic development and society involvement. In the manufacturing sector, "sustainable manufacturing is defined as the creation of manufactured products that use processes that are non-polluting, conserve energy and natural resources, and are economically sound and safe for employees, communities, and consumers [sustainable manufacturing]". Therefore, sustainable manufacturing encompasses green manufacturing processes and the output of the production processes--sustainable products. Sustainable products often refer to those products which "providing environmental, social and economic benefits while protecting public health, welfare, and environment over their full commercial cycle, from the extraction of raw materials to final disposition [sustainable products]."

There has been extensive research done in the area of sustainable production and marketing, especially in the studies to understand how different societal sectors respond as new governmental regulations come up and the environmental awareness increases in the public domain. The trend nowadays is that more and more consumers start to realize the importance of incorporating environmental concerns into their consumption decision making processes. A recent market survey suggests that 52%-59% of private households in the United States would be willing to pay a price premium to buy electricity that was produced using renewable energy technology [1999]. M. Janssen and W. Jager [2002] utilized simulation methodology to study the introduction process of green products to the market. Kleindorfer, Singhal and Wassenhove [2005], in their paper, discuss the challenges of integrating environment, health and safety concerns into green product design. In addition, green operations management and closed-loop supply chains issues are addressed from a conceptual perspective in the paper.

Game theory has been one of the most popular methodologies in the study of market competition in the sustainability domain. K. Conrad [2005] carried out a study on market implications of product differentiation when there exists an environmentally conscious consumer sector. A spatial duopoly model is utilized to determine how the phenomenon affects the prices and market shares. Governments and regulatory organizations are also taking steps to achieve the goal of sustainable development. Two examples include green production subsidy and tax reduction imposed by the government. S. Bansal and S. Gangopadhyay [2003] studies two types of policies (tax based policy and subsidy based policy) in the presence of consumers who are concerned about the environmental issues. Chialin Chen [2001] developed a quality-based model for analyzing the strategic and policy issues concerning the development of products with conflicting traditional and environmental attributes. R. H. Wiser and S. J. Pickle [1998] studied the green electricity market by conducting market surveys in California (one of the four pioneer states that emphasize sustainable development). They conclude that consumer education is critical in the green industry development process and the growth of the green market, in a large extent, relies on the public policies.

In real life, the process of green products penetrating into the manufacturing/production sector and then into the competitive market often begins with introducing green production departments in the ordinary production companies, mostly Original Equipment Manufacturers (OEMs). For example, Toyota produces both conventional internal combustion engine cars, such as Corolla, Avalon, Camry and hybrid electric vehicle, such as Prius and Touring [Toyota Corporation].There is a lack of literature in this study, especially from the quantitative point of view. The objective of this paper is to understand the environment related decisions facing firms, consumers and policy makers, and how to help green products better survive in the market competition. This study can assist these stakeholders make better decisions to achieve the win-win situation from the entire societal perspective.

This study considers the market competition between green and ordinary production sectors from a quantitative point of view. A game theoretic model with Nash equilibrium is developed and analyzed. Managerial and business insights for policy maker and business leaders are derived from the analyses and computational results. The remainder of the paper is organized as follows: the game theoretical model is introduced in section 2, including the Cournot model and the Nash equilibrium. Sensitivity analyses of the model parameters are discussed in section 3, and the numerical examples with managerial insights are utilized to demonstrate the approach in section 4. This paper concludes with insights and suggestions to consumers, manufacturing and government sectors in section 5.

2. Model Formulation

Companies introduce green manufacturing sector either due to legislation or marketing considerations at the green production initiation stage. Many green companies would have a mixture of both green and ordinary production sectors in the same company. In this section, the game theory model to analyze the market competition between conventional and sustainable production sectors is introduced.

2.1 Scenario Description

Suppose there are s Original Equipment Manufacturers (OEMs) in the market. Each OEM has both conventional production department that uses ordinary materials and/or techniques, and sustainable production department that uses green techniques and/or materials for production. We are mainly considering the scenario where there are both green and ordinary production sectors in the same company. We call them green and ordinary production departments, respectively. The competition among these production departments is assumed to be Cournot, which means that the OEM companies independently and simultaneously determine their supply quantities of green and ordinary production in order to maximize their own profits.

Notations:

q_i^O : the supply quantity by an ordinary production departments *i;*

q_j^G : the supply quantity by a green production departments *j;*

Q^O: the total supply of ordinary products in the market, where $Q^O := \sum_{i=1}^{s} q_i^O$;

Q_{-i}^O: the total supply of ordinary products in the market excluding the supply from ordinary production departments i , where $Q_{-i}^O = Q^O - q_i^O$;

Q^G : the total supply of ordinary and green products, where $Q^G := \sum_{j=1}^{s} q_j^G$;

Q_{-j}^G: the total supply of green products in the market excluding the supply from green production departments j , where $Q_{-j}^G = Q^G - q_j^G$;

c^O , c^G : unit production costs of ordinary and green products, respectively;

p^O , p^G : prices (price consumers consider when they make their consumption choices, including their conception of long-term consumption price and effect on the environment) of ordinary and green products, respectively;

ρ^O , ρ^G : cash prices (price consumers pay upfront when they make their purchases) of ordinary and green products, respectively.

2.2 Model Assumptions

In the model formulation, the following assumptions are made:

- All ordinary companies have the same unit production cost c^O, and all green companies have the same unit production cost c^G.
- Prices of the ordinary and green products are determined by the inverse demand functions:

$$p^O = a - b(Q^O + \theta Q^G), \tag{1}$$

$$p^G = a - b(Q^G + \theta Q^O). \tag{2}$$

- In the demand functions, a and b are positive constants, and θ is the substitution parameter. The constant a bears the meaning of the upper bound price (the price is so high that no one will choose to consume it). The constant b is the unit price decrease of the product. The substitution parameter θ usually lies between 0 and 1. If the ordinary and green products are highly substitutable, then the value of θ is close to 1; if these products are distinct and non-substitutable, then the value of θ is close to 0. A negative value of θ indicates the complementarity of the products.
- Price p consists of two components: the cash price ρ and the long-term consumption price λ. For example, ρ is the cash price of a light bulb on the price tag, while λ is the long-term electricity consumption price of the light bulb.
- Besides economical long-term consumption price paid by the consumer directly, environmental effect price could also be considered into λ. This is due to the fact that when consumers make their consumption choices, they may consider whether it is good or bad for the environment. The environmental effect price is paid by the whole society in the long run.
- Consumers are assumed to take both the cash price ρ and the long-term price λ into account in their purchasing behavior.

2.3 Model Formulation and Nash Equilibrium

In the model formulation, each OEM company produces both ordinary and green products. We call them "hybrid" companies. Their decision problem is to determine how many of each type of products (green or ordinary) to produce in order to maximize their own profits.

Suppose there are *s* such "hybrid" companies in the market. Given the total quantities of ordinary and green products by other companies $Q_{-k}^O = \sum_{i=1}^{s} q_i^O - q_k^O$ and $Q_{-k}^G = \sum_{i=1}^{s} q_i^G - q_k^G$, the profit of company *k* is:

$$
\begin{aligned}
&\pi_k(q_k^O, q_k^G; Q_{-k}^O, Q_{-k}^G) \\
&= (\rho^O - c^O)q_k^O + (\rho^G - c^G)q_k^G \\
&= (p^O - \lambda^O - c^O)q_k^O + (p^G - \lambda^G - c^G)q_k^G \\
&= \left[a - b\left(q_k^O + Q_{-k}^O + \theta Q^G\right) - \lambda^O - c^O\right]q_k^O + \left[a - b\left(q_k^G + Q_{-k}^G + \theta Q^O\right) - \lambda^G - c^G\right]q_k^G \\
&= -b\left(q_k^O\right)^2 - b\left(q_k^G\right)^2 - 2b\theta q_k^O q_k^G + \left[a - b\left(Q_{-k}^O + \theta Q^G\right) - \lambda^O - c^O\right]q_k^O + \left[a - b\left(Q_{-k}^G + \theta Q^O\right) - \lambda^G - c^G\right]q_k^G
\end{aligned}
\tag{3}
$$

To obtain the best response of OEM company *k*, we set the first derivative of $\pi_k(q_k^O, q_k^G; Q_{-k}^O, Q_{-k}^G)$ to be zero:

$$
\begin{bmatrix} \dfrac{\partial \pi_k}{\partial q_k^O} \\[2ex] \dfrac{\partial \pi_k}{\partial q_k^G} \end{bmatrix} = \begin{bmatrix} a - \lambda^O - c^O - b(Q_{-k}^O + \theta Q_{-k}^G) \\ a - \lambda^G - c^G - b(Q_{-k}^G + \theta Q_{-k}^O) \end{bmatrix} - \begin{bmatrix} 2b & 2b\theta \\ 2b\theta & 2b \end{bmatrix} \begin{bmatrix} q_k^O \\ q_k^G \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}
\tag{4}
$$

Therefore, the best response of company *k* is:

$$
\begin{aligned}
\begin{bmatrix} (q_k^O)^* \\ (q_k^G)^* \end{bmatrix} &= \begin{bmatrix} 2b & 2b\theta \\ 2b\theta & 2b \end{bmatrix}^{-1} \begin{bmatrix} a - \lambda^O - c^O - b(Q_{-k}^O + \theta Q_{-k}^G) \\ a - \lambda^G - c^G - b(Q_{-k}^G + \theta Q_{-k}^O) \end{bmatrix} \\
&= \frac{1}{4b(1-\theta^2)} \begin{bmatrix} 2 & -2\theta \\ -2\theta & 2 \end{bmatrix} \begin{bmatrix} a - \lambda^O - c^O - b(Q_{-k}^O + \theta Q_{-k}^G) \\ a - \lambda^G - c^G - b(Q_{-k}^G + \theta Q_{-k}^O) \end{bmatrix}
\end{aligned}
\tag{5}
$$

To prove that this is the maximum rather than a saddle point, we can take the second derivatives:

$$
\frac{\partial^2 \pi_k}{\partial^2 (q_k^O)^2} = -2b < 0 \tag{6}
$$

$$
\frac{\partial^2 \pi_k}{\partial^2 (q_k^G)^2} = -2b < 0 \tag{7}
$$

$$
\frac{\partial^2 \pi_k}{\partial (q_k^G) \partial (q_k^O)} = -2b\theta \tag{8}
$$

$$\frac{\partial^2 \pi_k}{\partial (q_k^O)^2} \frac{\partial^2 \pi_k}{\partial (q_k^G)^2} - \left[\frac{\partial^2 \pi_k}{\partial (q_k^G) \partial (q_k^O)} \right]^2 = -4b^2 (1-\theta^2) < 0 \tag{9}$$

Under Cournot-Nash equilibrium, we have $(Q_{-k}^O)^* = (s-1)(q_k^O)^*$ and $(Q_{-k}^G)^* = (s-1)(q_k^G)^*$. Substituting these two equations into equation for the best response of company *k* above, we have the quantity supply under equilibrium:

$$\begin{aligned} \begin{bmatrix} (q_k^O)^* \\ (q_k^G)^* \end{bmatrix} &= \frac{1}{b(s+1)} \begin{bmatrix} 1 & \theta \\ \theta & 1 \end{bmatrix}^{-1} \begin{bmatrix} a-\lambda^O - c^O \\ a-\lambda^G - c^G \end{bmatrix} \\ &= \frac{1}{b(s+1)(1-\theta^2)} \begin{bmatrix} 1 & -\theta \\ -\theta & 1 \end{bmatrix} \begin{bmatrix} a-\lambda^O - c^O \\ a-\lambda^G - c^G \end{bmatrix} \\ \forall k &= 1, \cdots, s. \end{aligned} \tag{10}$$

3. Sensitivity Analysis

In this section, we analyze how sensitive the equilibrium is to the parameters: substitution factor parameter θ, green production cost c_G, long-term consumption price for green product λ_G and number of hybrid companies in the market *s*.

The market share of green products under Cournot-Nash equilibrium is defined as:

$$\begin{aligned} \beta^G &= \frac{(Q^G)^*}{(Q^G)^* + (Q^O)^*} \\ &= \frac{(q^G)^*}{(q^G)^* + (q^O)^*} \\ &= \frac{a-\lambda^G - c^G - \theta(a-\lambda^O - c^O)}{(1-\theta)(2a-\lambda^O - c^O - \lambda^G - c^G)} \end{aligned} \tag{11}$$

The methodology used to analyze the sensitivity of the equilibrium to the parameter is also by taking the partial derivatives of the market share with respect to the corresponding parameters.

3.1. Sensitivity of β^G to θ:

$$\begin{aligned}
\frac{\partial\beta^G}{\partial\theta} &= \frac{\partial}{\partial\theta}\left[\frac{a-\lambda^G-c^G-\theta(a-\lambda^O-c^O)}{(1-\theta)(2a-\lambda^O-c^O-\lambda^G-c^G)}\right] \\
&= \frac{-(a-\lambda^O-c^O)(1-\theta)(2a-\lambda^O-c^O-\lambda^G-c^G)}{[(1-\theta)(2a-\lambda^O-c^O-\lambda^G-c^G)]^2} \\
&\quad + \frac{(2a-\lambda^O-c^O-\lambda^G-c^G)[a-\lambda^G-c^G-\theta(a-\lambda^O-c^O)]}{[(1-\theta)(2a-\lambda^O-c^O-\lambda^G-c^G)]^2} \qquad (12) \\
&= \frac{-(a-\lambda^O-c^O)(1-\theta)+a-\lambda^G-c^G-\theta(a-\lambda^O-c^O)}{[(1-\theta)]^2(2a-\lambda^O-c^O-\lambda^G-c^G)} \\
&= \frac{\lambda^O+c^O-\lambda^G-c^G}{[(1-\theta)]^2(2a-\lambda^O-c^O-\lambda^G-c^G)}
\end{aligned}$$

If $\lambda^O + c^O < \lambda^G + c^G$, then $\frac{\partial\beta^G}{\partial\theta} < 0$. This is true in most cases nowadays since cost of green production is often significantly higher than ordinary ones.

Engineering and Managerial Insights:

As long as the sum of cost and long-term price of the green product exceeds that of the ordinary one, a smaller substitution parameter is beneficial to increase the green market share. This result reinforces the importance of a smaller θ, which will increase the market share of green products under dynamic equilibrium.

Distinguishing green products from ordinary ones will help the growth of green production sector. Toyota Prius is popular not only because of the hybrid feature, but also due to its unique appearance.

3.2. Sensitivity of β^G to c^G:

$$\begin{aligned}
\frac{\partial \beta^G}{\partial c^G} &= \frac{\partial}{\partial c^G}\left[\frac{a-\lambda^G-c^G-\theta(a-\lambda^O-c^O)}{(1-\theta)(2a-\lambda^O-c^O-\lambda^G-c^G)}\right] \\
&= \frac{-(1-\theta)(2a-\lambda^O-c^O-\lambda^G-c^G)}{[(1-\theta)(2a-\lambda^O-c^O-\lambda^G-c^G)]^2}+\frac{[a-\lambda^G-c^G-\theta(a-\lambda^O-c^O)](1-\theta)}{[(1-\theta)(2a-\lambda^O-c^O-\lambda^G-c^G)]^2} \\
&= \frac{-(2a-\lambda^O-c^O-\lambda^G-c^G)+[a-\lambda^G-c^G-\theta(a-\lambda^O-c^O)]}{(1-\theta)(2a-\lambda^O-c^O-\lambda^G-c^G)^2} \\
&= \frac{-(1+\theta)(a-\lambda^O-c^O)}{(1-\theta)(2a-\lambda^O-c^O-\lambda^G-c^G)^2}
\end{aligned} \tag{13}$$

Engineering and Managerial Insights:

Since $(1+\theta)>0$ and $a-\lambda^O-c^O>0$, therefore, $\frac{\partial \beta^G}{\partial c^G}<0$. Decreasing the green production cost can help the growth of green production industry.

- In the short run, this can be achieved by subsidy to green product manufacturers and tax credit or tax deduction to green product consumers. According to Richard A. Chapo [2006], for Toyota Prius, the tax credits that come with each purchase certainly add to their popularity.
- In the long run, green companies should take steps to improve the production technology to bring down the cost. Watanabe, one of Toyota's top executives, said, "we need to improve the production engineering and develop better technology in batteries, motors, and inverters, and my quest is to produce a third-generation Prius quickly and cheaply." [Taylor, 2006]

3.3. Sensitivity of β^G to λ^G:

$$\begin{aligned}\frac{\partial \beta^G}{\partial \lambda^G} &= \frac{\partial}{\partial \lambda^G}\left[\frac{a-\lambda^G-c^G-\theta(a-\lambda^O-c^O)}{(1-\theta)(2a-\lambda^O-c^O-\lambda^G-c^G)}\right] \\ &= \frac{-(1-\theta)(2a-\lambda^O-c^O-\lambda^G-c^G)}{[(1-\theta)(2a-\lambda^O-c^O-\lambda^G-c^G)]^2}+\frac{(1-\theta)[a-\lambda^G-c^G-\theta(a-\lambda^O-c^O)]}{[(1-\theta)(2a-\lambda^O-c^O-\lambda^G-c^G)]^2} \\ &= \frac{-(2a-\lambda^O-c^O-\lambda^G-c^G)+[a-\lambda^G-c^G-\theta(a-\lambda^O-c^O)]}{(1-\theta)(2a-\lambda^O-c^O-\lambda^G-c^G)^2} \\ &= \frac{-(1+\theta)(a-\lambda^O-c^O)}{(1-\theta)(2a-\lambda^O-c^O-\lambda^G-c^G)^2} < 0\end{aligned} \tag{14}$$

Engineering and Managerial Insights:

- Decreasing the long-term consumption price of green products will increase the market share under dynamic equilibrium.
- Public awareness effects are incorporated into the long-term consumption price. For example, the long-term consumption price for Toyota Prius includes the customer's impression of the gasoline cost over its driving lifetime as well as the negative effect (cost) to the environment.
- Educational programs to increase the public awareness will be very useful. This is because that decreasing the consumer's conception of long-term consumption price of green products is good for the green production.

3.4. Sensitivity of β^G to *s*:

$$\begin{aligned}\beta^G &= \frac{(Q^G)^*}{(Q^G)^*+(Q^O)^*} = \frac{(q^G)^*}{(q^G)^*+(q^O)^*} \\ &= \frac{a-\lambda^G-c^G-\theta(a-\lambda^O-c^O)}{(1-\theta)(2a-\lambda^O-c^O-\lambda^G-c^G)}\end{aligned} \tag{15}$$

As we can see, $\frac{\partial \beta^G}{\partial s} = 0$, therefore, a change in the number of companies in the market won't change the market equilibrium.

Engineering and Managerial Insights:

- The number of companies in the market will not affect the market share of green production industry. Therefore, a company entering and leaving the market won't affect the market equilibrium. This conclusion is conter-intuitive since the more companies in the market, the more competitions there exist, which should affect the market share of green production department.
- One explanation is that every company will produce same mixture of green and ordinary products at market equilibrium. They are assumed to be symmetric at market equilibrium. Therefore, what really affects the market share of green products is the percentage of green and ordinary production of each company at the equilibrium.

In order to further demonstrate and explain the results and conclusions in this section, numerical examples to demonstrate model formulation and analyses are presented in the following section.

4. Numerical Examples

In this section, we demonstrate and validate the model formulation with some numerical examples.

We consider a market where there are $n(=100)$ automobile companies which produce both ordinary cars (cars with conventional internal combustion engine) and green cars with little negative effect to the environment. Toyota Prius (a hybrid electric vehicle in the automobile market) is chosen as the green product while its counterpart as the ordinary product is the Toyota Corolla 2008.

Model parameters:

- Production cost and long-term consumption cost of ordinary product: we use the same product (Toyota Corolla 2008) as ordinary product in both models, therefore, these two parameters stay the same: $c^O = \$12{,}299$ and $\lambda^O = \$16{,}403$.
- Production cost of green product: hybrid electric vehicle is said to be far more expensive than the manufacturer's suggested price [Jones, 2003]. Due to the fact

that the hybrid electric vehicle production technology and sales has been improved a lot [Jerome, 2007 1], we assume that the production cost of Toyota Prius is same as its listed price which is \$21,760 [Toyota Corporation].

- Long-term consumption cost of green product: both gasoline costs and emission costs are calculated into the total long-term consumption cost term. The gasoline costs are based on a price of \$3/gallon. The local and highway combined fuel economy for Toyota Prius is 46 mpg [Toyota Corporation]. The lifetime driving is assumed to be 150,000 miles. The emission costs are calculated to be \$440 based on the study conducted by Lave and Maclean [2002]. Therefore, the long-term consumption cost $\lambda^G = \$10,223$.
- Demand function parameters are $a = 10(c^O + \lambda^O)$ and $b = 0.0001a$. Substitution parameter is set to be $\theta = 0.9$. This is due to the fact that HEV and ordinary cars are very similar in terms of functionality.

We study this numerical example by answering the following questions:

1. How do hybrid companies perform in the market competition?

The market equilibrium scenario which compares the green car (Toyota Prius) production and ordinary car (Toyota Corolla) production sectors is summarized in table 1.

Table 1 A comparison of ordinary and green car production sectors under market equilibrium

	Ordinary Sector (Toyota Corolla)	Green Sector (Toyota Prius)
Production of a single company	52.26→52	40.94→41
Market supply	5226	4094
Cost (\$)	12299	21760
Cash price (\$)	14857	24285
Long-term price (\$)	16403	10223
Profit of a single company (\$)	133660	103380
Market share	56.07%	43.93%

We see from Table 1 that the overall market share of green products is relatively low. However, comparing the current automobile market situation and the market equilibrium derived here, there is still room for growth in the green production industry. Therefore, the objective here is to find out how green production industry can better survive and occupy more market share. This is done by investigating some other scenarios when model parameters change.

2. How does production cost of the green product (Toyota Prius) c^G affect the dynamic equilibrium?

In this scenario, the cost of green products is reduced by 10% due to tax reduction, and the market equilibrium is summarized in Table 2:

Table 2 A summary of market equilibrium after 10% reduction of green production cost

	Ordinary Sector (Toyota Corolla)	Green Sector (Toyota Prius)
Production of a single company	48.71→49	44.89→45
Market supply	4871	4489
Cost ($)	12299	19584
Cash price ($)	14857	22131
Long-term price ($)	16403	10223
Profit of a single company ($)	124570	114330
Market share	52.04%	47.96%

As we can see from Table 2, under market equilibrium, the market share of Toyota Prius has increased by 4% when the production cost of Toyota Prius has decreased by 10%. This might not be feasible in the short run, however, tax credit or subsidy for consumers and manufacturers respectively can achieve this goal in the near future. This scenario demonstrates the effectiveness of subsidy/tax reduction for green companies.

3. How does long-term consumption price for a green product (Toyota Prius) λ^G affect the dynamic equilibrium?

In this scenario, we consider how the long-term consumption price affects the market competition and the dynamic equilibrium.

Nowadays, the long-term price advantage of green products over ordinary ones is under realized. For example, the consumers probably know that Toyota Prius is more expensive and will save gasoline consumption over the lifetime. However, they may not be aware Toyota Prius can save over $6,000 over its driving lifetime.

In this scenario, the long-term price advantage of green products (Toyota Prius) over ordinary counterparts (Toyota Corolla) is unrealized, and λ^G is incorrectly perceived to be 10% larger than its true value: $(\lambda^G)' = 110\% \cdot \lambda^G = \$11245$.

The dynamic equilibrium is summarized in Table 3:

Table 3 A summary of market equilibrium after 10% increase of long-term price for Prius

	Ordinary Sector (Toyota Corolla)	Green Sector (Toyota Prius)
Production of a single company	53.93→54	39.09→39
Market supply	5393	3909
Cost ($)	12299	21760
Cash price ($)	14857	24275
Long-term price ($)	16403	11245
Profit of a single company ($)	137930	98302
Market share	57.98%	42.02%

This scenario also demonstrates the importance of public awareness of the green products' economical and environmental advantage, since it is easier to achieve in the short run.

4. How does substitution parameter θ affect the market equilibrium?

Suppose the green companies further distinguish their products with $\theta = 0.8$. This could be accomplished by improving the design of the products, or by administrative requirement, or by increased public preference for green products. The resulting market equilibrium is summarized in Table 4:

Table 4 A summary of market equilibrium after substitution parameter θ reduced to 0.8

	Ordinary Sector (Toyota Corolla)	Green Sector (Toyota Prius)
Production of a single company	52.02→52	46.36→46
Market supply	5202	4636
Cost ($)	12299	21760
Cash price ($)	14857	24285
Long-term price ($)	16403	10223
Profit of a single company ($)	133050	117070
Market share	52.88%	47.12%

As we can see from the computational results, the decrease in the substitution parameter can lead to an increase in the market share for green product (Toyota Prius). These results further demonstrate the importance of reducing the substitution parameter.

5. Conclusions

In this paper, a game theoretic model is formulated to study the competitions between ordinary and green companies/manufacturing sectors which produce the similar/same type of products with different techniques and costs. The competition among the Original Equipment Manufacturers (OEMs) is assumed to be Cournot. Each company independently and simultaneously determines their supply quantities of green and ordinary products in order to maximize their own profits.

The Nash equilibrium for this game theory model is obtained. Sensitivity analysis is also used to study the possible actions that could be taken to help increase the market share of green products in the market. These results are demonstrated with numerical examples.

The engineering and managerial insights are summarized as follows.

1. Green manufacturing sectors need to distinguish their products from ordinary ones to gain competitive edges in the market.
2. Public awareness of the advantage of green products is important for the healthy growth of green manufacturing sectors in the companies.

3. Subsidy/tax reduction could help increase the market share of green products in the market.

In summary, to distinguish green products from their ordinary counterparts, to increase public awareness and to impose tax benefits are among the effective policies/methods to better help green production industry survive and thrive in the fierce market competition. The major contribution of study is that the game theory model formulation provides a new perspective to analyze the market competition between green and ordinary production sectors. The effects of the government and regulatory organizations interventions are considered, such as tax reduction/subsidy for green products, standard on carbon dioxide emission and education for public awareness. The sensitivity analyses address more realistic market scenarios and investigate how the market share is influenced by various decisions. The mathematical model can provide both engineering and managerial insights for the manufacturers, consumers and the government regulatory department.

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