A Theory of Dynamic Biofuel Tax Credit

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Abstract

In this paper, we setup a social cost minimization problem for a government. Using dynamic optimization tools, we analytically shows how exogenous parameters could affect the optimal social cost and the optimal tax credit policy path.

Key words: Optimal Control, Biofuel, Tax Credit

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Introduction

Concerns about global warming have motivated many countries committing to reduce greenhouse gas (GHG) emissions by promoting the use of renewable energy. Bioethanol, primarily subcategorizing into corn ethanol and cellulosic ethanol, is usually considered as the most potential one due to its stability comparing to solar or wind energy. Wu, Wang and Huo (2007) reported that comparing to gasoline; corn ethanol could reduce 38.3% of GHG emissions in a natural-gas refinery plant while the reduction in emissions is about 90% with the cellulosic ethanol based on switchgrass or corn stover. Besides the motivation of reduction in GHG emissions, Rubin et al. (2008) stated that bioethanol also plays a key role in reducing the U.S. oil imports and rural development.

For these incentives, the U.S government began to subsidize the biofuel industry through the volumetric ethanol excise tax credit (VEETC) since 1978. The Energy Tax Act of 1978 provided a tax credit of \$0.40/gallon for bioethanol and gradually the tax credit increased to \$0.60/gallon in 1984. From then on, the tax credit was phased down and was set at \$0.45/gallon until December 2011. Although this ethanol tax credit has expired in 2012, this is only for corn ethanol producers. The cellulosic ethanol producers could still receive the tax credit of \$1.02/gallon at least until December 2013. Besides using the ethanol credit to limit the GHG emission, the climate change legislations (Clean Energy Jobs and American Power Act of 2009 and American Clean Energy and Security Act of 2009) propose to place caps of GHG emissions amount on some sectors such as transportation.

However, the ethanol subsidy is one of the most controversial parts among U.S. government policies. Numerous literatures studied the welfare and environmental impacts of biofuel subsidy over recent ten years but the conclusions are still in debate due to different economics assumptions. The first key assumption is that whether to internalize environmental benefits from the reduction in GHG emissions as the increase in use of biofuel. The second one is that even if internalizing the environmental benefits from the biofuel, the bioethanol subsidy may generate negative environmental externalities assuming that conventional gasoline and ethanol are imperfect substitutes or complements. The last assumption concerns about tax revenue loss from the government.

Without considering any environmental externality from biofuel, a traditional welfare analysis is still applied, stating that the tax credit would distort the market efficiency and lead to a deadweight loss in social welfare. Based on this assumption, Gardner (2007) estimated that the society would incur deadweight losses of $91 million in the short run and $665 million in the long run as a result of biofuel subsidy. Using a partial equilibrium model, Rajagopal et al. (2007) found that the biofuel subsidy would benefit gasoline consumers and corn consumers but hurt corn consumers and gasoline producers. The whole society would suffer a net loss if the U.S. gasoline producers lose more than $10.3 billion

Assuming conventional gasoline and ethanol are imperfect substitutes, the bioethanol subsidy would induce not only substitute effects but also income effects. As the bioethanol subsidy lowers the price of ethanol, consumer may demand more gasoline because their purchasing power increases. Following this assumption, Khanna, Ando and Tapheripour (2008) found that the optimal government policy is to impose tax of $0.04/gallon on ethanol and $0.08/gallon on gasoline. Then the ethanol subsidy of $0.51/gallon would increase the

GHG emissions by 20% and decreases the social welfare by \$19 billion comparing to the optimal policy.

In the U.S., ethanol and conventional gasoline are complements. The E85 fuel (blend of 15% conventional gasoline and 85% ethanol) has a great potential to reduce the GHG emission but there are only about eight million of E85 cars on U.S. road in 2009 (National Renewable Energy Laboratory, 2010). The bioethanol has been mainly used in the E10 fuel, which is blended of 90% conventional gasoline and 10% ethanol. The bioethanol tax credit would reduce the price of ethanol and further lower down the price of E10 fuel, resulting in a higher demand for blended fuels, especially for its primary component-conventional gasoline. This means that people would consume one more gallon of ethanol accompanying with nine more gallons of gasoline. Based on this assumption, Vedenov and Wetzstein (2007) showed that the optimal ethanol subsidy is \$0.22/gallon, much lower than \$0.51/gallon at that time. These literatures indicate that the increasing consumption of conventional gasoline due to the ethanol tax credit may mitigate the environmental benefits from the use of biofuel under the assumption of imperfect substitutes or complements between petroleum and ethanol. Hence, optimal tax credit should be much smaller or even negative.

Furthermore, the U.S. Treasury estimates an average tax loss of \$2.65 billion a year from the VEETC for the period 2005-2011. The amendment 220 (2011) reported that the tax revenue loss from ethanol subsidy is around \$6 billion in 2010. This huge tax loss is very conspicuous under the current deficit crisis of the U.S. federal government. Since the net effects of ethanol subsidy is ambiguous and the subsidy may induce a net social welfare loss, negative environmental externality and huge tax revenue loss, the U.S. federal government has cancelled VEETC in 2012. The failure of the ethanol subsidy policy implicates the urgent need of studying the optimal ethanol subsidy in a more comprehensive framework. This kind of research is meaningful and practical because the cellulosic ethanol subsidy is still effective. Furthermore, if the new optimal subsidy could overcome these shortcomings of the past VEETC, the policymakers could reuse this policy to promote the use of bioethanol.

Our study devotes to provide a social optimal ethanol subsidy to overcome these shortcomings in a general theoretic framework. It contributes to the existing literature in several important ways. First, our model incorporates the environmental externality and the subsidy cost simultaneously. The standpoint is that the government try to minimize the sum of environmental cost of GHG emission and ethanol subsidy cost while most previous literatures just emphasize on either environmental externality part (Vedenov and Wetzstein 2007; Khanna, Ando and Tapheripour 2008; de Gorter and Just 2008) or subsidy cost part (Gardner 2007; Rajagopal et al. 2007; de Gorter and Just 2009). As a result, the behavior of government is to use the minimum subsidy cost to internalize the environmental externality. Second, to the author's knowledge, this is the first study that uses an optimal control model to discuss the dynamic properties of optimal subsidy policy. In our model, the optimal subsidy policy is a dynamic path, rather than a static policy as previous literatures assume. The governments make the optimal ethanol subsidy based on the market factors (price of ethanol and gasoline) as well as the carbon emissions in the current period. This dynamic method would reduce/eliminate the negative environmental externality from the subsidy because we impose an upper bound on the consumption of gasoline by capping the carbon emission.

Theoretic Model

Consider a society with environmental social cost, denoted by function f: $f(x(t))$ where $x(t)$ is the carbon emission level at each time t. In order to reflect the fact that social environmental cost is increasing as carbon emission level increases, we assume that $f: \mathbb{R}^+ \to \mathbb{R}^+$ and the function is monotonically increasing in x.

Suppose that there exists a benevolent government that minimize the total cost functional where the total cost is the sum of the social cost and the subsidy level, denoted by $u(t)$:

$$\int_0^\infty e^{-rt}\,(f(x)+u)\,dt$$

where r is the discount factor. Essentially, our objective functional implicitly assumes that the government has the goal of using its policy tools to internalize the GHG emission externalities. This assumption, consequently, requires that the government is capable of accurately findind the functional form of social environmental cost, which is beyond the scope of this article.

In order to determine the equation of motion for GHG emission level at any given time, we have to look into the consumption of conventional fuel. On the consumption side, we assume that the dynamics of conventional fuel, denoted by c is following the differential equation:

$$\dot{c} = g(c, p_c, p_b, u)$$

where p_c, p_b deonotes the price of conventional fuel and bio-fuel resepctively. Here, the function g has a natural explanation of the growth rate of the consumption of conventional fuel over time. We assume that g is decreasing in p_cIt should be noted that the tax credit comes into the consumption dynamics. The rationality behind this formulation is that when tax credit increase, the equalibrium price of biofuel decreases which will cause movement of consumption on conventional fuel. For instance, if conventional fuel and bio fuel are complements, then an increase in tax credit will lead to higher demand on converntional fuel.

Now, to link the carbon emission level and covnventional fuel consumption, we assume that the carbon emission level is proportional to the conventional fuel: $x = a \cdot c$. The parameter $a \in [0,1]$ captures the proportion. It is easy to see that $\dot{x} = a\dot{c}$. And, combined with the dynamics of c, we have:

$$\dot{x} = a \cdot g(x/a, p_c, p_b, u)$$

Moreover, to capture the fact that government sets minimum GHG emission objective. We let $\bar{x}$ be the GHG emission cap, i.e. $x \leq \bar{x}$.

By the model setup above, we have the government's minimization problem:

$$\min J = \int_0^\infty e^{-rt} (f(x) + u)\, dt$$

$$s.t.\;\; \dot{x} = a \cdot g(x/a, p_c, p_b, u), x \leq \bar{x}$$

We may easily setup the Hamiltonian for the unconstrained problem:

$$H = e^{-rt}(f(x) + u) + \lambda a g(x/a, p_c, p_b, u)$$

And, with the minimum emission objective constraint, we setup the Lagrangian as follows:

$$L = e^{-rt}(f(x) + u) + \lambda a g(x/a, p_c, p_b, u) + \mu(\bar{x} - x)$$

It is self-explanatory that λ is the co-state variable for the Hamiltonian and μ is the Lagrange multiplier for the problem. Notice that an infite horizon is chosen for the problem, which implies an overlapping generations economy. A set of condition should meet for the optimized subsidy:

$$L_u = e^{-rt} + \lambda a g_u = 0$$

This is the first order condition for the optimality of the constrained problem. It is easy to see that the first term e^{-rt} is the discounted marginal cost of tax credit. The term, ag_u, determines the marginal effect of tax credit policy on the consumption growth rate over time. Then, multiplied by the co-state variable, the whole second term, $\lambda a g_u$ captures the marginal benifit of conventional fuel reduction. Therefore, the optimality condition $L_u = 0$

implies that on the optimal tax credit path, the discounted marginal cost of tax credit should be equal to its marginal effect on GHG emission reduction at any given time.

The second condition:

$$L_x = e^{-rt} f_x + \lambda g_{x/a} - \mu = -\dot{\lambda}$$

In our model, the co-state variable λ can be interpreted as the marginal effect of increasing the growth rate of GHG emission on the social environmental cost. Therefore, $\lambda \geq 0$ for all t. $L_x = -\dot{\lambda}$ gives the equation of motion for the co-state variable. And the equation tells us that the dynamics of the co-state variable is determined by three components: first is the discounted marginal social cost; second is the marginal value of consumption growth rate change; and the third component is the shadow price of the minimum GHG emission objective.

The last condition is the complementary slackness condition for the inequality constraint:

$$\mu \geq 0; \bar{x} - x \geq 0; \mu(\bar{x} - x) = 0$$

In order to analytically discuss the optimized solution, we need the following assumptions:
(1) H is quasiconcave in u.
(2) The opmimal solution path $u^*(t)$ exists uniquely.
(3) The finite crossing property as describe in Lafrance and Barney(1991).

Proposition 1 (Envelope Theorem) The minimized discounted sum of total cost is monotonically increasing in p_c and $\bar{x}$.

Proof. Now, we denote the vector of exogenous variables by α, i.e. $\alpha = [p_c, p_b, \bar{x}]$. Then, by the dynamic envelop theorem by Lafrance and Barney(1991), we have:

$$\frac{\partial J^*}{\partial \alpha} = \int_0^\infty \frac{\partial L}{\partial \alpha} dt$$

Then, by the formulation of L, we can easily show that:

$$\frac{\partial J^*}{\partial p_c} = \int_0^\infty \lambda^* a g_{p_c} dt$$

$$\frac{\partial J^*}{\partial \bar{x}} = \int_0^\infty \mu dt$$

Given that $\lambda^* > 0$, $a > 0$, and $g_{p_c} < 0$ for all t, we must have $\frac{\partial J^*}{\partial p_c} < 0$. Similarly, we have $\frac{\partial J^*}{\partial \bar{x}} \geq 0$, since $\mu \geq 0$. □

Proposition 1 gives the fundamental envelope results for the optimal control problem. And the intuition is the same as in the static case. The two comparative results both have vast practical implications. As p_c increases, consumers find it less attractive to use gasoline. Therefore, the automous reduction on conventional fuel consumption will reduce the social environmental cost without the need of tax credit adjustment. This will result in a derease on the total cost. As the same time, as $\bar{x}$ increases, the society becomes more tolerant about GHG emissions, which, in turn, increase social environmetal cost.

Corollary 1 The minimized discounted sum of total cost is monotonically increasing in p_b if conventional fuel and biofuel are complements, and is decreasing in p_b if the two fuels are substitutes.

Proof. Same as in propostion 1, we have:

$$\frac{\partial J^*}{\partial p_b} = \int_0^\infty \lambda^* a g_{p_b} dt$$

Notice that the sign of g_{p_b} will be positive if the two kinds of fuel are complements, be negative if they are substitutes. Therefore, the same logic follows. □

Proposition 2 (Comparative dynamics) The marginal effect of exogenous parameter α on the optimal tax credit is given by the matrix equation:

$$L_{u\alpha}\cdot u_{\alpha}^{*}=\begin{pmatrix} M_1 & M_2 \\ M_2 & M_3 \end{pmatrix}$$

where $M_1 = L_{xx}$, $M_2 = L_{x\alpha}$ and $M_3 = L_{\alpha\alpha}$.

Proof. The proof of the proposition is adopted from Caputo(2003). □

It should be noted that signing u_{α}^{*} requires specific functional forms or second order assumptions on each term. Without such information, u_{α}^{*} remains unsignable.

Proposition 3 (Behaivor of the costate variable) The dynamics of the costate variable λ is determined by $g_{x/a}$. Moreover, we have:

Proof. Notice that $L_x = e^{-rt}f_x + \lambda g_{x/a} - \mu = -\dot{\lambda}$. This forms a first order ordinary differential equation. The homogeneous equation yields the result: $\lambda = \lambda(0)e^{-g_{x/a}t}$. Therefore,$\lambda$ is increasing over time if $g_{x/a} < 0$ and vice visa.

Now, for the nonhomogeneous equation, we should have:

$$\lambda{=}\lambda\left(0\right)e^{-\int g_{x/a}dt}\int(-e^{-rt}f_x-\mu)e^{\int g_{x/a}dt}dt$$

which has the solution:

$$\lambda=\lambda\left(0\right)e^{-g_{x/a}t}\left(-\mu t-f_x t\frac{e^{-rt}}{r}\right)$$

□

Essentially, this proposition depicts the monotonicity and curvature of the co-state variable. From the proposition, we can tell that the shape of the co-state variable is determined by the behavior of the growth rate of the conventional fuel demand.

Conclusion

In this paper, we setup a overlapping generations framework and a social cost minimization problem for a government. Using dynamic optimization tools, we analytically shows how exogenous parameters could affect the optimal social cost and the optimal tax credit policy path.

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