AN OPTIMAL U.S. BIODIESEL FUEL SUBSIDY

by

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ABSTRACT

Enhanced environmental quality, fuel security, and economic development along with reduced prices of blended diesel are often used as justifications for U.S. federal excise tax exemption on biodiesel fuels. However, the possible effect of increased overall consumption of fuel in response to lower total price, mitigating the environmental and fuel security benefits, are generally not considered. Taking this price response into account, the optimal U.S biodiesel subsidy is derived. Estimated values of the optimal subsidy is less than the current subsidy, revealing the subsidy's environmental and security benefits are still questionable. However, positive environmental and security benefits from the biodiesel tax-exemption subsidy may be obtained if the subsidy is combined with an increase of the share of biodiesel in blended diesel.

INDEX WORDS: Biodiesel, Subsidy, Elasticity, Renewable Fuel

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CHAPTER 1

Determinants for an Optimal U.S. Biodiesel Fuel Subsidy

Biodiesel is a commercially viable, renewable, low carbon diesel replacement fuel that is widely accepted in the marketplace. The fuel meets an exact commercial fuel specification (ASTM D6751) and is the only domestically produced, commercial scale fuel that qualifies as an Advanced Biofuel under the Renewable Fuels Standard.[1]

The biodiesel tax incentive is structured in a manner that makes the fuel price competitive with conventional diesel fuel in the marketplace. The U.S. Jobs Creation Act of 2004 created a new excise tax credit for biodiesel mixtures, over 25 years after a similar tax credit for ethanol. Originally the subsidy was $1.00/gallon for virgin oils and animal fats; $0.50/gallon for recycled oils; currently it is $1.00/gallon for all sources other than fuels co-processed at petroleum refineries, which are not eligible.[2] This excise tax credit is compared to an excise tax of $0.244/gallon imposed on the sale of diesel fuel. These credits are available on a prorated basis if the product is sold as a blended product with petroleum based diesel fuel. For example, a B20 (20% biodiesel and 80% diesel) biodiesel blend would be eligible for a $0.20 credit if produced from virgin oil. (International 2005[3])

[1] President Obama Signs Bill Extending Biodiesel Tax Incentive Into Law, last accessed date Nov 9, 2011 http://www.biodiesel.org/news/taxcredit/default.shtm
[2] "Volumetric Biodiesel Excise Tax Credit"; last accessed date Dec 9, 2010 http://www.earthtrack.net/files/uploaded_files/FOE%20VEETC%20Evaluation%20FINAL.pdf
[3] International, Promar. (2005). Evaluation and analysis of vegetable oil markets: The implications of increased

Biofuels in general and biodiesel in particular are granted subsidies on the premise that are substitutes for imported fossil fuels, reduce air pollution and greenhouse gases, and stimulate economic growth.[4] Critics question these benefits by arguing the production process of biofuels is fossil-fuel intensive, the reduction in environmental degradation is minimal compared with the cost, and the economic development benefits are regional. Given those dichotomist views on the effects of the subsidy, the objective is to derive the socially optimal U.S. biodiesel subsidy with consideration of the environmental, fuel security, and economic development benefits. In contrast to the optimal ethanol subsidy developed by Vedenov and Wetzstein (2007)[5], biodiesel is modeled as a substitute for conventional diesel. While it is hypothesized that an increase in the subsidy does lower the price of vehicle fuels which stimulates additional consumption, the substitution effect of replacing biodiesel with conventional diesel tends to mitigate this effect. Based on this substitution hypothesis, the optimal biodiesel subsidy is derived under utility maximization behavior. The derived subsidy is then estimated given published parameter values, and sensitivities of the subsidy to elasticities and the marginal welfare gains from environmental and fuel security improvements are analyzed.

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demand for industrial uses on markets & USB strategy: 1-78.

[4] National Board of Biodiesel, http://www.biodiesel.org/

[5] Dmitry Vedenov and Michael Wetzstein, Toward an Optimal U.S. Ethanol Fuel Subsidy, 2007

CHAPTER 2

Literature Review

The biodiesel tax credit is an essential factor for profitability of producing biodiesel and maintaining the competitiveness of biodiesel with petroleum diesel as it reduces the price of biodiesel compared to petroleum diesel. However, the arguments about benefits and costs from biodiesel subsidies continue. Some positive justifications pertain to the externalities associated with reducing the need for U.S. oil imports and reducing carbon emissions (Energy Independence and Security Act of 2007[6]). The biodiesel subsidy can also promote rural economic development, such as the economic activity associated with the construction and operation of biofuel facilities (Dorr, 2006[7]), and higher commodity prices providing farm income (Tyner and Taheripour, 2007[8]).

Much of the literature on fuel taxation is primarily concerned with the impact that such taxes have on general economic growth, tax incidence, or market efficiency. In terms of biodiesel tax credits (subsidies), besides economic aspects, more attention is given to social welfare and environmental improvement. Decker et al. (2006)[9] conducted research on the determinants of state diesel fuel excise tax rates. Building on this

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[6] "Energy Independence and Security Act of 2007", last accessed date Jan 28, 2011 http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=110_cong_bills&docid=f:h6enr.txt.pdf

[7] Dorr, T. 2006. "Ethanol & Rural Development" Ethanol Across America White Paper, Fall 2006. Series Ethanol Across America, Clean Fuels Foundation, last accessed date January 2 2011

[8] Tyner, W.E., and F. Taheripour 2007. "Renewable Energy Policy Alternatives for the Future." American Journal of Agricultural Economics 89(5): 1303-1310.

[9] Christopher S. Decker · Mark E. Wohar; "Determinants of state diesel fuel excise tax rates: the political economy of fuel taxation in the United States"; last accessed date January 28 2011

research, more recent studies have reported tax levels to be sensitive to a variety of political and economic conditions. John M. Urbanchuk(2011)[10] studies the economic impact of removing the tax credits. It finds that the expiration of the tax credit and the accompanying 42 percent drop in production for 2010 resulted in the loss of nearly 8,900 jobs, a reduction in real GDP of $879 million, and a drop in household income of $485 million. Hammar et al. (2004)[11] investigated the determinants of gasoline tax rates across a panel of Western European countries, the United States, and New Zealand and found while low taxes encourage greater gasoline consumption, high levels of consumption lead to substantial pressure against tax rate increases. Political support, however, can take a variety of forms, particularly when considering industry's influence on candidates seeking political office. Urbanchuk (2009)[12] analyzed the economic impact of eliminating U.S. biodiesel tax credit. Rubin et al. (2008)[13] evaluated and compared the magnitude and sign of the four benefits that have been used to justify existing biofuel subsidies: energy independence, a reduction in greenhouse gas emissions, improvements in rural development related to biofuel plants, and farm income support. Though biodiesel produces less pollution than petro-diesel, it is more expensive and will only be a viable

[10] John M. Urbanchuk, Economic Impact of Removing the Biodiesel Tax Credit for 2010 And Implementation of RFS2 Targets Through 2015; last accessed date September 28 2011.
[11] Hammar, Henrik, Asa Lofgren and Thomas Sterner, "Political Economy Obstacles to Fuel Taxation," The Energy Journal, 25, n3, (2004): 1-17.
[12] John M. Urbanchuk, Director, LECG LLC; "Economic Impact of Eliminating the Biodiesel Tax Credit"; last accessed date Jan 28, 2011
[13] Ofir D. Rubin, Miguel Carriquiry, and Dermot J. Hayes; "Implied Objectives of U.S. Biofuel Subsidies"; last accessed date Jan 28, 2011

alternative if market prices of the products are comparable. Wassell, et al. (2005)[14] examines whether the external benefits from biodiesel use justify subsidies required for adoption outside of niche alternative fuel markets. De Gorter et al. (2009)[15] developed a framework to analyze the effects of a biofuel consumer tax exemption and the interaction effects with a price contingent farm subsidy. They determined as ethanol prices rise above the gasoline price by the amount of the tax credit, corn farmers gain directly while gasoline consumers only gain from any reduction in world oil prices due to the extra ethanol production. Domestic oil producers lose. Historically, the intercept of the ethanol supply curve is above the gasoline price. Hence, part of the tax credit is redundant and represents "rectangular" deadweight costs that dwarf triangular deadweight cost measures of traditional farm subsidies. Ian W.H. Parry (2009)[16] develops and implements an analytical framework for estimating optimal taxes on the fuel use and mileage of heavy-duty trucks in the United States. He estimates the optimal (second-best) diesel fuel tax at $1.12 per gallon and implementing it increases welfare by $1.34 billion per year. Optimizing over both fuel and mileage taxes, and differentiating mileage taxes by vehicle type and region, yields progressively higher welfare gains. The most efficient tax structure involves a diesel fuel tax of 69 cents per gallon and charges on trucks that vary

[14] Charles S. Wassell Jr.a, and Timothy P. Dittmer; "Are subsidies for biodiesel economically efficient?"; last accessed date Jan 28, 2011

[15] de Gorter, Harry and Just, David R.; "The Welfare Economics of an Excise-Tax Exemption for Biofuels"; last accessed date Jan 28, 2011

[16] Ian W.H. Parry; How should heavy-duty trucks be taxed?; last accessed date Aug 28, 2011

between 7 and 33 cents per mile; implementing this tax structure yields estimated welfare gains of $2.06 billion.

CHAPTER 3

Theoretical model

Previous studies have investigated the external costs of vehicle transportation in an attempt to develop an optimal fuel tax. Parry and Small (2005) identify a Pigovian and Ramsey tax along with congestion feedback as components of an optimal gasoline tax. Vedenov and Wetzstein (2007) apply the Parry and Small methodology to derive the optimal ethanol fuel subsidy. In terms of diesel fuel, Parry (2008) develops the optimal fuel and mileage tax for heavy-duty trucks. Using these studies as a guide, a theoretical model for an optimal biodiesel subsidy is developed.

The different market structure associated with diesel compared with ethanol necessitates a modification in the theoretical development of the optimal fuel subsidy. In contrast to ethanol as an additive for gasoline, biodiesel blends are a direct substitute for conventional petroleum diesel. For modeling the optimal biodiesel subsidy, let p_B and p denote the price per gallon of blended and conventional fuel, respectively, with *s* representing the per gallon biodiesel subsidy. For the blended fuel, denote α_R as the renewable fuel (biodiesel) share in blended fuel consumption, *B/F*, where *B* and *F* represent gallons of biodiesel and blended fuel consumption, respectively. A representative agent's budget constraint may then be specified as

$$X + (p_B - s\alpha_R)F + pF_O + H = I(s) \quad (1)$$

where X, F_O and H denote a composite consumption good associated with a numeraire price $p_X = 1$, the gallons of consumption of conventional fuel, and money expenditure on fuel efficiency, respectively. In (1), income, I, is influenced by the level of subsidy, given the assumption a subsidy promotes economic development which enhances an agent's income. Between blended and conventional fuel, and agent's choice will depend on whichever has the lowest price. An increase in the subsidy, s, will then lower the effective price of bended fuel, $p_B - s\alpha_R$, and an agent will adopt this blend when this effective price drops below the conventional diesel price p.

The presence of nonmarket affects, in the form of fuel security and pollution externalities along with government spending issues, are ignored by agents in their own driving and thus do not enter the agent's budget constraint (1). However, for determining the social optimal fuel subsidy they should be considered. Consistent with Parry and Small (2005), for such consideration, let vehicle travel, M, be produced according to a linear homogeneous function

$$M = M(F_T, H), \tag{2}$$

where F_T represents total fuel consumption $(vF + F_O)$ with v representing the adjustment parameter for the differential in blended and conventional fuel efficiency. This assumes a tradeoff exists between vehicle cost and fuel efficiency i.e. improved vehicle fuel efficiency leads to a higher sticker price. Given the 2% lower in fuel economy for B20,[17] $v = 1.02$.

Fuel security, A, is based on the aggregate level of fossil fuel consumption

$$\bar{F}_{OT} = \bar{F}_O + \bar{F}(1 - \alpha_R),$$

and aggregate fuel efficiency, $\bar{H}$,

$$A = A(\bar{F}_{OT}, \bar{H}), \tag{3}$$

where $\bar{F}_O$ represents aggregate conventional fuel consumption and $\bar{F}$ denotes aggregate blended fuel consumption with $\partial A/\partial \bar{F}_{OT} < 0$ and $\partial A/\partial \bar{H} > 0$.

The environmental effect of driving, P, is decomposed into air quality, P_M, and greenhouse gas emissions, P_F. It is assumed air quality depends on aggregate miles driven, $\bar{M}$, and aggregate fuel consumption associated with greenhouse gases,

$$\bar{F}(1 - \alpha_R \alpha_q) + \bar{F}_O,$$

$$P = P_M(\bar{M}) + P_F\left[\bar{F}(1 - \alpha_R \alpha_q) + \bar{F}_O\right], \tag{4}$$

$$dP_M/d\bar{M} > 0, \quad \partial P_F/\partial \bar{F} > 0, \quad \partial P_F/\partial \bar{F}_O > 0,$$

where α_q denotes the percentage reduction in greenhouse gases from renewable fuels.

The federal excise tax on diesel fuel is used for funding the governmental expenditures on highway development and improvements along with mass transit systems. As a federal biodiesel tax exemption, the biodiesel subsidy negatively affects the

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[17] Biodiesel Compared to Petroleum Diesel; last accessed date Aug 22, 2011 http://www.fueleconomy.gov/feg/biodiesel.shtml

government highway trust fund by requiring a redirection of funds from other governmental programs. Formally

$$G = \bar{F}(t - s\alpha_R) + t\bar{F}_O, \tag{5}$$

where G denotes government highway spending and t represents the diesel excise tax rates. With no subsidy, the total tax collections are $t(\bar{F} + \bar{F}_O)$ and the per-gallon subsidy s reduces these tax collections by $\bar{F}s\alpha_R$.

The fuel security, environmental externalities, and government highway spending enter into an agent's utility function along with an agent's satisfaction from the composite commodity, X, and miles of vehicle travel, M. As represented by Parry and Small (2005), let an agent have the quasi-linear utility function, U, associated with using a vehicle

$$U = u(X, M) + \gamma(G) - \delta(P) + \rho(A), \tag{6}$$

where variables G, P, and A are features of the agent's environment, so the agent perceives them as exogenous. The functions u, γ and ρ are quasi-concave, whereas δ is weakly convex representing the disutility from pollution. The external benefits of reduced pollution (both local air quality and greenhouse gases) and increased fuel security, as well as government cost of a biodiesel subsidy are embedded in (6).

Agent's Choice

The optimal subsidy based on individual agent's problem of maximizing (6) constrained by (1) is derived by the indirect utility function

$$V(s, G, P, A) = \max \mathcal{L}(X, F_T, H) = \max u[X, M(F_T, H)] + \gamma(G) - \delta(P) +$$

$$\rho(A) + \lambda\big[I(s) - X - (p_B - s\alpha_R)F - pF_O - H\big], \quad (7)$$

where λ is the Lagrange multiplier, the terms s, G, P, and A then become the model's parameters along with p_B and p which are suppressed because they are not varied with s. The F.O.C.s for (7) are

$$\partial\mathcal{L}/\partial X = u_X - \lambda = 0,\ \partial\mathcal{L}/\partial F = u_M M_{F_T} v - \lambda(p_B - s\alpha_R) = 0,$$

$$\partial\mathcal{L}/\partial F_O = u_M M_{F_T} - \lambda p = 0, \partial\mathcal{L}/\partial H = u_M M_H - \lambda = 0,$$

where the subscripts denote first partial derivatives of the respective functions. From these F.O.C.s

$$M_{F_T}/p = M_{F_T} v/(p_B - s\alpha_R) = \lambda/u_M = M_H, \quad (8)$$

From the first equality in (8), if p $> (p_B - s\alpha_R)/v$, then an agent will adopt blended fuel F. Otherwise he/she will not adopt the blended fuel.

Note that

$$p_B = (1 - \alpha_R)pv + \alpha_R p_R = pv + \alpha_R(p_R - pv) \quad (9)$$

where p_R represents the price of the renewable fuel, biodiesel. An agent will then adopt blended fuel F if $p > [pv + \alpha_R(p_R - pv - s)]/v$ which implies $(p_R - s)/v < p$. If the price of biodiesel net of the subsidy s adjusted for the fuel efficiency differential, v, is less than the price of conventional diesel, then an agent will adopt the blended fuel F.

An optimal subsidy, s*, would account for agents ignoring the effect of their own driving on aggregate mileage, $\overline{M}$, aggregate fuel consumption, $\bar{F}$, and aggregate fuel efficiency, $\overline{H}$. Incorporating this optimal subsidy into the adoption decision rule

$(p_R - s^*)/v < p$, will yield the social optimal determination of when to adopt. This is the general idea of the subsidy; the price of biodiesel can then be greater than the price of conventional diesel and still possibility result in adoption given the offsetting effects of the subsidy which accounts for nonmarket effects.

Welfare Effects

Deriving the biodiesel subsidy based on the nonmarket effects will yield the social optimal subsidy. As addressed by Parry and Small (2005), this derivation is based on the homogeneity property of $M(F_T, H)$, where the ratios of variables become functions of the subsidy only, i.e. $\alpha_{FM} = F/M = \alpha_{FM}(s)$, $\alpha_{FF_O} = F/F_O = \alpha_{FF_O}(s)$, $\alpha_{HM} = H/M = \alpha_{HM}(s)$. Thus $M = M(s)$, $F = F(s) = \alpha_{FM}(s)M(s)$, $F_O = F_O(s)$, and $H = H(s) = \alpha_{HM}(s)M(s)$.

The welfare effects of an incremental change in the biodiesel subsidy may then be determined by totally differentiating the indirect utility function (7) with respect to the subsidy level s. Noting that $\partial V/\partial s = \lambda[dI/ds + \alpha_R F + (d\alpha_R/ds)sF]$ (by the envelope theorem), and $\partial V/\partial G = \gamma' > 0$, $\partial V/\partial P = -\delta' < 0$, $\partial V/\partial A = \rho' > 0$, yields

$$dV/ds = \gamma' dG/ds - \delta' dP/ds + \rho' dA/ds + \lambda[dI/ds + \alpha_R F + (d\alpha_R/ds)sF] \quad (10)$$

The derivatives of s with respect to G, P, and A, given (5), (4), and (3), are

$$dG/ds = -\alpha_R F + (dF/ds)(t - s\alpha_R) - (d\alpha_R/ds)sF + t(dFo/ds), \quad (11a)$$

$$dP/ds = (\partial P_F/\partial F)[(dF/ds)(1 - \alpha_R\alpha_q) - (d\alpha_R/ds)\, \alpha_q F]$$
$$+(\partial P_F/\partial F_O)(dF_O/ds) + (dP_M/dM)(\partial M/\partial s), \quad (11b)$$

$$dA/ds = (\partial A/\partial F)[(dF/ds)(1 - \alpha_R) - (d\alpha_R/ds)\, F]$$

$$+ (\partial A/\partial F_O)(dF_O/ds) + (dA/dH)(\partial H/\partial s) \quad (11c)$$

In determining (11), the social welfare effects, aggregate mileage, $\bar{M}$, fuel consumption, $\bar{F}$, and fuel efficiency, $\bar{H}$ are no longer constant, so their partials with respect to s are the partials of M, F, and H. Higher levels of the subsidy result in a lower effective price for biodiesel and thus higher (lower) consumption of blended (conventional) fuel, $dF/ds > 0$, $dF_O/ds < 0$, and hence $\partial M/\partial s > 0$ and $dH/ds < 0$.

Substituting (11a) - (11c) into (10) and dividing by λ results in the marginal monetary welfare effect of the biodiesel subsidy s

$$\frac{dV/ds}{\lambda} = \left(\frac{\gamma'}{\lambda}\right)\left\{-F\alpha_R + \left(\frac{dF}{ds}\right)(t - s\alpha_R) - \left(\frac{d\alpha_R}{ds}\right)sF + t\left(\frac{dF_O}{ds}\right)\right\}$$

$$-\left(\frac{\delta'}{\lambda}\right)\left\{(\partial P_F/\partial F)\left[\left(\frac{dF}{ds}\right)(1 - \alpha_R\alpha_q) - \left(\frac{d\alpha_R}{ds}\right)\alpha_q F\right] + (\partial P_F/\partial F_O)(dF_O/ds)\right.$$

$$\left. + \left(\frac{dP_M}{dM}\right)\left(\frac{dM}{ds}\right)\right\} + \left(\frac{\rho'}{\lambda}\right)\left\{(\partial A/\partial F)\left[\left(\frac{dF}{ds}\right)(1 - \alpha_R) - \left(\frac{d\alpha_R}{ds}\right)F\right]\right.$$

$$\left. + (\partial A/\partial F_O)\left(\frac{dF_O}{ds}\right) + \left(\frac{dA}{dH}\right)(\partial H/\partial s)\right\} + \frac{dI}{ds} + \alpha_R F + \left(\frac{d\alpha_R}{ds}\right)sF. \quad (12a)$$

Following Parry and Small (2005), the externality effects are defined as

$E^{P_F F} = \left(\frac{\delta'}{\lambda}\right)(\partial P_F/\partial F)(1 - \alpha_R\alpha_q) > 0$, $\quad E^{P_F \alpha} = \left(\frac{\delta'}{\lambda}\right)(\partial P_F/\partial F)(\alpha_R F) > 0$,

$E^{AF} = \left(\frac{\rho'}{\lambda}\right)(\partial A/\partial F)(1 - \alpha_R) < 0$, $\quad E^{A\alpha} = \left(\frac{\rho'}{\lambda}\right)(\partial A/\partial F)F < 0$,

$E^{P_M} = \left(\frac{\delta'}{\lambda}\right)(\partial P_F/\partial M) > 0$, $\quad E^{AH} = \left(\frac{\rho'}{\lambda}\right)(\partial A/\partial H) > 0$,

$E^{P_F F_O} = \left(\frac{\delta'}{\lambda}\right)(\partial P_F/\partial F_O) > 0$, and $\quad E^{AF_O} = \left(\frac{\rho'}{\lambda}\right)(\partial A/\partial F_O) < 0$,

and rewrite (12a) as

$$(dV/ds)/\lambda = \alpha_R F + (d\alpha_R/ds)sF - \left(\frac{\gamma'}{\lambda}\right) F\alpha_R$$
$$+ \left[\left(\frac{\gamma'}{\lambda}\right)(t - s\alpha_R) - E^{P_F F} + E^{AF}\right](dF/ds)$$
$$+ \left[-\left(\frac{\gamma'}{\lambda}\right) sF + E^{P_F \alpha} - E^{A\alpha}\right](d\alpha_R/ds)$$
$$+ \left[t\left(\frac{\gamma'}{\lambda}\right) - E^{P_F F_O} + E^{AF_O}\right](dF_O/ds)$$
$$-E^{P_M}(\partial M/\partial s) + E^{AH}(dH/ds) + dI/ds. \qquad (12b)$$

As indicated from the marginal welfare effect of the biodiesel subsidy is decomposed into the direct and indirect effects. The direct effect of a change in the subsidy is the change in blended fuel consumption. The indirect effects are further decomposed into the effect a subsidy has on the nonmarkets of blended fuel consumption, the renewable fuel share, conventional fuel consumption, miles driven, and fuel efficiency, along with the income effect.

Marginal External Benefits

For further analysis and interpretation, it is convenient to express the marginal welfare effects (12b) in terms of elasticities. Define MEB as the net marginal external benefit of renewable fuel use

$$MEB = (-E^{P_F F} + E^{AF}) - \frac{E^{P_M}\beta}{\alpha_{FM}} + \frac{E^{AH}\zeta}{\alpha_{FH}} + \frac{(E^{P_F\alpha} - E^{A\alpha})\xi}{\alpha_{F\alpha}} + \frac{(-E^{P_F F_O} + E^{AF_O})\tau}{\alpha_{FF_O}}, \qquad (13)$$

where the parameters $\beta, \zeta, \ \xi, \tau, \alpha_{FM}, \alpha_{FH}, \alpha_{F\alpha}$, and α_{FF_O} are defined as

$$\beta = \frac{\left(\frac{\partial M}{\partial s}\right)F}{\left(\frac{dF}{ds}\right)M} = \epsilon_{Ms}/\epsilon_{Fs} > 0,$$

$$\zeta = \frac{\left(\frac{dH}{ds}\right)F}{\left(\frac{dF}{ds}\right)H} = \frac{\epsilon_{Hs}}{\epsilon_{Fs}} < 0,$$

$$\xi = \frac{\left(\frac{d\alpha_R}{ds}\right)F}{\left(\frac{dF}{ds}\right)\alpha_R} = \frac{\epsilon_{\alpha s}}{\epsilon_{Fs}} > 0,$$

$$\tau = \frac{\left(\frac{dF_O}{ds}\right)F}{\left(\frac{dF}{ds}\right)F_O} = \frac{\epsilon_{F_O s}}{\epsilon_{Fs}} < 0,$$

$$\alpha_{FM} = \frac{F}{M}, \alpha_{FH} = \frac{F}{H}, \alpha_{F\alpha} = \frac{F}{\alpha_R}, \alpha_{FF_O} = \frac{F}{F_O},$$

and $\epsilon_{Ms}, \epsilon_{Fs}, \epsilon_{Hs}, \epsilon_{\alpha s}$, and $\epsilon_{\mathrm{F_O}s}$denote the elasticities of mileage, blended fuel, fuel efficiency, renewable fuel share, and conventional fuel with respect to the subsidy, respectively.

MEB is composed fo the direct benefits of blended fuel use, $-E^{P_F F} + E^{AF},$ and indirect net external marginal benefits from a per unit change in blended fuel consumption. The direct marginal benefits are the effects of blended fuel use on greenhouse gas emission $-E^{P_F F}$ and fuel security E^{AF}. The indirect marginal benefits are changes in air quality, $\frac{E^{P_M}\beta}{\alpha_{FM}}$, fuel efficiency, $\frac{E^{AH}\zeta}{\alpha_{FH}}$, renewable fuel share, $\frac{(E^{P_F\alpha} - E^{A\alpha})\xi}{\alpha_{F\alpha}}$, and conventional fuel, $\frac{(-E^{P_F F_O} + E^{AF_O})\tau}{\alpha_{FF_O}}$, per unit change in blended fuel consumption.

An increase in the subsidy will stimulate additional blended fuel consumption *(* $\frac{dF}{ds}$ *> 0)*, which, in turn, will add to the greenhouse gas effect $(-E^{P_F F} < 0)$ and decrease fuel security *(*$E^{AF} < 0)$ resulting in lower MEB. The subsidy will also provide a positive incentive to increase miles traveled ($\frac{\partial M}{\partial s} > 0$) thus reducing air quality $\left(-\frac{E^{P_M}\beta}{\alpha_{FM}} < 0\right)$, creating a disincentive to invest in fuel efficiency $\left(\frac{E^{AH}\zeta}{\alpha_{FH}} < 0\right)$, and again negatively affecting MEB.

In contrast, MEB can be positively augmented if the subsidy increases the share of renewable fuel in the total fuel consumption and decreases the use of conventional fuel. From (13), an increase in renewable fuel share and/or a decrease in conventional fuel use will retard greenhouse gas emissions and enhance fuel security, $\frac{(E^{P_F\alpha} - E^{A\alpha})\xi}{\alpha_{F\alpha}} > 0$ and $\frac{(-E^{P_F F_O} + E^{AF_O})\tau}{\alpha_{FF_O}} > 0$. Therefore, for the biodiesel subsidy to result in a net positive MEB, it must provide a sufficient positive stimulus toward enhancing the share of biodiesel and/or decreasing conventional fuel in overall fuel consumption. These and other properties of MEB are summarized in the following proposition and corollary.

Proposition 1. *The responsiveness of blended fuel share to the biodiesel subsidy is inversely related to the associated responsiveness of conventional fuel to the subsidy. Specifically, the more elastic (inelastic) conventional fuel is to the subsidy the more inelastic (elastic) will be the fuel share elasticity.*

The proposition may be proved by first taking the derivative of $\alpha_R = B/F$ with respect to s

$$\frac{d\alpha_R}{ds} = \left[\left(\frac{dB}{ds}\right)F - \left(\frac{dF}{ds}\right)B\right]/F^2$$

Dividing both sides by α_R and multiplying through by s, yields

$$\epsilon_{\alpha s} = \frac{d\alpha_R}{ds}\frac{s}{\alpha_R} = \frac{dB}{ds}\frac{s}{B} - \frac{dF}{ds}\frac{s}{F} = \epsilon_{Bs} - \epsilon_{Fs} \tag{14}$$

The elasticity of renewable fuel share is equal to the difference between the elasticities of biodiesel and blended fuel consumption. As blended fuel becomes more responsive to the subsidy, relative to the elasticity of biodiesel, the elasticity of renewable fuel share becomes more inelastic. For a positive $\epsilon_{\alpha s}$, which enhances MEB, biodiesel must be more responsive to a change in subsidy than the blended fuel.

For establishing the relationship between the elasticities of fuel share and conventional fuel, decompose the elasticity of total fuel consumed, given $F_T = vF + F_O$

$$\epsilon_{F_T s} = \frac{d(vF+F_O)}{ds}\frac{s}{vF+F_O},$$

$$= \frac{dF}{ds}\frac{vs}{vF+F_O} + \frac{dF_O}{ds}\frac{s}{vF+F_O},$$

$$= \omega\epsilon_{Fs} + (1-\omega)\epsilon_{F_O s},$$

where $\omega = \frac{vF}{vF+F_O}$. The weighted sum of the blended fuel and conventional fuel elasticities is equal to the total fuel elasticity. Solving for the elasticity of blended fuel, ϵ_{Fs}, and substituting into (14) yields

$$\epsilon_{\alpha s} = \epsilon_{Bs} - \frac{\epsilon_{F_T s} - (1-\omega)\epsilon_{F_O s}}{\omega}$$

Noting that $\frac{\partial \epsilon_{\alpha s}}{\partial \epsilon_{F_O s}} = \frac{1-\omega}{\omega} > 0, \epsilon_{\alpha s} > 0$ and $\epsilon_{F_O s} < 0$ results in Proposition 1. A more elastic conventional fuel corresponds to a more elastic blended fuel which from (14) yields more inelastic fuel share elasticity.

As indicated from (13), MEB will increase as the elasticity of conventional fuel becomes more elastic. However, Proposition 1 indicates this increase in MEB is partially offset by a reduction in the elasticity of fuel share. This result is in contrast to the Vedenov and Wetsztein's derivation of MEB. The market structure of biodiesel, compared with ethanol, results in an additional term to MEB formula. This last term, measuring the effect of a biodiesel subsidy on conventional fuel consumed, provides additional marginal benefits for a biodiesel subsidy which is absent in the ethanol subsidy.

Vedenov and Wetzstein's Proposition 2 directly applies to (13), so the more responsive mileage, M, or fuel efficiency, H, is to a biodiesel subsidy, s, the lower is the MEB, and the more responsive the renewable fuel share, α_R is to s, the higher is the MEB. The addition of the term measuring the effect of a biodiesel subsidy on conventional fuel consumed augments their proposition yielding the following corollary.

Corollary. *The more responsive conventional fuel consumed, F_O, is to a biodiesel subsidy, s, the higher is the MEB.*

Optimal Biodiesel Subsidy

Setting first-order condition (12b) to zero and dividing by $\mathrm{dF/ds}$ yields

$$0 = MEB + \frac{\left[1-\left(\frac{\gamma'}{\lambda}\right)\right]\alpha_R s}{\epsilon_{Fs}} + \frac{\epsilon_{Is}}{\epsilon_{Fs}}/\alpha_{FI} + \left[1-\left(\frac{\gamma'}{\lambda}\right)\right]\left(\frac{\epsilon_{\alpha s}}{\epsilon_{Fs}}\right) s\alpha_R$$

$$+\left(\frac{\gamma'}{\lambda}\right)(t - s\alpha_R) + t\left(\frac{\gamma'}{\lambda}\right)(\epsilon_{F_O s}/\epsilon_{Fs})/\alpha_{FF_O}, \tag{20}$$

where $\epsilon_{Is} = \left(\frac{\partial I}{\partial s}\right)\left(\frac{s}{I}\right)$ and $\alpha_{FI} = \frac{F}{I}$. Solving for *s* then yields the optimal biodiesel subsidy per gallon of biodiesel

$$s^* = \frac{MEB\epsilon_{Fs} + \left(\frac{\epsilon_{Is}}{\alpha_{FI}}\right) + \left(\frac{\gamma'}{\lambda}\right)t[\epsilon_{Fs} + (\epsilon_{F_O s}/\alpha_{FF_O})]}{[\left(\frac{\gamma'}{\lambda}\right)(\epsilon_{Fs} + 1) - 1 - \epsilon_{\alpha s} + \left(\frac{\gamma'}{\lambda}\right)\epsilon_{\alpha s}]\alpha_R}\ . \qquad (21)$$

Similar to the optimal ethanol subsidy derived by Vedenov and Wetzstein, the optimal biodiesel subsidy, s^*, is the sum of three parts, the Pigovian subsidy $MEB\epsilon_{Fs}$, Ramsey subsidy $\left(\frac{\epsilon_{Is}}{\alpha_{FI}}\right)$, and the government marginal benefits from a change in total fuel consumption $\left(\frac{\gamma'}{\lambda}\right) t[\epsilon_{Fs} + \epsilon_{F_O s}/\alpha_{FF_O}]$. The Pigovian subsidy is the net external marginal benefits from a per unit change in blended fuel consumption, $MEB,$ times the responsiveness of this fuel consumption to a percentage change in the subsidy. Similar to a Ramsey tax, the optimal subsidy depends on the elasticities, in this case ϵ_{Is}. The more elastic income is to the subsidy, the higher the optimal level of the subsidy. The government marginal benefits are the marginal welfare effects times the tax rate times percentage change in total fuel consumption in response to percentage change in the subsidy. The Pigovian and Ramsey subsidies along with the government marginal benefits are all discounted by the per dollar of subsidy change in welfare,

$$\left[\left(\frac{\gamma'}{\lambda}\right)(\epsilon_{Fs} + 1) - 1 - \epsilon_{\alpha s} + \left(\frac{\gamma'}{\lambda}\right)\epsilon_{\alpha s}\right]\alpha_R.$$

CHAPTER 4

Parameter values

In this section, the following parameters values are calculated from literature review and current economic data: biodiesel proportion in blended diesel α_R, the percentage reduction in greenhouse gases from renewable fuels α_q, the ratio of blended fuel over conventional fuel α_{FF_O}, the amount of blended fuel F per vehicle per year F, fuel efficiency of $1/\alpha_{FM}$, the elasticity of mileage ϵ_{Ms}, the elasticity of vehicle fuel efficiency ϵ_{Hs}, the elasticity of blended fuel, ϵ_{Fs}, biodiesel ϵ_{Bs}, conventional diesel ϵ_{F_Os}, the income elasticity ϵ_{Is}, the government expenditure, γ'/λ. The rest are calculated based on the benchmark values and ranges from above: greenhouse gas costs $E^{P_F F_O}$, $E^{P_F F}$, $E^{P_F \alpha}$; air quality costs E^{AF}, E^{AF_O}, $E^{A\alpha}$ and engine efficiency, E^{AH}.

Benchmark values and parameter ranges used for estimating the optimal biodiesel subsidy are summarized in table 1. As indicated by the U.S. Department of Energy, 20% biodiesel and 80% petroleum diesel, B20, is the most common biodiesel blend in the United States.[18] The resulting $\alpha_R = 0.2$ was used as a benchmark.

Considering the percentage reduction in greenhouse gases from renewable fuels, EPA has reviewed the environmental effects of biodiesel using alternative time horizons and discount rates. Soy-based biodiesel can achieve 22% to -0.04%, and waste grease

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[18] B20 and B100: Alternative Fuels; U.S. Department of Energy; last accessed date Nov 28, 2010 http://www.afdc.energy.gov/afdc/fuels/biodiesel_alternative.html

biodiesel can achieve 80% reduction in greenhouse gases.[19] A report from National Biodiesel Board shows that neat biodiesel (100%biodiesel) reduces the net gain in CO_2 emissions by 78% compared with petroleum-based fuel.[20] For the analysis, the range of α_q is set from 0.8 to -0.0004 with the mean of 0.4 as the benchmark.

The annual gallons of biodiesel consumption is 317 million gallons in 2009 (EIA 2010),[21] thus consumption of blended diesel B20 is 0.317/0.2 = 1.585 billion gallons. Total diesel consumption is 42 billion gallons in 2008 (EIA 2010)[22]. The ratio of blended fuel over conventional fuel α_{FF_O} is set at 1.585/42 = 0.0377, with range of 0.03 to 0.042 as the consumption data from 2006 to 2008. The amount of blended fuel F per vehicle sets to be 4075 gallons per vehicle (FHWA 2009)[23], calculated by weighted average of different trucks. The federal excise tax on diesel is set \$0.244 per gallon (EIA).[24] The current subsidy is \$1 per gallon.

Fuel efficiency of $1/\alpha_{FM} = 23.5$ miles per gallon is based on the average U.S.

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[19] EPA Lifecycle Analysis of Greenhouse Gas Emissions from Renewable Fuels; EPA; last accessed date Nov 28, 2010 http://www.epa.gov/oms/renewablefuels/420f09024.htm

[20] Biodiesel as a Greenhouse Gas Reduction Option; National Biodiesel Board; last accessed date Nov 28, 2010 http://www.biodiesel.org/resources/reportsdatabase/reports/gen/20040321_gen-332.pdf

[21] Biodiesel Overview, 2001-2009, EIA, last accessed date Aug 22, 2011 http://www.eia.gov/totalenergy/data/monthly/pdf/sec10_8.pdf

[22] Estimated Consumption of Vehicle Fuels in the United States, by Fuel Type; EIA; last accessed date Aug 22, 2011 http://www.eia.gov/cneaf/alternate/page/atftables/attf_c1.html

[23] Highway Statistics 2008; U.S. Department of Transportation; last accessed date Nov 29, 2010 http://www.fhwa.dot.gov/policyinformation/statistics/2008/vm1.cfm

[24] Federal and State Motor Fuels Taxes; Energy Information Administration; last accessed date Nov 28, 2010 http://www.eia.doe.gov/pub/oil_gas/petroleum/data_publications/petroleum_marketing_monthly/current/pdf/enote.pdf

light truck fuel efficiency for 2008, with the range from 18 mpg to 30 mpg.[25] The elasticity of mileage $\epsilon_{Ms} = 0.15$, with a range of 0.12 to 0.4 employed Parry's survey also employed for this analysis. For the elasticity of vehicle fuel efficiency, ϵ_{Hs}, Phil (ect. 2003)[26] surveyed the literature and determined the elasticities to be in the range of -0.01 to -0.57, with the benchmark of -0.25.

In terms of other elasticity estimates, Hagler Bailly (1999)[27] estimated fuel price elasticities for road diesel, with benchmark of -0.10 with range of -0.05 to -0.15 in short run and benchmark of -0.40 with the range of -0.20 to -0.60 in long run. Agras and Chapman (1999)[28] using 1982-1995 U.S. data found the short-run price elasticities of VMT and MPG with respect to fuel price are -0.15 and 0.12, respectively, overall it is -0.25, their long-run fuel price elasticities are -0.32 for VMT and 0.60 for MPG, with an overall level of -0.92. Parry (2008)[29] surveyed the extensive literature on diesel and mileage own-price elasticities of demand, in context of trucks. His use of the price elasticity $\epsilon_{F_O p} = -0.4$ with a range of -0.31 to -0.47 is also employed in this analysis. The response of conventional fuel to the biodiesel subsidy, $\epsilon_{F_O s}$, is determined by noting that $\frac{\partial F_O}{\partial s}\frac{s}{F_O} = \frac{\partial F_O}{\partial P}\frac{P}{F_O}\frac{s}{F_O}$. From the F.O.C (8), $p = \frac{P_R - S}{v}$, so $\frac{\partial P}{\partial S} = \frac{-1}{v}$, then the elasticity is

[25] Cars: Fuel Economy; DieselNet; last accessed date Nov 28, 2010
http://www.dieselnet.com/standards/us/fe.php#cafe

[26] Phil Goodwin ect.; Elasticities of Road Traffic and Fuel Consumption with Respect to Price and Income: A Review; last accessed date Nov 29, 2010
http://www2.cege.ucl.ac.uk/cts/tsu/papers/transprev243.pdf

[27] Fuel Consumption With Respect to Fuel Price; Victoria Transport Policy Institute; last accessed date Aug 22, 2011
http://www.vtpi.org/tdm/tdm11.htm#_Toc161022579

[28] Same as above, http://www.vtpi.org/tdm/tdm11.htm#_Toc161022579

[29] Ian W.H. Parry; How should heavy-duty trucks be taxed?; 2007

$\epsilon_{F_O s} = -\epsilon_{F_O p}\frac{s}{vp}$. Given the current subsidy is \$1 per gallon,[30] $\epsilon_{F_O p} = -0.4$, and the adjustment parameter $v = 1.02$, assuming the price of diesel is 3.5, then $\epsilon_{F_O s} = -\epsilon_{F_O p}\frac{s}{vp} = -0.4\frac{1}{1.02*3.5} = -0.112$.

Limited analysis exists in estimating the price elasticity of demand for biodiesel, ϵ_{Bp_R}. In a report on French biodiesel, it determined that the biodiesel price elasticity is very elastic, with an average value of 2.15. But this elasticity is not homogeneous on the 2000-2008 period: there is a sharp increase of the elasticity value during the following years, with 4.56 and 4.04 estimates in 2006 and 2007 respectively.[31] For analysis it is assumed the biodiesel elasticity is $\epsilon_{Bs} = 2.15$ with a range of 2 to 4.56.

For elasticity of blended fuel, ϵ_{Fs}, here assume its price elasticity is the weighted average of conventional diesel and biodiesel, thus $\epsilon_{Fs} = \alpha_R\epsilon_{Bs} + (1-\alpha_R)\epsilon_{F_O s} = 0.2 * 2.15 + 0.8 * (-0.112) = 0.340$. For elasticity of renewable fuel share, $\epsilon_{\alpha s} = \epsilon_{Bs} - \epsilon_{Fs} = 2.15 - 0.340 = 1.81$. Thus we get $\beta = \epsilon_{Ms}/\epsilon_{Fs} = \frac{0.15}{0.34} = 0.441$, $\zeta = \epsilon_{Hs}/\epsilon_{Fs} = -\frac{0.25}{0.34} = -0.735$. This result in renewable fuel share/fuel, $\xi = \epsilon_{\alpha s}/\epsilon_{Fs} = \frac{1.81}{0.34} = 5.32$.

[30] Volumetric Biodiesel Excise Tax Credit; last accessed date Dec 9, 2010 http://www.earthtrack.net/files/uploaded_files/FOE%20VEETC%20Evaluation%20FINAL.pdf

[31] Virginie Doumax; "The French Biodiesel Production: An Assessment of the Impacts and Interaction Effects of Policy Instruments"; last accessed date Jan 29, 2011

The method developed by Dmitry (2007)32 is used for determining ϵ_{Is}. Noting that $\epsilon_{\mathrm{Is}} = \epsilon_{\mathrm{IF}}\,\epsilon_{\mathrm{Fs}}$, the elasticity of income with respect to the biodiesel subsidy is determined by first calculating ϵ_{IF} and ϵ_{Fs}. Considering ϵ_{IF}, the change in annual income involves assessing the economic impact of biodiesel plants. The impact of increased biodiesel demand and production on the United States' economy is derived from the direct effects of annual expenditures on soybean oil, other feedstocks, and inputs such as natural gas, other utilities, and labor to produce biodiesel. Spending for these goods and services represents the purchase of output of other industries. The spending associated with ongoing biodiesel production and investment spending on new plant capacity will circulate throughout the entire economy several fold. This progress will stimulate aggregate demand, support the creation of new jobs, generate additional household income, and provide tax revenue for government at all levels. According to National Biodiesel Board,[33] in 2006 the spending on plant expansions and new construction would increase gross output by $2.8 billion (2005 dollars) to gross output, adding $1.5 billion (2005 dollars) to GDP. Household income would increase by almost $850 million (2005 dollars), and as many as 11,700 jobs would be created in all sectors of the economy. According to John M. Urbanchuk (2011), with the tax credit reinstated and the supporting regulatory framework of the EPA's Renewable Fuels Standard, the biodiesel industry is seeing a real turnaround for 2011. Production jumped 69 percent in January of this year

[32] Dmitry Vedenov, Michael Wetzstein, Toward an optimal U.S. ethanol fuel subsidy; 2007
[33] John M. Urbanchuk, Economic Contribution of the Biodiesel industry, 2006; last accessed date Aug 22, 2011

and has been steadily climbing since. The study predicts the industry will support more than 31,000 jobs in 2011, generate income of nearly $1.7 billion to be circulated throughout the economy, and create more than $3 billion in GDP. Under projected expansion by 2015, that economic impact would grow even further to supporting more than 74,000 jobs, $4 billion in income, and some $7.3 billion in GDP. The economic activities created by meeting the RFS2 targets would place nearly $14 billion in the pockets of American households between 2011 and 2015[34] For analysis, a benchmark of $2.5 billion in annual income increase is used, with a range of $0.8 to $4 billion. Given the level of disposable personal income for 2009 was 10.79 trillion (Bureau of Economic Analysis, 2010),[35] combining these estimates yields ϵ_{IF} = $2.5/($10.79 $\times 10^3$)=0.235 $\times 10^{-3}$ and $\epsilon_{Is} = \epsilon_{IF}\,\epsilon_{Fs} = 0.235\times10^{-3} \times 0.340 = 0.08\times10^{-3}$, using the estimate of ϵ_{Fs} obtained earlier.

In estimating the contribution of highway capital to productivity, Nadiri and Mamuneas (1998) [36] determine the current net social rate of return on highway expenditures to be 10% but in the 1950s and 1960s it was as high as 35%. With these estimates, the net marginal welfare effect from highway expenditure, γ'/λ, is set at 1.10

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[34] John M. Urbanchuk, Economic Contribution of the Biodiesel industry, 2011; last accessed date Aug 22, 2011

[35] National Income and Product Accounts Table, Bureau of Economic Analysis; last accessed date Nov 28, 2010 http://www.bea.gov/National/nipaweb/TableView.asp?SelectedTable=298&ViewSeries=NO&Java=no&Request3Place=N&3Place=N&FromView=YES&Freq=Year&FirstYear=2002&LastYear=2009&3Place=N&Update=Update&JavaBox=no#Mid

[36] M. Ishaq Nadiri and Theofanis P. Mamuneas, Contribution of Highway Capital to Output and Productivity Growth in the US Economy and Industries; EIA; last accessed date Nov 28, 2010 http://www.fhwa.dot.gov/policy/gro98cvr.htm

with a range of 1.00 to 1.35.

As noted by Parry and Small (2005), current estimates of greenhouse gases costs for gasoline are very speculative due to unknown long-run consequences, the limited science of atmospheric dynamics, and possible technology advancements. In reviewing the literature on these cost estimates, they suggest a wide range of costs from \$0.02 to \$0.24 per gallon with a central value of \$0.06 for gasoline. From a report of EIA[37], the carbon dioxide emission factor for gasoline is 8.86, thus the dollar cost of the carbon dioxide emission per unit is 0.06/8.86= \$6.772 $\times 10^{-3}$ as the benchmark value with range from 2.257 $\times 10^{-3}$ to 0.027. According to EIA, the carbon dioxide emission factor for B100 is 0, B20 is 8.12, diesel is 10.15. Thus we adopt $\left(\frac{\delta'}{\lambda}\right)\left(\frac{dP_F}{dF_O}\right) = 0.0687$ with range of 0.023 to 0.27, $\left(\frac{\delta'}{\lambda}\right)\left(\frac{\partial P_F}{\partial F}\right) = 0.055$ with range of 0.0183 to 0.22

$$E^{P_F F} = \left(\frac{\delta'}{\lambda}\right)\left(\frac{\partial P_F}{\partial F}\right)\left(1 - \alpha_R \alpha_q\right) = 0.055\left(1 - \alpha_R \alpha_q\right) = 0.0506$$

$$E^{P_F F_O} = \left(\frac{\delta'}{\lambda}\right)\left(\frac{\partial P_F}{\partial F_O}\right) = 0.0687 \text{ with range of } 0.023 \text{ to } 0.27$$

and

$$E^{P_F \alpha} = \left(\frac{\delta'}{\lambda}\right)\left(\frac{\partial P_F}{\partial F}\right)(\alpha_R F) = (0.055)\ (0.2)\ (4075) = 44.8$$

[37] Fuel Carbon Dioxide Emission Coefficients; EIA; last accessed date Nov 28, 2010 http://www.eia.doe.gov/oiaf/1605/coefficients.html

In calculating the effect of driving on air quality, Parry (2008) assumes air pollution from vehicles is proportional to miles traveled. Using their estimates based on this assumption yields $E^{P_M} = \left(\frac{\delta'}{\lambda}\right)(\partial P_F/\partial M) = 0.02$ as the benchmark value with a range of 0.004 to 0.1.

In calculating the effect of biodiesel industry on the energy security, we apply the method developed by Vedenov and Wetzstein (2007). Wallsten and Kosec's (2005) analysis of the indirect cost of imported oil are one of the few investigations since 2003 (beginning of the Iraq conflict). They estimate the cost of annual defense outlays to maintain the capability to defend the flow of Persian Gulf oil particularly from Iraq. Their estimates include the direct economic cost to the U.S. for the next decade such as incremental military and other government resources allocated to Iraq, the opportunity cost of National Guard troops' lost civilian productivity, lives lost, and the costs of treating wounded soldiers. Associated with these costs are benefits (avoided costs) which include no longer enforcing U.N. sanctions and having removed Saddam Hussein's regime. Their estimates result in an annual cost of $34.9 billion with benefits of $11.7 billion yielding a net cost of $23.2 billion. Associated with this central net cost is a range of $19.0 to $27.7 billion. Vedenov and Wetzstein (2006) divided this cost by the annual consumption of gasoline, 134.1 billion gallons, results in an incremental cost of fuel security $(\rho'/\lambda)(\partial A/\partial F)$ = $0.173 per gallon of gasoline. Expanding this number to the biodiesel industry, with the annual consumption of 1.585 billion gallons blended diesel,

$(\rho'/\lambda)(\partial A/\partial F)$ = (1.585 billion gallons blended diesel)(\$0.173 per gallon of gasoline)/(134.1 billion gallons gasoline) = \$2.038 $\times 10^{-3}$ per gallon. With the annual consumption of diesel, 42 billion gallons, $(\rho'/\lambda)(\partial A/\partial F_O)$ = (42 billion gallons blended diesel)(\$0.173 per gallon of gasoline)/(134.1 billion gallons gasoline)= 0.0542 per gallon of conventional diesel. And hence

$$E^{AF} = \left(\frac{\rho'}{\lambda}\right)\left(\frac{\partial A}{\partial F}\right)(1-\alpha_R) = -2.038\times 10^{-3}\times(1-0.2) = -1.63\times 10^{-3}$$

$$E^{AF_O} = \left(\frac{\rho'}{\lambda}\right)\left(\frac{\partial A}{\partial F_O}\right) = -0.0542$$

and

$$E^{A\alpha} = \left(\frac{\rho'}{\lambda}\right)\left(\frac{\partial A}{\partial F}\right)F = -2.038\times 10^{-3} * 4075 = -8.305$$

The Union of Concerned Scientists (UCS)[38] determined that the owners of advanced heavy-duty tractor-trailers could save \$120,000 or more per truck over eight years, after paying back their initial \$62,000-per-truck investment in fuel efficiency, assuming that diesel fuel costs \$3.50 in real terms. This is equivalent to annual expenditures on fuel efficiency of \$7750 (7750=62,000/8) and a 4286 gal in fuel savings

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[38] Economic Costs and Benefits of Improving the Fuel Economy of Heavy-Duty Vehicles; Union of Concerned Scientists; last accessed date Nov 29, 2010
http://www.ucsusa.org/clean_vehicles/solutions/advanced_vehicles_and_fuels/economic-costs-and-benefits-improving-fuel-economy-heavy-duty-trucks.html

(120,000/(3.5*8)=4286). Using these parameters, $\partial F/\partial H$ is 4286/7750 = − 0.553, the proportion of F to H as α_{FH} = 0.523 (0.523=4075/7750), and $E^{AH} = -2.038 \times 10^{-3} \times (-0.553) = 1.127 \times 10^{-3}$ noting that

$$E^{AH} = (\rho'/\lambda)(\partial A/\partial H) = (\rho'/\lambda)(\partial A/\partial F)(\partial F/\partial H).$$

Finally, the last parameter is the proportion of fuel to income. With an annual consumption of blended diesel fuel of 1.585 billion gallons and a level of disposable personal income of $10.79 trillion, $\alpha_{FI} = 0.147 * 10^{-3}$.

CHAPTER 5

Results

Applying the benchmark parameter values from Table 1 directly to (21) yields an estimated optimal biodiesel subsidy s = $0.92 per gallon of biodiesel (Table 2), which turns out to be within the ballpark of the current highway tax exemption of $1.00 per gallon. As indicated from Table 2, the biodiesel fuel subsidy yields positive benefits from increased share of renewable fuel in the form of reduction in greenhouse gases and increased fuel security. These positive benefits are not overwhelmed by the negative externalities associated with the increased overall fuel consumption, which the subsidy in its current form stimulates by lowering the total fuel costs.

The net effect of the subsidy on greenhouse gases is positive, but for fuel use fuel security, air quality, and greenhouse gases are all negative. Attempting to increase the share of renewable fuels with a price subsidy, such as the biodiesel tax exemption, will not automatically lead to positive marginal external benefits unless total fuel consumption is non-positively responsive to the subsidy.

The Pigovian subsidy and Ramsey subsidy are both positive, however governmental marginal benefits are negative. The economic development benefits associated with the Ramsey subsidy of the biodiesel subsidy are the major justification supporting its social welfare benefits. The increased overall fuel consumption caused by the subsidy also augments the Highway Trust Fund, which results in a fairly large contribution of the government marginal benefits to the total marginal benefits of the subsidy.

Note that the optimal subsidy is positive because of the benefits of economic development and marginal external benefits; however the government spending is not positive. The results also indicate that justification of a federal biodiesel subsidy on environmental and fuel security grounds is reasonable with the major argument in favor of the subsidy resting primarily on the economic development benefits generated by increased production of biodiesel. If these economic benefits are mainly regional or confined to a particular set of states, then state subsidies may be more appropriate.

CHAPTER 6

Sensitivity analysis

The wide range of parameter values in Table 1 suggests the benchmark optimal subsidy in Table 2 has an associated rather large variance. In order to investigate the sensitivity of the optimal biodiesel subsidy, s*, to ranges of the parameter values, both individual parameter variation and Monte Carlo analysis were implemented. Figures 1 and 2 illustrate the response of the optimal biodiesel subsidy to a range of elasticities and external benefits and costs. As indicated from Figure 1, the optimal subsidy is positively related to elasticities of conventional fuel, income, and negatively related to the elasticity of biodiesel diesel and fuel efficiency. The optimal subsidy is very sensitive to income elasticity. To be specific, in Figure 1 a, $\partial s^*/\partial \epsilon_{\mathrm{Bs}} < 0$, the consumption of biodiesel, B, is more responsive to s when s* decreases. This indicates diminishing returns associated with the subsidy. As the subsidy increases, its impact on biodiesel consumption declines . In Figure 1 b, $\partial s^*/\partial \epsilon_{\mathrm{Fos}} > 0$, the consumption of conventional diesel, $\mathrm{F_O}$, is less responsive to s when s* increases. Again, results indicate the impact of the subsidy declines as it increases. In Figure 1 c, $\partial s^*/\partial \epsilon_{\mathrm{Hs}} < 0$, the fuel efficiency, H, is more responsive to s when s* increases. This is the reverse of the subsidy effects on elasticities of biodiesel and conventional diesel. At low subsidies, and percentage change in the subsidy does not elicit as large of a decline in fuel efficiency as a similar percentage change at a high subsidy level. In Figure 1 d, $\partial s^*/\partial \epsilon_{\mathrm{Is}} > 0$, the income, I, is more responsive to s when s* increases.

In terms of the external benefits and cost, Figure 2 illustrates the negative relations of the subsidy with government spending returns, $\frac{\gamma'}{\lambda}$, greenhouse gases, $E^{P_F F}$, and air quality cost, E^{PM}, fuel security cost in regard of conventional fuel $E^{AF_O}$and renewable fuel proportion $E^{A\alpha}$, and positive with cost of fuel security, E^{AH}, the external effects in regard to conventional fuel $(-E^{P_F F_O}+ E^{AF_O})$ and the external effects in regard to renewable fuel proportion $(E^{P_F\alpha} - E^{A\alpha})$. To be specific, in Figure 2 a, $\partial s^*/\partial \frac{\gamma'}{\lambda} < 0$, the returns to government spending, $\frac{\gamma'}{\lambda}$, increases when s* decreases. In Figure 2 b, $\partial s^*/\partial E^{P_F F}, < 0$, $E^{P_F F}$, decrease when s* increases, so the greenhouse gas costs $-E^{P_F F}$ increase when s* increase. This indicates, s* encourages more conventional diesel consumption and thus leads to increasing greenhouse gas costs. In Figure 2 c, $\partial s^*/\partial E^{P_M} < 0$. Similar to greenhouse gases, air quality cost, $-E^{P_M}$, increase when s* increases. In Figure 2 d, $\partial s^*/\partial E^{AF} > 0$, the fuel security cost, E^{P_M}, increases when s* increases. In Figure 2 e, the external effects in regard to conventional fuel $(-E^{P_F F_O}+ E^{AF_O})$ increases when s* decreases; in Figure 2 f, external effects in regard to renewable fuel proportion $(E^{P_F\alpha} - E^{A\alpha})$ increases when s* increases, with a non-sensitive response.

Both Figures 1 and 2 indicate that the optimal biodiesel subsidy, s*, is very sensitive to some parameter values. For developing a more precise estimate of the optimal subsidy, research leading to the narrowing of parameter ranges is warranted.

This sensitivity of the optimal ethanol subsidy was also demonstrated by Monte Carlo analysis. In particular, 5000 random draws of parameters in Table 1 were generated using two-sided power probability distributions over respective ranges of parameters. The drawn parameters were then used to calculate the optimal ethanol subsidy in (21), and to create an empirical CDF for the optimal subsidy. Table 3 lists the probabilities of optimal subsidy being below specific thresholds.

As indicated from Table 3, the probability of the optimal subsidy being nonpositive is only 5%. The effect the subsidy has on increasing biodiesel consumption with associated positive environmental and fuel security external benefits underlies this outcome.

CHAPTER 7

Implications

It is very important in public policy analysis to consider the market effects of such policies. The government providing market incentives for the establishment of a renewable fuels industry is a case in point. The objective of establishing a renewable fuel industry within the U.S. is to increase social welfare by improving air quality, reducing greenhouse gas emission, increasing energy security, and contributing to economic development. The U.S. Federal Renewable Fuels Standard (RFS2) takes a step in this direction by mandating a certain percentage of renewable fuels to be used in all vehicles. Biodiesel fuels are considered a newly emerging tool in meeting this mandate. From this research we find out a biodiesel subsidy will indeed result in benefits of improved air quality and fuel security along with reducing greenhouse gases. However, lower blends of biodiesel bear negative effects on social welfare, since lower blends of biodiesel content a high percentage of conventional diesels and can actually increase the usage of fossil fuels. In the long run, a solution to this conflict may lay in increasing the number of B20-capable vehicles and overall shift to higher-proportion of biodiesel blends so that biodiesel subsidies stimulate use of biodiesel rather than fossil fuels. In the short run, the solution, however unpopular, may be to increase the federal excise tax on conventional diesel so the socially undesirable effects of the biodiesel subsidy are nullified. This could result in positive marginal external benefits and associated Pigovian subsidy from the biodiesel subsidy. Combined with the positive Ramsey subsidy, this would yield net marginal benefits exceeding marginal costs. Without compensating for the increased fuel use from a biodiesel subsidy, e.g. by increasing the federal excise tax on diesel, the anticipated social benefits of the biodiesel tax exemption may not be achieved.

Table 1. Benchmark Values and Parameters Ranges

Parameter	Benchmark	Range
Proportion of biodiesel, α_R	0.2	
Biodiesel percent reduction in greenhouse gases, α_q	0.4	–0.0004 - 0.8
Truck efficiency, $1/\alpha_{FM}$ (miles/gallon)	23.5	18 - 30
Fuel consumption, F (annual gallons/vehicle)	4075	
Federal diesel excise tax, t (dollars/gallon)	0.244	
Biodiesel tax exemption, s (dollars/gallon)	1.00	
Elasticities		
Biodiesel to subsidy, ϵ_{Bs}	2.15	2 - 4.56
Diesel to subsidy, $\epsilon_{F_O s}$	–0.112	
Blended Diesel to subsidy, ϵ_{Fs}	0.34	0.314 - 0.822
Renewable fuel share to subsidy, $\epsilon_{\alpha s}$	1.81	1.686 - 3.738
Mileage to subsidy, ϵ_{Ms}	0.15	0.05 - 0.3
Fuel efficiency to subsidy, ϵ_{Hs}	–0.25	–0.01 - –0.37
Income to subsidy, ϵ_{Is}	0.08 ($\times 10^{-3}$)	0.05 - 0.3
Government welfare effect, γ'/λ	1.10	1 - 1.35
Externality effects		
Fuel consumption		
Greenhouse gases, $E^{P_F F}$ (dollar/gallon)	0.0506	0.012-0.29
Greenhouse gases, $E^{P_F F_O}$ (dollar/gallon)	0.0687	0.023 - 0.27
Fuel security, E^{AF} (dollar/gallon)	–1.63($\times 10^{-3}$)	–2.71 - –0.18
Fuel security, E^{AF_O} (dollar/gallon)	– 0.0542	–0.18 - –0.024
Air quality, E^{PM} (dollar/mile)	0.02	0.003-0.05
Engine efficiency, E^{AH}	1.127($\times 10^{-3}$)	0.36 - 3.53
Renewable fuel proportion		

Greenhouse gases, $E^{P_F\alpha}$ (dollars)	44.8	17 - 75
Fuel security, $E^{A\alpha}$ (dollars)	–8.305	–11.6 - –5.9
Ratios		
Fuel/engine efficiency, α_{FH}	0.523	0.12 - 0.89
Fuel/income, α_{FI}	0.147×10^{-3}	0.026 – 0.317
Blended Fuel/Conventional Fuel α_{FF_O}	0.0377	0.03 - 0.042

Table 2. Benchmark calculations of the optimal biodiesel subsidy

Elements	Estimates	
	Components	Total
Marginal benefits		0.121
Pigovian subsidy, $MEB\epsilon_{Fs}$	0.282	
Fuel use		
Greenhouse gases, $-E^{P_F F}\epsilon_{Fs}$ (dollar/gallon)	–0.017	
Fuel security, $E^{AF}\epsilon_{Fs}$ (dollar/gallon)	–0.555 ($\times 10^{-3}$)	
Air quality, $-\frac{E^{P_M}\beta}{\alpha_{FM}}\epsilon_{Fs}$ (dollar/mile)	–0.071	
Engine efficiency, $\frac{E^{AH}\zeta}{\alpha_{FH}}\epsilon_{Fs}$	0.539 ($\times 10^{-3}$)	
Renewable fuel proportion		
Greenhouse gases, $\frac{E^{P_F\alpha}\xi}{\alpha_{F\alpha}}\epsilon_{Fs}$ (dollars)	0.004	
Fuel security, $-\frac{E^{A\alpha}\xi}{\alpha_{F\alpha}}\epsilon_{Fs}$ (dollars)	0.738 ($\times 10^{-3}$)	
Conventional fuel change		
Greenhouse gases, $-\frac{(E^{P_F F_O})\tau}{\alpha_{FF_O}}\epsilon_{Fs}$ (dollars)	0.204	
Fuel security, $\frac{(E^{AF_O})\tau}{\alpha_{FF_O}}\epsilon_{Fs}$ (dollars)	0.161	
Ramsey Subsidy, $\epsilon_{Is}/\alpha_{FI}$	0.544	
Government Margin Benefit, $\left(\frac{\gamma'}{\lambda}\right)t[\epsilon_{Fs} + (\epsilon_{F_O s}/\alpha_{FF_O})]$	–0.705	
Marginal Costs		
Per dollar change in welfare, $\left[\left(\frac{\gamma'}{\lambda}\right)(\epsilon_{Fs}+1) - 1 - \epsilon_{\alpha s} + \left(\frac{\gamma'}{\lambda}\right)\epsilon_{\alpha s}\right]\alpha_R$		0.131
Marginal benefits/Marginal costs		
Optimal Biodiesel Subsidy		0.923

Table 3. Monte Carlo results for optimal biodiesel subsidy

Level, x (dollars/gallon)	Probability s*<x
0.0	0.0456
0.5	0.0864
1.00	0.1500
1.50	0.2258
2.00	0.3014
2.50	0.3850
3.00	0.4592
3.50	0.5344
4.00	0.6062
4.50	0.6612
5.00	0.7122

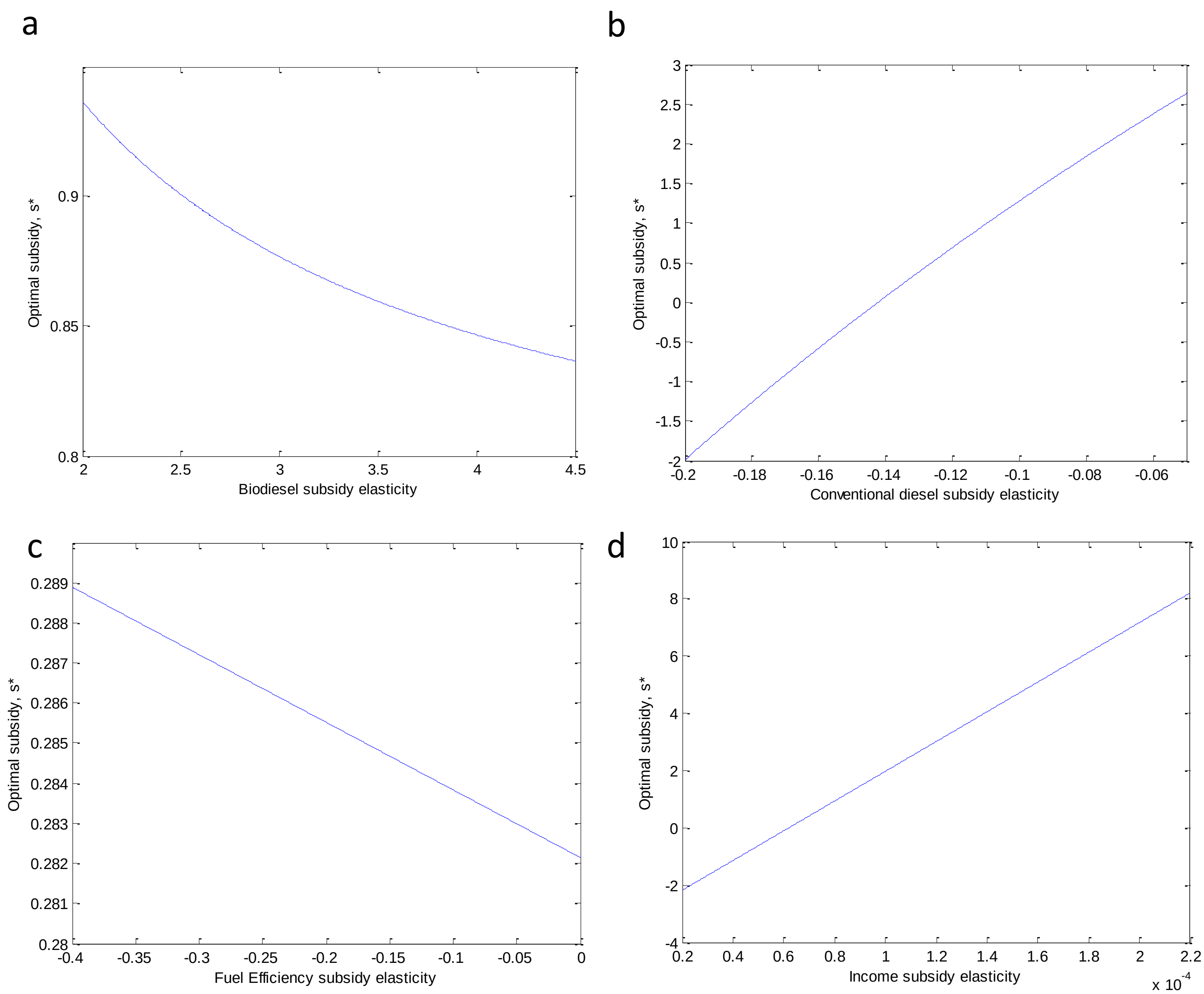

Figure 1 Response of the Optimal Biodiesel Subsidy (dollars/gallon of biodiesel) to a Range of Elasticity Estimates

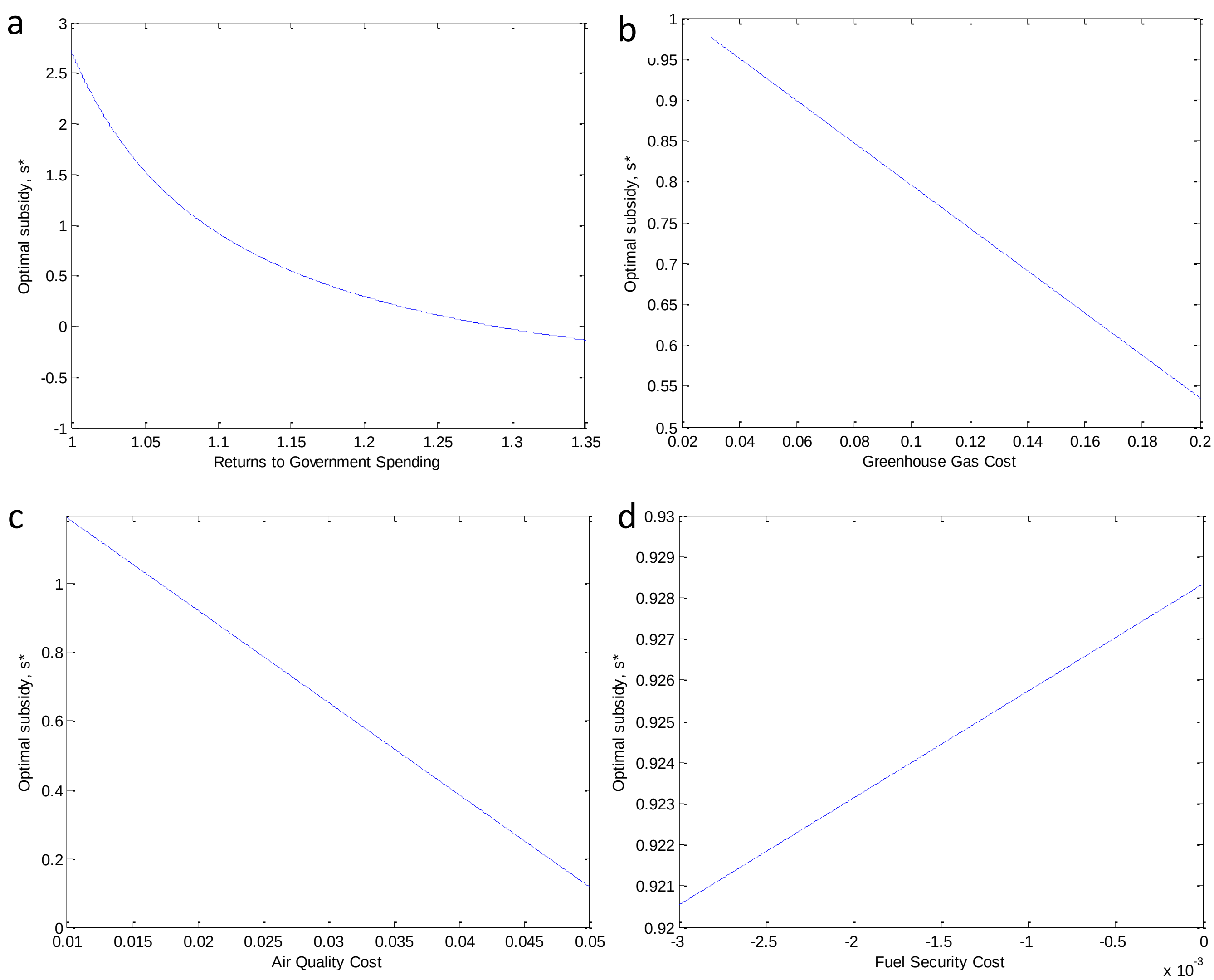

Figure 2-1 Response of the Optimal Biodiesel Subsidy (dollars/gallon of biodiesel) to a Range of External Benefits and Costs.

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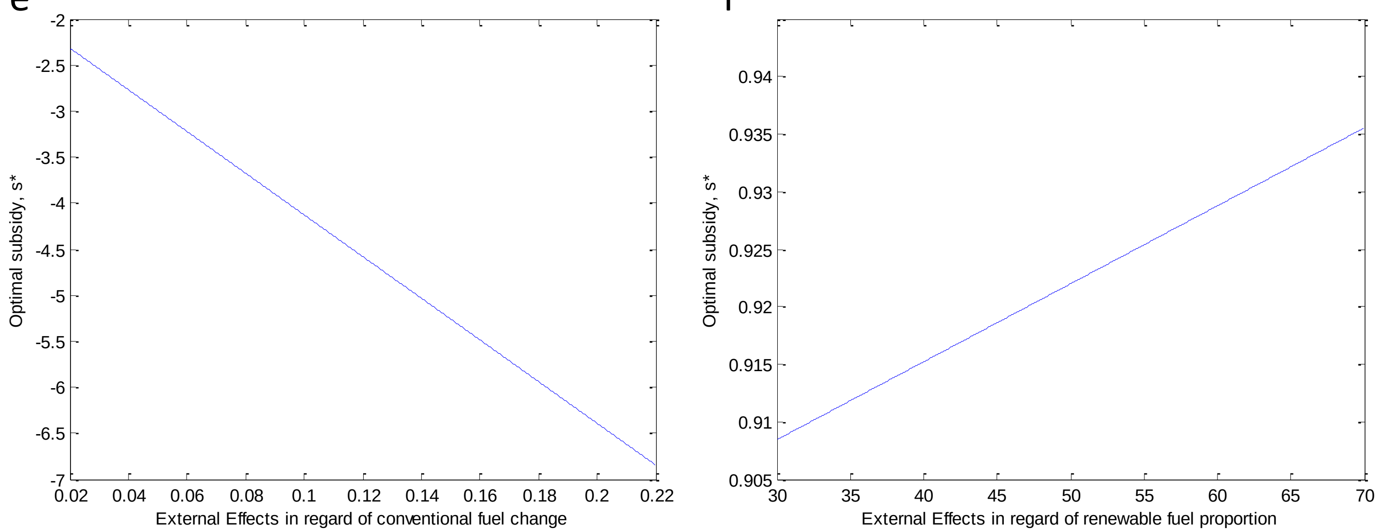

Figure 2-2 Response of the Optimal Biodiesel Subsidy (dollars/gallon of biodiesel) to a Range of External Benefits and Costs.

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