The U.S. Ethanol and Commodity Policy Labyrinth: Looking into Welfare Space to Analyze Policies that Combine Multiple Instruments

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Abstract: We analyze complicated ethanol/commodity policies not just in (q, p) space, but also in "policy space" and "welfare space." Specific advantages of conducting policy analysis in welfare and policy spaces are (1) it makes clearer the *distributional* consequences of policy change instead of focusing solely on the aggregate welfare consequences of policy change; (2) it can be used to analyze the effects of many (even infinitely many) policies instead of just a few; and (3) it makes clearer what it means for policies to be more/less "efficient," and for policy instruments to make each other more/less "efficient." We show the usefulness of our framework to critique various conclusions that have recently been expressed in the literature on ethanol policies that employ multiple instruments.

1. Introduction: biofuels policy analysis in (q, p) space

A central topic in recent analyses of U.S. ethanol policy has been how the use of policy instruments that intervene directly in the ethanol market, such as the Volumetric Ethanol Excise Tax Credit or the ethanol quantity mandate, interact with other ethanol policy instruments or with policy instruments that directly intervene in commodity markets, such as corn support prices. All of the published analyses have been conducted in what we will call "(q, p) space." That is, they have modeled market supplies and demands, and used geometric areas behind those supply and demand curves as welfare measures, such as "consumer surplus," "producer surplus," and Harberger deadweight triangles. Of course, such methods of measuring welfare in (q, p) space are standard and indispensible in agricultural policy analysis. But while conducting welfare analysis using diagrams in (q, p) space sometimes provides intuitive insight into why policies redistribute welfare and create deadweight, it is accompanied by important limitations, and these limitations have diminishing the comparability of the results reported in the literature. In short, it is fair to call the current state of the study of biofuels policy "labyrinthine." The overall objective of this article is to remind and demonstrate how changing the methodological venue to *welfare space* can help guide the researcher through the labyrinth of biofuels policy analysis.

We take two steps to accomplish our overall objective. First, we elaborate the limitations of policy analysis in (q, p) space, explaining how taking the extra step of mapping policy outcomes into welfare space can help the researcher deal with these limitations. We offer a brief critique of the applied biofuels policy literature by considering in welfare space some of its seemingly contradictory claims. We offer insights into some of the literature's principle confusions, and suggest how analysis in welfare space could aid greatly in a more comprehensive literature review.

Our second step is to demonstrate the relative ease with which applied policy analysis in welfare space can be conducted, and the benefits of conducting it. We will argue that while Josling (1974) and Gardner (1983) laid out a clear path for future policy research, and while *citation withheld* (1999) and *citation withheld* (2003) generalized Josling and Gardner's methods to make them applicable to the analysis of policy combining multiple instruments, surprisingly little empirical analysis conducted in welfare space has been reported in the agricultural economics literature.[2] To

[2] Some applied policy analysis in welfare space has appeared: *citation withheld* (1992) used surplus transformation curves to examine the redistributive implications of Common Agricultural Policy liberalization; and Kola (1993) examined the outcomes of supply control policies in welfare space. But on the whole, this valuable tool for applied policy analysis has been ignored.

demonstrate the practicality of policy analysis in welfare space, we map the policy space in de Gorter and Just's (2009) model into its welfare space, and point out insights gained from this methodology that are not easily obtained through (*q*, *p*) space analysis.[3]

2. Agricultural Policy Analysis in Welfare Space

Next we offer a quick review of the theoretical literature that discusses policy analysis in welfare space, and we offer formal definitions of some key terms.

2.1 Josling-Gardner surplus transformation curves

Conducting policy analysis in welfare space requires taking an additional step after conducting the traditional exercise of modeling market equilibriums in (*q*, *p*) space and examining in that space geometrically-based welfare measures. The additional step involves mapping, beginning in policy space and operating *through* (*q*, *p*) space to get to welfare space, the welfare consequences of many policies (*citation withheld* 2003.). In general, given modern number-processing technology and numerical methods for solving models for equilibrium, it is not difficult to conduct those mappings numerically, establishing an algorithm and then repeating it many times for different policies. As long as the political economy model being examined can be reasonably reduced to having two or three interest groups, the resultant mapping can show in either R^2 or R^3 the

[33] Critiquing any particular article is not our purpose. To make our points, we could have used other models (e.g., Bourgeon and Tréguer 2010) just as easily. We use the de Gorter and Just (2009) model because it is well-cited and it is fairly typical, in structure and methodology, of those models recently appearing in the agricultural economics literature on biofuels policy.

distributional consequences of many, many policies, which provides several opportunities not available using traditional (q, p)-space methods alone. These mappings largely depend on calculating welfare measurements repeatedly. This was not possible decades ago when (q, p)-space methodologies were developed. But it is possible now, even though applied analysis has largely stuck to traditional methodology instead of taking advantage of new opportunities afforded by new technologies.

Josling (1974) was the first agricultural economist to think about conducting welfare analysis is welfare space. He showed how mappings can be made from policy space to welfare space by changing a single policy instrument to parametrically define a curve that shows the transformations of interest group welfare that can be attained with that instrument. He pointed out obvious advantages of his approach, writing,

> *… by making a straightforward transformation from market variables to an objective space, one can discuss the choice of an optimal policy in the context of a set of rudimentary income distribution measures. This also leads to conclusions perhaps not immediately apparent from the literature on commercial policy.* (p. 245)

Gardner (1983) formalized and added structure to Josling's framework. He called Josling's mappings "surplus transformation curves." Gardner emphasized that conducting policy analysis in welfare space allows the researcher not simply to measure the deadweight cost of policies, but also shows how that deadweight is dependent on the *size of the transfer*. He writes,

> *The main innovation of this paper is to tie deadweight losses based on consumers' and producers' surpluses explicitly to surplus transfers.* (p. 225)

Here Gardner, like Josling, is emphasizing that examining policy in welfare space can clarify the very important *distributional consequences* of policy. Understanding these distributional consequences is necessary if researchers are to recommend policies that are politically realistic. Traditionally and often still, researchers have simply reported the "deadweight" costs of proposed policies, while paying little attention to which groups win and lose and by how much. We will show that some prominent published studies of biofuels policy have reported results in this way. In terms of agricultural political economy in the industrialized world, policies changes that carry less deadweight but greatly lower farmer income are not politically feasible, and in this sense not particularly interesting for the purposes of applied research.

2.2. A generalization of the surplus transformation curve: welfare manifolds

The central element of policy analysis in welfare space is the feasible welfare manifold (or just "welfare manifold"). The welfare manifold is a generalization of Josling-Gardner surplus transformation curves in that a welfare manifold can be used with models with *m* policy instruments and *n* interest groups, instead of simply for the case of two interest groups and one policy instrument. Next we will provide some formal definitions of the terms we are using. We will demonstrate later in the paper that we do this to avoid some of the confusion that has sprung out of the literature.

Following Harsanyi (1963, 1977), *citation withheld* (1999) and *citation withheld* (2003), let each of a model's *policy instruments* be a variable with its domain on the real number line. We denote a vector of generic policy instruments as $\mathbf{x} = (x_1, \dots, x_m)$. A *policy* is a particular value of $\mathbf{x}$, chosen from government's *set of feasible policies*, $X \subseteq R^m$.[4] Let $\boldsymbol{\alpha}$

[4] Here we are not considering the political feasibility of a policy, but rather only the technical (physical) feasibility. For example, it would be politically impossible currently for the U.S.

$= (\alpha_1, \ldots, \alpha_z)$ denote the model's parameters that change how welfare is a function of policy. These might be parameters of supply and demand functions. Let the set of a model's conceivable values of these parameter vectors be $A \subseteq \mathrm{R}^{2z}$.

Assume that economic agents in a model can be divided into I mutually exclusive groups, and index them $i = 1, \ldots, I$. Let $W = \{1, \ldots, I\}$ denote the set of such groups. For each group $i \in W$, assume that there exists a function h_i: $X \times A \to \mathrm{R}$ that defines how group i's welfare is dependent on policy and market parameters. The model's *welfare correspondence* is $\mathbf{h}(\mathbf{x},\boldsymbol{\alpha}) \equiv (h_i(\mathbf{x},\boldsymbol{\alpha}) : i \in W)$.

We are now ready to provide definitions that are central to our procedures:

Definition. The *welfare manifold* of an economic model that has policy space X and is parameterized by $\boldsymbol{\alpha}$ is,[5]

$$(1) \qquad H(X,\boldsymbol{\alpha}) = \{\mathbf{h}(\mathbf{x},\boldsymbol{\alpha}) : \mathbf{x} \in X\}.$$

The welfare manifold is the set of all welfare outcomes that the model could possibly come to, either in or out of the model's equilibrium.

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government to provide a support price for corn of $15 per bushel. Corn producers do not currently possess the political muscle to bring about a subsidy of that size. However, such a policy is physically feasible—given the resources of the U.S. government, this policy could be carried out given adequate political support. On the other hand, a negative production quota for corn is not physically feasible, as it is impossible to produce negative quantities of corn.

[5] *Citation withheld* (2011) present a generalization of the welfare manifold defined here, and call it a political economy manifold. In a political economy manifold, government is not the only player of the game. Rather, interest groups can "lobby" to affect the policy outcome.

Definition. For generic subsets $X^{sub} \subseteq X$ and $W^{sub} \subseteq W$, the *welfare submanifold* of an economic model that has policy space X and is parameterized by $\boldsymbol{\alpha}$ is,

$$(2) \qquad H_{W^{sub}}\left(X^{sub},\boldsymbol{\alpha}\right)=\left\{\mathbf{h}_{W^{sub}}\left(\mathbf{x},\boldsymbol{\alpha}\right):\,\mathbf{x}\in X^{sub}\right\}.$$

A Josling-Gardner surplus transformation curve is a particular type of submanifold in which W^{sub} consists of two groups, and all but one of the elements of X^{sub} is a scalar. (Only one instrument is changed while the others are held constant). When we use the term "policy analysis in welfare space," specifically we mean the examination and analysis of the properties of models' welfare manifolds and submanifolds.[6]

3. Using welfare manifolds to clarify the concepts of policy instrument complementarity and efficiency

We begin with quotes from recently published articles that discuss in various ways the "efficiency" of biofuels policies that use multiple policy instruments, and the "complementarity" of policy instruments. Some studies have concluded that ethanol policy instruments can make commodity policy instruments in some sense "more efficient"—that is, again in some sense, that ethanol policy instruments and commodity policy instruments are complements. For example, Bourgeon and Tréguer (2010, p. 371) state,

> … *[g]overnment may find it worthwhile to implement a biofuel programme to diminish the social cost of the farm support programme…*

Lapan and Moschini (2009, p. 27) reached similar-sounding conclusions about coupling fuel taxes with ethanol subsidies or ethanol mandates:

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[6] Submanifolds are themselves manifolds, and often we will use the term "manifold" to refer to either.

…in our setting, it would be better to be able to use two instruments, rather than only one of them.

In the following, we will show how analysis in welfare space makes obvious the points made in both quotations above: not just Lapan and Moschini's (2009) setting, but in *every setting in every political economy model*, it cannot be worse, and will almost always be better, to have two instruments available rather than one.

In contrast to the quotations above, Babcock (2008) and de Gorter and Just (2009, 2010) concluded that the joint use of various policy instrument combinations would be inefficient (that ethanol policy instruments and biofuels policy instruments are not complements):

> *Furthermore, the* [ethanol] *tax credit itself doubles the deadweight costs of the* [corn] *loan rate. Ethanol policies can therefore not be justified on the grounds of mitigating the effects of farm subsidy programs.* (de Gorter and Just 2009, p. 478)

> *The tax credit and ethanol production subsidies increase the tax costs and inefficiencies of the farm subsidy programs* (de Gorter and Just 2010, p. 18).

> *… it is highly undesirable to use ethanol policy instruments in combination* (de Gorter and Just 2010, p. 26).

> *… given that current farm subsidies have modest impacts on supply and market prices … it is doubtful that transferring money to corn growers via subsidized ethanol production is efficient, although the results presented here suggest that the transfers are large."* (Babcock 2008, p. 542).

The quotations above show very different interpretations of model results. Bourgeon and Tréguer (2010) and Lapan and Moschini (2009) conclude that it is a good idea for government to combine policy instruments, while de Gorter and Just insist that it is a bad idea. It would be easy to conclude simply that different studies have come to different conclusions about the efficiencies of various biofuels policy instruments because they have used different models to analyze use of different policy instruments implemented in different markets. By examining policy results in welfare space, we will show that this is not the case. The results of Bourgeon and Tréguer and Lapan and Moschini can be generalized to all political economy models. de Gorter and Just need to restate their conclusions to prevent them from being interpreted that combining policy instruments is often a bad idea. Combining policy instruments, when done well, is almost always a good idea.

3. Analyzing Policies that Combine Instruments: an Example from the Literature

3.1. Ethanol Policy Analysis in de Gorter and Just's (q, p) *space*

De Gorter and Just (2009) use their model[7] to study in (q, p) space the joint use of an ethanol tax credit and a feedstock support price. (Gardner (2007), Schmitz, Moss, and

[7] Our model is mathematically equivalent to de Gorter and Just's (2009) model, though presented it differently. We use the de Gorter and Just (2009) model because it is well known, and recently frequently cited. We judged that since the model is already familiar to many readers, we could concentrate on analyzing it in policy space and welfare space while spending less effort explaining the supply and demand model itself in (q, p) space.

Schmitz (2007), and Du, Hayes, and Mallory (2009) all also study joint use of these two instruments.) First we will quickly re-present the de Gorter and Just (2009) model to provide background. Then we will review the conclusions they came to by analyzing ethanol policies in (q, p)-space. We do this to later contrast their conclusions with those which are easily seen in welfare space..

As explained in de Gorter and Just (2009), in 2002-03, the U.S. set a corn target price at \$1.98/bu and an ethanol tax credit of \$0.51/gallon, equivalent to \$2.07/bu.[8] The policy was (P_T^{03}, t^{03}) = (\$1.98/bu, \$2.07/bu). The left-hand panel of figure 1 shows for 2002-03 de Gorter and Just's (2009) corn supply and demand curves, calibrated using the observed quantities and prices for the corn market, and the elasticities and functional forms that they described. (Color versions of our article's figures can be found in the supplementary appendix online.) We let $\boldsymbol{\alpha}$ denote the vector of the model's parameters, and $\boldsymbol{\alpha}^{03}$ denote the vector of the values of those parameters in the 2002-03 crop year. We denote parameter vectors for other crop-years similarly. We will offer

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[8] Quantities of fuel in figure 1 are given in units of million "buckets," and prices are given in \$/bucket, where one bucket equals 2.8/(1-0.31) = 4.06 gallons. In the de Gorter and Just (2009) model, this is how much ethanol on net comes from one bushel of corn, after the production of by-product feed is considered. It is convenient to abbreviate both "bushel" and "bucket" by "bu." (See de Gorter and Just (2009) for the interpretation of 2.8 and 0.31). Some of de Gorter and Meilke's reported results were based on an assumed tax credit of \$1.43/bu. For theoretical reasons that the authors explain but fail to apply, the correct number to use is \$2.07/bu = \$1.43/(1 – 0.31)/bu, which is the value we used in our analysis observed tax credit. This correction causes our numerical results to differ from de Gorter and Just's (2009).

only brief intuitive explanations of figures 1 and 2, as more complete descriptions of the basics of the model are provided in de Gorter and Just (2009).

In its right-hand panel, figure 1 depicts the corn-turned-to-ethanol market for crop-year 2002-03.[9] $D_{NE}^{\mathrm{dom}}(z, \alpha^{03})$ is the domestic demand for corn in non-ethanol uses.[10] $D_{NE}(z, \alpha^{03})$ is the total demand (domestic demand plus foreign excess demand) for corn in non-ethanol uses. $S_C(z, \alpha^{03})$ denotes the domestic corn supply curve.[11] $ES_C(z, P_T^{03}, \alpha^{03})$ shows the domestic corn-supplied-to-ethanol curve, that is, domestic corn supply minus total demand for corn not going to ethanol, the horizontal distance between curves $S_C(z, \alpha^{03})$ and $D_{NE}(z, \alpha^{03})$. $ES_F(z, \alpha^{03})$ is the foreign excess-supply-of-fuel curve, which is flat because in their empirical simulations de Gorter and Just (2009)

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[9] De Gorter and Just (2009) conducted their simulations using Microsoft Excel (Microsoft 2009). We were not able to obtain the values of the parameters used in the Excel spreadsheets with which they calculated their published results. But they did provide us with identical programs that were based on a slightly older set of parameter values. Our Mathematica (Wolfram Research, Inc. 2010) programs generate the same results that are generated by their Excel program based on the earlier values of the parameters.

[10] To avoid complications about whether a particular function in figures 1 and 2 is dependent on a "supply price" or a "demand price," we find it convenient to simply use "z" as a place-holding variable for the pertinent price of whichever function is being considered.

[11] To remain consistent with de Gorter and Just's (2009) analysis, we assume throughout that all corn producers are located domestically.

assume that the domestic country's ethanol market is small relative to the world fuel market.

Figure 1 illustrates that in the 2002-03 model, the ethanol tax credit t^{03} = \$2.07/bu impacted the U.S. ethanol and corn markets, but the corn target price P_T^{03} = \$1.98/bu had no effect on markets, because the tax credit and market conditions resulted in a corn market price of P_C^{D03} = \$2.32/bu that was above the target price. Therefore the producer and consumer prices were equal to the market price: P_C^{S03} = \$2.32/bu = P_C^{D03}. At the intersection of $D_{NE}(z, \alpha^{03})$ and $S_C(z, \alpha^{03})$ is $P_{NE}(\alpha^{03})$ = \$2.00/bu, the model's estimate of the equilibrium corn price that would have come about in 2002-03 had there been no government intervention. The model's calibrated world and domestic price of fuel is shown as $P_{FW}^{03} = P_C^{S03} - t^{03}$ = \$0.25/bu.[12]

3.1.1. In (q, p) space: use of one instrument

Because the target price was not set high enough to be effective in 2002-03, figure 1 illustrates in (q, p) space the effects of government effectively using just one policy instrument, the ethanol tax credit. World markets clear where the quantity (in buckets) of ethanol supplied to the world fuel market equals the quantity (in bushels) of corn supplied minus the quantity used for non-ethanol purposes. A no-arbitrage condition holds where the ethanol tax credit equals the market price of corn (per bushel) minus the world price of fuel (per bucket): $t^{03} = P_C^{S03} - P_{FW}^{03}$.

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[12] Without loss of generality, we can interpret P_{FW}^{03} as the world price of fuel minus a constant per-unit-of-ethanol corn processing cost. This interpretation is necessary, since clearly the world price of fuel was well above the model's calibrated value of \$0.25 per 4.06 gallons in 2003.

In figure 1, conducting a traditional (q, p) space analysis of the welfare consequences of the tax credit is straightforward. In the estimated non-intervention equilibrium for 2002-03, the corn producer surplus is area ($a + b$), and ($e + f$) represents domestic consumer surplus from consumption of corn not converted to ethanol.[13] But in the "observed" equilibrium corn producer surplus is a+b+c+d+e, domestic corn consumer surplus is f, and h+i shows the tax increase required by the policy. The change in corn producer surplus between the observed equilibrium and the estimated non-intervention equilibrium is $\Delta PS_c(P_T^{03}, t^{03}, \boldsymbol{\alpha}^{03}) = c+d+e$, and the change in domestic corn consumers' surplus is $-e$. Following Gardner (1983) and several others, we aggregate consumers and taxpayers into a single interest group. Then the model's estimated effect of the policy on consumer-taxpayer welfare is the summation of change domestic corn consumers' surplus minus the tax increase: $\Delta CT^{\text{dom}}(P_T^{03}, t^{03}, \boldsymbol{\alpha}^{03}) = -(e+h+i)$.

The estimated change in aggregate domestic social welfare for 2002-03 is $(\Delta PS_c(P_T^{03}, t^{03}, \boldsymbol{\alpha}^{03})+\Delta CT^{\text{dom}}(P_T^{03}, t^{03}, \boldsymbol{\alpha}^{03})) = c+d-h-i$ in figure 1. Its opposite, h+i-c-d, is the year's estimated deadweight cost (social loss) from the ethanol tax credit. Because area i is equal to area c, we can write $DW^{dom}(P_T^{03}, t^{03}, \boldsymbol{\alpha}^{03}) = h-d$. Area d can be interpreted as the domestic social gain from the policy's effect of raising the world's price of corn, and thereby exploiting foreign consumers to the benefit of domestic producers. Area h can be interpreted as the domestic social loss from undergoing the costs of using ethanol to produce fuel when all fuel could have been obtained in the form of gasoline at the constant price of P_{FW}^{03}.

[13] Domestic consumers also derive utility from fuel consumption, but since the fuel price remains constant, we can ignore consumer utility derived from fuel consumption.

In figure 2, we illustrate the welfare effects of a hypothetical program in which only the target price is effective. We have chosen (arbitrarily) a target price of $P_T' =$ \$2.80/bu for the illustration. If we assume that the tax credit is zero, then the welfare effects can be shown in the left-hand panel of figure 2 alone. The change in producer surplus is $j+k+l+m+o+p+q+r$. The world price of corn drops to $P_L(P_T', \alpha^{03}) = 1.42$, and domestic corn consumers gain t. Taxpayers pay $j+k+l+m+n+o+p+q+r+s+t+u+v+w+x$ for the deficiency payment, so consumers-taxpayers lose $j+k+l+m+n+o+p+q+r+s+u+v+w+x$. Deadweight loss is $n+s+u+v+w+x$.

3.1.2. In (q, p) space: use of multiple instruments

In figure 2 we illustrate in (q, p) space the model's predicted effects of the tax credit combined with a target price high enough to be effective. We have chosen (arbitrarily) a target price of $P_T' =$ \$2.80/bu for the illustration. The resultant estimated equilibrium can be illustrated by changing the corn-to-ethanol supply curve to $ES_c(z, P_T', \alpha^{03})$, where the function $ES_c(z, P_T, \alpha)$ is formally defined as,

$$ESc(z,P_T,\alpha) = \begin{cases} Sc(z) - D_{NE}\left(P_L\left(P_T,\alpha\right),\alpha\right), & z \le P_T \\ Sc(z,\alpha) - D_{NE}(z,\alpha), & z > P_T. \end{cases}$$

In the definition above, the price paid by consumers when only the corn target price is effective is defined by $P_L(P_T, \alpha) = D_{NE}^{-1}(S_C(P_{T.}\ \alpha), \alpha)$ for all $P_T \geq P_{NE}(\alpha)$. Equilibrium conditions imply that the supply price of corn must equal the world price of fuel plus the tax credit, and that the quantity of corn supplied minus the quantity used for non-ethanol purposes all goes to the fuel market. With the target price of $P_T' = 2.80$ and the tax credit of $t^{03} = 2.07$, the supply price is \$2.80/bu, and markets clear at a world corn price of $P_C^{D03} =$ \$2.32/bu. The quantity of corn converted to ethanol in this estimated equilibrium is $\delta = 2186$ million bu.

Comparing the new equilibrium under the target price of P_T' = 2.80 and the tax credit of t^{03} = 2.07 to the non-intervention equilibrium, the rise in corn producer surplus is area *j+k+l+m+o+p+q+r*, the fall in domestic corn consumer surplus is *o*, and the rise in taxes paid is rectangle *j+k+l+m+n* for the deficiency payment plus rectangle *y+z* for the ethanol tax credit. The change in aggregate domestic social welfare is *p+q+r-n-y-z*, and its opposite, *n+y+z-p-q-r* is the deadweight cost.

4.2. Policy Space

The welfare changes estimated and illustrated in (*q*, *p*) space in figures 1 and 2 are informative, but the information provided is quite limited. One limitation is that each figure shows the welfare effects of only two policies: figure 1 features a non-intervention[14] policy $\left(P_T^{na}, t^{na}\right)$ = (0, 0) and that year's "observed" policy $\left(P_T^{03}, t^{03}\right)$ = (1.98, 2.07); figure 2 shows the non-intervention policy, and a hypothetical policy (P_T', t^{03}) = (2.80, 2.07). Conclusions we might come to from figures 1 and 2 regarding the relative efficiencies of the policy instruments are applicable to the particular policies analyzed. It is not clear, however, that they can be generalized to all market situations and all levels of transfer. Drawing general conclusions from these diagrams may be inadvisable. Gardner (1983) made this point when comparing use of a target price and use of a production quota, but it has been widely ignored in the applied literature.

Figure 3 uses de Gorter and Just's (2009) model (calibrated to the year 2002-2003) to illustrate our arguments in "policy space," and demonstrates how examining

[14] Following (*citation withheld*), we use *na* ("no action") to denote non-intervention.

policies in "policy space" can provide a deeper understanding of a model's results.[15] (De Gorter and Just (2009) described these results in the text of their article, but we maintain examining their model in its policy space helps clarify the discussion.) Because two policy instruments are examined, policy space is a subset of $\mathbb{R}^2$, as shown in figure 3 with a corn target price variable and ethanol tax credit variable placed on the axes. Any policy available to this model's government can be represented by a point in figure 3. For example, in 2002-03, the observed policy (P_T^{03}, t^{03}) = (\$1.98/bu, \$2.07/bu) is point **R**, and (P_T', t^{03}) = (2.80, 2.07) is **U**. Note that at **Z** = (0, t^{03}), no target price is set, but the tax credit of \$2.07/bu is imposed. At **S** = (P_T^{03}, 0) the corn target price is set at its 2002-03 observed level, but no ethanol tax credit is offered. Point **Y** = (0, 0) illustrates a non-intervention policy, where the government uses neither the ethanol tax credit nor the corn target price instrument. We use X to denote set of all policies available to the model's government, and call it the *set of feasible policies*.[16] X is the union of four non-intersecting subsets: $X = X^{na} \cup X^1 \cup X^2 \cup X^3$. Subset $X^{na} = \{(P_T, t): P_T \leq P_{NE}(\alpha), t \leq P_{NE}(\alpha) - P_{FW}\}$, is the set of policies for which neither the target price nor the tax credit is effective.[17] (If the policy is in X^{na}, then there is "no action," that is, the government does not intervene in markets.) Policies **Y**, **S**, and **W** belong to this non-intervention area. Let

[15] De Gorter and Just (2009, 2010) and Bourgeon and Tréguer (2010) also analyzed use of a biofuels mandate instrument. Because of space limitations, here we do not address that aspect of their articles, though our general arguments apply there, as well.

[16] Here by "feasible" we mean technically feasible, not necessarily politically feasible, since there are policies but no politics in the model as so far presented.

[17] Technically, the sets X^{na}, X^1, X^2, and X^3 depend on the crop-year, that is, depend on α. We suppress α in the notation in figure 3.

(P_T^{na}, t^{na}) denote an arbitrary policy in X^{na}. $X^1 = \{(P_T, t): t > t_c(P_T, \alpha)\}$, is the set of policies in which only the tax credit is effective. $X^2 = \{(P_T, t): P_T > P_{NE}(\alpha), P_L(P_T, \alpha) - P_{FW} < t \leq t_c(P_T, \alpha)\}$ is the set of policies in which both the target price and tax credit are effective. $X^3 = \{(P_T, t): P_T > P_{NE}(\alpha), t \leq P_L(P_T) - P_{FW}\}$, is the set of policies in which only the target price is effective.

In the literature, studies of the welfare effects of ethanol policy have considered only a few policies, or some subset of all the feasible policies, in their analyses (e.g., Babcock 2008; Gardner 2007; Mallory 2011; Schmitz, Moss, and Schmitz 2007). Examining a model's policy space makes clear that there are infinitely many policies to compare, not just a few. Also, as we will discuss in more detail, examining policy space provides a reminder that the relationships among policies (such as if increased use of one policy in some sense increases the efficiency of another), might not be the same everywhere in X.

4.3. Welfare space and welfare manifolds in de Gorter and Just's (2009) model

In real-world political economies, the effect of policy on aggregate well-being probably does to some degree has political significance. But an even greater influence may come from interest groups competing for political spoils (as in Becker (1983), Grossman and Helpman (1994), Tullock (1967), and many other studies). Therefore if economists want to analyze not just what is technically possible, but also what is politically possible, understanding how policies affect the distribution of welfare among interest groups is of first importance. Welfare manifolds facilitate examination of policies' impacts on both the aggregate level and the distribution of welfare.

Before formally defining welfare manifolds and submanifolds, we will convey some basic concepts by considering policies that de Gorter and Just (2009) examined, and mapping them from "policy space," through (quantity, price) space, and onto "welfare space." From the de Gorter and Just (2009) model, we can derive two functions, $\Delta CT^{\text{dom}}(P_T, t, \boldsymbol{\alpha})$, the change in consumer-taxpayers' welfare compared to under non-intervention, and $\Delta PS_{\text{c}}(P_T, t, \boldsymbol{\alpha})$ the change in corn producers' surplus compared to under non-intervention. Shortening the notation, if we let $\mathbf{h}(P_T, t, \boldsymbol{\alpha}) \equiv (\Delta CT^{\text{dom}}(P_T, t, \boldsymbol{\alpha}), \Delta PS_{\text{c}}(P_T, t, \boldsymbol{\alpha}))$, the correspondence **h** maps any (target price, tax credit, parameter vector) ordered triple $(P_T, t, \boldsymbol{\alpha})$ onto welfare space. For example, as shown in figure 1, at R, = (P_T^{03}, t^{03}) = (1.98, 2.07), $\Delta CT^{\text{dom}}(P_T^{03}, t^{03}, \boldsymbol{\alpha}^{03}) = -(e+h+i) = -4128$, and $\Delta PS_{\text{c}}(P_T^{03}, t^{03}, \boldsymbol{\alpha}^{03})$ = c+d+e = 2822, and the resultant change-in-welfare outcome is shown at point **r** = (-4128, 2822) in figure 4. Similarly, the policies depicted in figure 3 by **S**, **U**, **V**, **W**, **Y**, **and Z** are mapped onto **s**, **u**, **v**, **w**, **y**, **and z** in welfare space in figure 4.[18] The most obvious mapping is **Y** in figure 3 to **y** in figure 4; because neither the target price nor the tax credit is used at **Y**, then neither interest group experiences a change in welfare relative to the non-intervention equilibrium, so $\Delta CT^{\text{dom}}(0, 0, \boldsymbol{\alpha}^{03}) = \Delta PS\text{c}(0, 0, \boldsymbol{\alpha}^{03}) = 0$. **W** and **S** belong to the set of non-intervention policies, X^{na}, since $\Delta CT^{\text{dom}}(\mathbf{S}, \boldsymbol{\alpha}^{03}) = \Delta CT^{\text{dom}}(\mathbf{W}, \boldsymbol{\alpha}^{03}) = \Delta CT^{\text{dom}}(\mathbf{Y}, \boldsymbol{\alpha}^{03}) = \Delta PS_{\text{c}}(\mathbf{S}, \boldsymbol{\alpha}^{03}) = \Delta PS_{\text{c}}(\mathbf{W}, \boldsymbol{\alpha}^{03}) = \Delta PS_{\text{c}}(\mathbf{Y}, \boldsymbol{\alpha}^{03}) = 0$. Therefore points **s** and **w** are equal to **y**. As already discussed, the policy at **Z** does not use the target price but sets the tax credit at t^{03} = \$2.07/bu; the interest groups' resultant welfare levels are shown in figure 1 as $\Delta CT^{\text{dom}}(0, 2.07, \boldsymbol{\alpha}^{03}) = -(e+h+i)$ and $\Delta PS_{\text{c}}(0, 2.07, \boldsymbol{\alpha}^{03}) = c+d+e$. Therefore $\mathbf{z} = (-(e+h+i), c+d+e)$ in welfare outcome space (figure 4). At **R**, we have P_T^{03} = \$1.98/bu and t^{03} = \$2.07/bu. In this case P_T is ineffective,

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[18] Figures 1, 2, 4, 5, 6, and 7 were generated in *Mathematica* (Wolfram Research, Inc. 2010). The programs can be viewed in the on-line appendix.

just as at **Z**. **R** and **Z** map onto welfare space to the same point, labeled **r** and **z** in figure 4.

Any of a model's welfare submanifolds is a subset of its welfare manifold. For example, take the set of policies on the line segment between **Y** and **Z** in figure 3. We name this set *YZ*, which is formally defined as $YZ = \{(P_T, t): P_T = 0 \text{ and } t \in [0, 2.07]\}$. Mapping this set of points in welfare space we get $H(YZ, \alpha^{03})$, which we denote $STC(P_T^{na}, t, \alpha^{03})$ and show as the (solid, thin) surplus transformation curve passing through points **y** and **z** in figure 4.

Using similar procedures, one can map any subset of *X* in policy space into welfare space, and hence be provided with a more complete view of the effects of alternative policies on the *distribution* of welfare among interest groups. In the most general case, we can map the entire set of technically feasible policies *X* from policy space onto welfare space. Doing this for the 2002-03 crop year in de Gorter and Just's (2009) model, the result is the welfare manifold, $H(X, \alpha^{03})$, shown by the shaded area in figure 4.

4.3.1. Using welfare manifolds and submanifolds to examine efficiencies of policies in the de Gorter and Just (2009) model

One of de Gorter and Just's (2009) main conclusions is that it was wasteful during the years of their empirical study for government to use the ethanol tax credit and corn target price policy instruments jointly. Comparing the lone use of the target price instrument with the joint use of both instruments, they concluded (p. 485),

> *If there were no loan program, then the social costs of the tax credit average $913 million… significantly lower than with both policies in place of $1,291 million. This represents the increase in total deadweight costs because of the loan rate.*

De Gorter and Just calculated the numbers quoted above by averaging results of over the six-year period of the study. We cannot duplicate those results in (q, p) space in order to map them into welfare space, because no individual set of supply and demand curves led to them. But, if instead of referring to the mean results, de Gorter and Just had referred to their 2001-02 results, then they could have written in parallel fashion the following:

> *If there were no loan program, then the social cost of the tax credit in 2001-02 would have been $405 million… significantly lower than with both policies in place of $763 million. This represents the increase in total deadweight costs because of the loan rate.*

Using figure 5, we can analyze this quote in welfare space. Point $\Delta\mathbf{u}^a = \mathbf{h}(0, 1.43, \boldsymbol{\alpha}^{02}) = (-1616.92, 1212.27)$ is the outcome of the policy that sets the tax credit at $t^{02} = 1.43$[19] and sets the target price at $P_T^{\mathrm{na}} = 0$. The deadweight cost of this policy is $-(-1616.92 + 1212.27) \approx 405$, the horizontal (or vertical) distance between $\mathbf{u}^a$ and the line through the origin with slope -1. This number is reported in table 3 of de Gorter and Just (2009, p. 485). Point $\Delta\mathbf{u}^b = \mathbf{h}(2.10, 1.43, \boldsymbol{\alpha}^{02}) = (-3196.38, 2433.03)$ is the outcome of the policy that sets the tax credit at $t^{02} = 1.43$ and the target price at $P_T^{02} = 2.10$. (This is the "observed" policy for 2001-02.) The deadweight cost of this policy is $-(-3196.38 + 2433.03) \approx 763$. Point $\Delta\mathbf{u}^c = \mathbf{h}(2.10, 0, \boldsymbol{\alpha}^{02}) = (-3072.90, 2433.03)$ is the outcome of the policy that

[19] We have explained that the tax credit of $0.51/gallon is equivalent to $2.07/bu. In their generation of their table 3, however, de Gorter and Just (2009) assumed an "observed" target price of $1.43/bu. We maintain that assumption in figure 5.

sets the tax credit at $t^{na} = 0$ and sets the target price at $P_T^{02} = 2.10$. The deadweight cost of this policy is -(-3072.90+2433.03) ≈ 640.

When the tax credit $t^{02} = 1.43$ is added once the target price of $P_T^{02} = 2.10$ is in place, the welfare outcome moves from point $\Delta\mathbf{u}^a$ to $\Delta\mathbf{u}^b$ in figure 5. It is true that this application of the tax credit with the target price in place results in greater deadweight loss. But to draw the normative conclusion that therefore the addition of the tax credit to the target price is a bad thing ignores the redistributive aspect of the policy change, which is that it takes welfare away from consumers-taxpayers, but provides additional welfare to producers. In fact, outcomes $\Delta\mathbf{u}^a$ and $\Delta\mathbf{u}^b$ are Pareto non-comparable, and it is difficult to draw any conclusions about whether the policy change is good or bad. It is easier to reach a normative conclusion about a policy change that raises the tax credit from 0 to $t^{02} = 1.43$ while maintaining the target price of $P_T^{02} = 2.10$. This policy change moves the welfare outcome from $\Delta\mathbf{u}^c$ to a Pareto-inferior point $\Delta\mathbf{u}^b$. As long as we are willing to accept the Pareto criterion as a normative guideline, we can conclude that once the target price of 2.10 is in place, it is a bad thing to raise the tax credit from 0 to 1.43.

The results just discussed above do not imply that it is necessarily a bad thing to use a target price and a tax credit jointly, however. Figure 5 only displays part of welfare space, with ΔCT^{Dom} in the interval [-5000, 0] and ΔPS_c in [0, 5000]. It appears that the Pareto frontier $H(X, \boldsymbol{\alpha}^{02})$ (the "northeast boundary" of the welfare manifold) is comprised of the surplus transformation curve $STC(P_T, t^{na}, \boldsymbol{\alpha}^{02})$. We can come to the conclusion that in this region, then, the best policy is to use the target price alone.[20] But figure 6 shows that this conclusion cannot be reached if greater transfers to producers are to be made. Figure 6 shows $STC(P_T, t^{na}, \boldsymbol{\alpha}^{02})$ does not make up the Pareto frontier for the region in which ΔPS_c is between 20,000 and 25,000, for instance. Point $\Delta\mathbf{u}^d$ = (-31,241.3 , 23,327) is the welfare outcome when the target price is set at 4.00 and the tax credit is not used. A Pareto-superior point $\Delta\mathbf{u}^e$ = (-30,804.9 , 23,327), which raises consumer-taxpayer welfare without affecting producer welfare, is obtainable by leaving the target price at 4.00 and setting the tax credit at approximately 0.94. In fact, above a transfer to producers of approximately 4900, all Pareto-optimal policies use the policy instruments jointly.

We are willing to claim that in general, in fact, making the "toolkit" of policy instruments available larger cannot be a bad thing. The reason is explained in (reference withheld). The Pareto-optimal policy $(P_T^*, t^*) = (4.00, 0.94)$ can be found by solving the following maximization problem (see Mas-Collel, Whinston, and Greene 1995, p. 328):

$$\underset{\substack{P_T \geq 0,\\ t \geq 0}}{Max}\left\{\Delta CT\left(P_T, t, \boldsymbol{\alpha}^{02}\right): \quad \Delta PS\left(P_T, t, \boldsymbol{\alpha}^{02}\right) \geq \Delta PS\left(4.00, 0, \boldsymbol{\alpha}^{02}\right)\right\}.$$

Note that this maximization problem is less constrained than,

$$\underset{\substack{P_T \geq 0,\\ t \geq 0}}{Max}\left\{\Delta CT\left(P_T, t, \boldsymbol{\alpha}^{02}\right): \quad \Delta PS\left(P_T, t, \boldsymbol{\alpha}^{02}\right) \geq \Delta PS\left(4.00, 0, \boldsymbol{\alpha}^{02}\right), t = 0\right\}.$$

This means that to achieve the level of change of producer surplus of 23,327, seen at point $\mathbf{u}^e$, at least as much and in general more consumer-taxpayer

[20] Of course, this doesn't mean that having the ethanol tax credit instrument available harms anything. Having an instrument available doesn't mean that that it has to be used.

welfare can be attained when we include t as an available policy instrument than when we do not. The policy instrument "toolkit" cannot be too large.

It is tempting to conclude from figure 5 that the target price policy instrument was better than the tax credit for the year 2001-02, since $STC(P_T, 0, \boldsymbol{\alpha}^{02})$ lies everywhere to the northeast of $STC(P_T, 0, \boldsymbol{\alpha}^{02})$. Examining figure 6 reveals that this would be a mistaken conclusion, and that if the government is constrained to use only one instrument, the best instrument to use would depend on the amount of welfare transferred to producers. For relatively small transfers, the target price is the best solitary instrument, but for larger transfers $STC(P_T^{\mathrm{na}}, t, \boldsymbol{\alpha}^{02})$ everywhere to the northeast of $STC(P_T, \mathrm{t}^{\mathrm{na}}, \boldsymbol{\alpha}^{02})$, and the tax credit is the best solitary instrument. However, asking which instrument is best when used alone begs the question since in general the best policy uses multiple instruments jointly. We provide an example in figure 6, which again shows the welfare manifold and some submanifolds for the De Gorter and Just (2009) model calibrated to 2001-02, but for $\Delta\mathbf{u}$ further to the northwest from those shown in figure 5. The diagram zooms in on to welfare outcomes, $\mathbf{h}(4.00, 0, \boldsymbol{\alpha}^{02}) = \Delta\mathbf{u}^d$, and $\mathbf{h}(4.00, 0.94, \boldsymbol{\alpha}^{02}) = \Delta\mathbf{u}^e$. Note that $\Delta\mathbf{u}^e$ is Pareto-superior to $\Delta\mathbf{u}^d$: it achieves the same amount of producer welfare while achieving a higher level of consumer-taxpayer welfare. Clearly, in this case adding a tax credit to an existing target price is a good thing.

We showed in figure 5 that in 2001-02, accomplishing a relatively small transfer to producers with a target price led to a smaller loss to consumers-taxpayers than when that transfer was accomplished with a tax credit. It is tempting, then, to declare that for small transfers to producers, the target price is the best instrument to use. But in figure 7, we show the model's welfare manifold and submanifolds for 2003-04. Comparing figure 6 to figure 7, we see that which policy instrument is "best" depends on the year and its market parameters $\boldsymbol{\alpha}^{04}$. In figure 7, for small transfers to producers, tax credit surplus transformation curve $STC(0, t, \boldsymbol{\alpha}^{04})$ lies "northeast" of the tax credit surplus transformation curve $STC(P_T, 0, \boldsymbol{\alpha}^{04})$. In this year, if one instrument had to be used alone in achieving a small transfer to producers, the tax credit was the instrument to use.

The bottom panel of figure 8 presents an interesting submanifold, which is implicitly defined by de Gorter and Just's (2009) model calibrated to the year 2003-04. The submanifold shows the welfare outcomes of the set of policies that maintain the target price at \$5.00/bu and vary the ethanol tax credit between 0 and \$4.03/bu. Technically, let S = $\{(P_T, t): P_T = 5.00, 0 \leq t \leq 4.03\}$, then according to definition (1), the curve shown is $H(S, \boldsymbol{\alpha}^{04})$. We label it $STC(5.00, t, \boldsymbol{\alpha}^{04})$. To understand the shape of this submanifold, it is necessary to understand that when the target price is 5.00, the critical tax credit is \$4.01. That is, tax credits less than or equal to \$4.01 do not affect the price of corn, and therefore do not affect corn producer surplus. These tax credits do affect consumer-taxpayer welfare, however. The top panel of figure 8 displays the affects raising the tax credit from 0 to \$4.03 on domestic consumer-taxpayer welfare. At tax credits below approximately \$1.37, a rise in the tax credit raises consumer-taxpayer surplus but for tax credits above approximately \$1.37, a rise in the tax credit lowers domestic consumer-taxpayer welfare. Point f in the top panel of the figure shows the level of ΔCT when the target price is 5.00 and the tax credit is zero. This point corresponds to point $\mathbf{u}^f$ in the top panel, where consumer-taxpayer welfare (that is, the change in welfare from its non-intervention value) is approximately -45,674, and corn producer welfare is 34,126. Raising the tax credit to fifty cents means that the policy is (5.00, 0.50), and the welfare outcome is $\mathbf{u}^g$ = (-44283, 34126). Given that the target price is 5.00, the highest level of consumer-taxpayer welfare that can be achieved is shown at point *h*, and the welfare outcome is $\mathbf{u}^h$ = (-43764, 34126). Further rises in the ethanol tax begin to hurt consumers-taxpayers. Raising it to 3.45, the welfare outcome is $\mathbf{u}^i$ = (-44764, 34126). Raising it further to 4.01 results in $\mathbf{u}^j$ = (-45191, 34126). The level 4.01 is the "critical" tax credit when the target price is 5.00. That is, tax credits above 4.01 raise the producer price above the target price of 5.00, and therefore render the target price ineffective. The welfare outcome of a tax credit of 4.03 and a target price of 5.00 is $\mathbf{u}^k$ = (-45563, 34395).

The surplus transformation curve in the bottom panel of figure 8 throws some light on various comments that have been made in the literature about the use of multiple policy instruments, and about whether use of one policy instrument makes use of the other more efficient. The figure reveals that, given a target price of 5.00, raising the tax credit from 0 to about 1.37 raises consumer-taxpayer welfare without lowering producer welfare. Clearly, either in terms of deadweight or in terms of Pareto efficiency, using both instruments and setting them at levels (5.00, 1.37) is better than using just the target price and implementing policy (5.00, 0). But raising the tax credit above 1.37 when the target price is 5.00 lowers consumer-taxpayer welfare. Thus, care must be taken when interpreting de Gorter and Just's (2009) statements quoted in the introductory section of this article:

- Increasing the ethanol tax credit/production subsidy need not lower the inefficiency of the farm subsidy policy instrument. As in figure 7, an increase in one instrument on can lead the economy to a Pareto superior, Pareto inferior, or

Pareto non-comparable welfare outcome, and similarly it can make deadweight costs increase, decrease, or remain unchanged.

- Analyzing the effects of an increase in the value assigned to one instrument is different from analyzing the effects of both instruments used together. It may be that at some policy, lowering the value of a policy instrument results in socially superior welfare outcome. But this need not imply that the value of that instrument should be set at the non-intervention level. However "optimal" is defined, the "optimal" policy can be different from the examined policy, and even less intervening than the examined policy, but this does not mean that it has to be the non-intervention value of the instrument. So, it may be a good idea to lower usage of one instrument, but that does not imply that the two instruments should not be used together.
- We have shown that using two instruments simultaneously in general (almost)[21] always can improve redistributive efficiency in comparison to using one policy instrument alone. This result generalizes Lapan and Moschini's (2009, p. 27) claim about using two policy instruments instead of one, and also Bourgeon and Tréguer's finding that a biofuels policy instrument can be used in conjunction with a crop support price instrument to improve redistributive efficiency. Our result is

[21] One can dream up cases in which it is optimal not to use a particular instrument—that is, set it at its non-intervention value. This is not generally the case, and when it is the case, the policy maker has the option of simply not using that instrument. Thus, having the instrument available cannot be a bad thing when the policy maker has the option of not using it. This point is obvious when we examine policy in policy space and welfare space, but it has not been well understood in the (q, p) space literature in general.

very general, and extends well beyond the study of biofuels policy and its interactions with commodity policy. The toolkit for biofuels policy is not too large.

4.3.2. Generalization to *m* policy instruments and *n* interest groups

Efficiency of policy instruments depends also on the dimension of the model being used to examine ethanol policy. We define 'dimension' by an ordered pair (*m*, *n)*, where *m* is the number of policy instruments that are at the government's disposal in the model, and *n* is the number of interest groups whose welfare is measured in the model. All economic models that attempt to address the question of whether policy is "efficient" have dimension. In our simulations, we followed Gardner (1983) and aggregated the groups of de Gorter and Just's (2009) into two: "corn producers," and "consumers-taxpayers." For example, de Gorter and Just's (2009) studied two policy instruments and four interest groups, namely corn producers, corn and fuel consumers, fuel producers[22] and taxpayers. Of course, if more than three interest groups are modeled, it becomes impossible to visualize the model's welfare manifold as we do in figures 4 and 5. But whether a policy is Pareto efficient can still be examined (reference withheld), as can whether deadweight costs are minimized given that particular welfare levels of

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[22] De Gorter and Just (2009) discuss theoretically the consequences of a downward-sloping rest-of-world excess supply curve for fuel, which implies that U.S. corn and ethanol policy can change the world price of fuel. But in their simulations, they assume that that excess supply is perfectly elastic, and so the world price of fuel is constant. Therefore in their theoretical discussion, policy can affect the welfare of "fuel producers," but in their simulations, it cannot. Whether fuel producers would be considered as one of the groups analyzed would depend on whether the theoretical model or the simulated model were used.

some of the interest groups must be held constant. Our framework can be extended to models using more than two policy instruments. De Gorter and Just (2008a, 2008b, 2009, 2010) have published a series of articles in which they examined the use of two policy instruments; they have combined, an ethanol import tariff, an ethanol tax credit and a mandate (2008a, 2008b), ethanol import tariff and a tax credit (2009), and they analyzed several policy instruments by studying the intersection of environmental, energy and agricultural policy (2010). A fruitful exercise would be to examine simultaneous use of more than two policy instruments. While such a policy might be "messy" in (quantity, price) space, once mapped into welfare space, the effects of different policies are more easily understood, and comparison of policies is easier. Model dimension can also be important in that if a model's number of interest groups less than the number of policy instruments, then Pareto efficiency of a policy is virtually assumed, and therefore little of interest about the Pareto efficiency of policy can be concluded using the model (reference withheld). Also, modeling multiple interest groups can be of great practical importance, especially when considering political-economic aspects of policy. The welfare of producers in non-corn grain markets matters. Baker (2008) discussed the potential importance of the welfare consequences of ethanol policy's effects in wheat and soybean markets. The effect of ethanol policy on livestock producers matters even more when we consider the real-world politics of ethanol policy.

5. Conclusions

Policy economists have been conducting welfare analyses for many decades. Most of the policies analyzed have used one policy instrument. But real-world governments use policy instruments jointly, and instruments implemented in one market can have influences on prices in other markets, and interact with policy instruments implemented in those markets.

Over the past few years, very interesting research has been conducted on biofuels policy. This research has recognized the importance of analyzing the joint use of multiple instruments. These papers have all examined the welfare effects of policy in (q, p) space, examining geometric areas behind and under supply and demand curves. While this approach is fruitful, when multiple policy instruments are examined in joint use, (q, p) diagrams quickly become complicated. We have chosen to call the resultant literature "labyrinthine." That different studies have come to opposite conclusions about the same policy interactions supports our choice of term, as does the very complex nature of the supply and demand diagrams used in the literature to analyze policy interactions. We recognize that these policy instrument interactions are inherently complex, and that in general there may be no easy way to analyze and present their effects. But our purpose of this article has been to present some tools to help simplify these tasks. We have shown that examined policy possibilities in "policy space," and then using welfare measures in (q, p) space to map available policies into "welfare space" can bring additional clarity and insight into the analysis. These tools have enabled us to conduct a clearer discussion of what it means for use of policy instrument to make use of another policy instrument more "efficient," have allowed us to better analyze the redistributive aspects of biofuels policies, have shown the feasibility and importance of analyzing whole sets of possible policies (as opposed to trying to make more general conclusions than analysis of just a few policies can provide). The tools have also made it easy for us to present the very general result that having more policy instruments available cannot be a bad thing.

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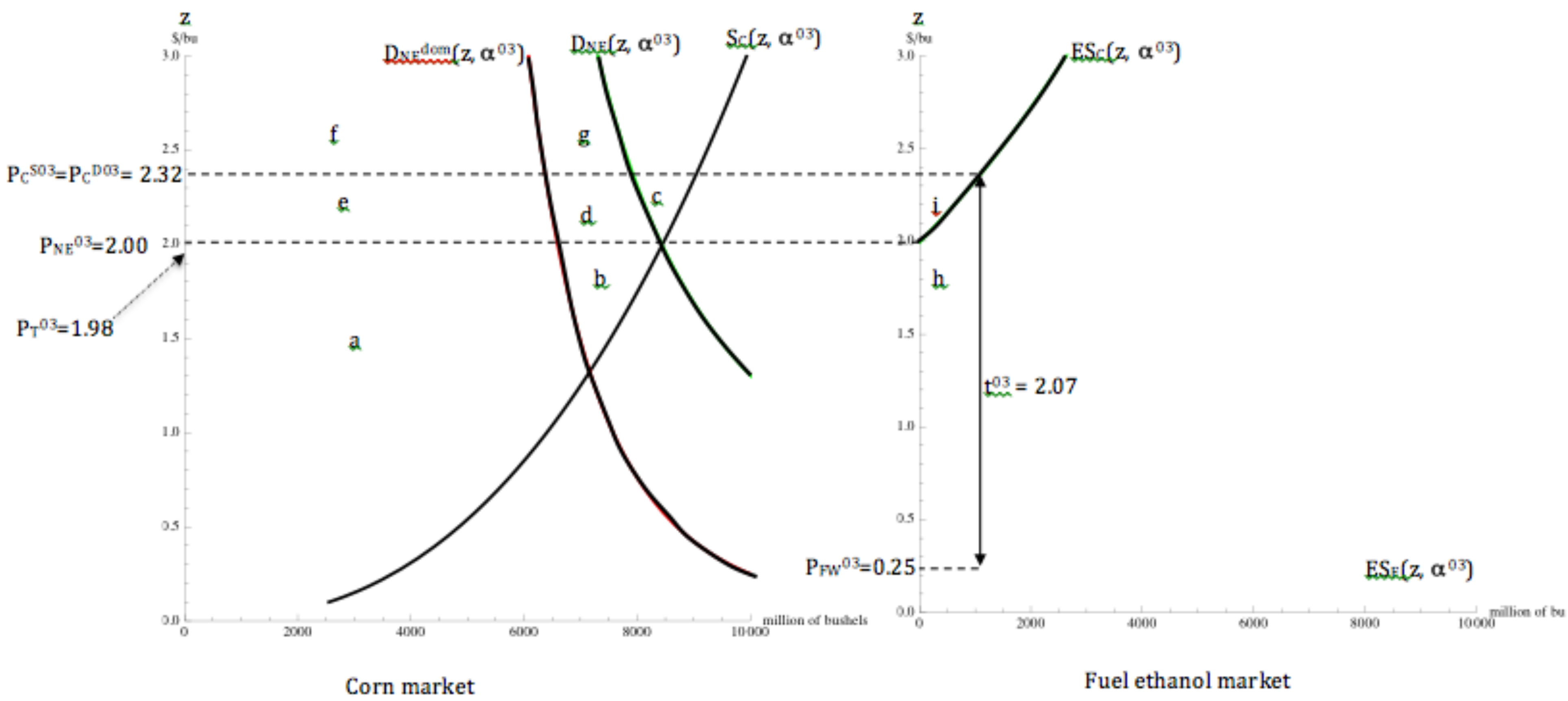

Figure 1. De Gorter and Just's (2009) Model of an Ethanol Tax Credit, Shown in (q, p)-space, for Crop-year 2002-03

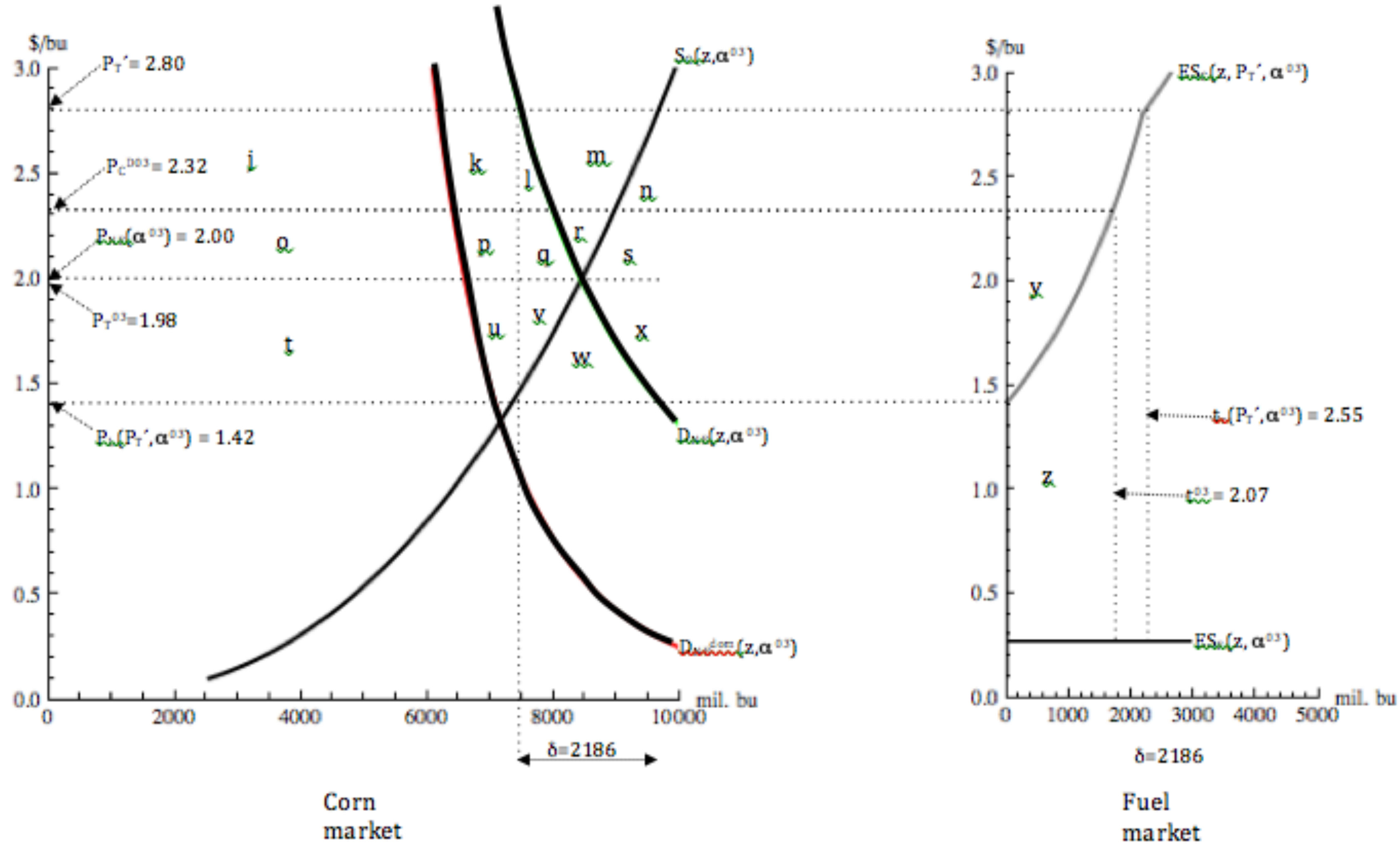

Figure 2. De Gorter and Just's (2009) Model in (q, p)-space, Calibrated to 2002-03, Showing a Target Price of $2.80/bu Used Jointly with an Ethanol Tax Credit of $2.07/bu

$$X=\{(P_T,t): P_T \geq 0, t \geq 0\} = X^{na} \cup X^1 \cup X^2 \cup X^3$$

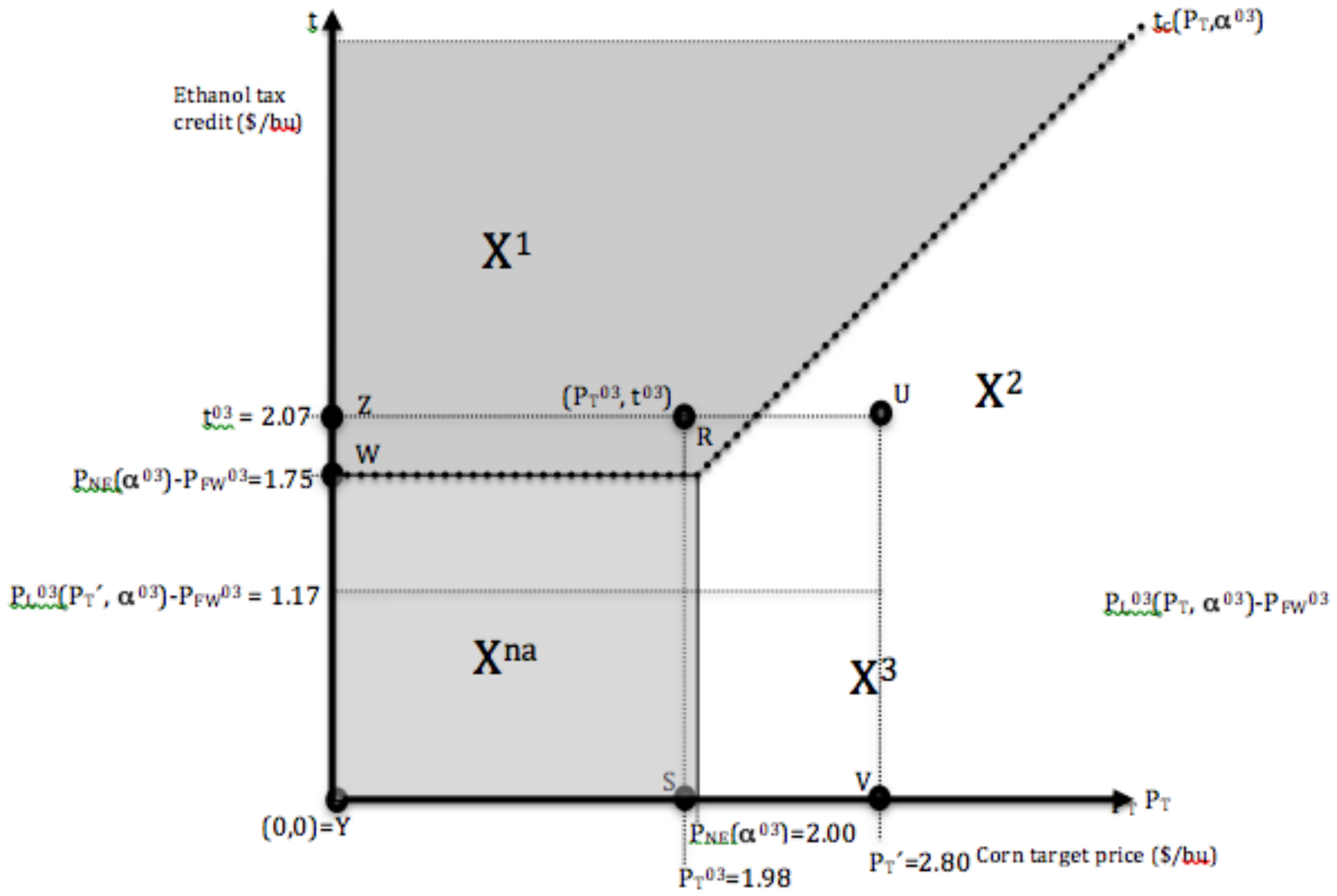

Figure 3. Policy Space, with the Observed Policy and Calculated Non-intervention Price for 2002-03

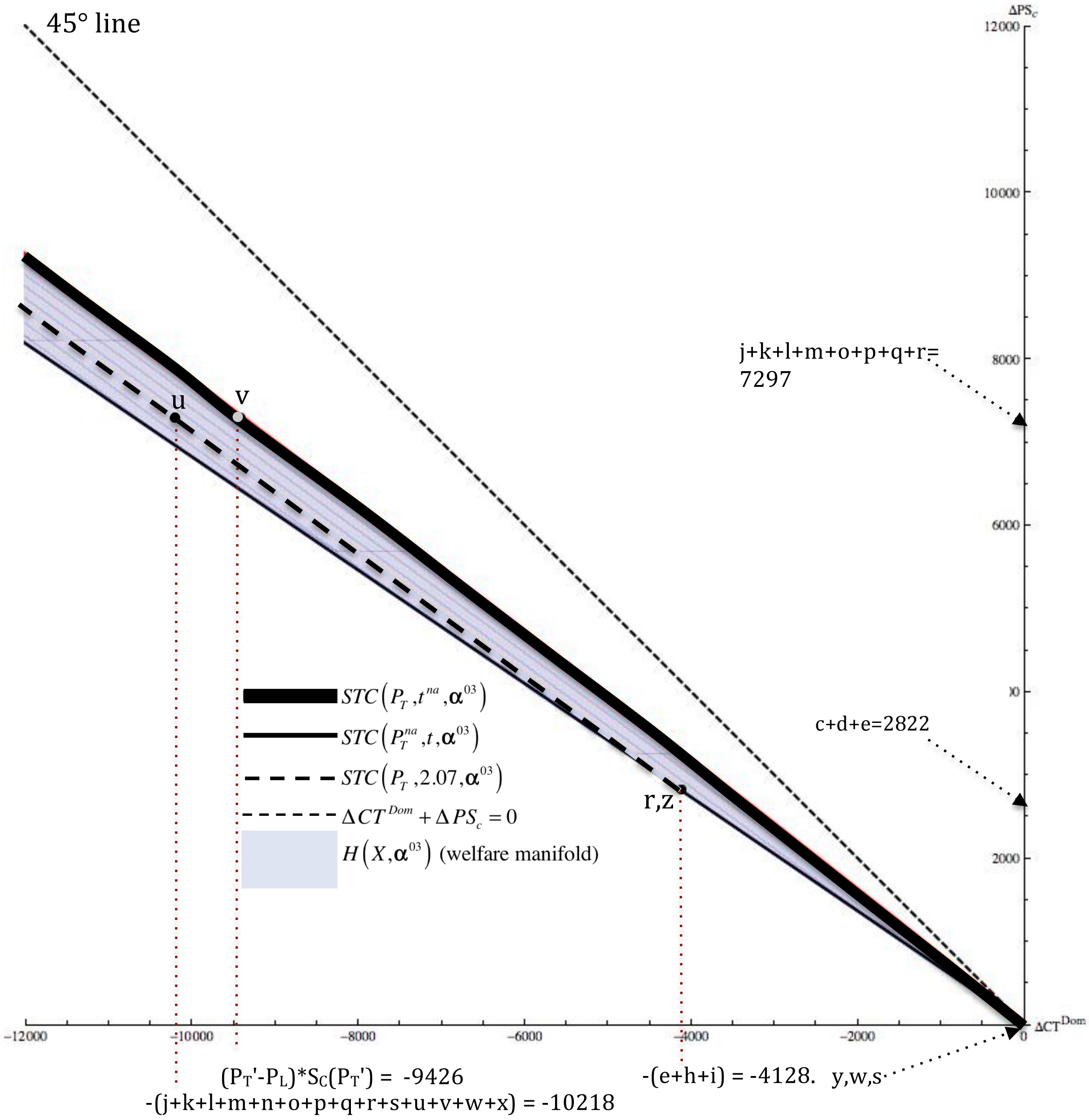

Figure 4. Welfare Space for the de Gorter and Just (2009) Model, in 2002-03

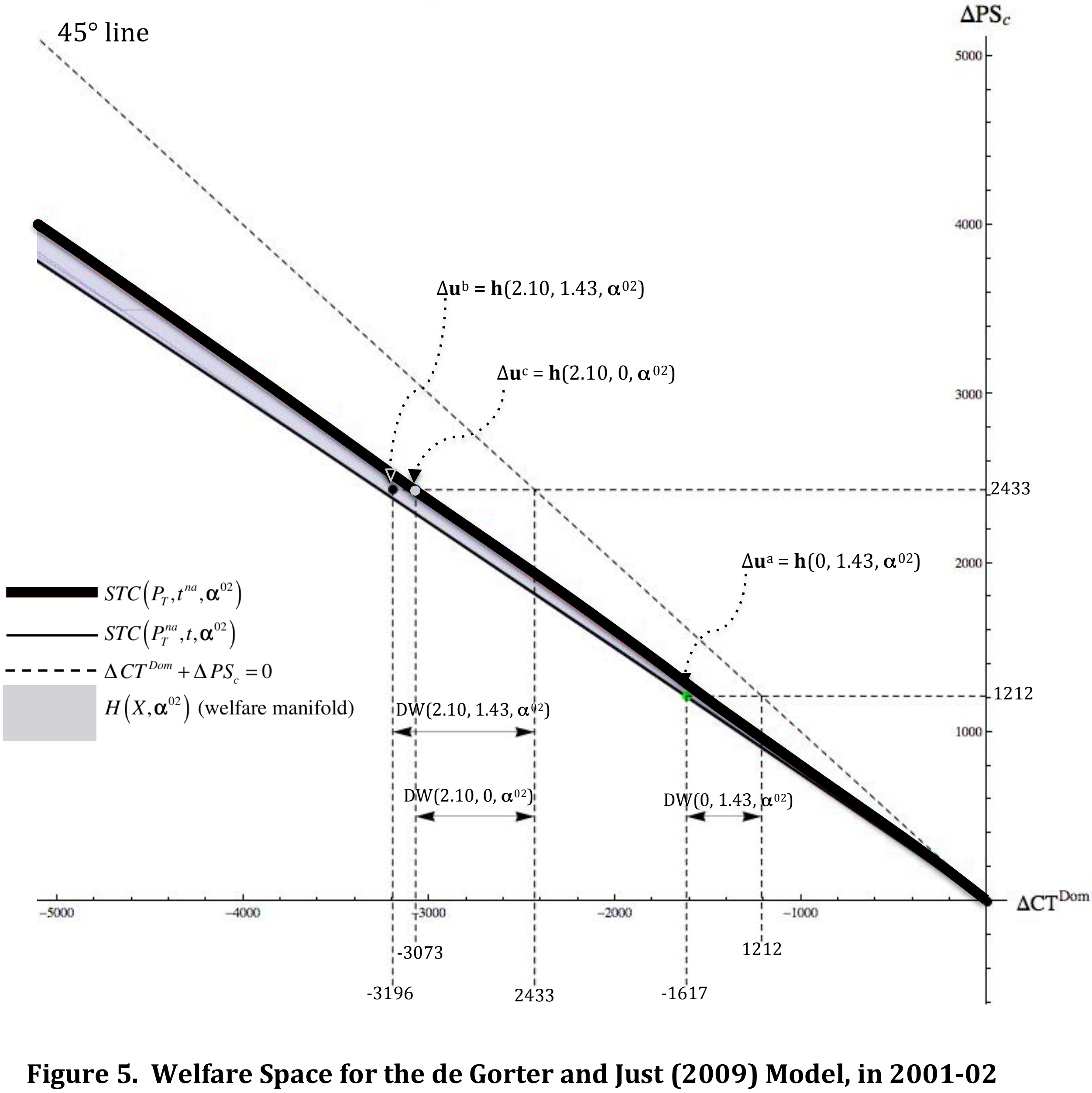

Figure 5. Welfare Space for the de Gorter and Just (2009) Model, in 2001-02

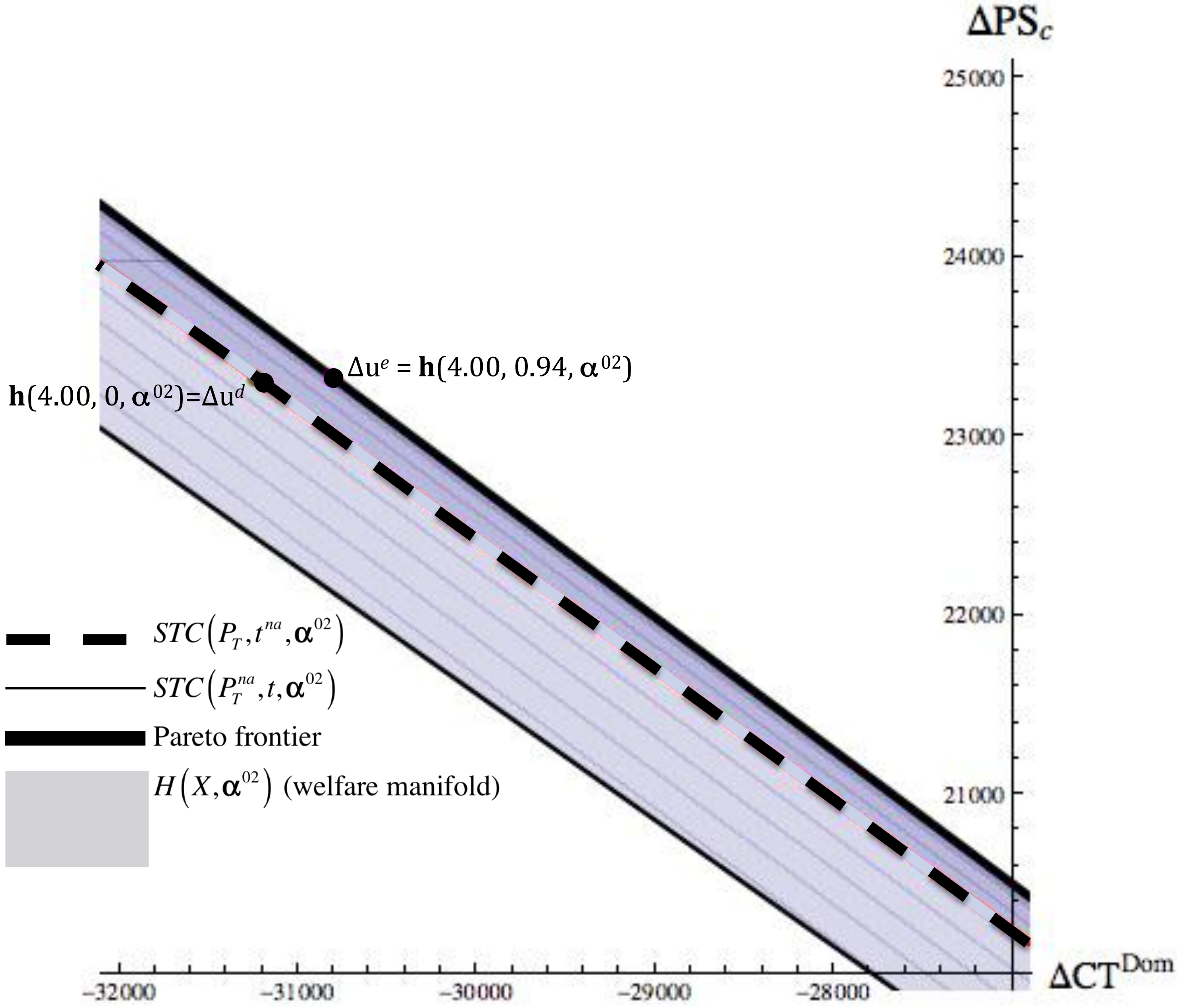

Figure 6. Welfare Space for the de Gorter and Just (2009) Model in 2001-02

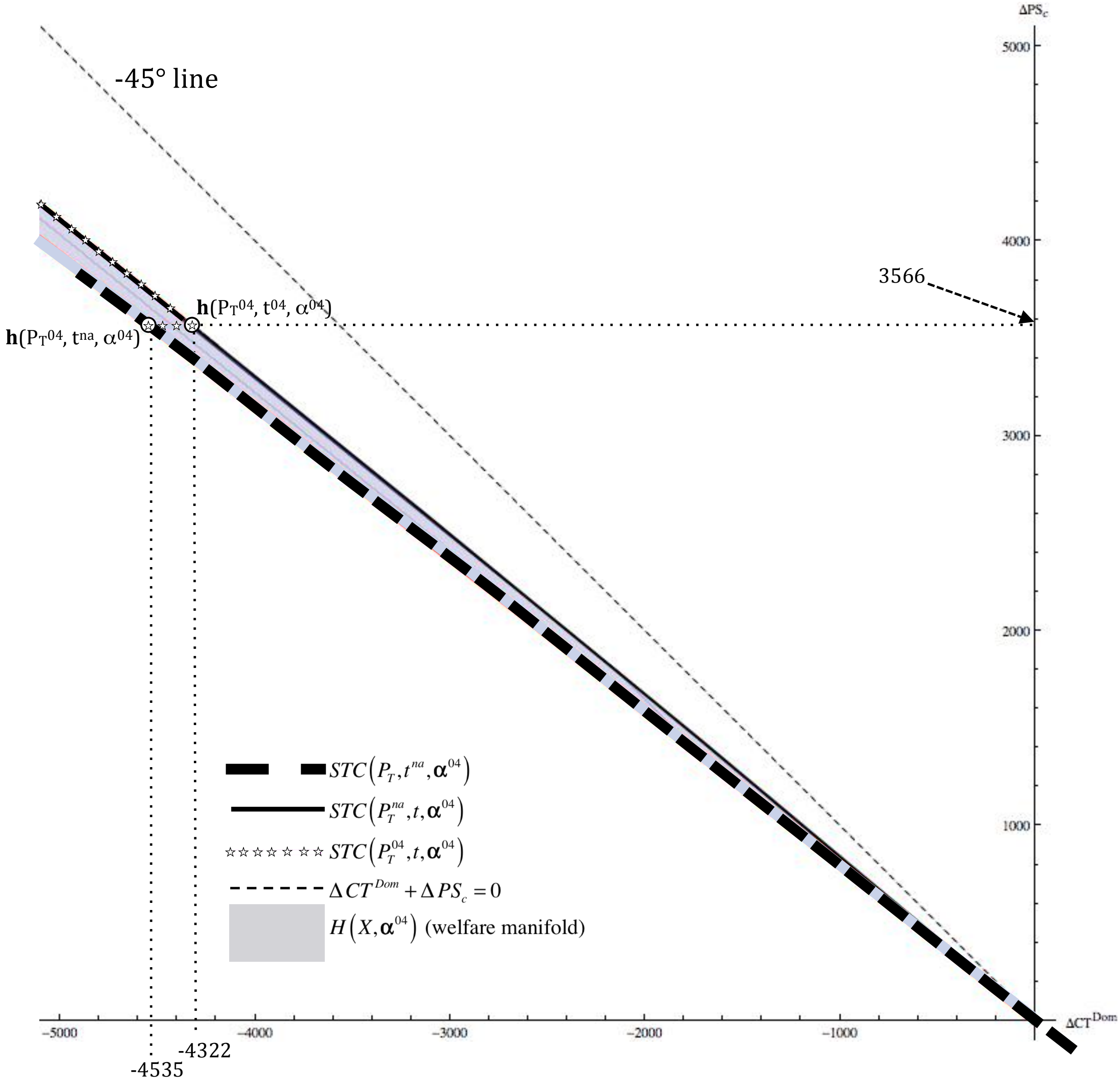

Figure 7. If Only One Instrument Is to Be Used to Make a Relatively Small Transfer to Producers, It Should Be the Tax Credit, in 2003-04

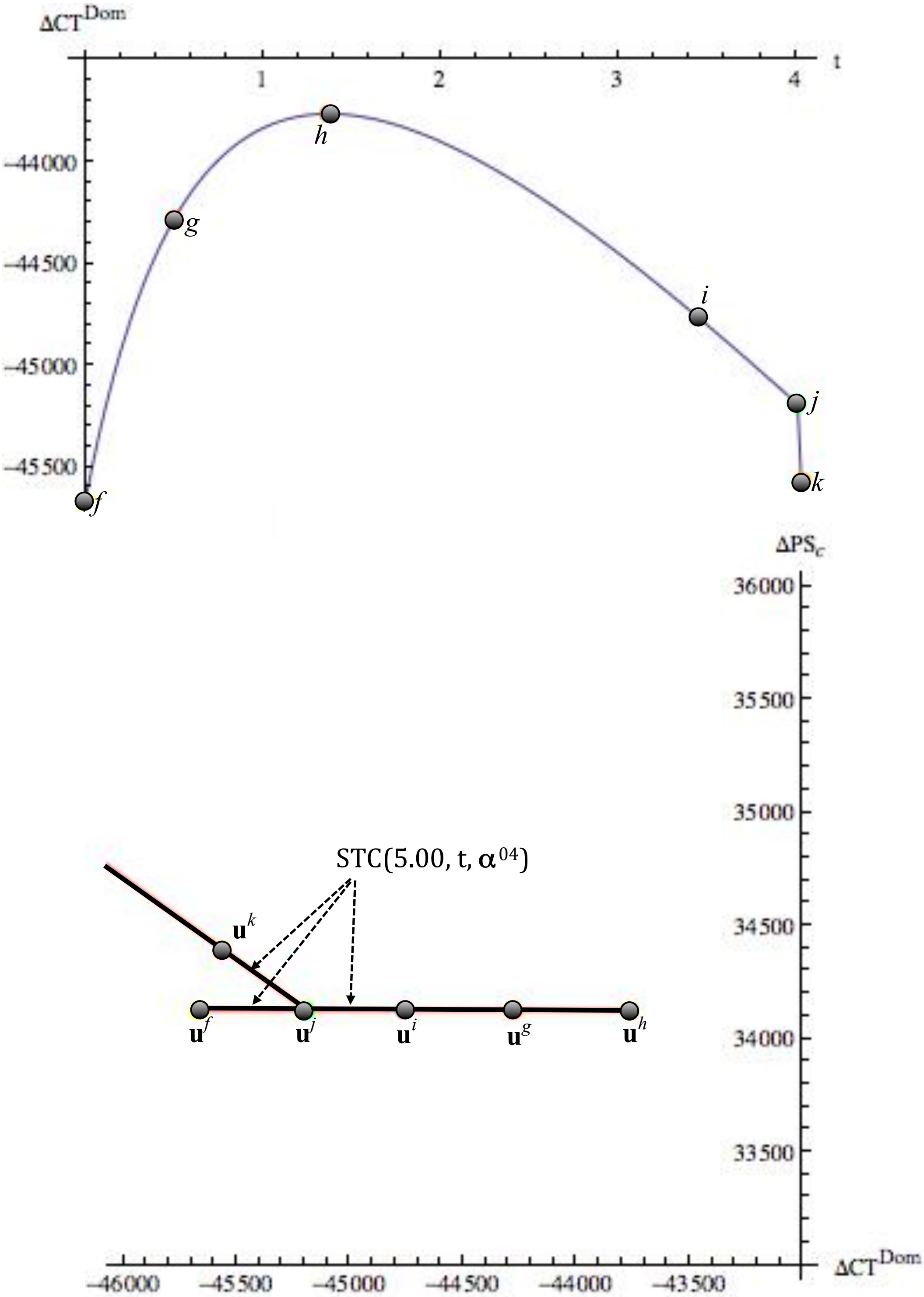

Figure 8. In 2003-04, Given a Target Price of $5.00, Increasing the Tax Credit Can Lead to a Pareto-superior or Pareto-inferior Welfare Outcome, Depending on the Value of the Tax Credit