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Effect of Investment Regulations and Subsidies on the Proliferation of Next Generation Vehicles in China

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We built a theoretical model of Bertrand competition among joint-venture automobile firms, and examined through numerical simulations the situations in which the Chinese government promotes either hybrid or electric vehicles. We took into account investment ratio regulations with regard to joint ventures and investigated the effects of investment regulations and subsidies that were considered part of environmental policy. Our results indicated that given the high manufacturing cost of electric vehicles and the high level of environmental damage caused by power generation, subsidies relating to hybrid vehicles lead to higher social welfare than those relating to electric vehicles.

Keywords: hybrid vehicles, electric vehicles, investment ratio regulation, subsidy

1. Introduction

Based on the emergence of global climate change and energy demand–supply issues, there is an increasing need for improvements vis-à-vis fuel consumption in vehicles, with respect to reductions in the CO_2 emissions from cars. Recently, in China, a proliferation of motorized transport has resulted from the country's remarkable economic development and growth. In 2009, China was number one in the world in terms of the production and sale of vehicles, surpassing the United States on a per-capita basis. In 2010, the annual number of vehicle sales in China surpassed 18.06 million units. The production of vehicles hit 18.26 million units in 2010, and both vehicle sales and production reached 18 million units by 2010 (China Automotive Technology and Research Center (CATRC), and China Association of Automotive Manufactures (CAAM)) [1, 2)]. In addition, the total number of vehicles in China was approximately 78.02 million units in 2010; it is expected to increase further. According to CATRC and CAAM[1)], the percentage of gasoline-powered vehicles is very high, compared to that of other types of vehicles. In China, next-generation vehicles such as electric vehicles have yet to gain widespread acceptance as private vehicles.

With the rapid growth of the automotive market in China, various problems—such as increase in vehicle fuel consumption, CO_2 emissions, and air pollution in big cities—have become serious issues. In addition, the trend of increasing CO_2 emissions implies that in the future, CO_2 emissions from electricity and vehicles in China will grow[7)]. It is thought that the promotion and widespread use of hybrid and electric vehicles will be effective in reducing CO_2 emissions and air pollution, on account of their advanced environmental technologies. According to the National Bureau of Statistics of China[8)], most power in China is generated by using coal, accounting for around 70% of all energy used in recent years; in terms of the total electricity supply, most of it consists of thermal power.

According to China's 12th Five-Year Plan, by 2011, 5% of newly produced vehicles will be new-energy vehicles, or those using next-generation technologies. However, in the field of new-energy vehicles, China is still lagging behind the world's advanced-technology standards; most existing Chinese technologies are still in experimental stages, and there have been few large-scale mass productions of such vehicles. Given the low quality of technology standards and the costs of infrastructure maintenance and new-energy vehicle introduction, is a national plan that aims to promote new-energy car use in China feasible? Although the use of energy-saving technologies and next-generation vehicles are expected to proliferate, and the introduction of electric vehicles has been promoted as a solution to climate change and energy demand–supply issues, will the widespread adoption of electric vehicles in China suffice in mitigating CO_2 emissions? Huo et al. (2010) have sought to answer such questions, but have focused exclusively on the costs (in terms of CO_2, SO_2 and NO_x emissions) of introducing electric vehicles (comparatively to gasoline hybrids and other conventional gasoline vehicles) in

China[6]. In this study, we take a different perspective.

The objective of this research is to consider and examine the present-day conditions of China's automotive industry and environmental–energy problems. We build a theoretical model to examine a situation in which the Chinese government promotes either electric vehicles or hybrid vehicles. Furthermore, we show the effects of investments (that is, technology transfers) and subsidies, both of which are considered components of the environmental–energy policy. Finally, we look to clarify the effects of investment ratio regulation on joint-venture firms. Studies on environmental regulations, policies, technological development and diffusion, have been conducted [3, 5, 9, 10]; however, we must note that it is possible for firms to acquire advanced technology from a foreign firm through the establishment of a joint venture, as a route of new-technology transfer or technological cooperation. Foreign firms, in entering the Chinese market, encounter governmental regulations with respect to foreign investment; for example, a joint venture with Chinese national companies is compulsory and a foreign investment percentage of less than 50% is mandatory. Therefore, while most previous studies do not consider the effects of investment ratio regulation on joint ventures, we analyze the effects using the Gangopadhyay and Gang (1994) model[4].

The structure of this paper is as follows. In Section 2, we build a theoretical model based on Bertrand competition among joint-venture firms. In Section 3, we present a numerical simulation analysis to investigate the effects of investments and subsidies. Finally, in Section 4, we provide concluding remarks.

2. Model

2.1 Assumptions

Let us start by explaining the basic assumptions inherent in the model. First, we consider a multi-stage game involving the price competition and technology transfer of foreign firms. Let us assume that two joint-venture firms supply differentiated goods. Foreign firms investing in the two joint-venture firms decide whether to provide an environmental–technology transfer (that is, investment). A foreign vehicle firm cannot enter the Chinese market without agreeing to joint management with a state-owned firm. In this model, two joint-venture firms and two investing foreign firms are considered as players. We assume that one joint-venture firm produces electric vehicles, and the other produces hybrid vehicles. We also assume that the government gives a subsidy to the Chinese consumer to support his/her purchase of a next-generation vehicle. Next-generation vehicles in China are produced through a joint venture with the foreign firm providing the necessary technology.

In this model, the action of each economic agent and the timing of the game are as follows:

Stage 0: The government decides the percentage of investment regulation and subsidy.
Stage 1: Foreign firms decide the amount of investment for technology transfer.
Stage 2: Joint-venture firms decide the price of the vehicles.

Given Stage 0, we analyze Stages 1 and 2.

2.2 The model's solution

2.2.1 Demand functions

In our study, we build a theoretical model and consider Bertrand competition where each joint-venture firm competes at a price for differentiated products (that is, vehicles). First, we set the demand function for the vehicles as follows:

$$x_1 = a - b\left(m_1 p_1 - \sqrt{e_1}\right) + \left(m_2 p_2 - \sqrt{e_2}\right), \quad (1)$$

$$x_2 = a - b\left(m_2 p_2 - \sqrt{e_2}\right) + \left(m_1 p_1 - \sqrt{e_1}\right), \quad (2)$$

where x_1 is the demand for electric vehicles and x_2 is the demand for hybrid vehicles. In Eqs. (1) and (2), m_1 and m_2 are the self-pay ratios for the purchase of electric and hybrid vehicles, respectively; therefore, $(1 - m_1)$ and $(1 - m_2)$ are the subsidy ratios for the vehicle purchases. Let p_1 and p_2 denote the vehicle prices and e_1 and e_2 denote the amounts of investment for technological development for the respective vehicle types. We assume that the marginal cost-reduction effects of e_1 and e_2 —which will be explained later—are gradually decreasing, and we specify them as the root of e_1 and e_2, respectively. Finally, a and b are parameters that describe the characteristics of the market[†].

Eqs. (1) and (2) show how the technology transfer affects consumer behaviors. The consumer's cost decreases when the technology transfer increases, because vehicles become more fuel-efficient. Inside the parentheses, m_1p_1 and m_2p_2 are the purchase prices of electric and hybrid vehicles, respectively; if the amount of investment increases, the fuel expenditure (that is, the electricity expense or gasoline cost) decreases. Thus, the consumer's total cost of driving decreases and the demand for vehicles increases. Moreover, an increase in a competitor's price (third term in Eq. (1)) leads to increased demand for electric vehicles.

2.2.2 Stage 2

We apply a backward induction to solve the game. First, we solve for the equilibrium of the Bertrand competition game in Stage 2, where each joint-venture firm competes at a price for vehicles. The joint-venture firms maximize the following profits, given e_1 and e_2 determined in Stage 1:

$$\pi_1 = (p_1 - c_1)x_1, \quad (3)$$

$$\pi_2 = (p_2 - c_2)x_2, \quad (4)$$

where π_1 and π_2 are the profits, and c_1 and c_2 are the marginal costs of a joint venture, for electric vehicles and hybrid vehicles, respectively. We assume that $c_1 > c_2$. In Eqs. (3) and (4), the profit function is derived as the income less the expenses. Using Eqs. (1) and (2), we have the following first-order conditions for the profit maximization of joint-venture firms:

$$\frac{\partial \pi_1}{\partial p_1} = a + bc_1m_1 + b\sqrt{e_1} + m_2p_2 - 2bm_1p_1 - \sqrt{e_2} = 0, \quad (5)$$

$$\frac{\partial \pi_2}{\partial p_2} = a + bc_2m_2 + b\sqrt{e_2} + m_1p_1 - 2bm_2p_2 - \sqrt{e_1} = 0. \quad (6)$$

From Eqs. (5) and (6), we have the following response functions:

$$p_1 = \frac{a + bc_1m_1 + b\sqrt{e_1} - \sqrt{e_2} + m_2p_2}{2bm_1}, \quad (7)$$

$$p_2 = \frac{a + bc_2m_2 + b\sqrt{e_2} - \sqrt{e_1} + m_1p_1}{2bm_2}. \quad (8)$$

From Eqs. (7) and (8), we obtain the Bertrand Nash equilibrium prices, as follows:

$$p_1^* = \frac{a + 2ab + 2b^2c_1m_1 + bc_2m_2 + (2b^2 - 1)\sqrt{e_1} - b\sqrt{e_2}}{(4b^2 - 1)m_1}, \quad (9)$$

$$p_2^* = \frac{a + 2ab + 2b^2c_2m_2 + bc_1m_1 + (2b^2 - 1)\sqrt{e_2} - b\sqrt{e_1}}{(4b^2 - 1)m_2}. \quad (10)$$

We assume that the response functions of the two joint-venture firms under Bertrand competition should satisfy the condition that the equilibrium price is larger than the marginal cost. In Figure 1, one example of the response functions is illustrated.

Substituting the values of the equilibrium prices into Eqs. (1) and (2), we derive x_1^* and x_2^* as the equilibrium production:

$$x_1^* = \frac{b\left(a + 2ab + c_1m_1 - 2b^2c_1m_1 + bc_2m_2 + (2b^2 - 1)\sqrt{e_1} - b\sqrt{e_2}\right)}{4b^2 - 1}, \quad (11)$$

$$x_2^* = \frac{b\left(a + 2ab + c_2m_2 - 2b^2c_2m_2 + bc_1m_1 + (2b^2 - 1)\sqrt{e_2} - b\sqrt{e_1}\right)}{4b^2 - 1}. \quad (12)$$

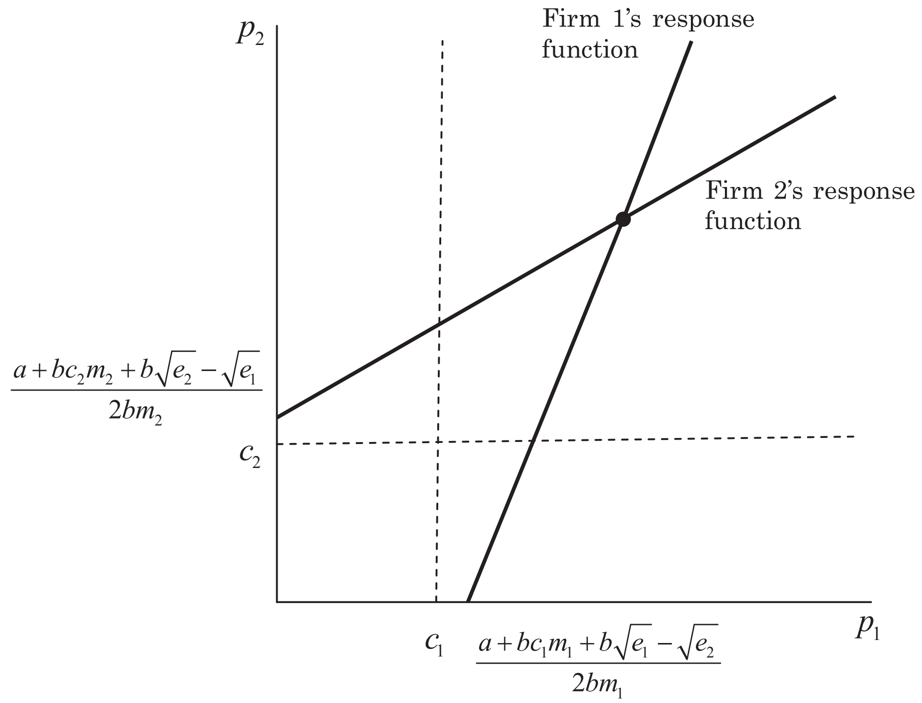

Fig. 1. Joint-venture firm's response function. The response functions are obtained based on Eqs. (7) and (8). The intersection of the two response curves is the Nash equilibrium.

Substituting the values of equilibrium prices and equilibrium production into Eqs. (3) and (4), we derive the equilibrium profits as follows:

$$\pi_1^* = \left(p_1^* - c_1\right) x_1^*, \qquad (13)$$

$$\pi_2^* = \left(p_2^* - c_2\right) x_2^*. \qquad (14)$$

We can rewrite the equilibrium profits as follows:

$$\pi_1^* = \frac{b\left(a + 2ab + c_1 m_1 - 2b^2 c_1 m_1 + bc_2 m_2 + \left(2b^2 - 1\right)\sqrt{e_1} - b\sqrt{e_2}\right)^2}{\left(4b^2 - 1\right)^2 m_1}, \qquad (15)$$

$$\pi_2^* = \frac{b\left(a + 2ab + c_2 m_2 - 2b^2 c_2 m_2 + bc_1 m_1 + \left(2b^2 - 1\right)\sqrt{e_2} - b\sqrt{e_1}\right)^2}{\left(4b^2 - 1\right)^2 m_2}. \qquad (16)$$

2.2.3 Stage 1

Next, we turn to Stage 1, where the foreign firms decide upon the amount of investment needed to maximize their profits, given the government decisions of m_1, m_2 and θ. The profits of the foreign firms are:

$$\Pi_1 = \left(1 - \theta\right)\pi_1^* - e_1, \qquad (17)$$

$$\Pi_2 = \left(1 - \theta\right)\pi_2^* - e_2, \qquad (18)$$

where θ is the possession rate of the joint-venture firm, so that $(1 - \theta)$ is the possession rate of the foreign firm.

The first-order conditions for the profit maximization of each foreign firm are as follows:

$$\frac{\partial \Pi_1}{\partial \mathrm{e}_1} = \frac{b\left(2b^2 - 1\right)\left(a + 2ab + c_1 m_1 - 2b^2 c_1 m_1 + bc_2 m_2 + \left(2b^2 - 1\right)\sqrt{e_1} - b\sqrt{e_2}\right)\left(1 - \theta\right)}{\left(4b^2 - 1\right)^2 m_1 \sqrt{e_1}} - 1 = 0, \qquad (19)$$

$$\frac{\partial \Pi_2}{\partial e_2} = \frac{b\left(2b^2 - 1\right)\left(a + 2ab + c_2 m_2 - 2b^2 c_2 m_2 + bc_1 m_1 + \left(2b^2 - 1\right)\sqrt{e_2} - b\sqrt{e_1}\right)\left(1 - \theta\right)}{\left(4b^2 - 1\right)^2 m_2 \sqrt{e_2}} - 1 = 0. \qquad (20)$$

Let e_1^* and e_2^* denote the amounts of equilibrium investment to satisfy Eqs. (19) and (20). In this case, from Eqs. (17) and (18), the equilibrium profits are as follows:

$$\Pi_1^* = \left(1 - \theta\right)\left(p_1^* - c_1\right)\left[a - b\left(m_1 p_1^* - \sqrt{e_1^*}\right) + \left(m_2 p_2^* - \sqrt{e_2^*}\right)\right] - e_1^*, \qquad (21)$$

$$\Pi_2^* = \left(1 - \theta\right)\left(p_2^* - c_2\right)\left[a - b\left(m_2 p_2^* - \sqrt{e_2^*}\right) + \left(m_1 p_1^* - \sqrt{e_1^*}\right)\right] - e_2^*. \qquad (22)$$

2.2.4 Stage 0

Finally, we consider investment ratio regulations and government subsidies, as per Stage 0. Let us assume that the Chinese government tries to maximize the domestic welfare, W. The social welfare, W_T is defined as the sum of the objective function of the Chinese government and the profit of the foreign firms. The Chinese government's objective function W is defined as the product of θ and the surpluses of the producer and consumer, less the environmental damage and the cost of taxation related to securing the subsidy budget.

$$W = \theta\pi_1^* + \theta\pi_2^* + CS_1 + CS_2 - D\left[\left(\bar{e}_1 - e_1^*\right)x_1 + \left(\bar{e}_2 - e_2^*\right)x_2\right] - \lambda\left[p_1^* x_1^*\left(1 - m_1\right) + p_2^* x_2^*\left(1 - m_2\right)\right], \qquad (23)$$

$$W_T = \pi_1^* + \pi_2^* + CS_1 + CS_2 - D\left[\left(\bar{e}_1 - e_1^*\right)x_1 + \left(\bar{e}_2 - e_2^*\right)x_2\right] - \lambda\left[p_1^* x_1^*\left(1 - m_1\right) + p_2^* x_2^*\left(1 - m_2\right)\right] - e_1^* - e_2^*, \qquad (24)$$

where D denotes the marginal environmental damage derived from power generation and vehicle use, and $\bar{e}_1$ and $\bar{e}_2$ represent CO_2 emissions from power plants and vehicles when there is no investment. Let us assume that $\bar{e}_1 > \bar{e}_2$; then, e_1^* is an investment in a technology that does not use much electricity, and e_2^* is an investment that promotes gas-mileage efficiency. We therefore consider e_1^* and e_2^* as reductions in CO_2 emissions resulting from investment. The parameter λ reflects the tax levy cost, and CS_1 and CS_2 are the consumer surpluses, expressed by the following equations:

$$CS_1 = \frac{1}{2}\left(\frac{a + b\sqrt{\bar{e}_1} - \sqrt{\bar{e}_2} + m_2 p_2}{bm_1} - p_1\right)x_1, \qquad (25)$$

$$CS_2 = \frac{1}{2}\left(\frac{a + b\sqrt{\bar{e}_2} - \sqrt{\bar{e}_1} + m_1 p_1}{bm_2} - p_2\right)x_2. \qquad (26)$$

3. Numerical simulation analysis

We conduct a numerical simulation to take into account an investment ratio regulation and a government subsidy. We substitute the equilibrium values into Eqs. (23) and (24), and calculate the numerical values. We use the parameters $c_1 = 2$, $c_2 = 1$, $a = 20$, $b = 2$, $m_1 = 0.8$, $m_2 = 0.8$, and $\lambda = 1$; $D = 0.01$ (low damage case), 0.035 (medium damage case), and 0.041 (high damage case); and $\bar{e}_1 = 240$ and $\bar{e}_2 = 160$. Huo et al. (2010) generate figures that describe the current fuel-cycle CO_2 emissions of electric vehicles powered by coal-based electricity, as well as the CO_2 emissions of hybrid electric vehicles; they explain that up to the year 2030, electric vehicles powered by coal-based electricity could increase CO_2 emssions at a rate higher than gasoline hybrid electric vehicles or gasoline internal combustion engine vehicles. However, in this analysis, we use CO_2 emissions data—namely, 240.0 g-CO_2/km traveled (for electric vehicles) and 160.0 g-CO_2/km traveled (for hybrid electric vehicles).

The results of the simulation analysis are presented in Figures 2, 3, and 4. In these figures, W_T and W are shown by the solid line (upper) curve and the dashed line (lower) curve, respectively. Among all cases, W_T and W in the case of low environmental damage are the highest. The vertical distance between the two curves represents the profit of the foreign firm; thus, when $\theta = 1$, there is no profit for the foreign firm. The figures show that in all cases, W_T is high when θ is close to zero.

In the case of low environmental damage, as in Figure 2 ($D = 0.01$), the Chinese government may not allow foreign capital to enter; it would make the foreign investment ratio regulation more strict, since the Chinese government's welfare is highest when $\theta = 1$. On the other hand, when the damage is high, as in Figure 3 ($D = 0.041$), the government prefers a small θ value, and it therefore relaxes the foreign investment ratio regulation. We might suppose the current state of the Chinese auto industry to approximate the low-damage case in Figure 2 that is, because the environmental damage of which the Chinese government is conscious is small, it applies investment ratio regulations. In Figure 4, which shows the results of the medium-damage case, the shape of the two curves is similar to those in Figure 3.

Next, Figures 5 and 6 show the effect of subsidies for electric vehicles and hybrid vehicles, respectively. We suppose $c_1 = 2$, $c_2 = 1$, $a = 20$, $b = 2$, $\lambda = 1$, $D = 0.035$, $\bar{e}_1 = 240$, $\bar{e}_2 = 160$, and $\theta = 0.5$. Figure 5 shows the relationship between m_1 and the welfare values W_T and W, holding $m_2 = 1$; Figure 6 shows the relationship between m_2 and the welfare values, holding $m_1 = 1$. When $(m_1, m_2) = (0.8, 1)$ and $(1, 0.8129)$, the subsidies take nearly equal value, whereas the welfare values are $W = 27.1722$ and $W_T = 124.097$ when $(m_1, m_2) = (0.8, 1)$, $W = 38.4073$, and $W_T = 136.327$ when $(m_1, m_2) = (1, 0.8129)$. This means that with the subsidy amounts being

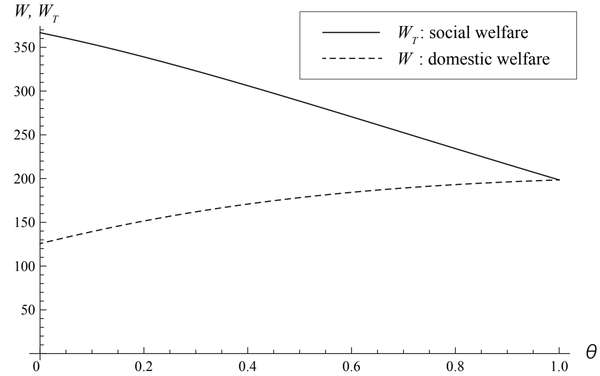

Fig. 2. Effect of investment regulation on welfare. Case of low environmental damage ($D = 0.01$).

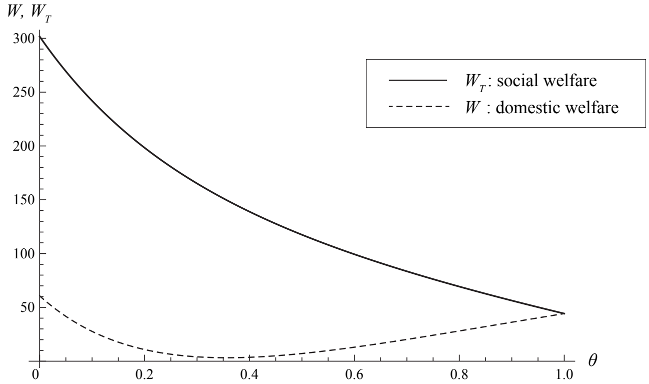

Fig. 3. Effect of investment regulation on welfare. Case of high environmental damage ($D = 0.041$).

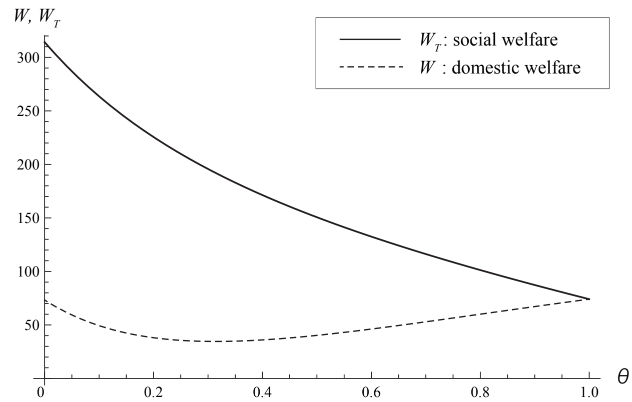

Fig. 4. Effect of investment regulation on welfare. Case of medium environmental damage ($D = 0.035$).

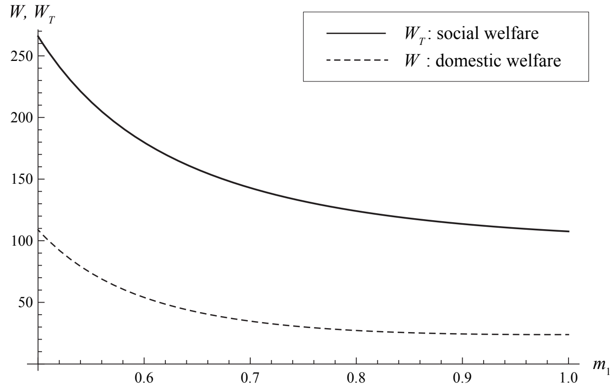

Fig. 5. Effect of subsidy for electric car. This figure shows the values of W_T and W when $m_2 = 1$.

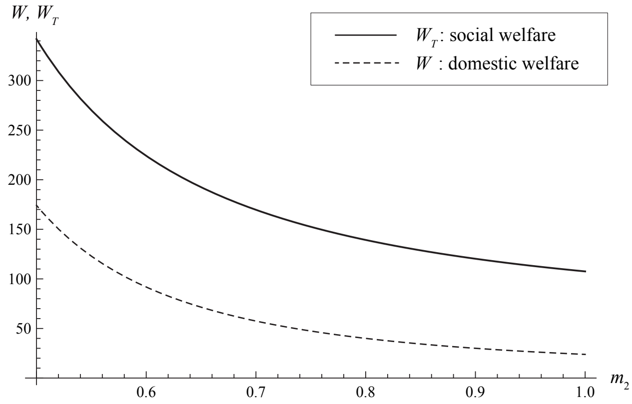

Fig. 6. Effect of subsidy for hybrid car. This figure shows the values of W_T and W when $m_1 = 1$.

approximately equal, the social welfare would be higher in the case of a subsidy for hybrid vehicles, compared to that for electric vehicles. Also, the results show that the welfare values are W = 24.3805 and W_T = 113.62 when (m_1, m_2) = (0.9, 1); W = 29.4435 and W_T = 119.15 when (m_1, m_2) = (1, 0.9076). Besides, we find that W = 34.7532 and W_T = 142.893 when (m_1, m_2) = (0.7, 1); W = 54.1118 and W_T = 164.007 when (m_1, m_2) = (1, 0.715). The above analysis supports that the higher the amount of subsidies, the higher is the welfare associated with hybrid vehicles. In summary, we assert that to increase the effectiveness of hybrid vehicles, it is better for the government to allocate a subsidy for their purchase, because they have been shown to generate the highest social welfare.

As explained above, our results show that in the case of low environmental damage, the welfare is the highest, and that in case of high environmental damage, given the rational behavior of the government, regulations on foreign firms are likely to be relaxed. We show that given the high manufacturing cost of electric vehicles and the high environmental damage created by power generation, subsidies for hybrid vehicles lead to higher social welfare than those for electric vehicles. CO_2 emissions may increase even if electric vehicles are made-widely available in China, given concomitant increases in coal–thermal power generation; as a result, it is better to follow a policy that aims to promote the efficient use of hybrid vehicles.

Our results align with those of Huo et al. (2010), who also show that, based on an analysis of different regions, it is desirable to expand the use of hybrid vehicles (relative to that of electric vehicles) in China. The main reason is that coal–thermal power generation represents the largest share of China's power supply. If the Chinese government continues to promote electric vehicles, it is likely that gasoline consumption in China will decrease, but CO_2 emissions from power generation will increase. Therefore, to reduce CO_2 emissions significantly, China needs to pay considerable attention to issues such as power-generation efficiency and the gas-mileage of cars. The main difference between our analyses and those of Huo et al. (2010) resides in the fact that we integrate the impacts of subsidies with those pertaining to investment ratio regulations.

4. Conclusions

In this paper, we consider the present state of the Chinese automotive industry and its environmental–energy policies, and analyze a situation in which the Chinese government would promote either electric vehicles or hybrid vehicles. Using a Bertrand competition model, we investigate the effects of investment ratio regulations and subsidies on the proliferation of next-generation vehicles in China.

The technology-transfer effect—that has played an important role in China's rapid economic growth, and continues to do so—is among the beneficial impacts of foreign direct investment. In fact, foreign firms transfer methods of production (that is, manufacturing) to affiliated local companies and disseminate them, contributing thereafter to China's industrial development. However, to mitigate global warming and address energy problems in China (where CO_2 emissions will continue to increase), the government should relax the investment ratio regulations that apply to foreign firms in the environmental–energy field and automobile (vehicle) sector.

In future research, we will consider the possibilities of using real data to investigate empirically the use of next-generation vehicles; we would also like to examine the effects of tax breaks with regard to eco-friendly car diffusion.

Note

† For the solution to be non-negative, we assume that $b \geq 1$ and that the parameter a is sufficiently large.

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