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Abstract

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Finally, when feed compounders discount the DDGS nutrient profile to ensure they are at or above any realized nutrient profile 90% of the time, the land-use credit for corn ethanol declines by 8.47% for DDGS in a swine feed ration.

Keywords

biofuel, DDGS quality, displacement rate, greenhouse gas accounting, land-use credit, optimal, stochastic LP, swine grower-finisher optimal feed ration

Disciplines

Agricultural and Resource Economics | Agricultural Economics | Economics | Natural Resource Economics | Oil, Gas, and Energy

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Land-Use Credits to Corn Ethanol: Accounting for Distillers Dried Grains with Solubles as a Feed Substitute in Swine Rations

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Abstract

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Finally, when feed compounders discount the DDGS nutrient profile to ensure they are at or above any realized nutrient profile 90% of the time, the land-use credit for corn ethanol declines by 8.47% for DDGS in a swine feed ration.

Keywords: biofuel, DDGS quality, displacement rate, greenhouse gas accounting, land-use credit, optimal, stochastic LP, swine grower-finisher optimal feed ration.

1. Introduction

Policy support inducing the development of biofuels has been justified along several major grounds, including energy independence, a reduction in greenhouse gas (GHG) emissions, improvements in rural development related to biofuel plants, and farm income support (Rubin, Carriquiry, and Hayes, 2008). These are apparent in both the 2005 and 2007 energy acts. Of the four justifications, there is least agreement on the impact of biofuels on GHG emissions. For example, Searchinger et al. (2008) report that in accounting from feedstock production to fuel use, corn ethanol matches gasoline in GHG emissions. And with the feedstock uptake credit, the use of biofuels may actually lower GHG emissions by 20%.[1] However, biofuel GHG emission gains may be more than adversely offset when land-use changes are accounted for. This last point is the source of many of the controversies on the impact of biofuels on the environment because land-use change is not a technical parameter with an objective basis but a behavioral outcome.

One key factor in GHG emissions accounting when land-use change is considered is the land-use credit given to corn as feedstock for ethanol production because of the potential of its by-product—distillers dried grains with solubles (DDGS)—as a livestock feed ingredient, replacing corn and soymeal. That is, a hectare of land used to produce corn feedstock for ethanol production should be adjusted to account for a land credit for land that is not planted to corn and soymeal because DDGS, a by-product of ethanol production, replaces these feed ingredients in a livestock feed ration. The land-use credit numbers that are reported in the literature range from 31% to 71% (Darlington, 2009).

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[1] The range of savings from current bioethanol technologies is -20% to 80% depending upon the feedstock, rates of fertilizer application, type of other energy source (coal, gas, or biomass), the heat and power source (simple boiler, CHP, or advanced turbine), and the specific use of co-products (Gallagher, 2008).

This wide land-use credit range can significantly contribute to making the biofuels sector either a net contributor or mitigator of GHG emissions. Behind this wide-ranging land-use credit rate is an important underlying assumption that can be equally subject to much contention: the displacement rates between DDGS and major feed ingredients, primarily corn and soymeal (Darlington, 2009; and Arora, Wu, and Wang, 2008[2]). This paper addresses the issues surrounding different estimates of displacement rate and land-use credit in the use of DDGS. In particular, the following questions are of interest:

- How can appropriate displacement rates of DDGS be estimated for major feed ingredients, such as corn and soymeal?
- Does it make a difference whether displacement rates are estimated based on an optimal feed formulation using least-cost optimization, or from feed rations in DDGS feeding trials?
- Given that DDGS have a variable nutrient profile, is it adequate to express displacement rates by a single point estimate, or is it better characterized by a distribution, instead? As a result, should not the land-use credit also be characterized by a distribution?
- Are displacement rate estimates conditional on behavioral response of feed compounders over the uncertainty of the DDGS nutrient profile?

These questions are examined in the use of DDGS in a swine grower-finisher feed ration.

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[2] Hereafter referred to as AWW.

2. Model

The basic model is a standard linear programming (LP) model to formulate a least-cost feed ration for finishing hogs used in Fabiosa 2008b. The optimization problem is to

$$[1] \qquad \text{Minimize } p'x$$

$$\text{subject to } \begin{array}{c} Ax\{\geq=\leq\}b \\ l \leq x \leq u \end{array}$$

where ***x*** is an *n x 1* matrix of structural decision variables, which in this case are the levels of feed ingredients to include in a feed hog ration (e.g., corn, soymeal, DDGS, and supplements for minerals and vitamins); ***p*** is an *n x 1* matrix of feed ingredient prices; ***A*** is an *m x n* matrix of technological coefficients representing the amount of nutrient from the respective source of feed ingredients, ***b*** is an *m x 1* matrix of right-hand-side constants such as feed nutrient requirements (e.g., energy, protein, minerals, and vitamins); ***l*** is an *n x 1* matrix of lower bound such as the non-negativity condition of the decision variables; and ***u*** is an *n x 1* matrix of upper bound such as the maximum inclusion rate of DDGS in the ration.

Because of the variability in the nutritional content of DDGS, we augment the LP program in [1] to be stochastic to account for the random elements in the ***A*** matrix. For this purpose we use a multivariate normal distribution to characterize the random nutritional content of DDGS, i.e.,

$$[2] \qquad n(a;\mu,\Sigma) = \frac{1}{(2\pi)^{N/2}|\Sigma|^{1/2}} e^{\left(-\frac{1}{2}(a-\mu)'\Sigma^{-1}(a-\mu)\right)}$$

where a is a matrix of random coefficient elements of the ***A*** matrix, μ is a vector of their mean values, and Σ is a variance-covariance matrix.

From the optimal feed ration solved from [1] and [2] we derive displacement rates for DDGS and the land-use credit for corn ethanol.

3. Data and Results

This study uses the same database developed in Fabiosa 2008a and 2008b for the swine feed ration. The nutritional requirement is taken from the recommendations of the Swine Nutrition, Growth, and Behavior Section of the Iowa Agriculture and Home Economics Experiment Station and the Animal Science Extension Section of Iowa State University, published in “Life Cycle Swine Nutrition” (Holden et al., 1996). The nutrient composition data of DDGS products from 40 ethanol plants were taken from the University of Minnesota Web site on DDGS at http://www.ddgs.umn.edu/ (Akayezu et al., 1998). The data include 40 ethanol plants from 11 states. The nutrient composition data of the rest of the feed ingredients are taken from the National Research Council (NRC, 1998). Prices of corn, soymeal, and DDGS are from the USDA Market News, and prices of mineral and vitamin supplements are from industry sources.

To ensure spatial consistency, we model a representative feed compounder located in Kansas City, Missouri. The prices of feed ingredients were updated from a USDA source on market prices for the year 2008. During this period, the price of #2 yellow corn is $182.74 per ton, $333.36 per ton for high-protein soymeal, and $168.17 per ton for DDG (27% crude protein, 10% fat, and 10% moisture).

Due to inherent variability originating from its feedstock and the batched biological fermentation process involved in ethanol production, the DDGS nutrient profile as a result is also variable (Giesemann et al., n.d.). Given the available data, this study considers 15 nutrients as random for swine, including metabolizable energy, crude protein, five specific amino acids (lysine, threonine, tryptophan, methionine, and cystine), and eight minerals (calcium, phosphorous, sodium, chlorine, iron, zinc, copper, and manganese). All the other nutrients, including vitamins, are assumed nonrandom. In addition, the digestibility rates of crude protein and the five selected amino acids are also considered as random.

We first estimate a base ration with no DDGS and a second ration with DDGS as a candidate feed ingredient using mean values of the random nutrients. Then we examine the impact of nutrient profile variability on feed cost, DDGS displacement rates, and land-use credit. To do this, we make 1,000 draws from the multivariate normal distribution in [2] to get new realizations of the random elements of the $\boldsymbol{A}$ matrix (i.e., DDGS nutrient profile). Then we reset the LP program in [1] with these new elements and solve for a new optimal feed ration for each draw. The LP solver in SAS (SAS, 2002) is used in all optimization problems.

We consider two assumptions about the variance-covariance matrix of the multivariate distribution. The first case uses the full variability of DDGS products with the variance-covariance matrix derived from the 40 ethanol plants. We also consider a second case, which assumes that ethanol producers or feed compounders are successful in reducing inter-plant sources of variability such that only intra-plant variance remains. However, with no intra-plant variability data, we simply scale down the variance-covariance matrix from the first case as our approximation of the variance-covariance matrix of the second case. Noll, Abe, and Brannon (2003) report a coefficient of variation for lysine for both inter-plant and intra-plant-only variation. Assuming that the mean is the same for samples from all sources and from within the sample source, then the ratio of the within-source and across-all-sources coefficient of variation will give a factor that can be used in scaling down the variance of lysine, which in this case is equal to 0.41. For lack of nutrient-specific inter- and intra-plant variability, we use the same factor in scaling down all the other elements of the variance-covariance matrix. Estimates of the distribution of displacement rates and land-use credit report both cases of full variance and intra-plant-only variance, but the discussion focuses only on the full variance case.

Table 1 shows the optimal base ration for the swine grower-finisher feed with no DDGS, which includes 78.23% corn, 18.78% soymeal, 0.56% dicalcium phosphate, 1.96% limestone, 0.29% salt, 0.11% trace minerals, and 0.08% vitamin pre-mix. When DDGS is included in the set of candidate feed ingredient with a 20% maximum allowable inclusion rate limit, the optimal feed ration has 20% inclusion rate and the share of corn is reduced by 18.77 percentage points, soymeal by 3.57, dicalcium phosphate by 0.56, and salt by 0.08. Also, limestone needs to increase by 2.98 percentage points to compensate for the low calcium content of DDGS. The feed ration with DDGS reduces the cost of the swine feed ration by 8.5% compared to the base ration.

The first issue we are interested in addressing is whether the basis of the feed rations matters, that is, feeding trial rations versus estimating them from feed rations derived from a least-cost optimization. The common practice, such as that used in the AWW study, is that estimates of displacements of corn and soymeal by DDGS have been based on feeding trials rather than feed ration formulation using least-cost optimization. The inclusion rate of DDGS in the former case is exogenously determined from the trial based primarily on technical considerations rather than chosen in an optimal manner from a least-cost optimization. The main difference in the approaches is that feeding trial rations always assume DDGS inclusion at the maximum allowable limit, whereas the rations from a least-cost optimization considers DDGS inclusion rate as an endogenous variable that is determined as part of the final solution of the optimization problem. The implication is that the optimal feed ration is not fixed and so neither are all the parameters that are based on it, including the DDGS inclusion rate, displacement rate, and land-use credit. They are affected by changes in the relative cost as well as the nutrient profile outcomes of candidate feed ingredients.

The results in this study, however, suggest that for the swine grower-finisher feed ration there is no big difference in these two approaches because DDGS turns out to be a very dominant feed ingredient in a swine feed ration.[3] That is, if the maximum allowable inclusion limit is relaxed, then the optimal feed ration will include much higher DDGS inclusion. Moreover, even with the nutrient profile variability, regardless of whether the nutrient profile drawn is high or low, the optimal inclusion rate of DDGS in the feed ration is almost always the maximum inclusion rate of 20%, which is similar to what is used in feeding trials. In this study, of the 1,000 draws of DDGS nutrient profile from the full variance case, only in one draw did the DDGS inclusion rate fall below 20%, to 18%. Moreover, when only intra-plant sources of nutrient profile variability are considered, all of the 1,000 draws of DDGS nutrient profile had an inclusion rate of the maximum allowable limit of 20%.

Next, we estimate the corn and soymeal displacement rates. There are two factors that contribute to the estimation of the displacement rate. The first is the impact of using DDGS on feed efficiency, if any. The second is substitution in a feed ration. Unlike ruminants that show feed efficiency improvement with the use of DDGS, monogastric

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[3] In studies in which DDGS is not a dominant feed ingredient, the difference is not small.

animals such as swine have a mixed response to no improvement in growth performance with the use of DDGS. AWW (2008) report two DDGS feeding studies that indicated equivalent growth performance from feed rations with and without DDGS. Also, Stein (2007) reports studies that resulted in excellent pig performance, but at the same time there were also studies with reduced pig performance. The feeding trial data reported in Stein 2007, table 8, show a much higher average daily gain of grower-finisher pigs fed with 10% and 20% DDGS compared to the control case with 0% DDGS. However, because DDGS fed animals also increased their average daily feed intake compared to the control animals, the feed conversion ratio of animals fed with 10% DDGS actually deteriorated to 2.94 pounds of feed for every one pound of weight gain compared to the 2.86 for the control animals. Animals fed with 20% DDGS had the same feed conversion ratio as the animals in the control group. Since the evidence is inconclusive either way, we assume in this paper that feeding DDGS does not affect growth performance of swine, and for grower-finisher pigs, a 20% inclusion rate is acceptable since it has comparable growth performance as the control case.

Without any efficiency gains, displacement rates of DDGS have an upper bound of one (1). A correct derivation of displacement rates from feed rations formulated using least-cost optimization is not a trivial exercise. If the introduction of DDGS displaces corn, soymeal, and other feed ingredients, while other feed ingredients needed to be added to meet all nutritional requirements of an animal, then simply dividing the change in corn and soymeal composition between a base ration without DDGS and a new ration with DDGS by the amount of DDGS added in the new ration overestimates the displacement rate.[4] In fact, a simple ratio of the change in corn and soymeal by the amount of DDGS added may sometimes exceed unity even in the absence of efficiency improvement. When DDGS is introduced in the new swine grower-finisher feed ration, corn and soymeal are displaced together with other feed ingredients. Since DDGS is a poor source of calcium, the new ration includes a significant increase in limestone. So when the displacement rate is estimated without taking into account the additional limestone, we sometimes get rates that are greater than one. We suggest an approach in this study in which we include both the DDGS and limestone as divisor to the change in corn and soymeal in estimating a correct displacement rate. In effect, it is as if we are defining a new feed ingredient—a calcium-enhanced DDGS.

Tables 2a and 2b show the difference in the displacement rate estimated using only the change in DDGS as divisor as used by AWW (2008) and what is used in this study whereby the sum of all ingredients that increased in a feed ration is used as divisor, instead. The displacement rate estimates in the first approach range from -0.75 to -1.09 pounds of corn for every pound of DDGS introduced in the ration, allowing this rate to exceed one. A displacement estimate by AWW (2008) of -0.89 falls within this range. In comparison, the displacement rate using our approach is bounded by one in the upper limit and is in the range of -0.72 to -0.94. As a result the mean displacement rate of the first approach is higher at -0.94 compared to our mean of -0.82. The first approach also has a higher coefficient of variation at 5.38% compared to 3.76% in the second approach. The difference in these two approaches is not minor since the DDGS land credit

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[4] This was the method used by AWW whereby 100 kg of DDGS and 1.5 kg of limestone were added in a swine feed ration to replace 89 kg of corn, 9.5 kg of soymeal, and 3 kg of dicalcium phosphate. Their displacement for corn was 0.89 and for soymeal was 0.095. The displacement rate is estimated using only the 100 kg of DDGS as the denominator and ignoring the 1.5 kg of limestone that was also added in the new ration when DDGS was introduced.

estimated using the displacement rate from the AWW (2008) method is 15% higher compared to the approach used in this study.

The displacement rate of soymeal is in the range of -0.092 to -0.209 with a mean of -0.16. The estimate by AWW (2008) is -0.095. There is more variability in the displacement rate estimate for soymeal in a swine ration with a coefficient of variation of 18.67%. This suggests that when a DDGS nutrient profile draw is on the low side, most of the limiting nutrients are the amino acids that are better replaced by soymeal.

Next, we compute for the land-use credit using the displacement rate estimates. Additional parameters needed in this computation are from the Food and Agricultural Policy Research Institute (FAPRI) (table 3). With 151 bushels per acre corn yield and 17 pounds of DDGS per bushel by-product in ethanol production, an acre of land planted to corn as feedstock for ethanol production would produce 2,567 pounds of DDGS. Given the displacement rates derived from the optimal feed ration with and without DDGS, the soybean yield of 42 bushels per acre and soybean-to-soymeal conversion rate of 0.73, we can compute the amount of land saved when DDGS replace corn and soymeal in a swine feed ration. Since soyoil is also reduced when soybean production is displaced, with the substitution of soymeal with DDGS in the ration we add back the amount of land necessary to replace the soyoil.[5]

Table 4a shows that the amount of land saved from the use of DDGS to replace corn in a swine feed ration is -0.25 per hectare of corn used for ethanol, with a coefficient of variation of 3.76%, while the land saved from the use of DDGS to replace soymeal is -0.22 with a coefficient of variation of 18.67%. We subtract from these land savings the

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[5] In our case, we use palm oil as a substitute because it has more oil content, and this avoids the circular process of replacing soymeal then soyoil, and then vice versa because they are joint products from soybeans.

amount of land needed to produce the equivalent palm oil to replace the reduction of soybean oil when less soybeans are produced because of the substitution of soymeal with DDGS. Table 4b shows that this land adjustment amounts to 0.02 with the same coefficient of variation. The total land savings, which is our estimate of the land-use credit for corn ethanol with DDGS used in swine feed rations, is in the range of -0.367 to -0.596. That is, for every hectare of corn that is used for ethanol production, a land-use credit of -0.45 should be accounted for, which represents the amount of land that is not used for production because DDGS substitutes corn and soymeal from the feed ration. In effect, only 0.55 hectare of land is added net per hectare of land used for corn ethanol. On average, 56.09% of the land-use credit is contributed by the substitution of corn, 48.46% is contributed by the substitution of soymeal, and the other 4.55% is the share of adjustment for the loss of soyoil when soymeal is substituted away.[6] We also show in figure 1, that if the distribution of the DDGS nutrient profile is tightened such that its variability is only intra-plant sources, estimates of displacement rates as well as the land-use credit will be more precise, ranging from -0.382 to -0.500. Also, for comparison purposes, we computed the land-use credit for swine using AWW (2008) displacement estimates and the yield assumptions used by Darlington (2009) and we get -0.264 land-use credit for the substitution of corn, and -0.131 for the substitution of soymeal, a land-use credit of -0.395, which is within the range estimated in this study.

Finally, we examined what happens when feed compounders, aware of the variability of their DDGS nutrient profile, but not knowing the exact nutrient profile outcome of their DDGS supply, may discount the nutrient profile they assume when

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[6] The share of land use credit for soyoil has an opposite sign as the share of corn and soymeal, making the sum of these shares 100.

formulating a feed ration so that at a certain chosen probability, which we refer to as safety level (e.g., say 90%), they are at or above any realized nutrient profile. In our example, we arbitrarily set the safety level. However, given enough information, one can also formulate the choice of a safety level in an optimization framework. For example, assume that there are two cost components that are associated with a given safety level. The first cost component increases with higher values of the safety level. This cost represents the forgone feed cost savings, which increases at higher values of the safety level. Added to this is the cost of a possible loss of weight gain performance associated with the excretion of excess nutrients in the diet, which are also likely to happen at higher safety levels. The second cost component is inversely related to the safety level that is associated with the loss of weight gain performance resulting from inadequate supply of nutrients relative to the requirement of the animal. Feed compounders would then choose the safety level that minimizes total cost (i.e., the sum of the two cost components). A hypothetical example is given in figure 2. The first type of cost with a positive slope is the cost associated with providing excess nutrients in the diet. The second type of cost with a negative slope is the cost associated with inadequate nutrients in the diet. In this example, the safety level that minimizes total cost occurs at 90%. When feed compounders use a 90% safety level in the swine ration case, the same amount of DDGS included remains at 20%. With fewer nutrients than the average nutrient profile, however, less soymeal is substituted compared to the mean nutrient profile; only slightly more corn is substituted, less additional limestone is needed, and more salt is added. In total 21.76 pounds is added compared to the 22.98 pounds for the mean nutrient profile. Taking the ratios to estimate the displacement rates, we get a higher displacement rate for corn, which partially compensates for the lower displacement of soymeal. The net effect on the land-use credit is a reduction of only 8.47% from the mean value.

4. Conclusion

Although contributing to a cleaner environment is one of the main justifications for policies supporting biofuels development, the evidence against or in favor of biofuels has been mixed and subject to much contention. It is widely accepted that, from feedstock production to fuel use, biofuels match or are even lower than fossil fuels in GHG emissions. With feedstock uptake, GHG emissions are actually lower for biofuels. However, when land-use changes are accounted for, the GHG balance may tip against biofuels. One of the central parameters in accounting for GHG emissions associated with land-use changes is land-use credit for corn ethanol from the use of its by-product—DDGS—as a substitute for corn and soymeal in livestock feed rations.

This study provides more precise estimates of the land-use credit for the use of DDGS in swine. First, we estimate displacement rates and land-use credits from optimal feed rations derived from a least-cost optimization rather than from feeding trial rations. We find that using feed ration changes from feeding trials and using changes between optimal feed rations may give comparable displacement rates in the case of a swine feed ration because DDGS is a dominant feed ingredient such that regardless of the variable nutrient profile outcomes, the maximum inclusion rate for DDGS is always reached in the optimal feed ration.

Second, absent any efficiency improvement impact in the use of DDGS, we propose an approach to calculate displacement rates that takes into account all changes in feed ingredients when DDGS is introduced in the ration. This approach imposes a bound on displacement rates between zero and one. Third, we fully account for DDGS nutrient profile variability and characterize displacement rates and land-use credits with a distribution rather than a single point estimate. The total land-use credit for DDGS in a swine feed ration ranges from -0.367 to -0.596 hectares. The land-use credit from substituting corn in the feed ration accounts for 56.09% and for soymeal it contributes 48.46%.

Finally, we consider and analyze the possibility that feed compounders may discount the DDGS nutrient profile that they assume when they formulate their ration to ensure that they are at or above any realized nutrient profile at a certain probability, which we refer to as the safety level (say 90%). At this safety level, the land-use credit for corn ethanol declines by 8.47% from the mean in the swine ration case.

Table 1. Composition of least-cost swine grower-finisher diets formulated with or without DDGS

	Alternative feed ration		
	No DDGS	With DDGS	Change
Feed Ration Ingredients	Pounds		
Corn	78.23	59.45	-18.77
Soymeal	18.78	15.21	-3.57
Dicalcium phosphate	0.56	0.00	-0.56
Limestone	1.96	4.94	2.98
Salt	0.29	0.21	-0.08
Trace minerals	0.11	0.11	0.00
Vitamin pre-mix	0.08	0.08	0.00
DDG	0.00	20.00	20.00
Total Weight	100.00	100.00	0.00

Table 2a. Distribution of DDGS corn displacement rate in swine grower-finisher feed ration

AWW approach			Study approach		
	Frequency			Frequency	
Displacement	Full	Intra	Displacement	Full	Intra
-1.092	*0.10*	*0.00*	-0.936	*0.10*	*0.00*
-1.081	*0.10*	*0.00*	-0.929	*0.00*	*0.00*
-1.070	*0.10*	*0.00*	-0.922	*0.00*	*0.00*
-1.059	*0.20*	*0.00*	-0.915	*0.10*	*0.00*
-1.048	*0.90*	*0.00*	-0.908	*0.10*	*0.00*
-1.037	*0.90*	*0.10*	-0.901	*0.20*	*0.00*
-1.026	*1.70*	*0.20*	-0.894	*0.50*	*0.00*
-1.015	*2.10*	*0.20*	-0.887	*0.60*	*0.00*
-1.004	*2.80*	*1.60*	-0.880	*0.80*	*0.10*
-0.993	*3.80*	*1.80*	-0.873	*1.70*	*0.30*
-0.982	*6.10*	*4.20*	-0.866	*3.70*	*0.50*
-0.971	*6.70*	*7.10*	-0.859	*3.40*	*1.10*
-0.960	*6.80*	*11.00*	-0.852	*4.20*	*2.50*
-0.949	*9.20*	*12.20*	-0.845	*6.30*	*4.80*
-0.938	*7.90*	*14.20*	-0.838	*7.40*	*7.80*
-0.927	*10.80*	*13.20*	-0.831	*8.60*	*9.30*
-0.916	*8.40*	*12.10*	-0.824	*9.00*	*15.60*
-0.905	*6.20*	*7.70*	-0.817	*10.30*	*14.10*
-0.894	*6.50*	*6.00*	-0.810	*9.40*	*12.80*
-0.883	*5.10*	*4.20*	-0.803	*7.90*	*12.10*
-0.872	*3.60*	*2.70*	-0.796	*6.50*	*7.90*
-0.861	*2.50*	*1.00*	-0.789	*5.50*	*4.90*
-0.850	*2.80*	*0.50*	-0.782	*3.80*	*3.40*
-0.839	*1.40*	*0.00*	-0.775	*3.10*	*1.60*
-0.828	*1.50*	*0.00*	-0.768	*1.70*	*1.00*
-0.817	*0.40*	*0.00*	-0.761	*2.00*	*0.20*
-0.807	*0.80*	*0.00*	-0.754	*1.20*	*0.00*
-0.796	*0.30*	*0.00*	-0.747	*0.80*	*0.00*
-0.785	*0.10*	*0.00*	-0.740	*0.50*	*0.00*
-0.774	*0.10*	*0.00*	-0.733	*0.20*	*0.00*
-0.763	*0.00*	*0.00*	-0.726	*0.20*	*0.00*
-0.774	*0.10*	*0.00*	-0.733	*0.20*	*0.00*
	100.00	*100.00*		*100.00*	*100.00*

Table 2b. Distribution of DDGS soymeal displacement rate in swine grower-finisher feed ration

AWW approach			Study approach		
	Frequency			Frequency	
Displacement	Full	Intra	Displacement	Full	Intra
-0.325	*0.10*	*0.00*	-0.296	*0.10*	*0.00*
-0.317	*0.00*	*0.00*	-0.289	*0.00*	*0.00*
-0.309	*0.00*	*0.00*	-0.281	*0.00*	*0.00*
-0.301	*0.00*	*0.00*	-0.274	*0.00*	*0.00*
-0.293	*0.00*	*0.00*	-0.267	*0.00*	*0.00*
-0.286	*0.00*	*0.00*	-0.259	*0.00*	*0.00*
-0.278	*0.30*	*0.00*	-0.252	*0.10*	*0.00*
-0.270	*0.20*	*0.00*	-0.245	*0.10*	*0.00*
-0.262	*0.20*	*0.00*	-0.238	*0.30*	*0.00*
-0.254	*0.60*	*0.00*	-0.230	*0.20*	*0.00*
-0.246	*1.30*	*0.00*	-0.223	*0.50*	*0.00*
-0.238	*1.30*	*0.10*	-0.216	*1.50*	*0.00*
-0.231	*1.80*	*0.60*	-0.209	*2.00*	*0.20*
-0.223	*2.70*	*0.90*	-0.201	*2.00*	*0.50*
-0.215	*3.60*	*3.40*	-0.194	*2.70*	*1.10*
-0.207	*6.50*	*4.60*	-0.187	*4.20*	*3.20*
-0.199	*6.90*	*5.80*	-0.179	*6.40*	*5.50*
-0.191	*8.30*	*12.20*	-0.172	*7.80*	*7.60*
-0.183	*10.70*	*12.60*	-0.165	*9.20*	*13.60*
-0.175	*10.40*	*15.60*	-0.158	*11.40*	*13.20*
-0.168	*9.30*	*15.70*	-0.150	*10.70*	*17.00*
-0.160	*8.20*	*10.70*	-0.143	*9.50*	*15.40*
-0.152	*6.60*	*8.70*	-0.136	*7.00*	*9.60*
-0.144	*5.50*	*4.70*	-0.129	*7.90*	*7.50*
-0.136	*5.70*	*2.80*	-0.121	*5.30*	*3.50*
-0.128	*3.50*	*1.20*	-0.114	*4.00*	*1.60*
-0.120	*2.30*	*0.10*	-0.107	*3.40*	*0.20*
-0.112	*1.70*	*0.20*	-0.099	*1.40*	*0.20*
-0.105	*0.80*	*0.10*	-0.092	*0.90*	*0.10*
-0.097	*0.90*	*0.00*	-0.085	*0.80*	*0.00*
-0.089	*0.20*	*0.00*	-0.078	*0.40*	*0.00*
-0.081	*0.40*	*0.00*	-0.070	*0.20*	*0.00*
	100.00	*100.00*		*100.00*	*100.00*

Table 3. Parameters used in land-use credit estimation

Variable	Unit	Values
Corn yield	bushels/acre	151.00
Soybean yield	bushels/acre	42.00
Palm oil yield	pounds/acre	3,756.00
Ethanol yield	galloons/bushel	2.60
DDG yield	pounds/bushel	17.00
Soybean to soymeal conversion	Number	0.73
Soybean to soyoil conversion	Number	0.14

Table 4a. Distribution of land-use credit for DDGS in swine feed ration for corn and soymeal substitute

DDGS use displacing corn			DDGS use displacing soymeal		
Land Credit	Full	Intra	Land Credit	Full	Intra
hectare	percent		hectare	percent	
-0.284	*0.10*	*0.00*	-0.413	*0.10*	*0.00*
-0.282	*0.00*	*0.00*	-0.403	*0.00*	*0.00*
-0.280	*0.00*	*0.00*	-0.392	*0.00*	*0.00*
-0.278	*0.10*	*0.00*	-0.382	*0.00*	*0.00*
-0.276	*0.10*	*0.00*	-0.372	*0.00*	*0.00*
-0.274	*0.20*	*0.00*	-0.362	*0.00*	*0.00*
-0.271	*0.50*	*0.00*	-0.352	*0.10*	*0.00*
-0.269	*0.60*	*0.00*	-0.342	*0.10*	*0.00*
-0.267	*0.80*	*0.10*	-0.332	*0.30*	*0.00*
-0.265	*1.70*	*0.30*	-0.321	*0.20*	*0.00*
-0.263	*3.70*	*0.50*	-0.311	*0.50*	*0.00*
-0.261	*3.40*	*1.10*	-0.301	*1.50*	*0.00*
-0.259	*4.20*	*2.50*	-0.291	*2.00*	*0.20*
-0.257	*6.30*	*4.80*	-0.281	*2.00*	*0.50*
-0.254	*7.40*	*7.80*	-0.271	*2.70*	*1.10*
-0.252	*8.60*	*9.30*	-0.261	*4.20*	*3.20*
-0.250	*9.00*	*15.60*	-0.250	*6.40*	*5.50*
-0.248	*10.30*	*14.10*	-0.240	*7.80*	*7.60*
-0.246	*9.40*	*12.80*	-0.230	*9.20*	*13.60*
-0.244	*7.90*	*12.10*	-0.220	*11.40*	*13.20*
-0.242	*6.50*	*7.90*	-0.210	*10.70*	*17.00*
-0.240	*5.50*	*4.90*	-0.200	*9.50*	*15.40*
-0.237	*3.80*	*3.40*	-0.189	*7.00*	*9.60*
-0.235	*3.10*	*1.60*	-0.179	*7.90*	*7.50*
-0.233	*1.70*	*1.00*	-0.169	*5.30*	*3.50*
-0.231	*2.00*	*0.20*	-0.159	*4.00*	*1.60*
-0.229	*1.20*	*0.00*	-0.149	*3.40*	*0.20*
-0.227	*0.80*	*0.00*	-0.139	*1.40*	*0.20*
-0.225	*0.50*	*0.00*	-0.129	*0.90*	*0.10*
-0.223	*0.20*	*0.00*	-0.118	*0.80*	*0.00*
-0.220	*0.20*	*0.00*	-0.108	*0.40*	*0.00*
-0.218	*0.20*	*0.00*	-0.098	*0.20*	*0.00*
	100.00	*100.00*		*100.00*	*100.00*

[*] negative land credit for lost soybean oil production

Table 4b. Distribution of land-use credit for DDGS in swine feed ration for soyoil substitute and total displacement

DDGS use displacing soyoil			DDGS use displacing all ingredients		
Land Credit	Full	Intra	Land Credit	Full	Intra
hectare	percent		hectare	percent	
0.009	*0.10*	*0.00*	-0.596	*0.10*	*0.00*
0.010	*0.10*	*0.00*	-0.589	*0.00*	*0.00*
0.011	*0.40*	*0.00*	-0.581	*0.00*	*0.00*
0.012	*0.80*	*0.00*	-0.574	*0.00*	*0.00*
0.013	*0.90*	*0.10*	-0.566	*0.00*	*0.00*
0.014	*1.40*	*0.20*	-0.559	*0.00*	*0.00*
0.015	*3.40*	*0.20*	-0.552	*0.00*	*0.00*
0.016	*4.00*	*1.60*	-0.544	*0.00*	*0.00*
0.017	*5.30*	*3.50*	-0.537	*0.10*	*0.00*
0.018	*7.90*	*7.50*	-0.530	*0.10*	*0.00*
0.019	*7.00*	*9.60*	-0.522	*0.30*	*0.00*
0.020	*9.50*	*15.40*	-0.515	*0.40*	*0.00*
0.021	*10.70*	*17.00*	-0.507	*0.70*	*0.00*
0.022	*11.40*	*13.20*	-0.500	*2.00*	*0.10*
0.023	*9.20*	*13.60*	-0.493	*2.10*	*0.20*
0.024	*7.80*	*7.60*	-0.485	*2.90*	*1.00*
0.024	*6.40*	*5.50*	-0.478	*4.00*	*1.90*
0.025	*4.20*	*3.20*	-0.470	*6.30*	*5.30*
0.026	*2.70*	*1.10*	-0.463	*7.50*	*7.50*
0.027	*2.00*	*0.50*	-0.456	*10.40*	*12.50*
0.028	*2.00*	*0.20*	-0.448	*11.70*	*15.60*
0.029	*1.50*	*0.00*	-0.441	*11.90*	*17.70*
0.030	*0.50*	*0.00*	-0.434	*9.50*	*15.10*
0.031	*0.20*	*0.00*	-0.426	*8.10*	*11.20*
0.032	*0.30*	*0.00*	-0.419	*7.30*	*7.50*
0.033	*0.10*	*0.00*	-0.411	*4.50*	*2.70*
0.034	*0.10*	*0.00*	-0.404	*4.00*	*1.30*
0.035	*0.00*	*0.00*	-0.397	*2.90*	*0.20*
0.036	*0.00*	*0.00*	-0.389	*1.60*	*0.10*
0.037	*0.00*	*0.00*	-0.382	*0.40*	*0.10*
0.038	*0.00*	*0.00*	-0.375	*0.90*	*0.00*
0.039	*0.10*	*0.00*	-0.367	*0.30*	*0.00*
	100.00	*100.00*		*100.00*	*100.00*

[*] negative land credit for lost soybean oil production

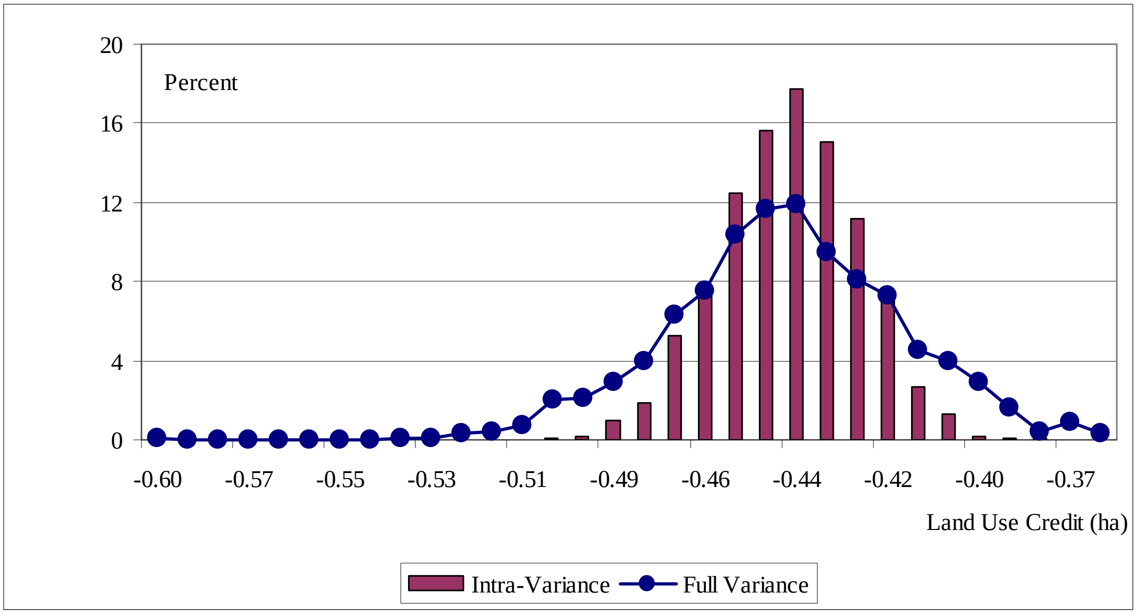

Figure 1. Distribution of land-use credit for corn ethanol

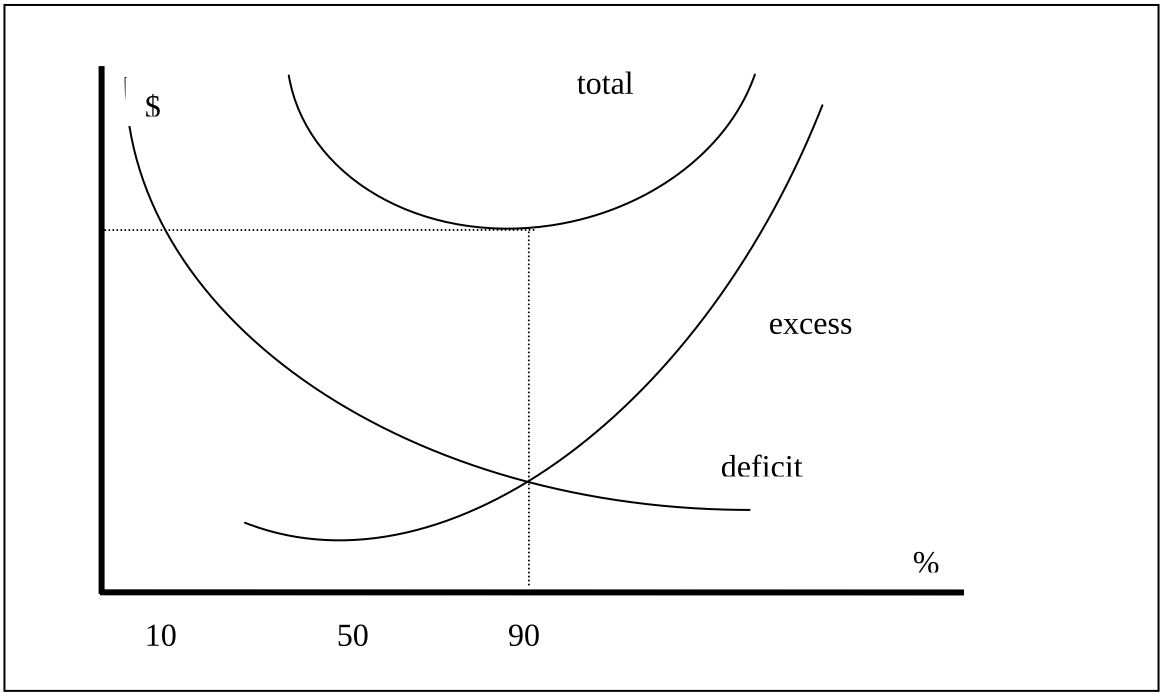

Figure 2. Hypothetical example of costs associated with safety level

6. References

Akayezu, J.M., J.G. Linn, S.R. Harty, and J.M. Cassady. 1998. "Use of Distillers Grain and Co-products in Ruminant Diets." Article on University of Minnesota Web site, Distillers Grains By-products in Livestock and Poultry Feeds. http://www.ddgs.umn.edu/articles-dairy/1998-Akayezu-%20MNC.pdf.

Arora, S., M. Wu, and M. Wang. 2008. "Update of Distillers Grains Displacement Ratios for Corn Ethanol Life-Cycle Analysis." Center for Transportation Research Energy System Division Argonne National Laboratory, http://www.transportation.anl.gov/pdfs/AF/527.pdf

Darlington, T.L. 2009. "Land Use Effects of U.S. Corn-Based Ethanol." Air Improvement Resource, Inc., Novi, MI. http://www.scribd.com/doc/13474497/Land-Use-Effects-of-US-Cornbased-Ethanol

Fabiosa, J.F. 2008a. "Distillers Dried Grain Product Innovation and Its Impact on Adoption, Inclusion, Substitution, and Displacement Rates in a Finishing Hog Ration." CARD Working Paper 08-WP 478, Center for Agricultural and Rural Development, Iowa State University.

Fabiosa, J.F. 2008b. "Not All DDGS Are Created Equal: Nutrient-Profile-Based Pricing to Incentivize Quality." CARD Working Paper 08-WP 481, Center for Agricultural and Rural Development, Iowa State University.

Gallagher, E. 2008. "The Gallagher Review of the Indirect Effects of Biofuels Production." Renewable Fuels Agency, London. (http://www.renewablefuelsagency.org/_db/_documents/Report_of_the_Gallagher_review.pdf).

Giesemann, M.A., M.L. Gibson, and K. Karges. n.d."The Ethanol Industry and Its Co-Products for Swine and Poultry Feeding: A Primer on an Emergent Industry." http://www.dakotagold.org/files/Ethanol20Industry20and20Co-Products20for20Swine20and20Poultry.pdf (accessed November 2008).

Holden, P., R. Ewan, M. Jurgens, T. Stahly, and D. Zimmerman. 1996. "Life Cycle Swine Nutrition." Iowa State University Extension publication PM-486.

National Corn Growers Association. n.d. "Corn Distillers Grain Value Added Feed Source for Beef, Dairy Beef, Dairy, Poultry, Swine, and Sheep, Missouri." http://www.ncga.com/livestock/PDFs/DistillersGrainsBooklet.pdf (accessed November 2008).

National Research Council (NRC). 1998. *Nutrient Requirements of Swine,* Tenth Revised Edition. 1998, Subcommittee on Swine Nutrition, Committee on Animal Nutrition, Board on Agriculture. Washington, DC: National Academy Press.

Noll, S.L., C. Abe, and J. Brannon. 2003. “Nutrient Composition of Corn Distiller Dried Grains with Solubles.” Presented at the 2003 Poultry Science Association Meeting, Madison, WI.

Rubin, O.D., M. Carriquiry, and D.J. Hayes, 2008. “Implied Objectives of U.S. Biofuel Subsidies,” CARD Working Paper 08-WP 459, Center for Agricultural and Rural Development, Iowa State University.

SAS Institute, Inc. 2002. SAS Release 9.1. SAS Institute Inc., Cary, NC.

Searchinger, T., R. Heimlich, R. Houghton, F. Dong, A. Elobeid, J. F. Fabiosa, S. Tokgoz, D. J. Hayes, and T. Yu. 2008. “Factoring Greenhouse Gas Emissions from Land Use Change into Biofuel Calculations.” *Science*, February 29, 2008: 1238-1240.

Stein, H.H. 2007. “Distillers Dried Grains with Solubles (DDGS) in Diets Fed to Swine.” Swine Focus #001, Dept of Animal Science, University of Illinois at Urbana-Champaign. http://www.distillersgrains.org/files/feedsource/swine_brochure.pdf (accessed November 2008).

U.S. Department of Agriculture (USDA). USDA Market News, WA GR 855. Agricultural Marketing Service, Washington, DC. http://www.ams.usda.gov/mnreports/wa_gr855.txt (accessed November 2008).