Econ 691H Final Proposal Draft

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The Short-run Welfare Assessment of Two New Energy Vehicle Policies in China

1. Introduction

1.1 Context

In the past decades, we have witnessed dramatic changes in human society. While technology development has made people's daily life more convenient than ever before, environmental issues keep turning more and more serious and concerning, with global warming being one of the most typical and urgent ones. Specifically, basic human activities, such as fossil fuel consumption, would cause the emission of greenhouse gases (GHG), including its main source carbon dioxide (CO_2), and lead to an increase of GHG level in the atmosphere. The time series data from Mauna Loa Observatory located in Hawaii have shown a significant upward trend for the monthly average CO2 level (NOAA 2017) [1].

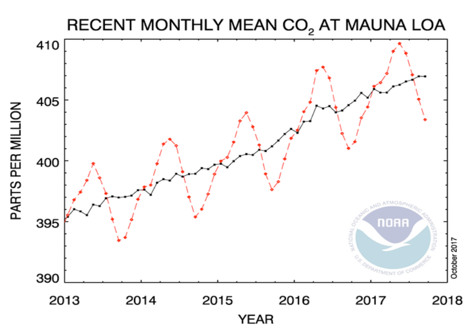
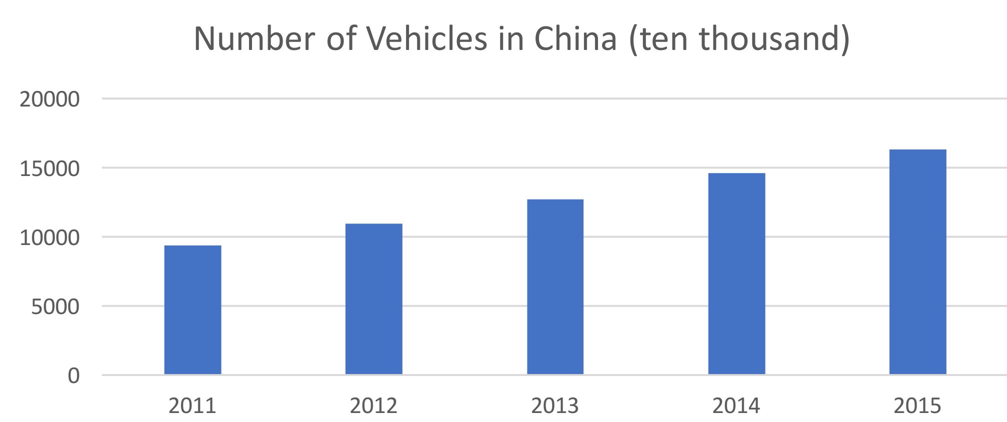


Figure [1]

The long-term damage of such growth is huge and pervasive, from the rise of sea level to temperature anomalies. In response, governments around the world have long been searching for strategies to regulate and control the CO_2 consumption, especially in automobile industries. In recent years, the burgeoning technology of new energy vehicle (NEV) has become an excellent alternative to the traditional gasoline and diesel based vehicles. This new option uses electricity, oxygen and hydrogen as fuel, releasing much less greenhouse gases into the atmosphere. As a result, even with consideration of high fixed cost (the technology research and development fees) and variable cost (some parts like the engine becoming more expensive to produce), the government still wants to promote NEV in that it makes possible for the transportation sector to get rid of its dependence on fossil fuel consumption. This is especially prevalent in China, a country that has a rapid growth in passenger car sales and is committed to reduce the country's CO_2 emission (Wang et al. 2015). According to National Bureau of Statistics of China (2017), the number of vehicles in China has increased from 9356.32 in the year of 2011 to 16284.50 in 2015 (in ten thousand), and the 2011-15 car compound growth rate is near 15% [2]. That being said, automobile has become one of the main sources of the country's CO_2 emission.



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1.2 Policies

Among all different policies issued by the government in the automobile sector, two of them focus heavily on promoting the use of new energy vehicle. The first one is government giving subsidies directly to companies for every new energy vehicle that they produce (MFPRC 2013, MFPRC 2015). Enacted firstly in 2013, the policy divides NEV into three specific classes. Passenger cars with either hybrid power (electricity + gasoline) or pure electricity power are rewarded based on their maximum single driving distance when using only electricity (R). Electric buses and trucks are subsidized by their different lengths. Lastly, distribution of the rewards for fuel cell cars that use mainly oxygen and hydrogen will just depend on their car types. Furthermore, the subsidy for every vehicle will decrease by 10% in 2014, and 20% in 2015 based on the level of 2013, as companies enlarge their NEV production capacity. The 2015 update of the policy is consistent with the old version. There are several emendations and a more specified classification of different NEV and their subsidies respectively.

The second policy, targeting especially passenger cars, on the other hand, introduces a double scores system (MIITPRC 2017). Specifically, every company will have two scores associated with their productions. The first score is the fuel consumption score, which assesses the fuel efficiency of the company's products with a set fuel economy target. Each model type of vehicles that companies produce has a target value of the fuel consumption (L/100 km), which is how many liters of fuels a car needs to travel 100 kilometers. All different target values are determined by the complete vehicle kerb mass (CM), namely the weight of a car and all necessary accessories on it, as well as the number of rows of seats (whether it is greater or equal to 2). Similarly, the corporate average fuel consumption target (T_{CAFC}), is the fixed sales-weighted average target of fuel economy that a company is required to reach. Its calculation is given by

$$T_{CAFC} = \frac{\sum_{i=1}^{N} T_i \times V_i}{\sum_{i=1}^{N} V_i} \tag{1}$$

where N is the total number of types, according to the classification, the company produce in a given model year. T_i is the fuel consumption target of vehicle type i, and V_i is the production volume of that type. Correspondently, the corporate average fuel consumption (CAFC), which is the actual value of the sales-weight fuel consumption during a model year of a car factory, is given by

$$CAFC = \frac{\sum_{i=1}^{N} FC_i \times V_i}{\sum_{i=1}^{N} V_i \times W_i} \tag{2}$$

where FC_i is the actual fuel consumption of vehicle type i, while W_i is a multiple coefficient. For NEV with one time travel distance using solely clean energy greater or equal to 50 km (R >= 50), W_i will equal to 5. That is to say, one new energy car counts for 5 cars in calculation for the current scenario. It is notable that such multiple will decrease in the future, turing to 2 in year of 2020. For vehicles with especially high fuel consumption values (<= 2.8L/100km), W_i will be 3.5 and also decline in the future. For all rest cases W_i will just be 1. The total fuel consumption score for a given company is the difference between its T_{CAFC} and CAFC value in a model year. The company will earn a positive score if the difference value is positive, and negative if the difference value negative.

The other part in this system is the new energy score. Companies will earn certain scores for every NEV that they produce based on different NEV types. Every Hybrid power car using both electricity and gasoline will earn 2 points. The points per car for vehicles using pure electricity is 0.012×R+0.8 (same R as mentioned before), while the unit score for fuel cell passenger cars is 0.16×P, with P (kW) being the measurement of cell efficiency. In general, the new energy score is similar to the subsidy policy, but the real capital is replaced by virtual credit and there are distinctions in the calculation. Furthermore, for those large companies with an output of more than

30,000 cars per year, there is a new energy score requirement proportional to the corporation's total output starting from 2019.

The mechanism of the policy is that if a company earns a positive fuel consumption score, it can either bank the score for future (with a certain rate of discount and can be saved up to three years), or transfer the score to affiliated enterprises (in terms of holdings). If the score is negative, however, the companies has to adapt one or more of the following ways: (1). Use the banked scores from own company of previous years. (2). Use scores from affiliated corporations. (3). Use the positive new energy score from own company to compensate for the negative part. (4). Buy new energy score from other companies. It is noteworthy that the positive new energy score, after meets its own requirement, cannot be saved for future use but has no limitation for trading. In contrast, the positive fuel consumption score is not available in the credit transaction market.

Kwoka (1983) cast doubt on the fuel consumption saving function of such policy in the short-run in his analysis of the corporate average fuel economy (CAFE), which was firstly enacted in 1975 in United States and in general holds the similar idea to the double score policy. Kwaka's main concern is that while CAFE has definitely driven companies' sales mix to change in favor of the high MPG cars, it does not necessarily force the merchants to maintain their previous production level. Hence, a rise in the total sales may not decrease the CO_2 emission. However, as for the case of the dual-credit system in China, since the fuel consumption for hybrid and electric cars is counted as their equivalent electricity consumption, and for fuel-cell cars is just 0 (MIITPRC 2017), they make far less CO_2 than traditional automobiles, or can be seen as cars with very high MPG. Thus, a large increase of the NEV sale will not offset the policy's efficiency. In conclusion, the dual-score policy will reduce CO_2 emission in that it sets an average fuel economy standard, impedes the traditional vehicle production, and, just like the subsidies policy, gives incentives for either NEV production or NEV technology innovation.

The purpose of this paper is to establish a model assessing and comparing the short-run economic welfare of the two policies. That is, the economic benefits gain from the two policies as well as their underestimated value of reducing fuel consumption. Since the double score policy has been enacted in 2017, when the subsidy standard from government keeps decreasing and plays little role in the market, it is intuitively reasonable to compare the two policies to see whether the dual-score system is a success alternative of the subsidy policy in promoting NEV in China. This paper will examine the two policies independently, while in reality, when the new policy comes in effect, it is followed by the old one, and before the second new policy is enacted, there was still limitations of fuel consumption set by the government.

2. Literature Review

The assessment of the subsidies policy is relatively straightforward since the only deviation away from the market production equilibrium scenario is government interfering by giving subsidies and thus changing the optimal solution in terms of the price and quantities of each car model and type as well as motiving technology innovation. Wang et al. (2015) use game theory to analyze the interaction between the government and car producers. Specifically, they apply both static and evolutionary game models and come up with a result that is fairy intuitive. In short, without subsidies and penalties, and the innovation cost is higher than the traditional production cost, profit will be companies' primary concern. On the contrary, if there are incentive policies or customer value more on the NEV, manufacture will change their strategy to build more new-energy cars.

On the other hand, the effectiveness of the double score policy tends to be relatively harder to measure. Not only does it include more variables and constraints, but it also has been implemented just recently. As a result, previous research of this policy is relatively rare. However, we are able to make an analogy to the corporate average fuel economy regulation in the US. This policy sets a minimum standard of the fuel efficiency for passenger cars and light trucks that each manufacturer is required to meet (Kwoka 1983; Rubin et al. 2009; Liu et al. 2014), serving the similar function to the fuel consumption score. Rubin et al. (2009) put a focus on the fuel economy credits that are allowable to trade. One can make connection of that with the new energy score trading mechanism. They find that the greatest potential cost savings from tightening the CAFE standard occur when the credit system has the greatest flexibility, with both trading among firms and among different vehicle classes (passenger cars & trucks) being permitted. Kwoka (1983) builds a model predicting the pricing behavior of a single company under the CAFE constraint, with only two car models being sold in the market, in a time period when remarkable technological improvements are infeasible. By employing prices that decrease the sales of low MPG cars and increase the sales of high MPG cars, the merchant is able to meet the policy requirement while maximizes its profit. The theoretical model of this paper will be based on Kwoka's model. However, modification will be made to transform it to be in accord with the condition of the fuel consumption credit. Moreover, the model will also be extended to include the new energy score and become a good measurement of the whole dual-score system. Greene (1991), while focuses on the pricing strategies for manufacturers when there is no inter-firm interaction, indicates that the effectiveness of changing sales mix will be small compared to that of technology updating, if condition permits. Liu et al. (2014) use model based on Greene's, and come up with the similar conclusion. They also investigate the impact of fee-bate policies on fuel economy improvement.

3. Model Formulation

3.1 General Assessment

The overall measurement of welfare will be given by

$$\mathrm{tw} = \pi + \mathrm{cs} + \mathrm{ext} + \mathrm{r} \tag{3}$$

where the total welfare is denoted by tw; the profits of companies under the policy is denoted by π; consumer surplus is denoted by cs; externality, the benefits from a reduction of CO_2 emission is denoted by ext; and finally, r stands for the revenue of government in implementing the policy. The control group here will be the total welfare if neither policy is implemented. Two basic assumptions are being made throughout the paper. First, a short-run assessment means that there is not enough time for companies to innovate their technology to reach a higher fuel economy. Second, there is no interaction between companies other than credit trading. In addition, when applying Kwoka's model, there are several more assumptions (1983): generally, we would like to pay attention to only one company, and there are only two types of cars being sold by the firm: the traditional energy vehicles (TEV) and the new energy vehicles (NEV). Furthermore, since the policies will only affect the supplier side, the demand curves for both vehicle types remain unchanged. They are assumed to be linear and each can be written as a function between the its own price and quantity as well as the price of the other model:

$$p_i = \alpha_i - \beta_i q_i + \gamma_i p_j \quad \mathrm{i,j} = 1{,}2 \quad \mathrm{i} \neq \mathrm{j} \tag{4}$$

Note that α_i, β_i and γ_i are all positive. It is intuitively reasonable since the price and quantity of the same item has a negative relationship, and the prices of substitute goods are positively related, while α_i is just a constant. We denote TEV as 1 and NEV as 2. Also, assume that the only cost for producing a car is the variable cost, as denoted by C_1 and C_2 for, respectively. As a result, the profit function of the firm is given by:

$$\pi = p_1q_1 + p_2q_2 - c_1q_1 - c_2q_2 \tag{5}$$

In that case, the optimal profit quantities, q_1^* and q_2^* of that firm, are derived by calculating the first order condition of π in terms of q_1 and q_2 while using formula (4):

$$q_1^* = \frac{\alpha_1+\gamma_1 p_2-c_1}{2\beta_1}\,;\ q_2^* = \frac{\alpha_2+\gamma_2 p_1-c_2}{2\beta_2} \tag{6a; 6b}$$

And this is how the firm will perform in the control group with no policy restriction at all. The iso-profit curve is given by the figure below [3]. Point A represents the optimal solution.

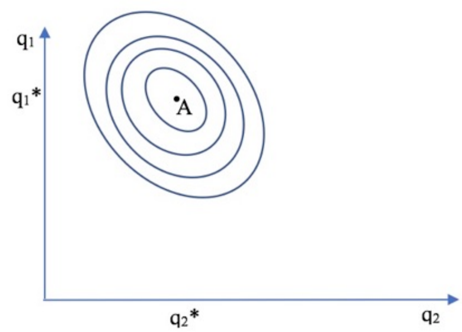

Figure [3]

The equations (4), (5), (6a) and (6b) are important, because not only are we able to get the profit value and therefore understand the company's production strategies, we can also calculate the consumer surplus and externality, both functions of q_1* and q_2*.

Finally, the revenue of the policy incurs exogenously. As for the subsidy policy, the revenue will be the government's expenditure and will therefore be negative. For the double score policy, however, the revue will be zero because there is no direct cost and also no gains for the government, since it is assumed that the penalties of earning a negative score will be large and unfavorable to all companies so that everyone in the market want to obey the rule. The punishment, if any, also violates the policy's initial consideration for decreasing the CO_2 emission.

3.2 the Fuel Consumption Credit

We now add the fuel consumption credit requirement into the model. Remember that the positive score implies that T_{CAFC} is bigger than or equal to CAFC. Hence, in the one-firm-two-model scenario:

$$T_{CAFC} = \frac{T_1 q_1 + T_2 q_2}{q_1 + q_2} \geq \frac{FC_1 q_1 + FC_2 q_2}{W_1 q_1 + W_2 q_2} = CAFC \tag{7}$$

Since vehicle 1 is the normal TEV, W_1 equals 1. W_2, on the other hand, will be greater than 1 and FC_2, as mentioned before, will be much smaller than FC_1. For simplicity, we take W_2 as 1 and FC_2 as 0. Now the constraint becomes:

$$\frac{T_1 q_1 + T_2 q_2}{q_1 + q_2} \geq \frac{FC_1 q_1}{q_1 + q_2} \tag{8}$$

The equation (8) is more favorable than (7) as it gives a direct linear association between q_1 and q_2 and still shows the different values of TEV and NEV in satisfying the fuel consumption target. Assume that the constraint is binding, for the profit of TEV is usually higher than that of NEV. Producer thus always wants to have a sales mix such that the actual value of fuel consumption is equal to the average fuel economy standard. As a result, the formula (8) now becomes an equation and we can get the corresponding Lagrange function:

$$\mathrm{L} = p_1 q_1 + \ p_2 q_2 - \ c_1 q_1 - \ c_2 q_2 + \lambda(FC_1 q_1 - T_1 q_1 - T_2 q_2) \tag{9}$$

Derive the partial derivatives of the L with respect to q_1, q_2 as well as λ, and set them equal to 0:

$$\frac{\partial \mathrm{y}}{\partial q_1} = \alpha_1 - 2\beta_1 q_1 + \gamma_1 p_2 - c_1 + \lambda(FC_1 - T_1) = 0 \tag{10a}$$

$$\frac{\partial \mathrm{y}}{\partial q_2} = \alpha_2 - 2\beta_2 q_2 + \gamma_2 p_1 - c_2 + \lambda(-T_2) = 0 \tag{10b}$$

$$\frac{\partial \mathrm{y}}{\partial \lambda} = FC_1 q_1 - T_1 q_1 - T_2 q_2 = 0 \tag{10c}$$

By reformulating equation (10c), now we can get the relationship between the optimal solution q_1^{**} and q_2^{**}:

$$q_2^{**} = \frac{FC_1 - T_1}{T_2} q_1^{**} \tag{11}$$

$\frac{FC_1 - T_1}{T_2}$, which is the ratio between q_1^{**} and q_2^{**} when the company tries to conform the fuel consumption score requirement, can be denoted as R. Use R and solve formula (10a) and (10b), the expression of q_1^{**} can be written as follow:

$$q_1^{**} = \frac{(\alpha_1 + \gamma_1 p_2 - c_1) + R(\alpha_2 + \gamma_2 p_1 - c_2)}{2(\beta_1 + \beta_2 R^2)} \tag{12a}$$

And the optimal quantity for NEV, q_2^{**}, is simply R times q_1^{**}.

$$q_2^{**} = R\,\frac{(\alpha_1 + \gamma_1 p_2 - c_1) + R(\alpha_2 + \gamma_2 p_1 - c_2)}{2(\beta_1 + \beta_2 R^2)} \tag{12b}$$

It is noteworthy that the equation (12a) and (12b) are exactly the same as the optimal result in Kwoka's model analyzing CAFE constraint (1983), except the ratio value R having different expressions. The reason for the discrepancy is from the different setups of the two policies. In CAFE regulation, there is a uniform standard for the fuel economy, which is derived by the harmonic mean of each vehicle's fuel MPG value. As for the fuel consumption score, on the other hand, each type of car has its own target consumption value, and in calculation the sales-weighted arithmetic mean is employed. In conclusion, the formula (12) shows that the fuel consumption part of the double credit policy can be treated the same as the CAFE policy.

As a result, just like Kwoka's analysis, we can subtract q_1^* from q_1^{**} and q_2^* from q_2^{**} to study the impact of the fuel consumption constraint on the firm's production combination. As expect, the difference for FEV is negative and the difference for NEV is positive. This indicates that the positive score requirement will urge the car producer to change its selling decision, deviating from its original optimal solution and manufacturing more new energy vehicles. Such change is visualized by the following graph [4]. Here at point B (q_1^{**}, q_2^{**}), the fuel consumption constraint line is tangent to the iso-profit curve, representing the new optimum production bundle:

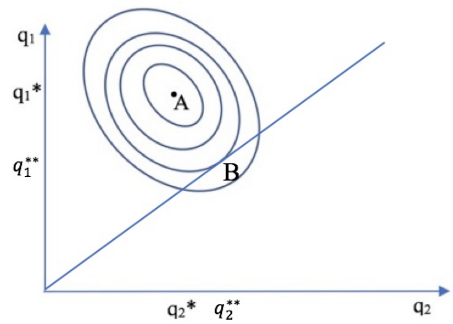

Figure [4]

3.3 the Fuel Consumption & New Energy Credit

The next step is to include the new energy credit into the model. Note that in this case the trading of the score and the interaction between the two score are still not considered, so the two scores will put two different constraint on the corporation. As mentioned before, the new energy score requirement is proportional to the company's total output. This ensures that to enlarge the production, usually tradition gasoline-based automobiles, the firm must manufacture more new energy cars as well. Such requirement can be expressed as:

$$\mathrm{M}(q_1 + q_2) \leq N q_2 \tag{13}$$

where M is the fraction and is expected to increase every year. In 2019, which is the staring year, the M will be equal to 10% (MIITPRC 2017). N is the score value for each NEV and is assumed to be a constant for simplicity. On the other hand, the fuel consumption condition remains unchanged and is given by formula (8).

However, for this case, since both requirements set linear relationships between q_1 and q_2, it is unrealistic to assume both inequalities to be always binding. So the Lagrange multiplier method, which only works when constraints are equations, is not applicable. We should thus adopt Kuhn–Tucker conditions, a general version of the Lagrange multiplier method that deals with inequality scenarios. The new Lagrange function is now given by:

$$\mathrm{L} = p_1 q_1 + p_2 q_2 - c_1 q_1 - c_2 q_2 +$$

$$\mu_1(FC_1 q_1 - T_1 q_1 - T_2 q_2) + \mu_2(Mq_1 + Mq_2 - Nq_2) \quad (14)$$

To maximize L, the Kuhn–Tucker conditions require that:

$$\frac{\partial \mathrm{y}}{\partial q_1} = \alpha_1 - 2\beta_1 q_1 + \gamma_1 p_2 - c_1 + \mu_1(FC_1 - T_1) + \mu_2(M) = 0 \quad (15a)$$

$$\frac{\partial \mathrm{y}}{\partial q_2} = \alpha_2 - 2\beta_2 q_2 + \gamma_2 p_1 - c_2 + \mu_1(-T_2) + \mu_2(M - N) = 0 \quad (15b)$$

$$\mu_1(FC_1 q_1 - T_1 q_1 - T_2 q_2) = 0 \quad (15c)$$

$$\mu_2(Mq_1 + Mq_2 - Nq_2) = 0 \quad (15d)$$

$$\mu_1, \mu_2 \geq 0 \quad (15e)$$

Formula (15e) gives the non-negativity property for μ_1 and μ_2, while the two constraints give the negativity property of the parts in parenthesis in equation (15c) and (15d). Therefore, we divide the result into four cases:

1. $\mu_1 = 0$ and $\mu_2 = 0$, which indicates that both constraints are unbinding. Put them back to formula (15a) and (15b). We can derive the same value q_1* and q_2* as in equation (6a) and (6b). This scenario, however, is infeasible, if we assume the policy that we study has at least some influences on the current automobile industry.
2. $FC_1 q_1 - T_1 q_1 - T_2 q_2 = 0$ and $\mu_2 = 0$, which implies that the new energy score is unbinding. This is the same situation as the last section when there is only fuel consumption credit. The result will be formula (12a) and (12b)

3. $\mu_1 = 0$ and $Mq_1 + Mq_2 - Nq_2 = 0$, which, in contrast, indicates that the new energy constraint is binding. The new relationship between the optimal quantities $q_1^{\sim}$ and $q_2^{\sim}$ is therefore:

$$q_2^{\sim} = \frac{M}{N-M} q_1^{\sim} \tag{16}$$

If denoting $\frac{M}{N-M}$ still as R, we will reach the same optimal solution as formula (12a) and (12b) by solving equation (15a) and (15b), excepting the distinction in R values. This implies that the effectiveness of the new energy score is analogous to that of the fuel consumption credit. That is, increasing fuel economy and setting minimum NEV production scale will have similar effects on the company's sales mix. It is intuitively reasonable as both constraints are linear.

4. $FC_1q_1 - T_1q_1 - T_2q_2 = 0$ and $Mq_1 + Mq_2 - Nq_2 = 0$. This is the rare case when both constrains are binding, and it requires that the two Rs, $\frac{FC_1 - T_1}{T_2}$ and $\frac{M}{N-M}$, are equal. However, as both T_1, T_2, M and N are fixed by the policy, and FC_1 is the characteristic of the vehicle, the equality can be seen as just numerical coincidence and has no additional meaning.

Like in previous sections, we can interpret the impact of putting two constraints together on the car producer via a graph [5].

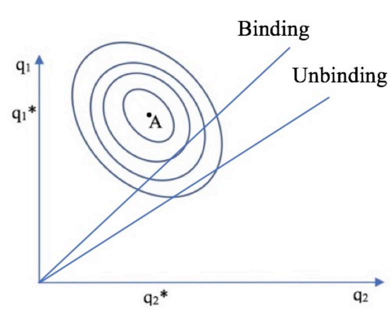

Figure [5]

3.4 the Double Score System

For now, we would like to set M to be 0, which assumes the new energy credit to be always unbinding. This assumption is justified by the following reasons. First, the only difference for the two policies is just the values of R, which is a constant. Thus, excluding the new energy score requirement will not lead to different conclusions but largely simplify the calculation as no classified discussion is needed anymore. Second, as mentioned before, the constraint does not apply to everyone, only targeting corporations with a total output greater than 30,000 cars per year. Furthermore, the constraint will not come into practice until 2019, so in 2018 M is equal to 0.

Finally, we employ the rest part of the double score policy into the model, which is what the firm can do if they earn a negative fuel consumption score (new energy credit now always being positive). Among the four feasible ways, the first one of using banked scores from the past will not be considered, because it violates the first basic assumption of the model about the time period. When calculating credits from early years, the discount rate will be applied the problem will change into a long-run assessment. Likewise, the second method of transferring scores from affiliated companies is also excluded since it goes against the second basic assumption that no other interaction between firms besides credit trading is allowed. As a result, for the case of the model, the corporation can either take advantage of its own positive new energy score, or buy it from others to compensate for the negative part of the fuel consumption point.

Note that the fuel consumption requirement is now more flexible and also easier to satisfy than in previous section, when the only response the firm can make is to change is sales mix. Hence, they now have more options, being able to gain more profit while still meet the standard. For one, every NEV that it produces will now not only offset the high value of FC_1, but also create N available energy score that can be added on the corporate average fuel consumption target (since

M is equal to 0). As a result, the former production combination can bring the firm a positive fuel consumption score and it can choose to be a credit seller in the market to further enlarge its profit. On the other hand, the company may believe that TEV has much higher value than NEV, so it wants to produce more TEV if condition allows. In that case, the car manufacturer will become a credit buyer in the market. Moreover, the role of seller and buyer is interchangeable, so that the firm who performs as a seller currently can alter its production strategy to be a buyer with no barrier. Hence, the one-firm-two-model scenario can continue being used, otherwise we'll need two companies to establish the score trading market. However, we would assume the price of the credit has already been in its equilibrium state, p_c^*, so that the corporation will not be a seller and a buyer at the same time, selling its new energy score for profit while buy it from the market to fulfill the policy. With all these conditions and assumptions, we are able to form the new profit function of the company, which is given by:

$$\pi = p_1 q_1 + p_2 q_2 + p_c^* N q_{sell} - c_1 q_1 - c_2 q_2 - p_c^* N q_{buy} \tag{17}$$

where Nq_{sell} is the amount of score being sold and Nq_{buy} the amount being bought. It is noteworthy that since the new energy score is produced along with the production of NEV, q_{sell} is always less than or equal to q_2.

The new fuel consumption credit constraint can be written as:

$$\frac{T_1 q_1 + T_2 q_2}{q_1 + q_2} \geq \frac{FC_1 q_1}{q_1 + q_2} - N q_{buy} - N(q_2 - q_{sell}) \tag{18}$$

The "either/or" requirement for the role the company take in the market is just:

$$q_{sell} q_{buy} = 0 \tag{19}$$

Since formula (18) is binding can be treated as an equation and formula (19) is already an equality, the Lagrange multiplier can once again be used. The corresponding Lagrange function is:

$$\mathrm{L} = p_1 q_1 + p_2 q_2 + p_c^* N q_{sell} - c_1 q_1 - c_2 q_2 - p_c^* N q_{buy} +$$

$$\lambda_1\left(\frac{FC_1q_1}{q_1+q_2}-\frac{T_1q_1+T_2q_2}{q_1+q_2}-Nq_{buy}-N(q_2-q_{sell})\right)+\lambda_2(q_{sell}q_{buy}) \tag{20}$$

Solve the first order condition for L, we would get:

$$\frac{\partial \mathrm{y}}{\partial q_1}=\alpha_1-2\beta_1q_1+\gamma_1p_2-c_1+\lambda_1\left(\frac{FC_1q_2-T_1q_2+T_2q_2}{(q_1+q_2)^2}\right)=0 \tag{21a}$$

$$\frac{\partial \mathrm{y}}{\partial q_2}=\alpha_2-2\beta_2q_2+\gamma_2p_1-c_2+\lambda_1\left(\frac{-FC_1q_1-T_2q_1+T_1q_1}{(q_1+q_2)^2}-N\right)=0 \tag{21b}$$

$$\frac{\partial \mathrm{y}}{\partial q_{sell}}=p_c^*N+\lambda_1(N)+\lambda_2(q_{buy})=0 \tag{21c}$$

$$\frac{\partial \mathrm{y}}{\partial q_{buy}}=-p_c^*N-\lambda_1(N)+\lambda_2(q_{sell})=0 \tag{21d}$$

$$\frac{\partial \mathrm{y}}{\partial \lambda_1}=\frac{FC_1q_1}{q_1+q_2}-\frac{T_1q_1+T_2q_2}{q_1+q_2}-Nq_{buy}-N(q_2-q_{sell})=0 \tag{21e}$$

$$\frac{\partial \mathrm{y}}{\partial \lambda_2}=q_{sell}q_{buy} \tag{21f}$$

We first consider the special case when both q_{sell} and q_{buy} are equal to zero. Under this circumstance, no trade will happen even when transaction is permitted. Put this condition back to equation (21e) and reformulate, we get a quadratic equation of q_2:

$$\mathrm{N}q_2^2+(Nq_1+T_2)q_2+(T_1-FC_1)q_1=0 \tag{22}$$

Solving the equation derives the relationship between the optimum solutions q_1^{***} and q_2^{***}:

$$q_2^{***}=\left(-Nq_1^{***}-T_2+\sqrt{N^2q_1^{2***}+2NT_2q_1^{***}+T_2^2-4NT_1+4NFC_1}\right)/2N \tag{23}$$

Thus, there is a non-linear relationship between the optimal quantity of NEV and that of PEV. Note that there is a $-Nq_1^{***}$ term outside the square root, which means that when q_1 is relatively small, an increase in q_1 actually decreases the respective value of q_2. This implies that the company has to reduce the NEV in order to keep the fuel consumption score at 0. In other words, the firm has already earned a positive fuel consumption credit for small q_1, and it can manufacture more traditional energy vehicles. Put back equation (23) to formula (21a) and (21b), the value of q_1^{***}

and q_2^{***} can be calculated. If in that case the company still has unused production capacity, then there are automatically two ways for the firm: either increasing q_1 and becoming a buyer, or increasing q_2 and becoming a seller. Under this circumstance, to keep the manufacture indifferent between the two options, the equilibrium price of the net new energy score should be equal to the difference between the marginal profit of FEV and NEV :

$$p_c^* = \frac{(p_1 - c_1) - (p_2 - c_2)}{N + \delta} \tag{24}$$

where δ denotes the amount of credit the firm needs to purchase to produce one more car, and will increase when q_1 keeps rising. Finally, for the unbalanced situations, when the trading happens, either formula (21c) or (21d) will lead to the same result. That is, the Lagrange multiplier, λ_1, is equal to -p_c^*. Intuitively, this indicates that the marginal cost for the company to reach a stricter fuel economy target is the marginal value of the score.

3.5 the Subsidies Policy

For the subsides policy, to keep the consistency, we would continue the use of the one-company model. With subsidies, the marginal revenue of the new energy vehicles will increase. As a result, the car producer will certainly change its sales mix in favor of the NEV, thus resulting in a new profit function, as given by:

$$\pi = p_1 q_1 + (p_2 + s) q_2 - c_1 q_1 - c_2 q_2 \tag{25}$$

where s denotes the value of subsidies and is assumed to be a constant. Since there is no extra constraint, the maximized situation can be achieved by:

$$q_1^{****} = \frac{\alpha_1 + \gamma_1 p_2 - c_1}{2\beta_1}; \; q_2^{****} = \frac{\alpha_2 + \gamma_2 p_1 + s - c_2}{2\beta_2} \tag{26}$$

As expected, compared to q_1^{****}, the value of q_2^{****} is now relatively larger than before the subsidies.

3.6 Miscellaneous

The specific formula for consumer surplus change needs further study. It will, however, be a function of the difference between the optimal quantities with and without the policies for both the TEV and the NEV. The change of the externality, Δext, on the other hand, will be proportional to the reduction of the quantity of TEV, given the assumption that NEV does not release CO_2.

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