Government Taxation Schemes to Reduce Fertilizer Runoff

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INTRODUCTION

Fertilizers are an essential input in maintaining high crop productivity. N-fertilizer use in agriculture causes environmental degradation and green house gas emissions. Amongst the most important environmental impacts of fertilizer use are the high levels of nitrates found in fresh water systems and nitrous oxide going into the atmosphere. Given the wide use of nitrogen based fertilizers, governments have tried to reduce their usage implementing policies aimed at their reduction. Since much empirical evidence has emerged recently to support the fact that non point-source pollution can be reduced by directly targeting agricultural production practices (Bontems and Thomas, 2000), with taxation being the most popularly used, not many studies have focused on direct comparisons of total output taxes versus a direct input taxation scheme. This study will focus on assessing the two taxation schemes using the novel state contingent approach developed by Chambers and Quiggin (2000). The introduction of risk, insurance and different climatic conditions will add towards the importance of the study, given the way in which they affect the farmer's choice of fertilizer quantities.

Under the right climatic conditions, Nitrogen containing fertilizers are responsible for producing a higher yielding crop. The opposite occurs when these climatic conditions are not optimal; in this case, fertilizer can substantially lower crop yields. According to Houghton en al (1997), a significant amount of nitrogen contained in the fertilizers is lost from agricultural soils through leaching, runoff, and trough nitrous oxide emissions. This loss is incremented when bad weather conditions are predominant. Under these conditions fertilizer can also cause toxicity for the plants. The uncertainty brought by the use of fertilizer, given these conditions, has caused the farmer to treat fertilizers as a risk complement input (Chambers and Quiggin, 2000). The farmer's attitudes toward risk have shown to significantly cause distortions from optimal levels of polluting inputs (Babcock, 1998). This is an important reason why risk attitude is crucial in determining the overall effects of environmental policies. Leathers and Quiggin (1991) demonstrated that a nitrogen tax, for instance, could well lead to modifications in fertilizer use that are opposite to policy goals in terms of environment conservation. It has also been extensively documented that the actions of farmers change in the presence of insurance and when facing climatic uncertainty. Using the state contingent approach, including two states of the environment (weather conditions) we analyze the two taxation schemes taking into account the uncertainty faced by the farmer. The approach incorporates this uncertainty caused by the two states of the environment and the uncertainty of using N based fertilizers.

Input use is modeled using the Beaker diagram of input transformation developed by Chambers, 1997. This diagram helps to incorporate the way in which the different inputs are transformed, given the two states, into an efficient frontier of total output production. This diagram also helps us to incorporate pollution into the model. Non-point source pollution is affected by the state of the environment that is realized after fertilization has been done. When bad weather conditions prevail, pollution has a tendency to increase. In such a case, fertilizer runoff is greater and total production is lower. In this case we use the Beaker diagram to map input transformation into pollution production. This gives us a pollution production frontier for both states. This type of approach helps us to change the output and pollution frontiers when facing the two tax schemes by responding to changes in the use of the different inputs in the presence of uncertainty. This differs from the approaches that have been done on the subject which link fertilizer use directly with pollution, and simply convert a decrease or increase of fertilizer use into a decrease or increase of pollution respectively.

The purpose of this article is to address two different taxation schemes implemented to reduce pollution taking a new approach which incorporates uncertainty from the environment and from the use of fertilizers. The two taxation schemes include a tax implemented on total output against a direct tax on fertilizer. The state contingent approach developed by Chambers and Quiggin is used to analyze this problem. The results prove surprising in that they show that a tax directly on fertilizers could increase pollution. Although the results show that this type of tax will lead to a decrease in the use of fertilizers, there are many other things that should be considered in order to properly asses the effectiveness of reducing pollution.

Model

The model consists of a social planner, the farmer, society, and an insurance agent. The initial assumptions are:

- Output and input prices are non stochastic, farmers take these prices as given.
- Farmers are risk averse.

- The farmer chooses inputs and outputs jointly in a preference maximizing fashion.

There are two states of the environment, based on weather conditions. A good state represented by "G" and a bad state by "B", both states belong to the set of states of nature. $\{G, B\} = S \in \Omega$.

The farmer has a vector **z** of outputs $\in \Re^2_+$ which include the crop "q" and pollution "n". The vector of inputs x $\in \Re^2_+$ includes nitrogenous fertilizers "x_F" and other inputs "x_O". The state contingent approach, that we follow, is modeled by the input correspondence described below.

Input correspondence

State-contingent Production technology (Chambers and Quiggin) is modeled by a continuous input correspondence. In our case it maps: X: $\Re^{2x2}_+ \rightarrow \Re^2_+$, meaning that it maps vectors of state-contingent outputs, z, into inputs capable of producing them:

$$X(z)=\{x \in \Re^2_+ : x \rightarrow canproduce \rightarrow z\}$$

The vector of inputs includes x_F (fertilizer) and x_O (other inputs). Any x chosen will produce a state. This vector of inputs is committed prior to the resolution of uncertainty. So if state s ϵ Ω is realized (picked by nature) and the producer has chosen the ex ante input-output combination (x,z), then the realized or ex post output vector is z^s. As a by-product the farmer also produces pollution (n^s) which constitutes a burden to society and is given, as a function of fertilizer use and other inputs, by the formula $n^s=n(x_F)+n(x_O)$. Where $n(x_F)$ is greater than $n(x_O)$.

Inputs are divided into two categories given the way farmers choose them; that is, they are complementary between input choices and more or less risky states of nature. In this manner inputs are classified into risk complements and risk substitutes. Chemical Fertilizers can significantly increase yield if correct weather conditions prevail, but can also significantly decrease yield when these conditions don't prevail. They are risk complements since they often amplify the dispersion of state contingent outputs (risk increasing). Risk substitute (risk reducing) inputs do the opposite; they dampen the dispersion of state contingent outputs. Having this in mind we can say that an input is a risk complement if more of it is used in producing riskier state-contingent output bundles than in producing less risky production arrays.

When analyzing fertilizer use and the farmer's response to different policy scenarios it is imperative to model the farmer's attitude toward the use of fertilizer and how he views using more or less of it. In our case the tax implemented in both, output and fertilizer input, has to model the farmer's choice of fertilizer amount given the risks involve in applying different quantities of fertilizer.

<u>Revenue Cost Function</u>

The state contingent approach also is modeled by a revenue cost function. The state contingent revenue vector r=pz has typical elements of the form: $\sum_m p_{ms} z_{ms} \geq r_s, s \in \Omega$. In this case m=1 (one type of output). Producers are concerned with state contingent revenue and not with the amount of pollution that they produce. That is, they only care about the total revenue that they will get given a realized state. We consider the revenue cost function used for the state contingent approach:

C(**w**,**r**,**p**)= $\min\left\{ w\cdot x : x \in X(z), \sum_{m} p_{ms} z_{ms} \geq r_s, s \in \Omega \right\}$, if there exists a feasible state-contingent output array capable of producing r and ∞ otherwise. We assume that C(w,r,p) is smoothly differentiable in all state-contingent revenues.

Preferences

The farmer's preferences following from Yaari (1969) and Quiggin and Chambers (2000) are represented by a continuous and increasing function W: $\Re^s \rightarrow \Re$, of his vector of state contingent net returns: $\mathbf{W}(y) = r - (w\cdot x)1_s$ where, **1s** is the S-dimensional unit vector. So the producer's preferences can be expressed as using the revenue cost function:

W(**y**)=**r**-C(w,**r**,p)$\mathbf{1_s}$

Preference ordering:

The farmer is risk averse with respect to the probability vector $\boldsymbol{\pi}$ if

$W(\bar{y}1^s) \geq W(y) \quad \forall y$, where $\bar{y}1^s$ is the state-contingent outcome vector with $\bar{y} = \sum_{s\in\Omega} \pi_s y_s$ in every state of nature. The importance of this is that it helps us to note that the risk averse farmer will always choose the certainty outcome.

Assuming W(y) is smoothly differentiable, the vector of subjective probabilities is unique and proportional to the marginal rate of substitution between state-contingent incomes along the equal-incomes vector. More concretely, without loss of generality, if preferences are smoothly differentiable then,

$$\pi_s = \frac{W_s(c1^s)}{\sum_{t \in \Omega} W_t(c1^s)} \qquad s \in \Omega, c \in \Re$$

Pictorially, therefore, the fair-odds line, which gives the locus of points having the same expected value in any state and whose slope is given by minus the relative probabilities, is given by the slope of the tangent to the producer's indifference curve at the bisector. This is illustrated in Figure 1.

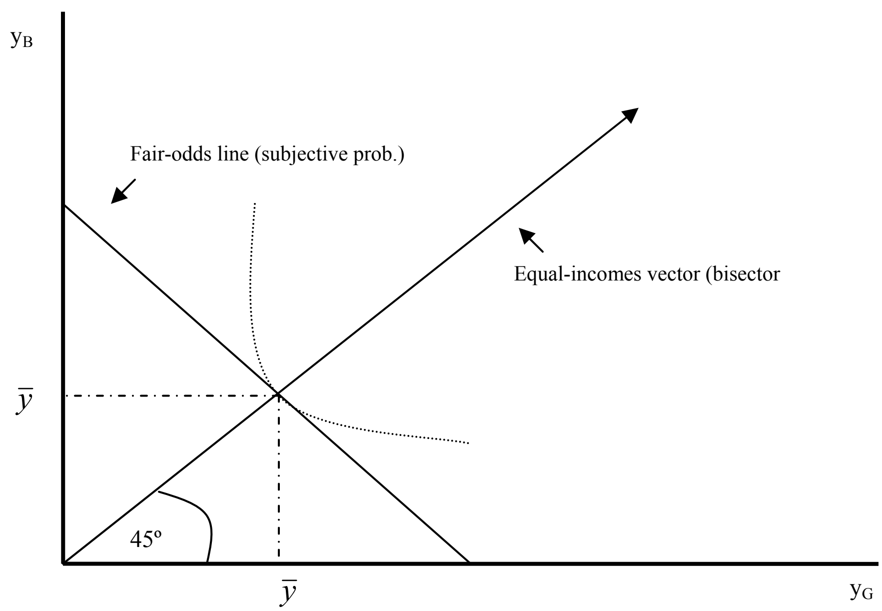

Figure 1. Risk-averse preferences

In order to have W(y)≥W(y') for every risk averse, and having the fact that the outcome **y**' has been derived from **y** by a multiplicative spread. We have that y' will be a riskier state if it moves away from the certainty point given by the intersection of the Fair-odds line and the Equal-incomes vector.

Chambers and Quiggin (2000) introduce the term generalized Schur-concavity of W: A preference function W: $\Re^{s} \to \Re$ is generalized Shur-concave for π if $y \precsim_{\pi} y' \Rightarrow W(y) \geq W(y')$. A term that is conditional on the probability measure π. Although Shur-concavity is explained in depth by Chambers and Quiggin, the general concept will be taken for the purpose of this study.

Risk neutrality and risk averse production equilibria

<u>Risk neutral Farmer</u>

For the risk neutral farmer we have the following problem. He solves:

$\max_{r}\left\{\sum_{s\in\Omega}\pi_{s}\sum_{m=1}^{M}p_{ms}z_{ms}-c(w,z)\right\}$, which can be reduced to the S-dimensional problem:

$$\max_{r}\left\{\sum_{s\in\Omega}\pi_{s}r_{s}-C(w,r,p)\right\}$$
$$\max_{r}\{\pi_{G}r_{G}-C(w,r,p),\pi_{B}r_{B}-C(w,r,p)\}$$

FOC:

$$\pi_{s}-C_{s}(w,r,p)\leq 0,\quad r_{s}\geq 0,\quad s\in\Omega$$

We can see that the marginal cost of increasing revenue in any state is at least equal to the subjective probability of that state. This means that the producer equilibrium for a risk neutral farmer is represented by a hyperplane being tangent to her isocost curve. The slope of this hyperplane is determined by the ratio of the producer's subjective probabilities (the fair odds line). The isocost curve is determined by the equilibrium level of revenue-cost. Instead of determining an optimal mix of outputs as in the non-stochastic, multi-product case, the producer equilibrium determines the optimal mix of state contingent revenues. This helps us to interpret the producer's subjective probabilities as the producer's subjective prices of the state-contingent revenues.

Figure 2 represents the risk neutral production equilibrium. As demonstrated by Chambers and Quiggin, the risk neutral farmer will produce at the optimal state contingent revenue mix. Same production as if there was no uncertainty.

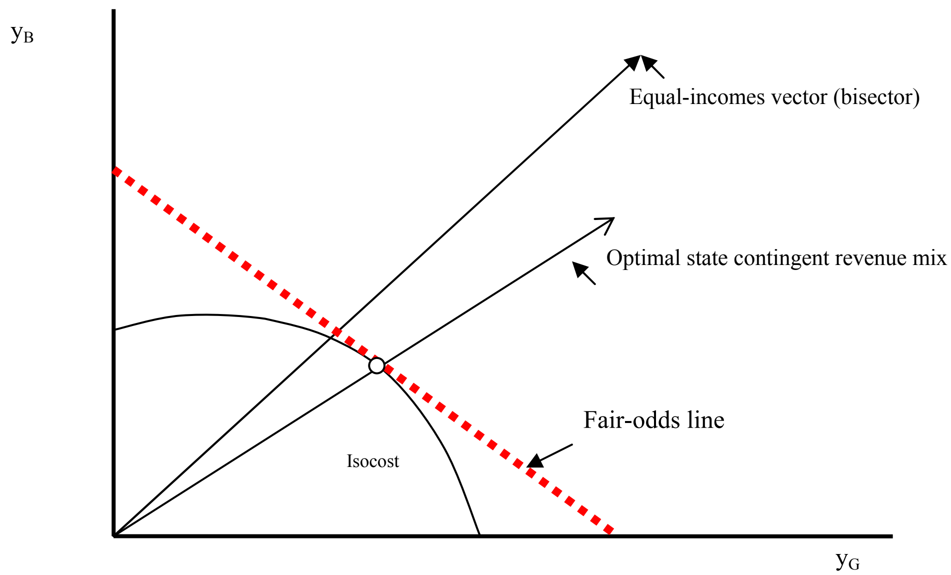

Figure 2. Risk-neutral equilibrium

Summing the first order conditions we get:

$$\sum_{s\in\Omega} C_s(w,r,p) \geq \sum_{s\in\Omega} \pi_s = 1 \qquad (1)$$

Looking at figure 1 and at equation (1) we can see that the left hand side of the expression represents the derivative of the cost function in the direction of the equal-revenue ray (bisector). So $\sum_{s\in\Omega} C_s(w,r,p)$ is the marginal cost of increasing all state contingent revenues by the same small amount. (1) also requires that this cost be at least as large as the uniform increase in returns. If it were not, the decision maker could increase profit with certainty by increasing each state-contingent revenue. For an interior solution (1) must hold as an equality.

Risk averse farmer

For the risk averse farmer, he chooses state-contingent revenues to maximize:

$$W(y) = W(r - C(w,r,p)1_s)$$

$$\max_r W\{r_G - C(w,r,p), r_B - C(w,r,p)\}$$

FOC: assuming r>0

$$W_G(1 - C_G) - W_B C_G = 0$$
$$-W_G C_B + W_B(1 - C_B) = 0$$

$$W_G - C_G(W_G + W_B) = 0$$
$$W_B - C_B(W_G + W_B) = 0$$

$$\frac{W_G}{(W_G + W_B)} = C_G$$
$$\frac{W_B}{(W_G + W_B)} = C_B$$

Summing the first order conditions we get:

$\sum_{s\in\Omega} C_s(w,r,p) \geq 1$ and $r_s \geq 0$ with complementary slackness.

From this we can see that the risk averse farmer chooses a revenue vector that is in the efficient set. We can also see that there exists a probability vector for a risk neutral farmer that will make him choose the same as the risk averse farmer but these probabilities derived from the efficient frontier are not the subjective ones like the risk neutral. This means that the fair odds line will cut the isocost curve from under, since he will not be willing to take riskier states. To him, the fair odds line is below the segment of the efficient set where the good outcome will happen. He produces where the isocost meets the indifference curve. From this we can see that the shape of the farmer's preference map hinges crucially on his subjective probabilities.

Comparing Risk neutral and risk averse production equilibria

Now it is good to distinguish between the risk neutral and averse farmer equilibria. A risk neutral for an interior solution chooses his state-contingent revenue so that:

$$\frac{C_G(w,r,p)}{\pi_G} = \frac{C_B(w,r,p)}{\pi_B}$$

Also, summing the risk neutral FOC's and by complementary slackness we have that:

$$\sum_{s\in\Omega}\pi_G r_G - \sum_{s\in\Omega} C_S(w,r,p) r_S = O$$

We can see with this equation that for a risk neutral farmer the marginal profitability of increasing the optimal state contingent revenue vector is zero.

Graphically, in figure 3 we can see that depending on how risk averse the farmer is, he will produce in the efficiency set. He will choose to produce between point A, where the completely risk averse farmer with max-min preference produces, and point B which is the risk neutral equilibrium.

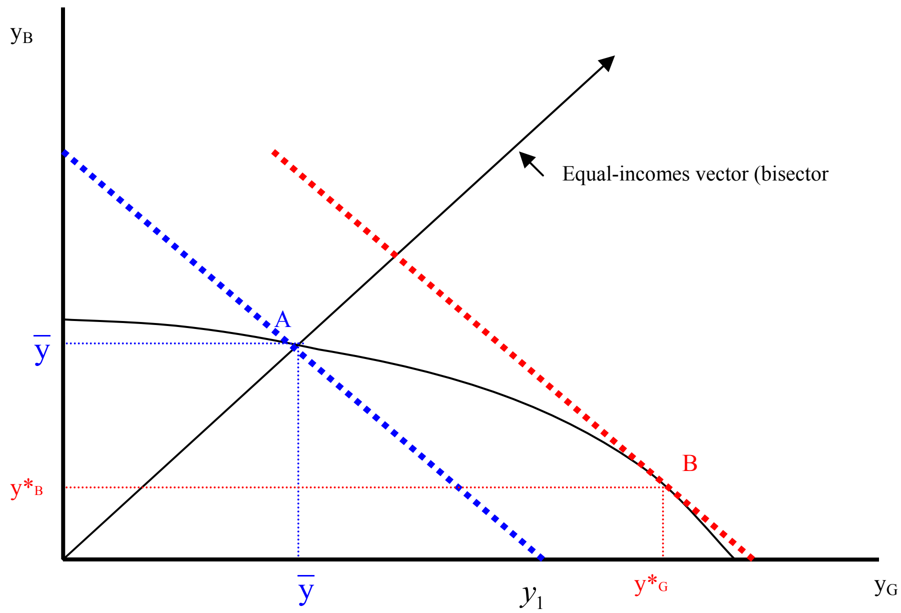

Figure 3. Risk-neutral and risk averse production equilibria

Since the indifference curves of a risk averse have to be tangent to the fair-odds line along the bisector (risk averse farmer always prefers certainty) this increases the subjective probability of a state leading to a rotation of all the decision maker's indifference curves along the bisector.

Taking into account the case of the risk averse farmer, Chamber and Quiggin provide a characterization of Schur concave preference functions used for modeling the state contingent approach. They derive Lemma 1 which helps us to analyze the different tax schemes.

Lemma 1 if W( ) is generalized Schur-concave and once continuously differentiable everywhere on its domain, then

$\left(\frac{W_G(y)}{\pi_G}-\frac{W_B(y)}{\pi_B}\right)(y_G-y_B)\leq 0$, for all G and B.

Now looking at the FOC of the risk averter and Lemma1, we have that for an interior solution an optimally chosen state contingent revenue vector must be risk aversely efficient with respect to π:

$$r_G \geq r_B \Leftrightarrow \frac{C_G(w,r,p)}{\pi_S} \leq \frac{C_B(w,r,p)}{\pi_B}$$
$$or \qquad (2)$$
$$\left(\frac{C_G(w,r,p)}{\pi_S} - \frac{C_B(w,r,p)}{\pi_B}\right)(r_G - r_B) \leq 0$$

Described as the risk-aversely efficient set for π. Because the preference function is generalized Shur-concave, then, in the neighborhood of the equilibrium, the revenue-cost function must behave as though it, too, were generalized Shur-concave. Generalized Schur-convex revenue-cost structures are characterized by the fact that there is always a cost advantage to producing a nonstochastic revenue (cheaper).

By complementary slackness, as long as the preference function is differentiable,

$$\frac{\sum_{S\in\Omega} W_S(y) r_S}{\sum_{S\in\Omega} W_S(y)} = \sum_{S\in\Omega} C_S(w,r,p) r_S$$

Along with expression (2) this implies an inverse covariance between the elements of the state contingent revenue vector r and the vector with typical element, $C_S(w,r,p)/\pi_S$. Hence we conclude:

$$\sum_{S\in\Omega} C_S(w,r,p)\left(r_G - \sum_{B\in\Omega} \pi_B r_B\right) \leq 0$$

This implies that a risk-averter with generalized Shur-concave preferences will choose an optimal state contingent revenue vector that is characterized by the fact that a small radial expansion of it will lead to an increase in expected profit.

Generally speaking, therefore, the risk-averter does not equate his marginal rate of transformation between state-contingent revenues to the ratio of probabilities as a risk neutral individual would. Furthermore, the risk-averter operates on a smaller scale than a risk-neutral producer in the sense that the former can radially expand his optimal state contingent revenue vector and increase profit while the latter cannot. In a word, the risk averter trades off expected return in an effort to provide self-insurance against the price and revenue risk that he faces. And because the preference function is generalized Shur-concave, then, in the neighborhood of the equilibrium, the revenue-cost function must behave as though it, too. Accordingly, in that neighborhood, there must be a negative correlation between marginal cost and the level of the state-contingent revenues.

Input Use

By Sheppard's Lemma and n = f,o

$$x_n(w,r,z) = \frac{\partial C(w,r,p)}{\partial w_n}$$

Since we have output and input prices the same for all states, comparing input demands by risk neutral and risk averse farmers is done by simply comparing the same input demand function evaluated at two different optimal state-contingent revenue vectors. Generally speaking, comparing different input demands arising from the same technology requires the ability to compare different state contingent revenue vectors.

Different state contingent revenue vectors can be compared usefully in two dimensions. One of them, comparing their relative expected returns (expansion effect) and another containing some measure of riskiness (pure-risk effect) keeping means constant. A risk averse farmer will trade off some increase in expected returns in return for a reduction of riskiness.

The use of inputs is modeled by a beaker diagram in the state contingent approach. The beaker diagram displayed in Figure 4 pictures the case of two inputs. The bottom line shows the amount of resources available for acquiring inputs, going from left to right indicates fertilizer usage and from right to left the amount of other inputs. The two different curves represent the production functions for the two inputs. The curve that goes up higher represents how output is changed as you increment fertilizer, also representing production in the good state. This curve shows how production is affected by the use of fertilizer going from a bad state to a good state. The lower curve shows the transformation of the other inputs and the production in the bad state. The left vertical axis represents returns in the bad state and the one in the right represents returns in the good state. If a certain amount of fertilizer is chosen the rest of the resources will be spent on the other inputs. In the case that the good state is realized the returns will be given by drawing a line from the amount of fertilizer chosen to the good state production curve and then joining this point with the respective point in the good state axis. In the case that a bad state occurs, we simply see where the line coming out from the input choice selection meets the bad state production curve and see where it is in the bad state axis. This point gives us the return in the bad state.

In Figure 4 we can see the input selections by both a risk averse farmer, point A, and by a risk neutral farmer, point B. Depending on how risk averse the farmer is he will choose the input mix between points A and B on the bottom input use line.

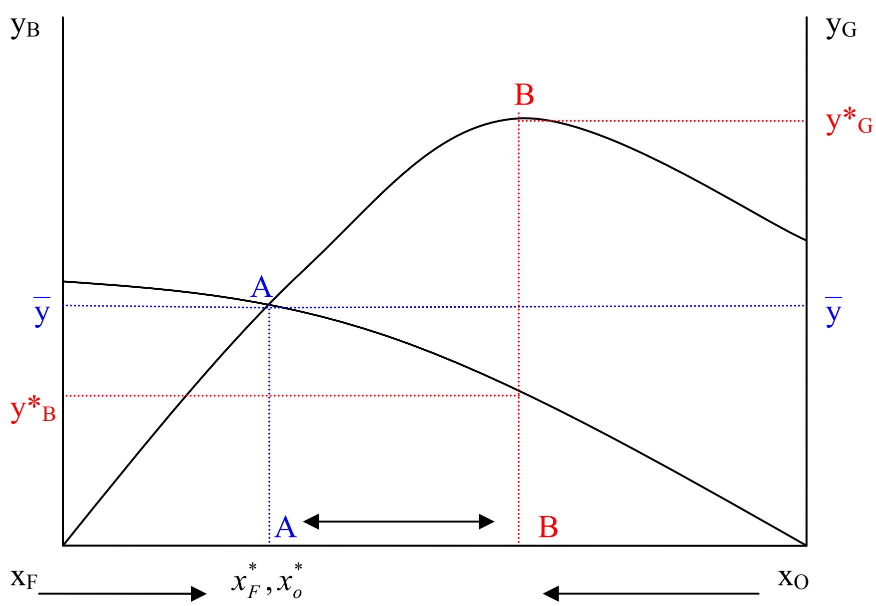

Figure 4. Beaker diagram showing input use for risk averse and risk neutral farmers.

The beaker's diagram points transfer into the state contingent graph, by mapping the returns in each case into an n-state graph. In our case it contains two states. Figure 5 shows how the production efficient frontier maps from a beaker diagram into the state contingent n-dimensional graph. This figure also maps our case where a good state produces more revenue than a bad state.

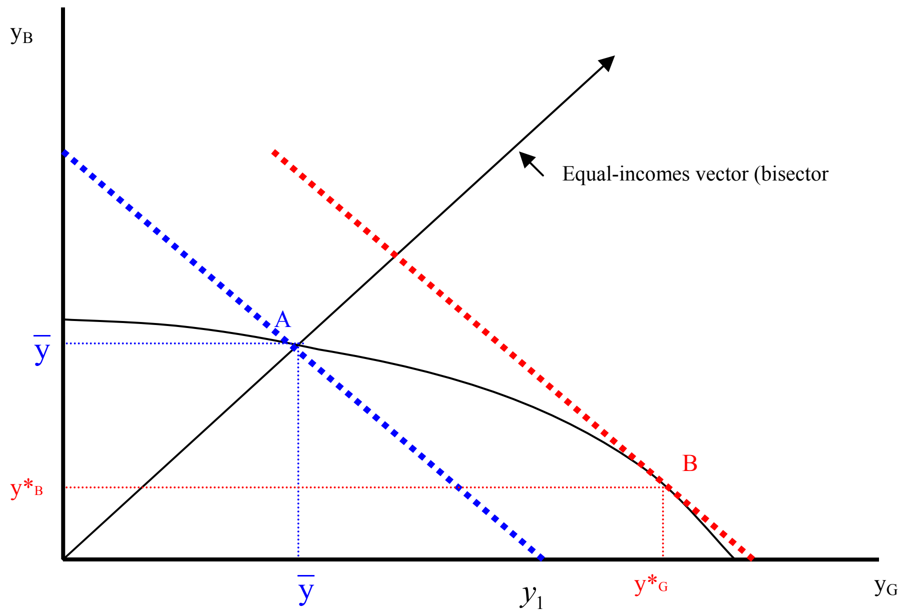

Figure 5. The Two state production frontier given by the beaker diagram (Figure 4)

In the presence of actuarially fair insurance with no loading factors, Chambers and Quiggins, demonstrate that farmers will produce at the same equilibrium as a risk neutral farmer would. That is, the farmer will choose to produce at the optimal state contingent revenue mix array. So in order to analyze the effects of the different tax schemes in the presence of insurance we will have to see what happens to the risk neutral equilibrium and how its input choices are affected.

Since input and output prices are the same for all states, comparing input demands by risk neutral and risk averse farmers is done by simply comparing the same input demand function evaluated at the two different optimal state-contingent revenue vectors. For the study, because there are two states and only one output, the stochastic production-function technology illustrates z and X(z) by: $X(z)=\{x:z_G=f(x,G),z_B=f(x,B)\}$ in the Beaker diagram. Assuming the technology displays an state contingent product-transformation curve (isocost) curve with skewness towards the good state's return like in the case of production of a given crop subject to bad or good climate conditions as seen of figure 5.

Pollution

The beaker diagram can also be used to show the amount of pollution caused by the different inputs. But different from before, the amount of pollution does not increase with an increase of fertilizer use. Pollution is state contingent. It also reaches a state where pollution does not increase even if you increase fertilization since it is take up by the plant. But if you keep increasing the amounts of fertilizer, runoff will again begin to cause problems and pollution will discharge again. Figure 6 shows the Beaker diagram picturing the two inputs, fertilizer and other inputs, and the pollution functions that each creates. The two vertical axes show the pollution in the good and bad state.

For the production choices of both the risk neutral and averse farmers, the amount of pollution caused by them will be given by different points between A and B in Figure 6.

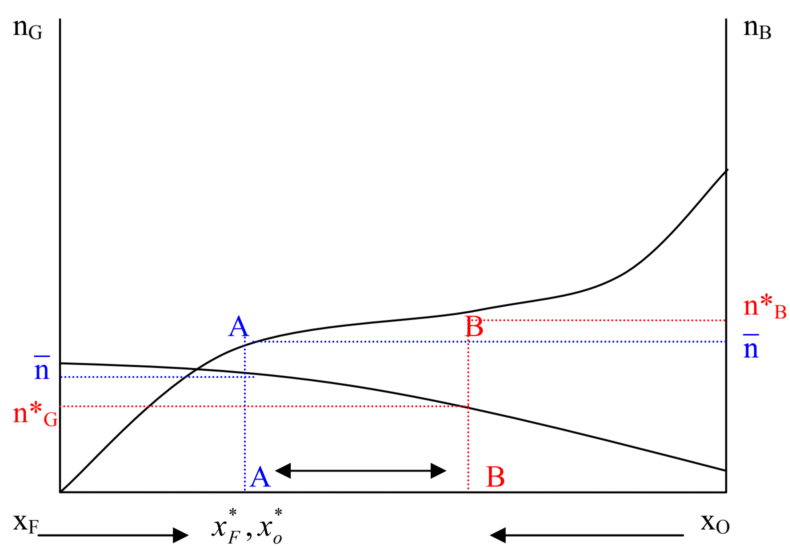

Figure 6. Beaker diagram showing input use for risk averse and risk neutral farmers and the effects of pollution.

When we transpose this into the 2-state dimension graph, Figure 7 we can see that the skeweness of the pollution production frontier will be toward the bad state. This differs from the returns production frontier which is skewed to the good state (Figure 5).

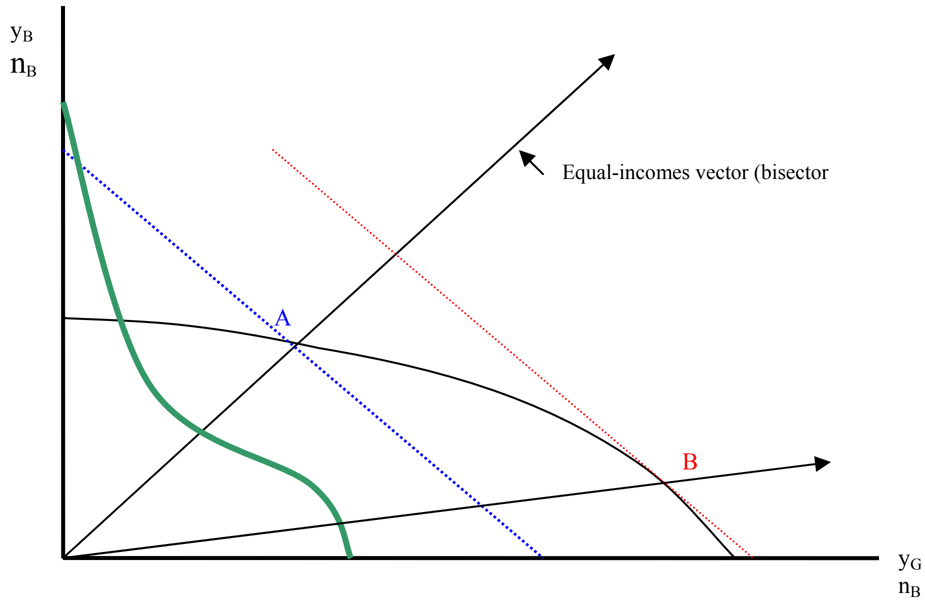

Figure 7. Pollution and returns efficient frontiers.

In figure 7 we can see how pollution is modeled with respects to the production efficient frontier. Higher amounts of pollution will occur in the bad state and lower pollution in the lower state. Farmers will produce using the maximum amount of fertilizer possible in order to obtain the most returns. In pollution terms this means that they produce pollution at the end of the pollution "steady" state given by the saddle point. This is the point where pollution starts to climb again after being relatively flat.

<u>Taxes on Output</u>

When faced by a total output tax the farmer will solve the following problem:

$$\max_{r}\{(1-t)z_G - C(\bullet), (1-t)z_B - C(\bullet)\}$$

$$C_G = \frac{W_G(1-t)}{W_G + W_B} \qquad C_B = \frac{W_B(1-t)}{W_G + W_B} \qquad \text{First order conditions}$$

$$C_G + C_B < 1$$

As it is intuitively, we can see that the farmer will produce lower than the efficient frontier that was characterized by $C_G+C_B=1$. Graphically we have that the efficient frontier in the 2-state dimensional graph has decreased compared to the optimal efficient frontier (Figure 6). The decrease in returns is the same for all states, that is, the taxation will be the same in either state. Since the decrease is proportional, the risk neutral farmer will stay in his optimal revenue mix input choice.

This also suggests that the effects of insurance won't be affected since the farmer will produce in the same place as he was producing, but his amplitude of production choices will be lowered. This happens since the distance between the totally risk averse farmer and the risk neutral farmer will be shortened.

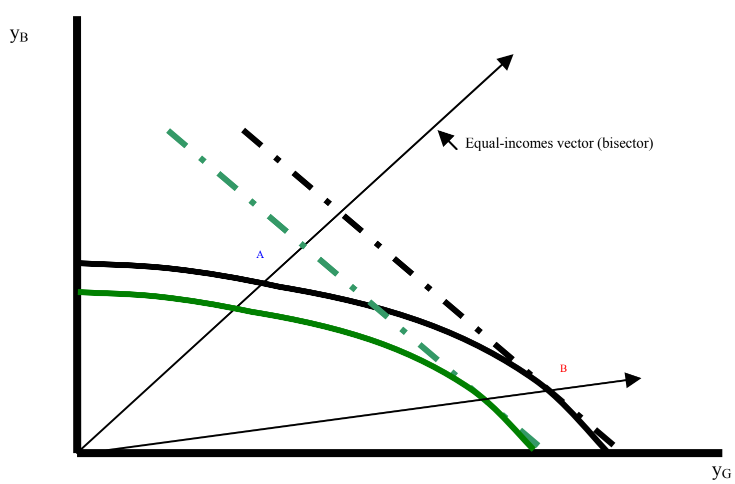

Figure 8. Output tax and the change in the production efficient set

Taking a look at how this transposes into the Beaker diagram (Figure 7), we can see that the production functions that transfer into returns of each input will be lowered in equal amounts. At the end this tax will bring a lower return for the use of each input, decreasing the amount used of each in a relatively equal amount.

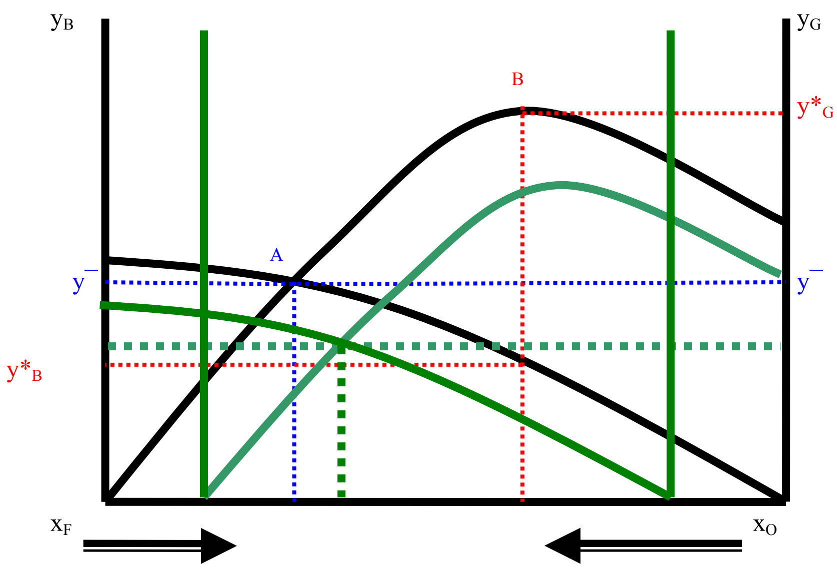

Figure 9. Output tax and input use

For the case of pollution and what happens when there is an output tax, we can see that total pollution in both states will fall since the lower returns will mean that the farmers will use less of both outputs. This is explained in Figure 10. But since the risk-averse farmer is producing at the optimal revenue mix point, fertilizer use will be at the maximum point, given the new conditions. This means that pollution will continue to be at the maximum point right after the saddle point as explained in the beaker diagram.

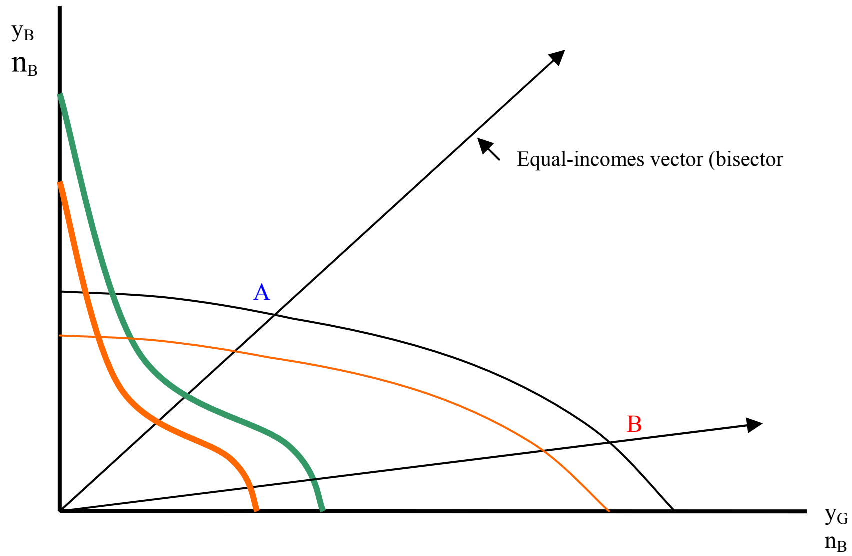

Figure 10. Pollution and Production affected by an output tax

<u>Taxes on fertilizer</u>

The effects of a tax directly on fertilizer will also lower the efficient production set, but not in the same manner as a total output tax. Since the farmer could spend all his money in the other inputs, he will still face the efficient set of this input. In the case of fertilizer the efficient set will decrease given that the tax will lower the returns of this input. In Figure 11, the Beaker diagram shows the effect on the production functions of both inputs if there is a tax implemented only in fertilizer.

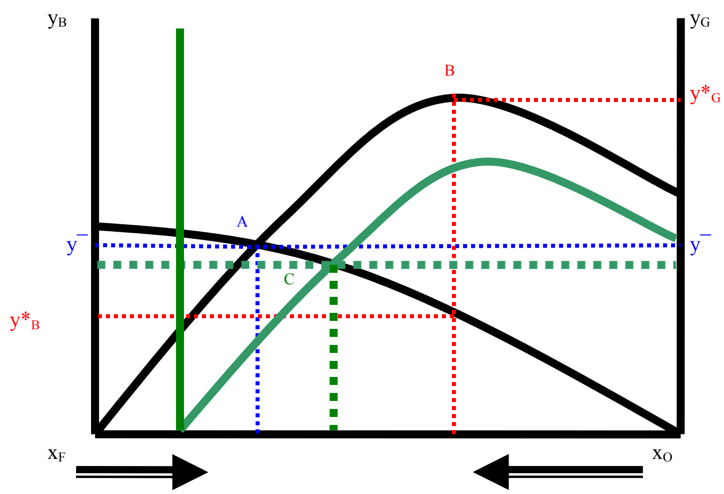

Figure 11. Beaker Diagram showing input use and a tax on fertilizer

As Figure 11 shows, the left axis will move in representing the lower production frontier of the fertilizer input. The right axis will not move the amount and production function of the other input will not be affected by a tax implemented on fertilizers. This traduces into the 2-state dimension graph by shifting down the good state returns skew. This happens since the fertilizer is responsible for the incremented returns in the good state.

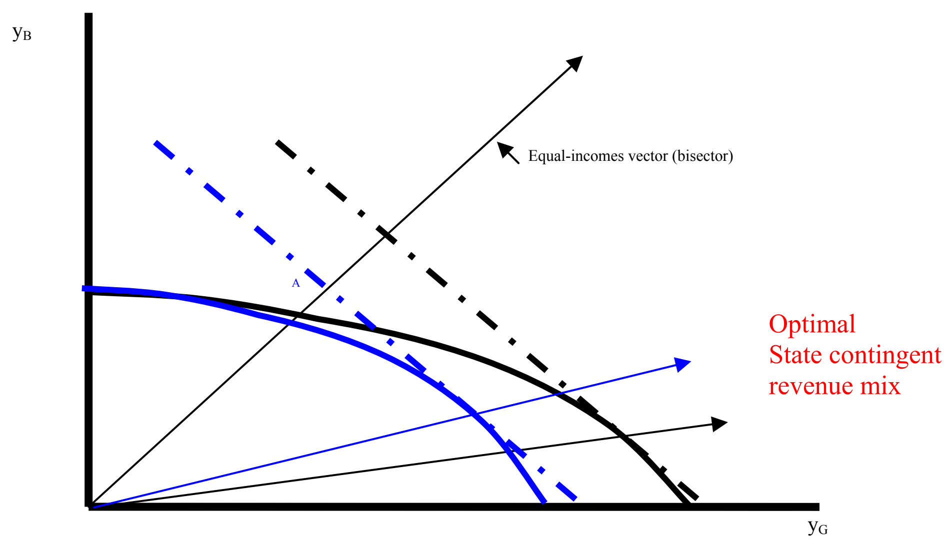

Figure 12. Fertilizer tax and the efficient production frontier

In Figure 12, we can see that a tax on fertilizer will cause the efficient frontier to shift in, but only in the good state side. This will make the optimal state contingent revenue mix to shift inward. This means that the risk neutral farmer will choose a different state contingent revenue mix than before, lowering the amount of fertilizer used in proportion with the other inputs. The effects of the insurance will be minimized, since the risk neutral farmer will be producing at the risk averse part of the efficient frontier.

Looking at Figure 13, pollution will decrease in a similar manner as with the total output taxes. The reason of the similar shift lies in the way in which the use of the most polluting input decreases with the input tax. Since the farmer is going to be producing at a different input choice mix, the total pollution could be at a higher point of the pollution frontier than before the tax was implemented. His new input choice mix could be more damaging causing more runoff and pollution.

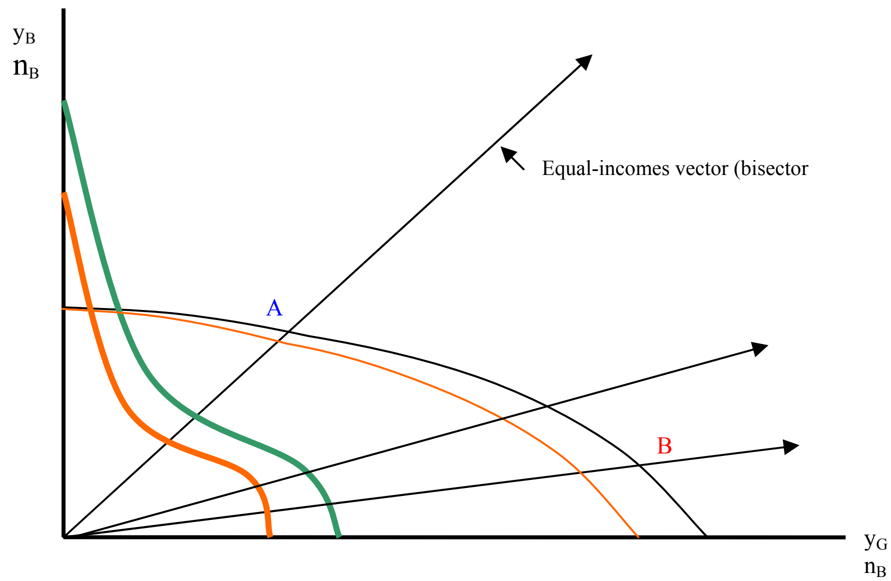

Figure 13. Pollution and Production affected by a fertilizer tax

CONCLUSIONS

Comparing the taxation schemes, we can see that both taxes will lower the boundary of the efficiency set. The difference between them is given by the way in which the efficient set is lowered. In the case of the output tax, the efficient set decreases proportionally both in the good and bad state causing a decrease on the returns of both inputs. Since fertilizer is the input responsible for the high output and returns in the good state, the decrease of the efficient set due to a fertilizer tax only occurs in the good state.

The farmer's option to forgo the use of fertilizer also causes this shift inward of the efficient set, but only from the good state.

A risk averse farmer in the presence of insurance, facing an output tax, will reduce the use of fertilizer but will stay in the same state contingent revenue mix. This means that the farmer will choose the same input proportions as with no taxes but in a lesser amount. This type of tax will not change the insurance effects on the farmer's input choice selections. In the absence of insurance the effects of an output tax are similar to the insured farmer. This can be seen by the proportional decrease in the transformation curves from both states, which keeps the input mix proportional to the non taxed input mix. In the two taxation cases the use of both fertilizer and other inputs will go down, but the decrease will be proportional causing a proportional inward shift both in the good and bad states. With the decrease of fertilizer use, runoff will also decrease. The pollution efficient set will shift inwards, and the farmer will be polluting at the point where the saddle point, at the pollution beaker diagram, starts ascending again. This is the point at which fertilizer is best absorbed by the plants.

The two tax schemes will dampen the risky outcomes on both states. This means that the segment of the efficient set between the completely risk averse and the risk neutral farmer will decrease. This could cause the farmer to use more fertilizer than before, being fertilizer a risk complement input.

A tax on fertilizer will cause a decrease on the returns of the good state. This type of tax will shift the efficient set inward, but this shift will only be in the good state. The farmers will change their optimal state contingent output revenue mix causing the effects of insurance to be affected by this tax. The risk neutral farmer will move inwards in the efficient production set and produce more as a risk averse farmer, because of the added risk on fertilizer use. The input selection proportions will change, given the interaction of the other inputs with fertilizer this change could cause more runoff than by choosing the optimal input choice mix. In the same manner this type of tax will affect the risk averse farmer, since in order to stay in the certainty outcome he might have to use more fertilizer than before.

Given the interaction of fertilizer with other inputs, it is very important to assess the changes that applying different input mixes on the crop will have on total runoff. Runoff depends on the type of irrigation, soil tillage and other practices which for our study are included in other inputs. A tax on fertilizer could also make the farmer change certain practices that prevent the field from loosing fertilizer by runoff, trying to improve the conditions for the plant to absorb as much as possible. Resources needed for analyzing the different practices necessary to obtain a new optimal mix have also to be analyzed before implementing a tax on inputs.

A total tax on output will keep the farmer using the optimal input mix. This will be beneficial if the different input proportions given by the fertilizer tax cause more environmental damage than by the optimal mix. Before installing a tax policy, the social planner has to take into account that the farmer produces at the efficient frontier of the other inputs only if the fertilizer input does not affect the productivity of them. That is, a tax on inputs will be better only if the effect of reducing nitrogen does not cause a reduction of the productivity of the other inputs, or if a new input choice mix does not cause more environmental damage than before. Although this study has shown a way to use a new approach in order to analyze two taxation schemes, it will be important to further the study including a mathematical model. For this, related data should be generated or acquired and a simulation could be run in order to determine the different scenarios in which both taxation schemes will be better or worse.

BIBLIOGRAPHY

1. Babcock, B. A. *The effects of Uncertainty on Optimal Nitrogen Applications*. Rev. Agr. Econ. 14. pp 271-80. July 1992.
2. Babcock, B.A., Hennessy, D.A. *Input Demand under Yield and Revenue Insurance.* American Journal of Agricultural Economics. 78. pp 416-27. May 1996.
3. Bomtems, Philippe., Thomas, Alban. *Information Value and Risk Premium in Agricultural Production: The Case of Split Nitrogen Application for Corn*. American Journal of Agricultural Economics. 82. pp 59-70. February 2000.
4. Chambers, Robert. Quiggin, John. *Uncertainty, production, choice, and agency : the state-contingent approach* Cambridge ; New York : Cambridge University Press, 2000.

5. Chambers, R. G., and Quiggin, J. *Decomposing Input Adjustment sunder price and production uncertainty.* American Journal of Agriculture Economics. 83. pp 20-34. February 2001.
6. Houghton, J. T., L. Meira Filho, B. Lim, K. Tranton, I. Manaty, Y. Bonduki, Griggs and B. Callander. *Intergovernmental Panel on Climate Change Greenhouse Gas Inventory Reporting Instructions.* Volume 2. Bracknell, U.K.: IPCC WGI Technical Support Unit. 1997.
7. Horowitz, J.K., and E. Lichtenberg. *Insurance, Moral Hazard, and Chemical Use in Agriculture* American Journal of Agricultural Economics. 69. pp 523-31. August 1987.
8. Kulshreshtha, S. N., M. Bonneau, M. Boehm, and J.C. Giraldez. *Canadian Economic and Emissions Model for Agriculture (C.E.E.M.A. version 2.0).* Ottawa: Agriculture and Agri-Food Canada. 2002.
9. Leathers, H.D., Quiggin, J.C. *Interactions between Agricultural and Resource Policy: The Importance of Attitudes toward Risk.* American Journal of Agricultural Economics. 73. pp 757-64. August 1991.
10. Yarii, M. *The Dual Theory of Choice under Risk.* Econometrica 55. pp 95-115. January 1987.