Welfare Impacts of Agri-Environmental Policies in an Open Economy: A Numerical General Equilibrium Framework

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Abstract

This paper uses a numerical general equilibrium model to evaluate the welfare impacts of alternative agri-environmental policies in an open economy while recognizing the presence of distortionary agricultural support subsidies and factor income taxes. In this context, the paper indicates that a revenue-neutral budget reform, which cuts all distortionary agricultural support subsidies and pays released funds as a lump-sum transfer payment to the land owner, increases welfare and reduces nitrogen run-off. It also shows that, at low levels of nitrogen reduction targets (less than 40 percent reduction in applied nitrogen), a tax on crop production is the most efficient policy while, at higher levels, a tax on applied nitrogen is more efficient. From the numerical results, the paper concludes that a reduction in nitrogen run-off can generate a double dividend (an economic gain over and above the environmental gains) at low levels of nitrogen reduction targets because they reduce the provision of distortionary agricultural support subsidies and because a part of the burden of these policies can be passed on to foreign consumers of agricultural products through the world market. This paper supports revenue-neutral budget reforms that reduce distortionary domestic agricultural support subsidies, release more funds for decoupled payments, and subsidize nitrogen reduction activities.

Keywords: Environmental instrument choice; Agricultural pollution; Agricultural support subsidies, Agricultural exports, Second-best regulation, Trade

1. Introduction

According to the Uruguay Round Agreement and more recent multilateral trade negations in Doha, the World Trade Organization (WTO) members committed to limiting their agricultural support subsidies that distort production and trade of agricultural products (Ingo and Nash, 2004). In compliance with this limit and in response to the public concerns over the harmful environmental consequences of agricultural products, the US government has been making some reforms in the agricultural support subsidies. These reforms which are reflected in the Farm Security and Rural Investment Act (FSRIA) of 2002 seeks to reduce distortionary agricultural support subsidies, increase decoupled support payments to farmers, and allocate more funds for environmental protection programs in agriculture (Westcott et al., 2002). These reforms are likely to have significant environmental and welfare impacts on the US economy. This paper develops a stylized numerical general equilibrium model based on the theory of environmental regulation in the second-best setting[1] in the context of an open economy to explore and quantify the magnitude of these impacts.

A second-best setting is selected here because the government finances substantial agricultural subsidies through distortionary taxes. The USDA has paid about $114 billion to farmers through the conservation and commodity support programs between the calendar years 1995 and 2002[2]. The WTO classified domestic support subsidies into three categories: amber, blue and green. Based on the WTO agreements, the amber box subsidies were considered as the most production and trade distorting payments, because they provide incentives to increase agricultural production. In 2000, about 73 percent of the US agricultural subsidies were classified under the amber box (Young et al., 2002). While the US is moving towards decoupled payment, there are still many agricultural commodities whose production the government supports through distortionary subsidies. In the FSRIA of 2002, these include, but are not restricted to price support subsidies, crop insurance indemnities, and market loss assistance payments. The USDA has classified these items under the amber box (Westcott et al., 2002). The FSRIA also allocates some funds for decoupled subsidies such as countercyclical payments. Some economists believe that these payments are indeed not decoupled from production (Young and Westcott, 2000).

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[1] Throughout this paper, the term "second-best" refers to a setting with prior distortionary income and commodity taxes/subsidies.

[2] For more information on agricultural subsidies see EWG Farm Subsidy Database at http://www.ewg.org.

Claassen et al. (2004) indicates that agricultural support subsidies have the potential to adversely affect water quality. According to this paper acres with high potential for nutrient run-off and leaching are located mostly in areas with relatively high government commodity payments. The paper also shows that fertilizer application accounts for more than 48 percent of all nitrogen loadings to surface water in areas where nitrogen run-off per unit of land is high and for more than 20 percent where run-off is low.

An obvious way to reduce agricultural pollution would then be to reduce distortionary agricultural subsidies. This would also reduce the need to raise revenue through distortionary income taxes. For these reasons reduction in agricultural subsidies can improve social welfare. However, a complete reduction in agricultural subsidies may not be possibly feasible or efficient to achieve desired environmental objectives. A reduction in subsidies may have to be supplemented with other environmental policies such as a nitrogen tax or a nitrogen reduction subsidy. While the reduction in distortionary agricultural subsidies would raise welfare, environmental policies may impose costs on the economy. Since the US is a large exporter of agricultural products, it is possible to shift some of the burden of environmental policies through higher prices to foreign consumers[3]. We therefore, examine the impacts of various combinations of domestic subsidy and environmental policies in the context of an open economy. In particular, the policies we look are a nitrogen run-off tax, a nitrogen run-off reduction subsidy, a tax on crop production and a “two-part instrument” - a combination of the second and the third policies. We indicate that these policies are different in their impacts on input and output prices and, therefore, in their impacts on welfare.

The paper uses data on the US economy for 2002 to calibrate parameters of a stylized general equilibrium model. Some parameters such as elasticities of substitution between the primary inputs in the supply side of the model and between the final goods in the demand side of the model are taken from the literature. Welfare impacts of alternative policies are measured using an extended definition of equivalent variation (EV). Unlike the simple definition of EV, the extended definition captures changes in both the prices and wealth. In this paper, we examine the

[3] Since the US is a largest exporter of agricultural products in the world, its domestic agri-environmental policies have the potential to affect prices of these commodities in the world market (Sumner 2002).

cost effectiveness of the alternative policies for given levels of nitrogen reduction targets. Hence, we do not value environmental gains from reduction in nitrogen run-off.

Numerical results indicate that reduction in the distortionary agricultural subsidies generate considerable welfare gains. Simulation results indicate that a 100 percent reduction in these subsidies can generate up to $1175 million of welfare gains. In addition, this policy can reduce nitrogen application by 8.5 percent. In general, numerical results indicate that all alternative policies to reduce nitrogen run-off may generate a double dividend at low levels of nitrogen reduction targets. The tax on crop production is the most efficient policy at low levels of nitrogen reduction targets. The numerical results also indicate that the relative efficiency of alternative policies is sensitive to the level of nitrogen reduction targets.

This paper proceeds as follows. Section 2 reviews the theoretical background. Section 3 presents the numerical model. Section 4 describes the benchmark data and calibration process. Section 5 presents simulation results. Section 6 contains sensitivity analyses. The final section presents the conclusions.

2. Literature Review

This paper is built on the theory of environmental regulation in the presence of pre-existing distortionary taxes. This theory has been an attractive subject in the field of environmental economics in the past three decades. Two important and parallel issues have been discussed in this field. Several papers study optimal commodity taxation in the presence of externalities (pollution). These papers show that the interaction between environmental taxes and pre-existing income taxes can affect social costs of environmental regulation[4]. Some papers have been built on this finding to study if environmental levies can generate a "double dividend". Existence of a double dividend is a controversial debate among environmental economists. Early papers in this field argue that revenues from environmental levies can be used to cut distortionary income taxes and improve efficiency[5]. This is known as the *"revenue recycling effect"*. These papers argue that the revenue recycling effect generate some gains over and above the environmental benefits and create a "double-dividend". More recent papers in this field show

[4] Examples: Sandmo (1975), Bovenberg and Mooij (1994), Fullerton (1997), Schöb (1997), Cramer, Gahvari, and Ladoux (2001), and Metcalf and NBER (2003).

[5] Examples: Terkla (1984), Lee and Misiolek (1986), Baumol and Oates (1988), Oates (1991), and Pearce (1991).

that the interaction between environmental levies and pre-existing taxes decreases economic efficiency[6]. This is known as the *"tax interaction effect"*. These papers reject the double-dividend hypothesis and indicate that the welfare reducing tax interaction effect offsets the welfare enhancing revenue recycling effect.

The choice between alternative policies for environmental regulation in a second-best setting is also an important issue in this field. Several papers have applied analytical and numerical general equilibrium models to study cost effectiveness of air pollution regulation programs and carbon taxes policies[7]. In these papers, alternative policies are typically an emissions tax, a set of emissions permits, a tax on production of fuels, and the command and control policies. These papers show that the emissions tax can be more efficient than other policies in the second-best setting if environmental tax revenues are used to reduce other distortionary taxes.

Most papers which reject the double dividend hypothesis and those which study the choice between alternative policies for air pollution regulation in the second-best setting are constructed on a "classical structure", which relies on the following simplifying assumptions: first, labor is the only primary input; second, there is only one pre-existing distortion in the economy - either a tax on labor or a commodity tax; third, the abatement technology is separable from the production technology, also known as the "end-of-pipe" abatement technology assumption; and fourth, the economy is closed.

Relaxing these assumptions can provide different results. Introducing more primary inputs into the model, existence of distortionary subsidies, links between domestic environmental policies and terms of trade are key factors that can affect cost effectiveness of alternative policies to control pollution and increase possibility of gaining a double dividend from environmental regulation. In this paper, we remove these restricting assumptions. We expand the classical structure to study the welfare impacts of agri-environmental policies in the presence of agricultural subsidies in the context of an open economy.

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[6] Examples: Bovenberg and Mooij (1994), Fullerton and Metcalf (1997), Fullerton (1997), and Goulder et al. (1999).
[7] Examples: Ballard and Medema (1993), Parry (1997), Goulder, Parry, and Burtraw (1997), Parry, Williams, and Goulder (1998), and Goulder et al. (1999).

3. The Numerical Model

Consider an open economy with one representative consumer, two producers, and a regulator. Each producer produces only one final good. Hence, there are two final goods: a dirty good (crops) and a clean good (other goods and services). Output of the dirty and clean goods, and their consumer prices are indicated by *X*, *Y*, p_X , and p_Y , respectively.

The resources used in production of both goods are labor, land, and capital. Endowments of these resources are indicated with $\overline{L}$, $\overline{R}$, and $\overline{K}$, respectively, and they are fixed. The wage rate, *w*, is selected as the numeraire. Prices of land and capital are indicated with r_R and r_K , respectively. The dirty good uses nitrogen fertilizer in its production process as well.

The economy imports nitrogen fertilizer, N_X , at a constant price of p_N and exports some part of the dirty good, *x*, at the domestic price of p_X . Indeed, we assume free trade with no tariff. The demand for exports, $x(p_X)$, is downward sloping, with a constant price elasticity of ε_x . The balance of this trade, *RES*, can be positive or negative and is defined as follows:

$$RES + p_N N_X = p_X x(p_X) . \qquad (3\text{-}1)$$

Land and capital are fully utilized. However, the consumer consumes some part of the labor endowment as leisure. Domestic markets are all competitive and agents are price takers.

3.1. The Representative Consumer

The representative consumer derives utility from consumption of goods, leisure, and foreign reserve and disutility from environmental damages due to nitrogen run-off from production of the dirty good, *E*. The utility function is given by the following two-level constant elasticity of substitution (CES) utility function:

$$U = \left\{ \alpha_l (l)^{\frac{\sigma_u - 1}{\sigma_u}} + (1-\alpha_l) \left(\left(\alpha_X X_d^{\frac{\sigma_C - 1}{\sigma_C}} + (1-\alpha_X) Y_d^{\frac{\sigma_C - 1}{\sigma_C}} \right)^{\frac{\sigma_C}{\sigma_C - 1}} \right)^{\frac{\sigma_u - 1}{\sigma_u}} \right\}^{\frac{\sigma_u}{\sigma_u - 1}} + \varphi RES - \phi E . \qquad (3\text{-}2)$$

In this utility function, X^d and Y^d indicate domestic demands for the dirty and clean goods, respectively, and l is leisure, σ_u is the elasticity of substitution between leisure and consumption goods, σ_C is the elasticity of substitution between the two consumption goods, α_l and α_X are distribution parameters, φ indicates marginal utility of the reserve, and ϕ indicates marginal damage of nitrogen run-off. In this utility function, we consider reserves as an opportunity to import other goods from the world market. Alternatively, we can interpret reserves as an unintended public asset/debt. The representative consumer takes *RES* and *E* as given. These variables do not affect the choice between consumption and leisure and between consumption of the dirty and clean goods because the above utility function is strongly separable in *E* and *RES*.

The consumer supplies labor, land, and capital and receives a lump sum transfer, *G*, from the government. The consumer budget constraint is defined as follows:

$$RES + p_X X^d + p_Y Y^d = (1-t_L)L + (1-t_R)r_R\overline{R} + (1-t_K)r_K\overline{K} + \pi + G \,. \qquad (3\text{-}3)$$

Here t_L, t_R, and t_K are flat marginal tax rates on labor, land, and capital incomes, respectively[8], and π stands for profit from production activities if there is any. The first order conditions of the utility maximization determine X^d, Y^d, and *L* as functions of prices, tax rates, endowments and transfer payments.

3.2. Producers and Production Functions

Assume two representative producers: a farm which uses labor, land, capital, and nitrogen to produce the dirty good and a firm which uses labor, land, and capital to produce the clean good. The clean good is a composite good, which includes clean agricultural products as well. We model production processes with the two-level production functions. Sato (1967) originally introduced this type of production function. The two-level production functions have been widely used in literature[9]. This type of production function provides a simple and convenient way to build up CES production functions with more than two factors of production. In a two-level production function, production is first a function of two composite inputs, which are called mechanical and biological inputs. Then, production of each composite input is a

[8] To avoid complexity, in this paper we assume $t_L = t_R = t_K$.

[9] Examples are Binswanger 1974, Kawagoe et al. 1985, Thirtle 1985, Abler and Shortle 1992.

function of two inputs. The biological input is a function of land and fertilizer and the mechanical input is a function of capital and labor. The production functions are written as:

$$O_i = \gamma_{ii} \left\{ \alpha_{ii} B_i^{\rho_{ii}} + (1-\alpha_{ii}) M_i^{\rho_{ii}} \right\}^{\frac{1}{\rho_{ii}}}, \qquad \text{for } i=X \text{ and } i=Y, \qquad (3\text{-}4)$$

$$B_i = \gamma_{Bi} \left\{ \alpha_{Bi} R_i^{\rho_{Bi}} + (1-\alpha_{Bi}) N_i^{\rho_{Bi}} \right\}^{\frac{1}{\rho_{Bi}}}, \qquad \text{for } i=X \text{ and } i=Y, \qquad (3\text{-}5)$$

$$M_i = \gamma_{Mi} \left\{ \alpha_{Mi} L_i^{\rho_{Mi}} + (1-\alpha_{Mi}) K_i^{\rho_{Mi}} \right\}^{\frac{1}{\rho_{Mi}}}, \qquad \text{for } i=X \text{ and } i=Y. \qquad (3\text{-}6)$$

Here O_i, B_i, and M_i represent outputs of final goods, the composite biological inputs, and the mechanical inputs, respectively. In these production functions, α's and γ's are distribution and adjustment parameters. In addition, $\rho_{ii} = \frac{\sigma_{ii} - 1}{\sigma_{ii}}$, $\rho_{Bi} = \frac{\sigma_{Bi} - 1}{\sigma_{Bi}}$, and $\rho_{Mi} = \frac{\sigma_{Mi} - 1}{\sigma_{Mi}}$, where σ_{ii} are the elasticities of substitution between the biological and the mechanical inputs, σ_{Bi} are the elasticities of substitution between land and nitrogen and σ_{Mi} are the elasticities of substitution between labor and capital. It is assumed that production of Y does not need nitrogen. This implies that $\alpha_{BY} = 1$, which in turn implies $B_Y = \gamma_{BY} R_Y$. The first order conditions for the firms' input-hiring decisions determine demands for inputs as a function of input prices and outputs.

3.3. The Nitrogen Run-Off Function

In general, nitrogen run-off is a function of soil characteristics, H, climatic conditions, M, nutrient management technology, T, and applied nitrogen for crop production. We can summarize the relationship between these variables at a macro level with the following function:

$$E = E(H, M, T, N_X).$$

To avoid complexity, we assume $E(\cdot)$ is a linear homogenous function in N_x. This assumption implies that:

$$E = \psi(H, M, T) N_X.$$

Since we use an aggregated static general equilibrium model with a representative consumer and a representative crop producer and because our model is abstracted from random variables, it is reasonable to assume that *H*, *M*, and *T* are constant and given variables. This means that $\psi(\cdot)$ is a constant parameter in our model. Indeed, in our model, ψ is a constant delivery coefficient which transfers applied nitrogen to nitrogen run-off. In short, the nitrogen run-off function is given by:

$$E = \psi N_X . \qquad (3\text{-}7)$$

3.4. Alternative Policies

We first examine a revenue-neutral reform which cuts all distortionary agricultural support subsidies and pays released funds as a lump-sum (decoupled) transfer payment to the land owner (the representative consumer). Then we study four policies to reduce nitrogen run-off from crop production. These policies are a nitrogen run-off tax (policy *I*), a nitrogen run-off reduction subsidy (policy *II*), a tax on the production of the dirty good (policy *III*) and a "two-part instrument"[10] (policy *IV*) - a combination of the second and third policies. We use the two-part instrument to study a revenue neutral policy that reduces distortionary agricultural support subsidies and allocates released funds to subsidize activities that reduce nitrogen run-off. Notice that since we assume a linear homogeneous relationship between applied nitrogen and nitrogen run-off and because there is no heterogeneity in the model, we can replace the tax on nitrogen run-off with a tax on applied nitrogen. For the same reason, we can replace the nitrogen run-off reduction subsidy with a subsidy per unit of reduction in applied nitrogen.

3.5. The Government

The government has several regulatory functions. It supports production of the dirty good through subsidies financed through income taxes including taxes on labor, land, and capital. It also seeks to control nitrogen run-off. Finally, the government pays a lump-sum transfer, *G*, to

[10] It is well known that sources of agricultural pollution are not observable and monitoring the movements of nonpoint-source pollution is often impractical or too expensive. Fullerton (1997) suggests a simple remedy for this problem. He shows that, when sources of pollution are not observable, the emissions tax can be entirely replaced by the equivalent combination of a subsidy to all clean inputs plus an additional tax on output. Based on this suggestion, a reduction in the price support subsidies can be interpreted as an additional tax on agricultural output. Furthermore, those government subsidies which encourage farmers to use environmental friendly practices (such as green payments) can be considered as a subsidy on the clean input. Notice that, in this paper, a subsidy on clean inputs is replaced by a nitrogen reduction subsidy.

the consumer. The government is committed to a certain level of real lump-sum transfer. Therefore, it adjusts G with changes in the prices of consumption goods. The following equations define the government budget constraint under alternative policies:

$$t_E E + t_L L + t_R r_R \bar{R} + t_K r_K \bar{K} = S_o O_X + G \ , \qquad \text{under policy } I,$$

$$t_L L + t_R r_R \bar{R} + t_K r_K \bar{K} = S_a (E_0 - E) + S_o O_X + G \ , \qquad \text{under policy } II,$$

$$t_X O_X + t_L L + t_R r_R \bar{R} + t_K r_K \bar{K} = S_o O_X + G \ , \qquad \text{under policy } III, \text{ and}$$

$$t_X O_X + t_L L + t_R r_R \bar{R} + t_K r_K \bar{K} = S_o O_X + S_a (E_0 - E) + G \ , \qquad \text{under policy } IV.$$

Here t_E, S_o, S_a, E_0, and t_X indicate a tax rate on each unit of nitrogen run-off, a subsidy on each unit of output of the dirty good, a subsidy per unit of reduction in nitrogen run-off, total amount of nitrogen run-off in the absence of environmental regulation, a and tax per unit of output of the dirty good, respectively. Notice that the left hand sides of the above equations are government revenues and the right hand sides are government expenditures.

3.6. Equilibrium Conditions

In equilibrium, supply must equal demand for all inputs and outputs, government revenues should equal government expenditures, applied nitrogen (or nitrogen run-off) should equal a target, and reserves plus value of imported nitrogen should equal value of exports. This means that, in general equilibrium, the following conditions must hold:

$$O_X = X_d + x \ , \qquad (3\text{-}8) \qquad\qquad O_Y = Y_d \ , \qquad (3\text{-}9)$$

$$N_X = \bar{N} \ , \qquad (3\text{-}10) \qquad\qquad RES + p_N N_X = p_X x \ , \qquad (3\text{-}11)$$

$$REV_J = EXP_J \ , \qquad (3\text{-}12) \qquad\qquad K_X + K_Y = \bar{K} \ , \qquad (3\text{-}13)$$

$$R_X + R_Y = \bar{R} \ , \qquad (3\text{-}14) \qquad\qquad L_X + L_Y = \bar{L} \ . \qquad (3\text{-}15)$$

Here REV_J and EXP_J indicate government revenues and expenditures under policy J (J=I, II, III, and IV), respectively. Here, $\bar{N}$ indicates the nitrogen run-off target that the government wants to reach. Because technologies exhibit constant returns to scale, it is possible to reduce the equilibrium conditions to equations (3-10)-(3-15). In addition, by Walras' Law when equilibrium conditions (3-10)-(3-14) hold then equation (3-15) must also hold. Therefore, given a targeted level for nitrogen run-off, it is possible to find equilibrium prices, the income tax rate, and the policy enforcement variable under each alternative policy except for under the two-part instrument. Under the latter policy, the following equilibrium condition must also hold:

$$t_X X = S_E (E_0 - E) . \qquad (3\text{-}16)$$

4. Data

Table 1 summarizes the data, which depicts the US economy in 2002. In this table, the US economy is divided into two sectors: a dirty sector, which produces crops and a clean sector which provides other goods and services. Taheripour (2005) describes the benchmark data in more detail. In addition to the benchmark data, some parameters are taken from the literature. The uncompensated labor supply elasticity of $e_L = 0.15$ is taken from Goulder et al. (1999). The price elasticity of $e_{p_Y} = 1.0$ is assigned to the demand of the clean good based on the work of Kyer and Maggs (1997). Their work indicates that the price elasticity of aggregate demand for the US economy was around 1.0 during the time period of 1965-90. This value is adopted because the clean good approximately represents the aggregate demand for the US economy. Based on the Database for Trade Liberalization Studies[11], the price elasticity of $e_{p_X} = 0.5$ is assigned to the domestic demand of the dirty good. This number represents an inelastic demand for crop products. Many papers report inelastic demand for food and for agricultural products [12]. Finally, we assume that the elasticity of demand for crop products in the world market is equal to $\varepsilon_x = 0.9$. These elasticities are used to calibrate parameters of the utility function. In addition, elasticities of substitution in the production functions are taken from Balisteri et al. (2002) and Horan et al. (2002). They are shown in table 2. We also do sensitivity analyses to check how results change due to changes in the selected parameters.

5. Simulation Results

In this section, we first examine the full subsidy-cut policy. Then we assess impacts of the alternative policies to reduce nitrogen run-off.

To facilitate comparison among alternative policies an *equivalent variation* measure (*EV*) with the following extended definition[13] is calculated[14] for each level of nitrogen reduction target:

$$EV = e(p^0, u^1) - e(p^0, u^0),\ u^0 = v(p^0, m^0) \text{ and } u^1 = v(p^1, m^1).$$

Here $e(\ ,\ )$ and $v(\ ,\ )$ stand for the expenditure and indirect utility functions, p^0 and p^1 represent vectors of prices (including prices of inputs) in the absence and presence of environmental regulation, and m^0 and m^1 indicate wealth in the absence and presence of environmental regulation, respectively. In this definition, wealth includes all types of income, leisure, and trade reserves. This definition captures changes in both the prices and wealth. In this definition, a positive amount of *EV* represents welfare gain. In the rest of this section, we present welfare impacts of alternative policies.

5.1. The Full Subsidy-Cut

Table 3 summarizes impacts of this policy on the key variables of the US economy. First of all, this policy increases welfare by $1,175 million. In addition, this policy reduces applied nitrogen by 8.5 percent. While the full subsidy-cut reduces rental rate of land by 4.5 percent it does not reduce payments to the land owner because the land owner receives released funds from agricultural subsidies as a lump-sum payment. The full subsidy-cut increases payments to the land owner by 17.8 percent. Note that agricultural support subsidies drive up the rental rate of land because this policy increases the demand for land without changing supply.

The full subsidy-cut has two price effects: the output price and input price effects. These effects arise because subsidy cuts affect the relative prices of goods and the relative prices of inputs. The output price effect raises the price of the dirty good by 5.9 percent and reduces the price of the clean good by .02 percent. As a result, this policy decreases domestic consumption of the dirty good by 4.2 percent. It also reduces exports of the dirty good by 7.8 percent. As we mentioned earlier, the full subsidy-cut reduces the rental rate of land. The input price effect of the policy reduces the price of capital moderately. Therefore, the conclusion is that the subsidy-cut policy

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[11] See Sullivan et al. (1989)
[12] For example see Yen et al. (2003)
[13] This definition is designed based on the question 3.I.12 of Mas-Collel, Whinston, and Green (1995).

works in favor of labor and increases the wage rate relative to the price of other inputs. The input and output price effects move out about 13.5 million acres of homogenized land from crop production. This means that the subsidy-cut policy forces the representative farmer to use less land for crop production due to an increase in the rental rate of land. We can call this a "reverse slippage effect".

In conclusion, the full subsidy-cut is a welfare enhancing policy which also improves environmental quality through less nitrogen run-off from crop production and completely removes distortionary impacts of the agricultural support subsidies. Of course, magnitudes of the impacts of this policy on the welfare and other economic variables depend on the exogenous parameters that we assumed in this paper. However, our sensitivity analyses indicate that the above conclusion remains valid for reasonable changes in the value of exogenous parameters.

5.2. Impacts of Alternative Policies to Reduce Nitrogen Run-Off

Here, we first compare cost effectiveness of alternative policies for the same level of reduction in nitrogen run-off. Then we compare impacts of these policies on the other variables. We use this method for several values of nitrogen reduction targets (from 0 to 50 percent reduction in nitrogen run-off).

5.2.1. Welfare Impacts

The welfare impacts of alternative policies for several values of nitrogen reduction targets (from 0 percent to 50 percent) are depicted in figure 1. This figure indicates that all policies generate some welfare gains at low levels of nitrogen reduction targets. That is, we observe gains for levels below 38 percent for the nitrogen run-off tax, below 20 percent for the nitrogen run-off reduction subsidy, below 40 percent for the tax on production, and finally below 26 percent for the two-part instrument. The maximum amounts of gains that these policies generate are about \$500 million, \$140 million, \$2448 million, and \$187 million, respectively. These numbers appear at 20 percent, 10 percent, 22 percent, and 14 percent levels of nitrogen reduction targets, respectively. As figure 1 indicates, gains increase with the level of nitrogen reduction target until they reach to their maximum point. After that, gains decrease as the level of nitrogen reduction target goes up. Finally, at high levels of nitrogen reduction targets, all policies become costly and

[14] In this calculation benefits from changes in $\phi(E)$ are ignored. Indeed, the first dividend is not included in the definition of EV.

they impose some welfare losses. Figure 1 clearly indicates that all policies generate some double dividend at low and middle levels of nitrogen reduction targets, but they also cause some losses at high levels.

The tax on production of the dirty good generates more gains than other policies at the low and middle levels of the nitrogen reduction targets because of several reasons. It increases the price of the dirty good more rapidly than the other policies do. Therefore, it reduces the demand for the dirty good faster than do the other policies. This policy generates more gains from trade because it improves the terms of trade. In addition, the tax on production generates a strong revenue recycling effect which makes the policy more attractive at low and middle levels of nitrogen reduction targets. This policy is the worst policy at high levels of nitrogen reduction targets because it fails to encourage the representative farmer to decrease nitrogen per unit of output, which imposes considerable amount of costs on the economy at high levels of nitrogen reduction targets. At high levels of nitrogen reduction targets, the tax on nitrogen run-off is the most efficient policy because it raises the price of nitrogen (price plus tax) and encourages farmers to apply less nitrogen in crop production.

Figure 1 indicates, that at all levels of nitrogen reduction targets, the nitrogen reduction subsidy policy generates less gains (or more losses at high levels) than the tax on nitrogen. These two policies have the same impact on the producer's behavior because both increase the price of nitrogen fertilizer. However, the former policy increases government expenditures and raises the income tax rate, which reduces its efficiency. In addition, the nitrogen run-off reduction subsidy generates some rents for the consumer, which in turn reduces the labor supply.

Figure 1 also shows that regardless of the tax on production of the dirty good, the tax on nitrogen run-off and the nitrogen run-off reduction subsidy are the best and the worst policies at all levels of nitrogen reduction targets. The two-part instrument is always placed in between these two policies.

Finally, numerical results declare that, for the low and middle levels of nitrogen reduction targets (less than 40 percent) the tax on production of the dirty good is the most efficient policy, while at high levels (more than 40 percent) the tax on nitrogen works better than other policies. This means that ranking of policies depends on the level of nitrogen reduction target.

5.2.2. Price Effects

The alternative policies affect prices of goods and factors of production differently. Table 4 shows price effects of these policies for three levels of nitrogen reduction target: 10 percent, 20 percent, and 50 percent reduction in nitrogen. As this table indicates for a 10 percent reduction in nitrogen, the price of the dirty good goes up by 3.39 percent, 3.38 percent, 11.43 percent, and 3.52 percent under the tax on nitrogen, the nitrogen reduction subsidy, the tax on production and the two-part instrument, respectively. These figures indicate that all policies raise the price of the dirty good but the tax on production raises the price faster. The tax on production of the dirty good directly derives up the price, but the tax on nitrogen and the nitrogen reduction subsidy only affect this variable through the production costs. Figure 2 depicts impacts of alternative policies on the price of the dirty good for several values of nitrogen reduction targets (0 percent to 50 percent). Note that all policies reduce the price of the clean good slightly.

Table 4 also indicates that for a 10 percent reduction in nitrogen target, the price of land goes up by 3 percent, 3.01 percent, and 2.81 percent under the tax on nitrogen, the nitrogen reduction subsidy, and the two-part instrument, respectively. However, for the same level of nitrogen reduction target, the tax on production of the dirty good reduces the price of land by 7.02 percent. Figure 3 compares impacts of alternative policies on the price of land for several values of nitrogen reduction target. Note that all alternative policies reduce the price of capital slightly.

5.2.3. Impacts of Policies on Consumption and Export

All alternative policies reduce the domestic consumption and exports of the dirty good due to an increase in its price. However, since tax on production raises the price of the dirty good more than other policies do, it causes more reduction in the domestic consumption and exports. As table 4 indicates, for a 10 percent reduction in nitrogen, domestic consumption of the dirty good falls by 1.81 percent, 1.81 percent, 5.72 percent, and 1.88 percent under the tax on nitrogen, the nitrogen reduction subsidy, the tax on production, and the two-part instrument, respectively. Since demand for the dirty good in the world market is more elastic than in the domestic market, all alternative policies reduce exports faster than domestic consumption. Table 4 shows that for a 10 percent reduction in nitrogen, exports of the dirty good fall by 2.96 percent, 2,95 percent, 9.28, and 3.06 percent under the pre mentioned alternative policies, respectively. Figures 4 and 5 compare impacts of alternative policies on domestic consumption and exports of the dirty good for several values of nitrogen reduction targets.

5.2.4. Other Impacts

While all policies reduce applied nitrogen, the tax on production provides less incentive for the representative farmer to reduce nitrogen per unit of output. Table 4 shows that, for a 10 percent reduction in nitrogen run-off target, the tax on production reduces the index of applied nitrogen per unit of output by about 4.54 percent, while for the same level of target other policies reduce this index by about 8.3 percent. Figure 6 compares the index of applied nitrogen per unit of output for several values of nitrogen reduction targets under the alternative policies. This figure shows that, as the level of target goes up, the gaps between indices of applied nitrogen per unit of output under the tax on production and other policies become wider.

The alternative policies affect the income tax rate differently. Table 4 shows that for a 10 percent reduction in nitrogen run-off, the income tax rate goes down by about 0.06 percent under the tax on production but it either remains constant or goes up under other policies. Table 4 indicates that, at a 50 percent reduction in nitrogen, the income tax rate goes up under all policies. However, but it rises faster under the nitrogen reduction subsidy policy, which does not generate revenues from environmental regulation, but rather raises government expenditures. Figure 7 depicts impacts of alternative policies on the income tax rate for several values of nitrogen reduction targets (0 percent to 50 percent).

Table 4 shows that, for a 10 percent reduction in nitrogen run-off, land in production of the dirty good goes down by about 1.42 percent under the tax on production, but it goes up by 0.56 percent under other policies. This indicates that the tax on production forces the representative farmer to use less land in crop production, while other policies encourage the farmer to apply more land. Figure 8 depicts changes in the allocated land for production of the dirty good for several values of nitrogen reduction targets.

6. Sensitivity Analysis

To test impacts of alternative parameterizations on the simulation results, three more sets of parameters are tested. In the first set, the elasticity of labor supply is reduced from 0.15 to 0.11. This affects calibrated parameters of the utility function. In the second set, the elasticity of substitution between land and nitrogen fertilizer in production of the dirty good is reduced from 1.25 to 0.75. This affects the calibrated parameters in sector *X*. In the third set, we test several values for the elasticity of demand for exports of the dirty good. In the base case scenarios, we assumed that $\varepsilon_x = 0.9$. We test sensitivity of the results to this parameter for $\varepsilon_x = 1$ and $\varepsilon_x = 1.1$.

In short, a reduction in the elasticity of labor supply (from 0.15 to 0.11) reduces economic gains of the tax on production and increases gains of other alternative policies. In addition, reduction in the elasticity of labor supply changes the relative efficiency of alternative policies in favor of the nitrogen reduction subsidy and the two-part instrument. A reduction in the elasticity of substitution between land and nitrogen fertilizer (from 1.25 to 0.75) makes substitution between nitrogen and land difficult and raises the costs of all policies at high levels of nitrogen reduction targets significantly. Finally, results are not sensitive to the elasticity of demand for exports of the dirty good.

7. Conclusion

In this paper, we applied a general equilibrium model to examine impacts of agri-environmental reforms on the US economy. Numerical results indicate that reduction in the distortionary domestic agricultural support can reduce nitrogen run-off and improve welfare if the government returns released funds to the land owner. This paper indicates that all examined alternative policies to reduce nitrogen run-off generate some economic gains over and above the environmental benefits at low levels of nitrogen reduction targets. This indicates that environmental regulation may generate a double dividend in agriculture. In addition, we indicate that a tax on the crop production is more efficient than a tax on applied nitrogen at low and middle levels of nitrogen reduction targets. However, at high levels of nitrogen reduction targets a tax on applied nitrogen performs better than other policies. Finally, this paper indicates that the government can use a two-part instrument (a tax on production of the dirty good plus a nitrogen reduction subsidy) to reduce nitrogen run-off from crop production. This policy is costless for a considerable range of nitrogen reduction target.

Table 1. Benchmark data (in millions of 2002 dollars except as otherwise noted)

Description	*Dirty Good*	*Clean Good*	*Total*
Value added at the producer price	87718	8908190	8995908
Subsidy (the price support)	9513	0	9513
Value added at the consumer price	78205	8908190	8986395
Export (payments for fertilizer)	15168	0	15168
Consumption at the consumer price	63037	8908190	8971228
Consumption at the producer price	70705	8908190	8978896
Leisure	0	0	2871434
Labor income	20894	5139655	5160549
Land income	27462	9912	37373
Capital income	24194	3758624	3782818
Land (million acres)	341	1222	1563
Homogenized land (million acres)	1148	415	1563
Capital stock	585325	22827675	23413000
Homogenized capital	149744	23263256	23413000
Fertilizer (nitrogen content in million metric tons)	12		12
Mechanical inputs	45089	8898279	8943367
Biological inputs	42629	9912	52541
Marginal income tax rate (percent)			40
Government expenditures (G)			1595427

Source: Taheripour (2005).

Table 2. Selected Parameters

Description of Parameter	*Value*	*Source*
Uncompensated labor supply elasticity	0.15	Goulder (1999)
Uncompensated price elasticity of demand for the dirty good	0.5	Steven et al. (2003)
Uncompensated price elasticity of demand for the clean good	1.0	Kyer and Maggs (1997)
Elasticity of substitution between the biological and the mechanical inputs in production of X	0.5	Horan et al. (2002)
Elasticity of substitution between land and nitrogen fertilizer in production of X	1.25	Horan et al. (2002)
Elasticity of substitution between labor and capital in production of X	0.585	Balisteri et al. (2002)
Elasticity of substitution between the biological and the mechanical inputs in production of Y	0.5	Horan et al. (2002)
Elasticity of substitution between labor and capital in production of Y	0.951	Balisteri et al. (2002)

Table 3. Impacts of the full subsidy-cut (in percentage except as otherwise noted)

Description	*Change in the variable due to subsidy cut*
Price of the dirty good	9.49
Price of the clean good	-0.02
Price of land	-5.94
Price of capital	-0.03
Production of the dirty good	-4.83
Domestic consumption of the dirty good	-4.23
Exports of the dirty good	-7.84
Production of the clean good	0.02
Applied nitrogen	-8.47
Land in production of the dirty good	-1.19
Land in production of the clean good	3.12
The equivalent variation (EV) in millions of 2002 dollars	1175.00

Table 4. Impacts of alternative policies to reduce nitrogen run-off (in percentage except as otherwise noted)

Variable	*Target: 10 percent reduction in nitrogen run-off*			
	Change in variable under alternative policies			
	Tax on nitrogen run-off	*Nitrogen run-off reduction subsidy*	*Tax on production of the dirty good*	*Two-part instrument*
Price of the dirty good	3.39	3.38	11.43	3.52
Price of the clean good	0.00	0.00	-0.02	0.00
Price of land	3.01	3.00	-7.02	2.81
Price of capital	0.00	-0.01	-0.02	-0.01
Production of the dirty good	-1.81	-1.81	-5.72	-1.88
Domestic consumption of the dirty good	-1.58	-1.59	-5.02	-1.65
Exports of the dirty good	-2.96	-2.95	-9.28	-3.06
Production of the clean good	0.00	-0.01	0.03	-0.01
Index of applied nitrogen per unit of output	-8.43	-8.43	-4.55	-8.28
Tax on income	0.00	0.06	-0.06	0.06
Land in production of the dirty good	0.56	0.56	-1.42	0.53
Land in production of the clean good	-1.47	-1.47	3.73	-1.38
Welfare (EV in millions of 2002 dollars)	354.88	140.27	1584.27	170.74
Rank based on EV	2	4	1	3

Table 4. (Continue)

Variable	*Target: 30 percent reduction in nitrogen run-off*			
	Change in variable under alternative policies			
	Tax on nitrogen run-off	*Nitrogen run-off reduction subsidy*	*Tax on production of the dirty good*	*Two-part instrument*
Price of the dirty good	11.93	11.90	44.65	13.45
Price of the clean good	0.00	-0.01	-0.07	-0.01
Price of land	10.44	10.39	-21.69	8.23
Price of capital	-0.02	-0.05	-0.09	-0.06
Production of the dirty good	-5.98	-5.99	-18.14	-6.68
Domestic consumption of the dirty good	-5.26	-5.27	-16.15	-5.89
Exports of the dirty good	-9.65	-9.62	-28.27	-10.74
Production of the clean good	-0.01	-0.03	0.09	-0.02
Index of applied nitrogen per unit of output	-25.55	-25.54	-14.49	-24.99
Tax on income	0.04	0.26	-0.07	0.23
Land in production of the dirty good	1.85	1.85	-4.98	1.49
Land in production of the clean good	-4.85	-4.86	13.07	-3.90
Welfare (EV in millions of 2002 dollars)	376.28	-462.89	2121.78	-140.20
Rank based on EV	2	4	1	3

Table 4. (Continue)

Variable	*Target: 50 percent reduction in nitrogen run-off*			
	Change in variable under alternative policies			
	Tax on nitrogen run-off	*Nitrogen run-off reduction subsidy*	*Tax on production of the dirty good*	*Two-part instrument*
Price of the dirty good	24.43	24.33	106.54	30.34
Price of the clean good	0.00	-0.03	-0.15	-0.04
Price of land	20.92	20.80	-37.46	12.63
Price of capital	-0.05	-0.13	-0.24	-0.13
Production of the dirty good	-11.25	-11.26	-32.36	-13.49
Domestic consumption of the dirty good	-9.95	-9.98	-29.30	-11.97
Exports of the dirty good	-17.86	-17.80	-47.94	-21.22
Production of the clean good	-0.02	-0.07	0.12	-0.04
Index of applied nitrogen per unit of output	-43.66	-43.65	-26.08	-42.21
Tax on income	0.14	0.66	0.29	0.54
Land in production of the dirty good	3.46	3.47	-10.10	2.22
Land in production of the clean good	-9.08	-9.10	26.51	-5.83
Welfare (EV in millions of 2002 dollars)	-1107.09	-3105.41	-4387.52	-2023.72
Rank based on EV	1	3	4	2

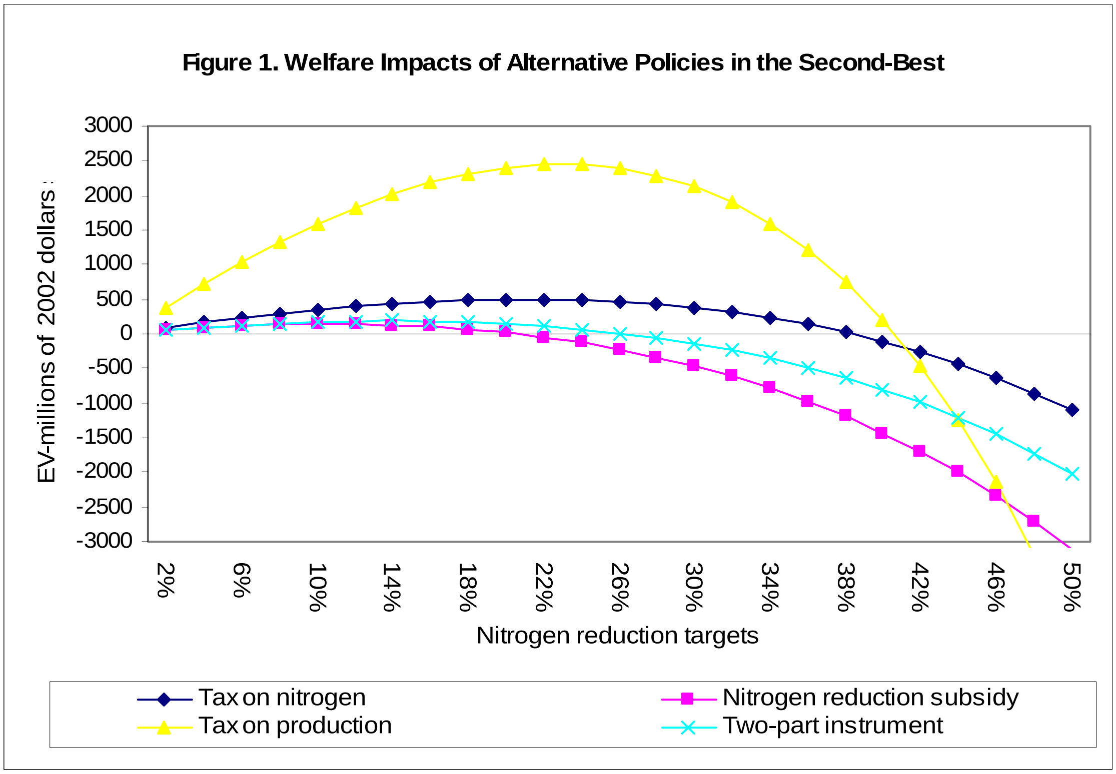


Figure 1. Welfare Impacts of Alternative Policies in the Second-Best
EV-millions of 2002 dollars
3000
2500
2000
1500
1000
500
0
-500
-1000
-1500
-2000
-2500
-3000
2%
6%
10%
14%
18%
22%
26%
30%
34%
38%
42%
46%
50%
Nitrogen reduction targets
Tax on nitrogen
Nitrogen reduction subsidy
Tax on production
Two-part instrument

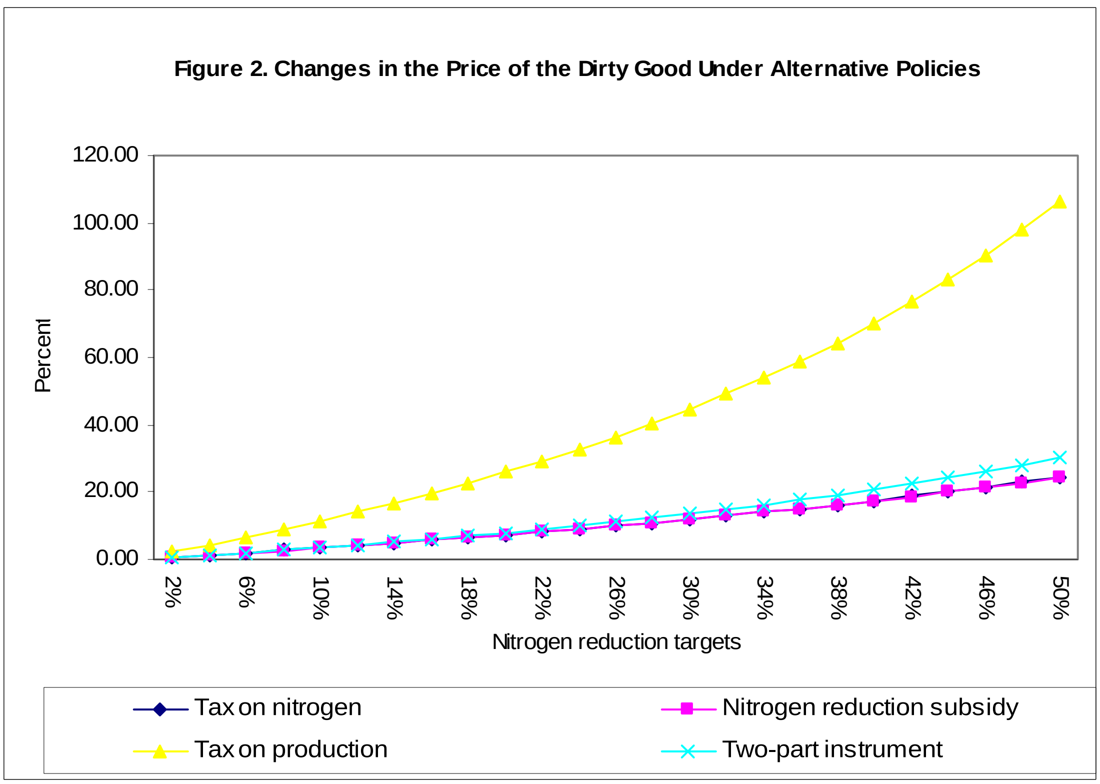


Figure 2. Changes in the Price of the Dirty Good Under Alternative Policies
Percent
120.00
100.00
80.00
60.00
40.00
20.00
0.00
2%
6%
10%
14%
18%
22%
26%
30%
34%
38%
42%
46%
50%
Nitrogen reduction targets
Tax on nitrogen
Nitrogen reduction subsidy
Tax on production
Two-part instrument

Figure 3. Changes in the Price of Land Under Alternative Policies

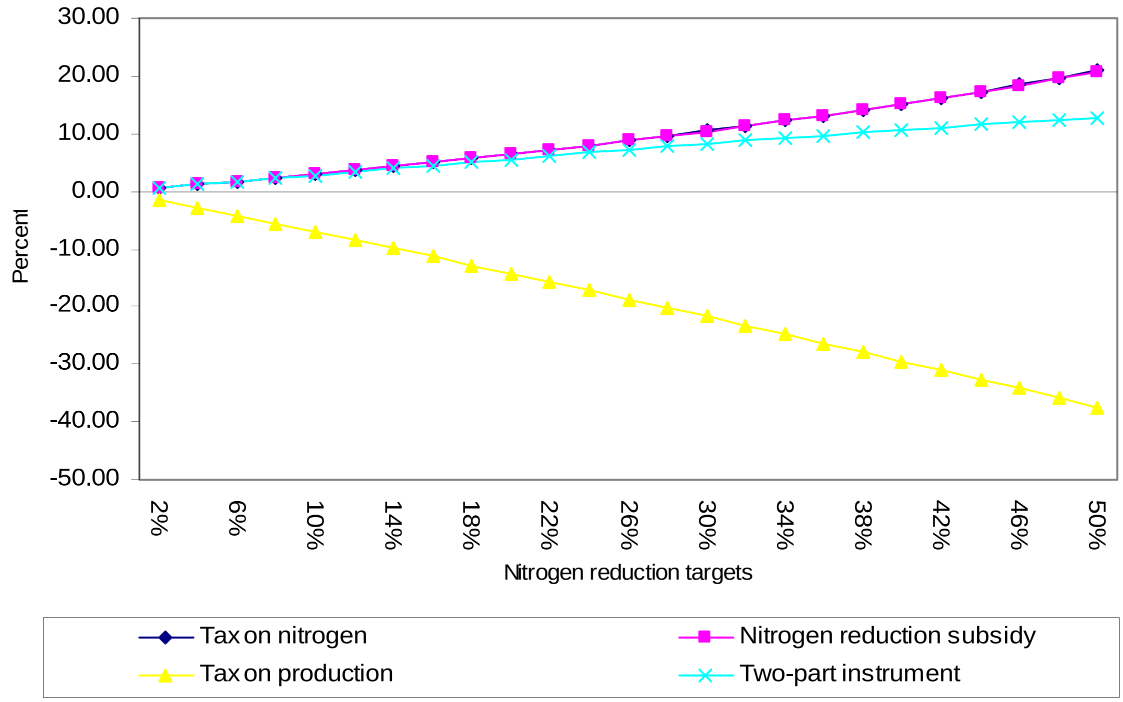


Figure 4. Changes in Domestic Consumption of the Dirty Good under Alternative Policies

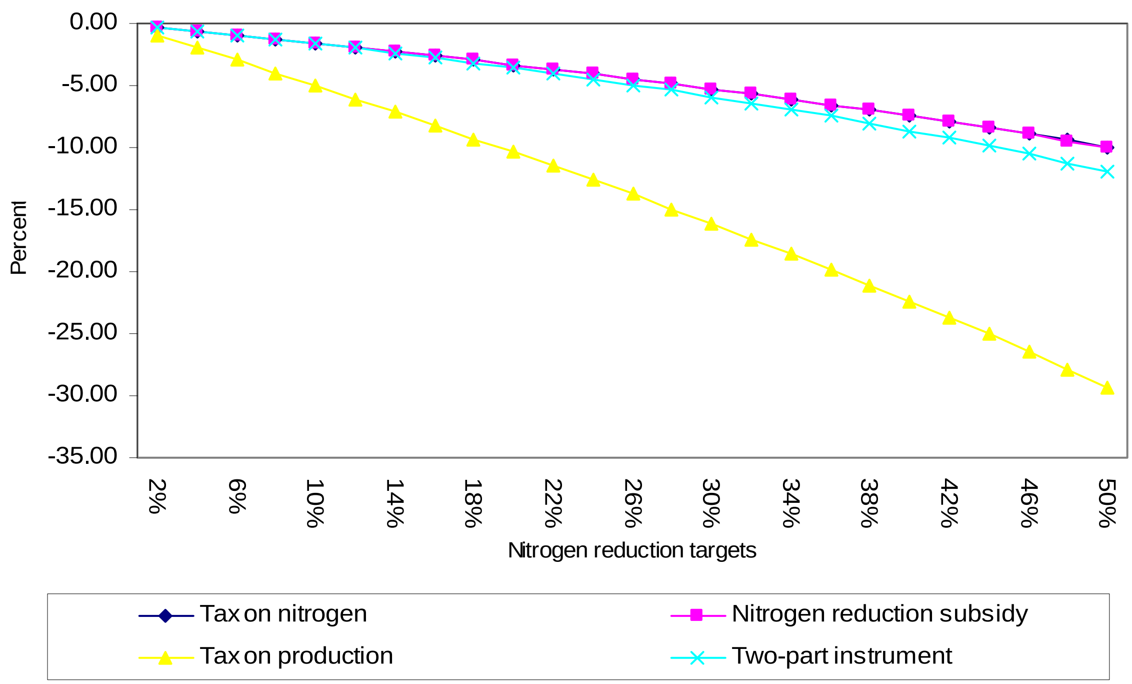


Figure 5. Changes in the Exports of the Dirty Good Under Alternative Policies

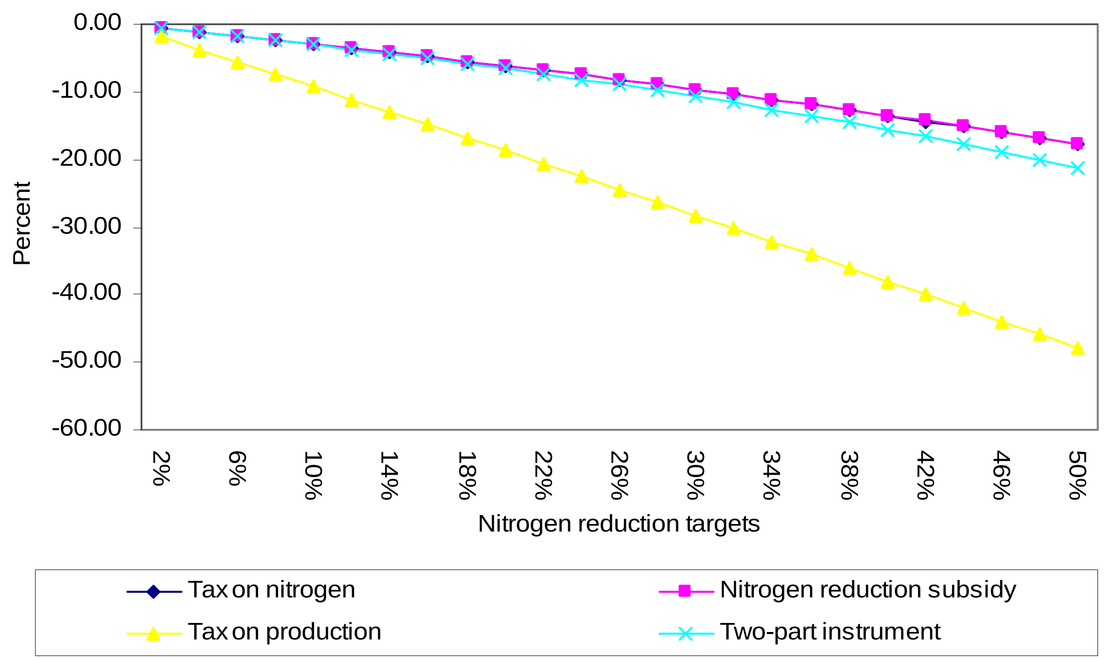
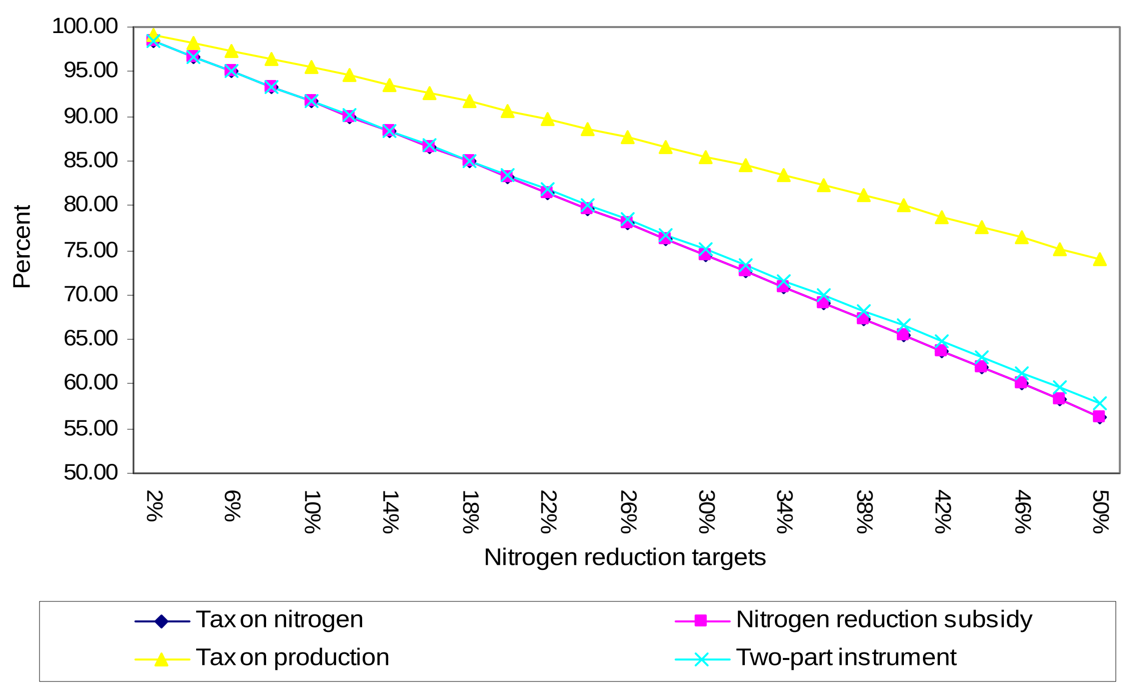


Figure 6. Index of Applied Nitrogen Per Unit of Output under Alternative Policies



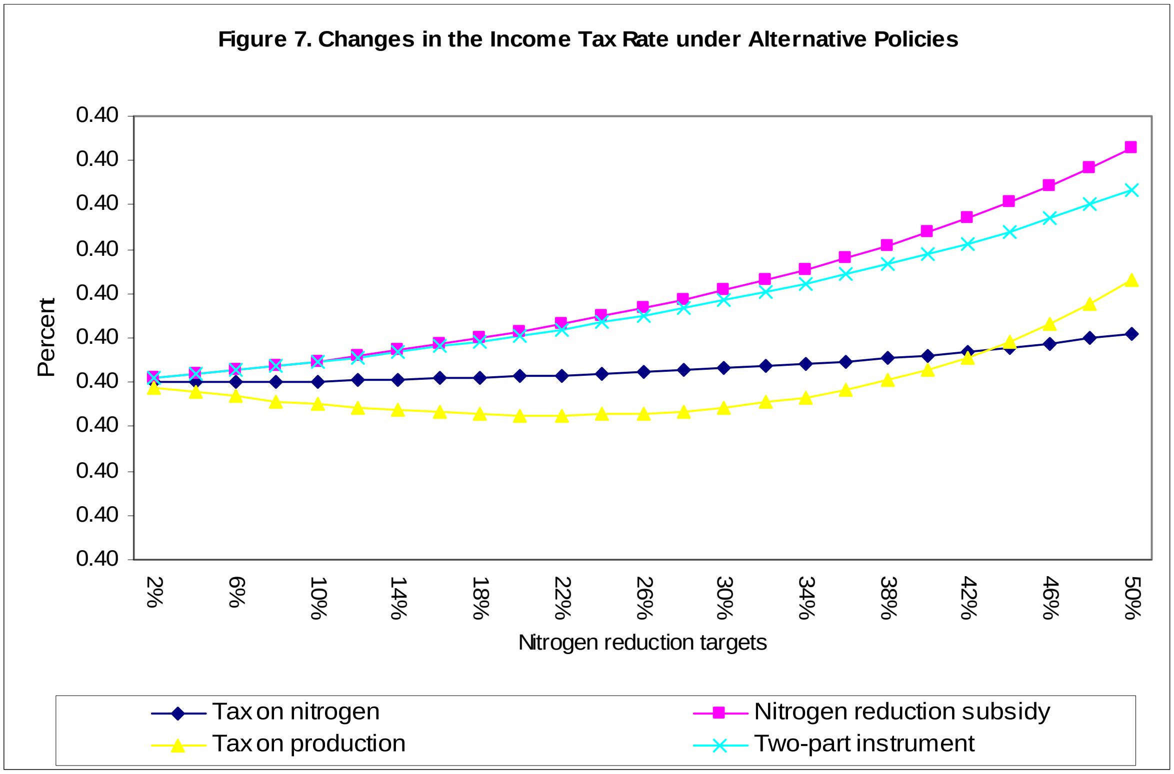


Figure 7. Changes in the Income Tax Rate under Alternative Policies
0.40
0.40
0.40
0.40
0.40
0.40
0.40
0.40
0.40
0.40
0.40
Percent
2%
6%
10%
14%
18%
22%
26%
30%
34%
38%
42%
46%
50%
Nitrogen reduction targets
Tax on nitrogen
Nitrogen reduction subsidy
Tax on production
Two-part instrument

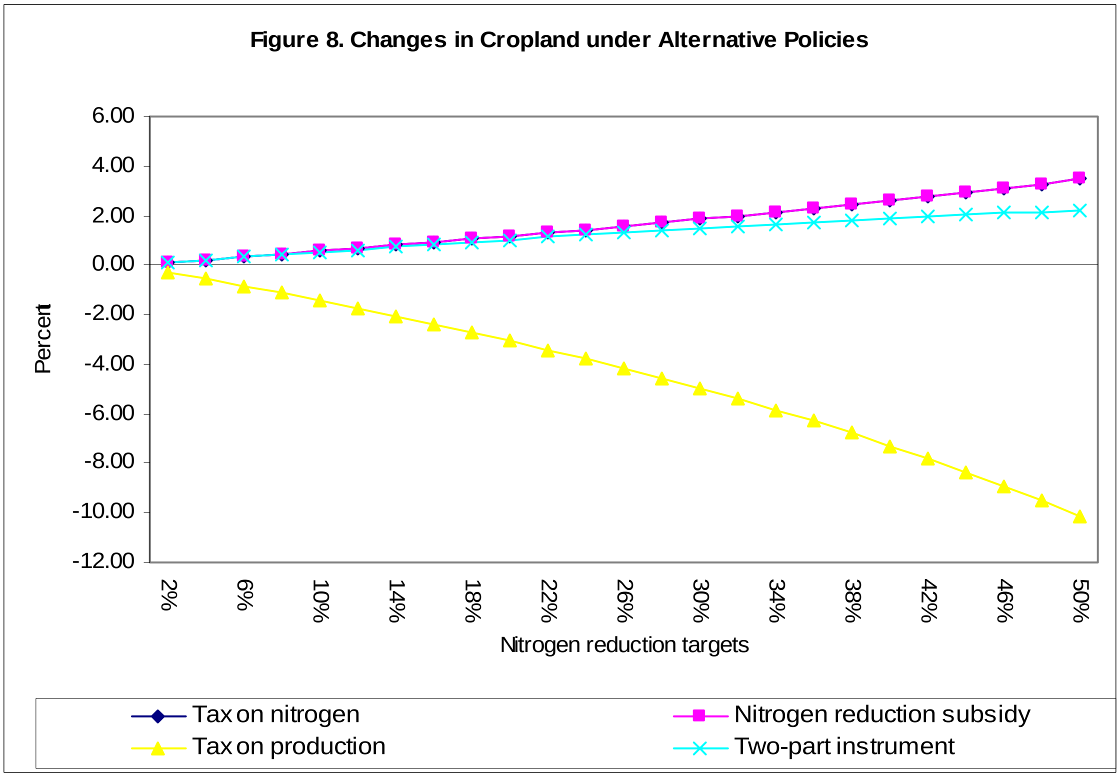


Figure 8. Changes in Cropland under Alternative Policies
6.00
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
-12.00
Percent
2%
6%
10%
14%
18%
22%
26%
30%
34%
38%
42%
46%
50%
Nitrogen reduction targets
Tax on nitrogen
Nitrogen reduction subsidy
Tax on production
Two-part instrument

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