Welfare Impacts of Alternative Public Policies for Environmental Protection in Agriculture in an Open Economy: A General Equilibrium Framework

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Abstract

This paper uses stylized analytical and numerical general equilibrium models to evaluate the welfare impacts of alternative policies for reducing nitrogen run-off from agricultural production in an open economy while recognizing the presence of distortionary agricultural support subsidies and factor income taxes. The alternative policies examined here are a nitrogen run-off tax, a nitrogen run-off reduction subsidy, a tax on the production of agricultural goods, a "two-part" instrument - a combination of the second and the third policies, and land retirement. The paper uses an analytical model to express the welfare impacts of each policy into several components and compares these components across alternative policies. From the analytical model the paper concludes that all alternative policies, except land retirement, may generate a double dividend 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. The numerical results indicate that all policies, except for land retirement, generate some welfare gains at low levels of nitrogen reduction targets in the first and second best settings when nitrogen and other inputs are substitutable. Gains are higher in the second best setting. As the level of nitrogen reduction increases, all policies become costly and they impose net welfare costs. These costs are higher in the second best setting. The numerical results also indicate that the relative efficiency of alternative policies is sensitive to the level of nitrogen reduction target.

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

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 stylized analytical and numerical general equilibrium models based on the theory of environmental regulation in the second best setting[1] in the context of an open economy to examine 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, a "two-part instrument" - a combination of the second and the third policies, and land retirement.

Using analytical and numerical general equilibrium models the paper shows that all alternative policies to reduce nitrogen-runoff, except for land retirement, may generate a double dividend 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. Using an extended definition of equivalent variation the paper ranks alternative policies at different levels of nitrogen reduction targets and shows that the tax on production of the agricultural good is the most efficient policy at lower levels of nitrogen

[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 2003).

reduction targets, but it is the worst one at higher levels. The paper also indicates that suggested budget reforms are welfare enhancing.

This paper proceeds as follows. Section 2 reviews the literature. Section 3 presents the analytical general equilibrium model and decomposes welfare impacts of alternative policies. Section 4 describes the numerical model and simulation results. Section 5 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 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

[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).
[6] Examples: Bovenberg and Mooij (1994), Fullerton and Metcalf (1997), Fullerton (1997), and Goulder et al. (1999).

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.

This paper removes restricting assumptions. It expands the space of primary inputs and includes essential inputs land, capital, and nitrogen fertilizer into the model. This modification makes substitution between primary inputs possible and improves reliability of the analytical and numerical results significantly[8]. Unlike the classical structure where the pre-existing distortionary labor tax is the focal point, this paper makes the interaction between the agri-environmental subsidies and the tax system the center of attention[9]. The "end of pipe" abatement technology is not an appropriate assumption in agriculture. It is not possible to separate abatement activities from production in agriculture. Hence, this paper does not separate these activities and define pollution as a part of production technology. Finally, since the US exports a large portion of its agricultural products to the world market and its domestic agri-environmental

[7] Examples: Ballard and Medema (1993), Parry (1997), Goulder, Parry, and Burtraw (1997), Parry, Williams, and Goulder (1998), and Goulder et al. (1999).
[8] For more discussion about this modification and its consequences see (Taheripour 2005).
[9] Shah and Larson (1992) in a partial equilibrium framework showed that, in the presence of subsidies on fossil fuels, carbon taxes generate a double dividend.

policies have the potential to affect prices of agricultural products in the world market, this paper evaluates welfare impacts of these policies through the trade channel[10] as well.

3. The Analytical 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 the clean good and their consumer prices are indicated with *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 $\bar{L}$, $\bar{R}$, and $\bar{K}$, 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 parts of agricultural product, x , at the domestic price of p_X . Indeed, we assume free trade with no tariff. The demand for export, $x(p_X)$, 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:

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

Land and capital are fully utilized. However, the consumer consumes some parts of labor endowments 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:

$$U = u(X^d, Y^d, l) - \phi(E) + \varphi(RES) . \qquad \text{(3-2)}$$

In this utility function X^d and Y^d indicate domestic demands for the dirty and the clean goods respectively, $l = \bar{L} - L$ is leisure and *L* is labor supply. In this utility function: *u(.)* is increasing

[10] Proost and Regemorter (2004) claim that an increase in the price of an exporting dirty good due to environmental

in consumption of both goods and leisure and is quasi-concave; $\phi(E)$ is increasing in nitrogen run-off and is weakly convex; and $\varphi(RES)$ is increasing in reserves and is weakly concave. The representative consumer takes *E* and *RES* as given. 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 the 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:

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

Where t_L, t_R, and t_K are flat tax rates on labor, land, and capital incomes respectively and π stands for profit from production activities if there is any. For simplicity assume there is no tax on profits and transfer payments. The following demands for goods, the supply of labor and the indirect utility function, *V*, can be derived from the utility maximization:

$$X^d = X(p_X, p_Y, (1-t_L), (1-t_R), (1-t_K), r_R, r_K, \bar{R}, \bar{K}, G, \pi)\,, \tag{3-4}$$

$$Y^d = Y(p_X, p_Y, (1-t_L), (1-t_R), (1-t_K), r_R, r_K, \bar{R}, \bar{K}, G, \pi)\,, \tag{3-5}$$

$$L = L(p_X, p_Y, (1-t_L), (1-t_R), (1-t_K), r_R, r_K, \bar{R}, \bar{K}, G, \pi)\,, \tag{3-6}$$

$$V = v(p_X, p_Y, (1-t_L), (1-t_R), (1-t_K), r_R, r_K, \bar{R}, \bar{K}, G, \pi) - \phi(E) + \varphi(RES)\,. \tag{3-7}$$

3.2. Producers and Production Functions

Production functions are assumed to be constant returns to scale (CRS) and they are represented as follows:

$$X = X(L_X, R_X, K_X, N_X)\,, \tag{3-8}$$

$$Y = Y(L_Y, R_Y, K_Y)\,. \tag{3-9}$$

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regulation may shift the burden of regulation to citizens of other countries.

Due to the assumption of CRS, the marginal and average cost functions of each good are equal to each other, and are represented below as functions of input prices:

$$C_X = C_X(r_R, r_K, p_N), \qquad (3\text{-}10)$$

$$C_Y = C_Y(r_K, r_R). \qquad (3\text{-}11)$$

Where C_X and C_Y are the marginal costs of the clean and the dirty goods respectively. The wage rate is the numeraire and hence it is drooped from the marginal cost functions.

Since markets are competitive, prices equal marginal costs in the absence of regulations:

$$p_X = C_X(r_R, r_K, p_N), \qquad (3\text{-}12)$$

$$p_Y = C_Y(r_K, r_R). \qquad (3\text{-}13)$$

Competitive markets and constant returns to scale technologies impose zero profits in both sectors in the absence of regulation.

In equilibrium, the supply of the clean good must equal its domestic demand and the supply of the dirty good must equal its domestic demand plus exports. That is:

$$Y = Y^d \qquad (3\text{-}14)$$

$$X = X^d + x(p_X) \qquad (3\text{-}15)$$

Furthermore, market clearing conditions for the primary and intermediate inputs should also be satisfied.

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 abstract 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:

$$E = \psi N_X . \qquad (3\text{-}16)$$

3.4. Alternative Policies

We examine five regulation 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*), a "two-part instrument"[11] (policy *IV*) - a combination of the second and the third policies, and land retirement (policy *V*). We use the two-part instrument to study a revenue neutral policy that reduce distortionary agricultural support subsidies and allocate released funds to subsidize activities that reduce nitrogen run-off.

Notice that since we assume a liner homogenous 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 a subsidy per unit of output, S_o, and seeks to control nitrogen run-off. The government also taxes incomes and pays a lump-sum transfer, *G*, to the consumer. The government is committed to a certain level of real lump-sum transfer. Therefore, it adjusts *G* with changes in

[11] 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 prices of consumption goods. At equilibrium government revenues must equal government expenditure under all alternative policies.

3.6. Definitions

To express results in short terms, we define the partial equilibrium marginal costs of public funds (MCPF) from the labor tax as follows:

$$MCPF = (1+M)\text{, where } M = \frac{-t_L(\frac{\partial L}{\partial t_L})}{L + t_L(\frac{\partial L}{\partial t_L})}. \qquad (3\text{-}17)$$

We also define the partial equilibrium marginal excess burden (MEB) of the labor tax as follows:

$$MEB = M' = \frac{-t_L(\frac{\partial L^C}{\partial t_L})}{L + t_L(\frac{\partial L}{\partial t_L})}. \qquad (3\text{-}18)$$

Where superscript of *C* indicates compensated derivative of labor supply with respect to the labor tax. Notice that these measures are basically distinguishing between the compensated and uncompensated labor supply elasticities. Finally, I define the share of lump-sum transfer in total income of the representative consumer with the following expression:

$$S_G = \frac{G}{(1-t_L)L + (1-t_R)r_R\bar{R} + (1-t_K)r_K\bar{K} + \pi + G}. \qquad (3\text{-}19)$$

We finally define λ as the consumer's marginal utility of income.

3.7. The Welfare Impacts of Alternative Policies

This section provides second order welfare assessments of alternative policies. We first disaggregate welfare impacts of alternative policies into several components and then we compare similar components across alternative policies to examine their cost effectiveness.

3.7.1. The Nitrogen Run-Off Tax

Assume nitrogen run-off is observable and the government uses tax on nitrogen run-off to reduce this pollution. Consider a revenue-neutral tax imposed on each unit of nitrogen run-off[12]. The government uses revenues from this tax to cut only tax on labor[13]. Under this policy the government budget constraint is as follows:

$$t_E E + t_L L + t_R r_R \overline{R} + t_K r_K \overline{K} = S_o X + G . \qquad (3\text{-}20)$$

And the consumer price of the dirty good is equal to:

$$p_X = C_X(r_R, r_K, p_N + \psi t_E) - S_o . \qquad (3\text{-}21)$$

Consider now an incremental increase in the nitrogen run-off tax rate. To examine welfare impacts of this policy, we first derived total differentiation of the utility function with respect to t_E. Then we found components of this equation through different steps. In these steps we used equations (3-1) and (3-3) through (3-21) to trace welfare impacts of the policy from all markets. In this process we applied Slutsky equation and Shepard's lemma to shrink final result into compact components[14]. Equation (3-22) shows the final result. In this equation each positive component represents a positive change in the welfare and vice versa.

$$\begin{aligned}
\frac{1}{\lambda}\frac{du}{dt_E} = {} & \underbrace{+\left(t_E \frac{dE}{dt_E}\right)}_{\text{Primary Pigouvian Effect}} \underbrace{+\left((1-\varepsilon_x)\frac{dp_X}{dt_E}x\right) - \left((1-\frac{d\varphi}{dRES})\frac{dRES}{dt_E}\right) - \left(p_X \frac{dx}{dt_E}\right)}_{\text{Primary Trade Effect}} \\
& \underbrace{-(1+M)S_o\left(\frac{dX^d}{dt_E} + \frac{dx}{dt_E}\right)}_{\text{Price Support Effect}} \underbrace{+M\left\{\left(E + t_E\frac{dE}{dt_E}\right) + \overline{R}\left(t_R\frac{dr_R}{dt_E}\right) + \overline{K}\left(t_K\frac{dr_K}{dt_E}\right)\right\}}_{\text{Revenue Recycling Effect}} \\
& \underbrace{-\left((1+M)t_L\left(-\frac{\partial L}{\partial p_X}\right) + M'(X-x)s_G\right)\frac{dp_X}{dt_E} - \left((1+M)t_L\left(-\frac{\partial L}{\partial p_Y}\right) + M'Ys_G\right)\frac{dp_Y}{dt_E}}_{\text{Tax Interaction Effect}} \\
& \underbrace{-(1+M)t_L\left\{\left(-\frac{\partial L}{\partial r_R}\right)\frac{dr_R}{dt_E} + \left(-\frac{\partial L}{\partial r_K}\right)\frac{dr_K}{dt_E}\right\}}_{\text{Income Replacement Effect}}
\end{aligned} \qquad (3\text{-}22)$$

[12] Alternatively, the government can impose a tax rate of $t_N = \psi t_E$ on consumption of nitrogen. These two tax policies are identical in this economy. For details see Taheripour (2005).

The first component which is labeled *primary Pigouvian effect* is well known in the literature and indicates the primary (marginal) costs of nitrogen run-off reduction[15]. The negative primary Pigouvian effect contains efficiency costs of two types of substitutions in the economy: substituting away from nitrogen fertilizer to other inputs in production of the dirty good and substituting away from consumption of the dirty good to the clean good and leisure. The first substitution effect reduces applied nitrogen per unit of output of the dirty good and the second one reduces consumption of the dirty good.

The second component which is labeled *primary trade effect* has three subcomponents. The first subcomponent measures changes in the export value of the dirty good due to an increase in t_E. This term is positive when the price elasticity of demand for the dirty good in the world market, ε_x, is less than one. In this case an increase in t_E decreases export volume but increases export value. Since the US is a large exporter of agricultural products, in the rest of this paper we assume $\varepsilon_x < 1$. The second subcomponent measures changes in the utility of reserves due to an increase in t_E. The sign of this effect depends on two factors: magnitude of the marginal utility of reserves, $\frac{d\varphi}{dRES}$, and direction of change in the reserves due to an increase in t_E, i.e. $\frac{dRES}{dt_E}$. An increase in the nitrogen run-off tax raises reserves because it reduces consumption of nitrogen and raises export value of the dirty good. Therefore, when the marginal utility of reserves is high, more than one, then the second component also is positive and improves welfare. Otherwise the second component is welfare reducing. Finally, the third subcomponent measures an increase in the utility due to diverted exports to domestic consumption.

Therefore, when $\varepsilon_x \leq 1$ and $\frac{d\varphi}{dRES} \geq 1$ then the trade effect is welfare enhancing because a part of the burden of the tax on nitrogen run-off is moved to the rest of the world. The overall primary impact of the nitrogen run-off tax in the first best setting depends on the magnitudes of the

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[13] It is straight forward to consider tax cut on other inputs. For a case with tax cut on other inputs see Taheripour (2005).

[14] More details on these steps are provided in Taheripour (2005).

[15] For a large amount of change in t_E, this primary effect is equal to the familiar loss triangle. This means: $\int_0^{t_E} \left(-t_E \frac{dE}{dt_E} \right) dt_E = t_E (E_0 - E)/2$.

primary effects. When the primary Pigouvian effect is less than the primary trade effect then it is possible to experience a double dividend in the first best setting.

The third component which is labeled *price support effect* reflects gains due to reduction in total payments for agricultural support subsidies. This term equals the product of the marginal cost of public funds and reduction in agricultural support subsidies due to reduction in production of the dirty good. This effect indeed indicates that an increase in t_E reduces the efficiency cost of agricultural subsidies. This is consistent with the conclusion of Lichtenberg and Zilberman (1986). They showed that pre-existing regulation reduces the cost of environmental regulation. Later on, I will show that when the magnitude of the price support effect is large enough it can also generate a double-dividend.

The fourth component which is labeled *revenue recycling effect* measures gains due to the labor tax cut. This secondary effect has three subcomponents. The first subcomponent shows the marginal revenues from an increase in t_E. The second and the third subcomponents measure the marginal revenues from changes in the prices of land and capital due to an increase in t_E. When nitrogen fertilizer and other inputs are substitutable, then an increase in the run-off tax raises the prices of land and capital eventually. Recall that labor is the numeraire good and wage rate equals one. This means that an increase in t_E raises government revenues from tax on land and capital as well. When the government uses new revenues to cut the tax rate on labor it decreases the efficiency cost of labor tax.

The fifth component which is labeled *tax interaction effect* reflects the efficiency costs due to interaction between changes in the prices of goods and the labor tax rate. This component has two major subcomponents. The first subcomponent is the tax interaction effect due to changes in the price of the dirty good. This is a positive and welfare reducing item, because the nitrogen run-off tax raises the price of the dirty good. The second subcomponent is the tax interaction effect due to changes in the price of the clean good. The sign of this subcomponent depends on the direction of changes in the price of the clean good. The price of the clean good is increasing in the price of capital and land. Hence, when prices of both capital and land go up then the price of the clean good also increases. This makes the overall tax interaction stronger. However, if the price of either capital or land decreases then the price of the clean good does not significantly change and it moderates the overall tax interaction effect.

The sixth component which is labeled *income replacement effect* reflects the impacts of the policy on the labor supply due to changes in the prices of land and capital. As discussed earlier, when nitrogen fertilizer and other inputs are substitutable, then an increase in t_E eventually raises the prices of land and capital. This means that an increase in t_E may raise share of non-labor income in the total income of the consumer. More rents discourage labor supply[16]. In this case, the sign of the income replacement effect is negative and welfare reducing. That is not the case when fertilizer and other inputs are not substitutable. Indeed, in a model with only one primary input the income replacement effect does not exist.

We now explain how pre-existing taxes and the agricultural support subsidies together affect the whole cost of the nitrogen run-off tax. For simplification we assume that t_R and t_K equal zero. In addition assume that $p_N = 0$ and that the economy does not export and hence there are no reserves. Under these simplifying assumptions equation (3-22) shrinks to equation (3-23). In this equation a letter mane is assigned to each effect and some effects are split into two terms. Notice that the trade effect is dropped from this equation because it is assumed that the world price of fertilizer is zero and the economy does not export.

$$\begin{aligned}\frac{1}{\lambda}\frac{du}{dt_E} = & \underbrace{+t_E\frac{dE}{dt_E}}_{A}\ \underbrace{-(1+M)S_o\frac{dX}{dt_E}}_{B}\ \underbrace{+M\left(E+t_E\frac{dE}{dt_E}\right)}_{C} \\ & \underbrace{-\left((1+M)t_L\left(-\frac{\partial L}{\partial p_X}\right)+M'Xs_G\right)\frac{dp_X}{dt_E}}_{D1}\underbrace{-\left((1+M)t_L\left(-\frac{\partial L}{\partial p_Y}\right)+M'Ys_G\right)\frac{dp_Y}{dt_E}}_{D2} \\ & \underbrace{-(1+M)t_L\left\{\left(-\frac{\partial L}{\partial r_R}\right)\frac{dr_R}{dt_E}+\left(-\frac{\partial L}{\partial r_K}\right)\frac{dr_K}{dt_E}\right\}}_{E}\end{aligned} \qquad (3\text{-}23)$$

Consider now a large increase in the nitrogen run-off tax from zero to t_E. The whole cost of this tax equals $\int_o^{t_E}(A+B+C+D1+D2+E)dt_E$. Define $\Delta A = \int_o^{t_E} A dt_E$ and so on for other terms.

[16] Numerical results verify this argument.

Given these definitions, the ratio of the whole cost of the nitrogen run-off tax relative to the primary cost is:

$$\frac{\Delta A + \Delta C + \Delta D1}{\Delta A} + \frac{\Delta B}{\Delta A} + \frac{\Delta D2 + \Delta E}{\Delta A} . \qquad (3\text{-}24)$$

Now, for a moment, suppose that labor is the only primary input in the model and the agricultural support subsidy does not exist. Also, assume that in the absence of regulation, all prices are equal to one. Under these assumptions, the cost ratio would be equal to $\frac{\Delta A + \Delta C + \Delta D1}{\Delta A}$. Based on Goulder et al. (1999), we can show that $\frac{\Delta A + \Delta C + \Delta D1}{\Delta A} = 1 + M$. Since M is positive, this means that the overall cost of the policy is larger than the primary cost. Hence, in the absence of the price support program, when there is only one primary input in the model, a double dividend does not exist.

Now we return land and capital to the model, remove the unit price assumption and maintain the assumption that there is no price support program. In this case, the cost ratio equals $(1 + M) + \frac{\Delta D2 + \Delta E}{\Delta A}$. Here the sign of $\frac{\Delta D2 + \Delta E}{\Delta A}$ depends on the direction of changes in the rental rates of land and capital. If $\frac{dr_R}{dt_E}$ and $\frac{dr_K}{dt_E}$ are positive and then $\frac{\Delta D2 + \Delta E}{\Delta A}$ is positive as well. In this case there is no chance for a double-dividend. However, if either $\frac{dr_R}{dt_E}$, $\frac{dr_K}{dt_E}$, or both is/are negative then there is a chance to observe a double dividend.

Now take into account the agricultural support subsidies. Here, when $\frac{\Delta B}{\Delta A}$ is large enough, it is possible to experience a double dividend, because the term $\frac{\Delta B}{\Delta A}$ is negative. This is an important result which indicates that the nitrogen run-off tax in the presence of a price support program can generate a double dividend and improve efficiency. The magnitude of $\frac{\Delta B}{\Delta A}$ depends on the amount of subsidies per unit of output and the size of changes in the production of the dirty good due to changes in the nitrogen run-off tax rate.

Finally, we return to the open economy with $p_N > 0$. As discussed before when $\varepsilon_x \leq 1$ and $\frac{d\varphi}{dRES} \geq 1$, then the trade effect is welfare enhancing and the tax on nitrogen run-off may generate a double dividend. .

In conclusion, the primary trade effect and the price support effect are two welfare improving items that can offset all or some parts of welfare reducing effects. When they offset all welfare reducing effects, a double dividend will occur.

3.7.2. The Nitrogen Run-Off Reduction Subsidy - the Nitrogen Reduction Subsidy

Traditionally, agricultural environmental regulation in the US has been supported by the government subsidies. Environmental subsidies are paid in different ways to encourage farmers to reduce pollution. The 2002 Farm Act allows the government to assist crop producers with conservation and environmental improvement on working land. Under this act cost sharing or incentive payments can be provided for a range of practices including but not restricted to nutrient management, conservation tillage (Westcott et al., 2002). Here, we study welfare impacts of these payments.

Suppose that the nitrogen run-off is observable and the government pays some subsidies, S_a, per unit of reduction in nitrogen run-off to improve water quality[17]. In addition, suppose the government pays subsidies per unit of output of the dirty good. It pays transfer payments as well. Subsidies and transfer payments are financed from taxes on all sources of income. The government budget constraint in this case is:

$$t_L L + t_R r_R \overline{R} + t_K r_K \overline{K} = S_o X + S_a (E_0 - E) + G . \qquad (3\text{-}25)$$

Here, E_0 represents the total amount of nitrogen run-off in the absence of environmental regulation. Other variables were defined earlier. Under this policy the price of the dirty good is:

$$p_X = C_X (r_R, r_K, p_N + \psi S_a) - S_o . \qquad (3\text{-}26)$$

The key difference between the nitrogen run-off reduction subsidy and the tax on nitrogen run-off is that the former policy raises the government expenditures. In addition, it generates some rents equal to $\pi = S_a E_0$ for the producer of the dirty good. Consider now an incremental increase in the nitrogen run-off reduction subsidy. Welfare impacts of this change are expressed into several components in equation (3-27). In this equation it is assumed that the government does not change t_R, t_K, and S_o.

$$\frac{1}{\lambda}\frac{du}{dS_a} = \underbrace{+\left(S_a\frac{dE}{dS_a}\right)}_{Primary\ Pigouvian\ Effect} \underbrace{+\left((1-\varepsilon_x)\frac{dp_X}{dS_a}x\right)-\left((1-\frac{d\varphi}{dRES})\frac{dRES}{dS_a}\right)-\left(p_X\frac{dx}{dS_a}\right)}_{Primary\ Trade\ Effect}$$
$$\underbrace{-(1+M)S_o\left(\frac{dX^d}{dS_a}+\frac{dx}{dS_a}\right)}_{Price\ Support\ Effect} \underbrace{+M\left\{\left(E-E_0+S_a\frac{dE}{dS_a}\right)+\bar{R}\left(t_R\frac{dr_R}{dS_a}\right)+\bar{K}\left(t_K\frac{dr_K}{dS_a}\right)\right\}}_{Revenue\ Recycling\ Effect} \tag{3-27}$$
$$\underbrace{-\left((1+M)t_L\left(-\frac{\partial L}{\partial p_X}\right)+M'(X-x)s_G\right)\frac{dp_X}{dS_a}-\left((1+M)t_L\left(-\frac{\partial L}{\partial p_Y}\right)+M'Ys_G\right)\frac{dp_Y}{dS_a}}_{Tax\ Interaction\ Effect}$$
$$\underbrace{-(1+M)t_L\left\{\left(-\frac{\partial L}{\partial r_R}\right)\frac{dr_R}{dS_a}+\left(-\frac{\partial L}{\partial r_K}\right)\frac{dr_K}{dS_a}+\left(-\frac{\partial L}{\partial \pi}\right)E_0\right\}}_{Income\ Replacement\ Effect}$$

A comparison of (3-22) with (3-27) indicates that in the latter equation $E_0 - E$ is replaced with E. In addition, in equation (3-27) there is a new term $\frac{\partial L}{\partial \pi}E_0$ in the income replacement effect. Other corresponding components and terms in these equations look similar.

Principally, the nitrogen run-off tax and the nitrogen run-off reduction subsidy have similar impacts on producers' resource allocation decisions. However, the former policy is more efficient than the latter one for two main reasons. Under the latter policy the government raises income tax rates, because it needs more revenue to finance the policy. If the government raises revenues from the labor tax, it generates efficiency costs. Indeed, this policy generates a reveres revenue recycling effect. In addition, the subsidy policy reduces labor supply more than the tax policy. Notice that both policies discourage labor supply because they reduce the real wage. However, the subsidy policy generates some rents which reduce labor supply more.

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[17] Alternatively, the government can pay $S_N = \psi S_a$ on each unit of reduction in consumption of nitrogen. These two subsidy policies are identical in this economy. For details see Taheripour (2005)

3.7.3 Tax on Output of the Dirty Good - Reduction in Subsidies per Unit of Output

Suppose the government levies a flat tax rate, t_X, on each unit of output of the dirty good to reduce nitrogen run-off[18]. The government uses revenues from this tax to reduce income taxes. Under this policy the government budget constraint would be equal to:

$$t_X X + t_L L + t_R r_R \bar{R} + t_K r_K \bar{K} = S_o X + G . \tag{3-28}$$

The key difference between the nitrogen run-off tax and the tax on output of the dirty good is that the latter policy does not affect the farmer's resource allocation decision because it does not change the price of nitrogen. Therefore, the farmer does not reduce applied nitrogen per unit of output. In this case the price of the dirty good is equal to:

$$p_X = C_X(r_R, r_K, p_N) + t_X - S_o . \tag{3-29}$$

Consider now an incremental increase in the tax on output of the dirty good. Welfare impacts of this change are expressed into several components in equation (3-30). In this equation it is assumed that the government does not change t_R, t_K, and S_o.

$$\begin{aligned}
\frac{1}{\lambda}\frac{du}{dt_X} = \; & \underbrace{+\left(t_X \frac{dE}{dt_X}\right)}_{\text{Primary Pigouvian Effect}} \; \underbrace{+\left((1-\varepsilon_x)\frac{dp_X}{dt_X}x\right) - \left((1-\frac{d\varphi}{dRES})\frac{dRES}{dt_X}\right) - \left(p_X \frac{dx}{dt_X}\right)}_{\text{Primary Trade Effect}} \\
& \underbrace{-(1+M)S_o\left(\frac{dX^d}{dt_X} + \frac{dx}{dt_X}\right)}_{\text{Price Support Effect}} \; \underbrace{+M\left\{\left(X + t_X \frac{dX}{dt_X}\right) + \bar{R}\left(t_R \frac{dr_R}{dt_X}\right) + \bar{K}\left(t_K \frac{dr_K}{dt_X}\right)\right\}}_{\text{Revenue Recycling Effect}} \\
& \underbrace{-\left((1+M)t_L\left(-\frac{\partial L}{\partial p_X}\right) + M'(X-x)s_G\right)\frac{dp_X}{dt_X} - \left((1+M)t_L\left(-\frac{\partial L}{\partial p_Y}\right) + M'Ys_G\right)\frac{dp_Y}{dt_X}}_{\text{Tax Interaction Effect}} \\
& \underbrace{-(1+M)t_L\left\{\left(-\frac{\partial L}{\partial r_R}\right)\frac{dr_R}{dt_X} + \left(-\frac{\partial L}{\partial r_K}\right)\frac{dr_K}{dt_X}\right\}}_{\text{Income Replacement Effect}}
\end{aligned} \tag{3-30}$$

A comparison of (3-22) with (3-30) indicates that the nitrogen run-off tax and the output tax generate different primary Pigouvian effects. In addition, they are different in their revenue

[18] This policy can be considered as a reduction in the distortionary agricultural subsidies as well.

recycling effects. Other corresponding components and terms look similar. The differences between the welfare impacts of these policies are discussed in detail in the rest of this subsection.

As argued before, the nitrogen run-off tax reduces run-off from two channels: from reduction in used nitrogen per unit of output and from reduction in consumption of the dirty good. Contrary to the nitrogen run-off tax, the output tax does not raise the price of nitrogen run-off. Therefore, it does not reduce used nitrogen per unit of output. However, it increases the price of the dirty good sharply which eventually reduces its demand. Reduction in demand forces less production of the dirty good which eventually leads to less nitrogen run-off. These arguments can be used to conclude that the tax on output generates higher primary costs than the tax on nitrogen run-off because the former policy causes a larger reduction in consumer surplus.

While the tax on output generates higher primary Pigouvian costs, it generates larger trade gains, because the price of the dirty good grows faster under this policy. Compared to the tax on nitrogen run-off, reduction in the production of the dirty good is larger under the tax on production. Hence, this policy drives up the price of the dirty good faster and generates more gains from trade channel.

In short, in the first best setting, whether the tax on the output of the dirty good is more or less efficient than the nitrogen run-off tax depends on the magnitudes of the primary Pigouvian and the trade effects of these policies.

In what follows the secondary impacts are compared. As argued $\frac{dX}{dt_E} < \frac{dX}{dt_X}$. This implies that $S_o \frac{dX}{dt_E} < S_o \frac{dX}{dt_X}$. This means that the tax on output of the dirty good generates a higher price support effect which is an advantage for this policy in the second best. In addition, this policy generates a larger revenues recycling effect, because it raises the government revenues faster than the tax on nitrogen. This provides an additional advantage for this policy as well. On the other hand, the tax interaction effect is larger under the tax on output, because it raises the price of the dirty good faster. This is a major disadvantage for this policy in the second best. The magnitudes of the income replacement effects of these policies also matter, but it is difficult to compare them without more simplifying assumptions.

In general, in the second best setting, whether the tax on output of the dirty good is more or less efficient than the tax on nitrogen depends on the magnitudes of the primary and secondary impacts of these policies.

3.7.4. The Two-Part Instrument

Consider now a revenue neutral subsidy reform in agriculture. Suppose the government reduces the distortionary agricultural support subsidies per unit of agricultural good and uses released revenues to increase the nitrogen run-off reduction subsidies. Indeed, this is a combination of an output tax and a nitrogen run-off reduction subsidy. This reform is similar to the two-part instrument which is suggested by Fullerton (1997). Fullerton has suggested a tax on output plus a subsidy to all clean inputs but the two-part instrument in this paper is a tax on output plus a nitrogen run-off reduction subsidy.

Here it is assumed that $dt_L = dt_R = dt_K = 0$. This means that the government does not use released revenues to cut income taxes. The welfare impacts of this reform are presented in equation (3-31).

$$\frac{1}{\lambda}\frac{du}{dS_a}\Big|_{dS_a=dt_X} = \underbrace{+\left(S_a\frac{dE}{dS_a}\right)}_{\text{Primary Pigouvian Effect}} \underbrace{+\left((1-\varepsilon_x)\frac{dp_X}{dS_a}x\right)-\left((1-\frac{d\varphi}{dRES})\frac{dRES}{dS_a}\right)-\left(p_X\frac{dx}{dS_a}\right)}_{\text{Primary Trade Effect}}$$

$$\underbrace{-S_o\left(\frac{dX^d}{dS_a}+\frac{dx}{dS_a}\right)}_{\text{Price Support Effect}} \underbrace{-\left(t_L\left(-\frac{\partial L}{\partial p_X}\right)+M'(X-x)s_G\right)\frac{dp_X}{dS_a}-\left(t_L\left(-\frac{\partial L}{\partial p_Y}\right)+M'Ys_G\right)\frac{dp_Y}{dS_a}}_{\text{Tax Interaction Effect}} \tag{3-31}$$

$$\underbrace{-t_L\left\{\left(-\frac{\partial L}{\partial r_R}\right)\frac{dr_R}{dS_a}+\left(-\frac{\partial L}{\partial r_K}\right)\frac{dr_K}{dS_a}+\left(-\frac{\partial L}{\partial \pi}\right)E_0\right\}}_{\text{Income Replacement Effect}}$$

A comparison of (3-22) and (3-27) with (3-31) indicates that the tax on nitrogen, the nitrogen reduction subsidy, and the two-part instrument generate similar primary effects.

The comparison also reveals that the tax on nitrogen generates revenue recycling effect, the nitrogen reduction subsidy generates reverse revenue recycling effect, and the two-part instrument does not generate the revenue recycling effect. Hence, from this perspective, the two-part policy is more costly than the nitrogen run-off tax but is more efficient than the nitrogen run-off reduction subsidy. In addition, the two-part instrument generates weaker price support effect because under this policy the price support effect does not scaled by *(1+M)*.

While the two-part instrument does not generate a revenue recycling effect and it has weaker price support effect, it can be argued that the tax interaction effect and the income replacement effect under this policy are smaller than the corresponding effects under the nitrogen run-off tax and the nitrogen reduction subsidy. Under the latter policies, the tax interaction effect and the income replacement effect are enlarged by the marginal cost of public funds. The two-part instrument generates moderate secondary impacts because it does not seriously affect the labor market. This argument is confirmed by the simulation results later.

In short, it is reasonable to argue that the overall welfare impact of the two-part instrument is less than the overall impact of the tax on nitrogen and more than the overall impact of the nitrogen reduction subsidy. This argument is also confirmed by the simulation results.

3.7.5. Land Retirement

Suppose that the government wants to reduce nitrogen run-off by retiring some land. The government can finance this policy by taxing sources of incomes and/or reducing subsidies per unit of output. Assume that the government rents land from the owner (the consumer) at the market price and assume total expenditure of this policy equals to $r_R R_G$. Here, R_G stands for the retired lands. The government budget constraint for this policy is:

$$t_L L + t_R r_R \bar{R} + t_K r_K \bar{K} = r_R R_G + S_o X + G \qquad (3\text{-}32)$$

Under this policy, the farmer does not have an incentive to reduce nitrogen run-off per unit of output because it does not change the price of the polluting input. Under this policy the price of the dirty good would be equal to:

$$p_X = C_X(r_R, r_K, p_N) - S_o \qquad (3\text{-}33)$$

The welfare impacts of an incremental change in the retired lands are presented and labeled in equation (3-34).

$$
\begin{aligned}
\frac{1}{\lambda}\frac{du}{dR_G} = & \underbrace{-\left(C_X(r_R, r_K, p_N)\frac{\partial X}{dR_G}\right)}_{Primary\ Pigouvian\ Effect} \underbrace{+\left((1-\varepsilon_x)\frac{dp_X}{dR_G}x\right)-\left((1-\frac{d\varphi}{dRES})\frac{dRES}{dR_G}\right)-\left(p_X\frac{dx}{dR_G}\right)}_{Primary\ Trade\ Effect} \\
& \underbrace{-(1+M)S_o\left(\frac{dX^d}{dR_G}+\frac{dx}{dR_G}\right)}_{Price\ Support\ Effect} \underbrace{+M\left\{-\left(r_R+R_G\frac{\partial r_R}{dR_G}\right)+\bar{R}\left(t_R\frac{dr_R}{dR_G}\right)+\bar{K}\left(t_K\frac{dr_K}{dR_G}\right)\right\}}_{Revenue\ Recycling\ Effect} \\
& \underbrace{-\left((1+M)t_L\left(-\frac{\partial L}{\partial p_X}\right)+M'(X-x)s_G\right)\frac{dp_X}{dR_G}-\left((1+M)t_L\left(-\frac{\partial L}{\partial p_Y}\right)+M'Ys_G\right)\frac{dp_Y}{dR_G}}_{Tax\ Interaction\ Effect} \\
& \underbrace{-(1+M)t_L\left\{\left(-\frac{\partial L}{\partial r_R}\right)\frac{dr_R}{dR_G}+\left(-\frac{\partial L}{\partial r_K}\right)\frac{dr_K}{dR_G}\right\}}_{Income\ Replacement\ Effect}
\end{aligned}
\quad (3\text{-}34)
$$

Equation (3-34) indicates that the primary Pigouvian effect of this policy equals to the value of marginal product of land. Comparing with the nitrogen run-off tax, the land retirement generates higher primary Pigouvian effect because this policy does not force farmers to reduce nitrogen run-off per unit of output. This policy raises the rental rate of land, because endowment of land is fixed and taking away some land from production raises the marginal product of the active land. When land and other inputs, in particular nitrogen, are substitutable then an increase in the rental rate of land forces farmers to use more capital, labor, or even more nitrogen fertilizer per unit of output. The government can also generate an incentive for farmers to transfer some land from sector *Y* to sector *X*, if targets only planted land in sector *X.* Therefore, this policy does not reduce used nitrogen per unit of output when nitrogen fertilizer and other inputs are substitutable. Indeed, this policy restricts both sectors because reduction in land raises prices of capital and land and both sectors suffer from this policy. Therefore, as long as land and other inputs are substitutable land retirement fails to reduce nitrogen per unit of output. This raises the cost of this policy significantly. When inputs are complements and it is not possible to substitute nitrogen with other inputs then the land retirement can be considered as an attractive policy.

4. The Numerical Model

The numerical model follows the analytical model and it depicts the US economy at a macro level. The representative consumer derives utility from goods and leisure according to the following two-level constant elasticity of substitution (CES) utility function:

$$U = \left\{ \alpha_l (l)^{\frac{\sigma_u - 1}{\sigma_u}} + (1-\alpha_l) \left(\left(\alpha_X X_d^{\frac{\sigma_C - 1}{\sigma_C}} + (1-\alpha_X) Y_d^{\frac{\sigma_C - 1}{\sigma_C}} \right)^{\frac{\sigma_C}{\sigma_C - 1}} \right)^{\frac{\sigma_u - 1}{\sigma_u}} \right\}^{\frac{\sigma_u}{\sigma_u - 1}} + \varphi RES - \phi E \,, \quad (4\text{-}1)$$

In this utility function 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.

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[19]. 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, first, production is a function of two composite inputs: which are called mechanical and biological inputs. Second, production of each composite input is a 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:

$$O_i = \gamma_{ii} \left\{ \alpha_{ii} B_i^{\rho_{ii}} + (1-\alpha_{ii}) M_i^{\rho_{ii}} \right\}^{\frac{1}{\rho_{ii}}}, \qquad \text{for } i=X \text{ and } i=Y, \qquad (4\text{-}2)$$

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

$$M_i = \gamma_{Mi} \left\{ \alpha_{Mi} L_i^{\rho_{Mi}} + (1-\alpha_{Mi}) K_i^{\rho_{Mi}} \right\}^{\frac{1}{\rho_{Mi}}}, \qquad \text{for } i=X \text{ and } i=Y. \qquad (4\text{-}4)$$

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

Where 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, and $\rho_{ii} = \frac{\sigma_{ii} - 1}{\sigma_{ii}}$, $\rho_{Bi} = \frac{\sigma_{Bi} - 1}{\sigma_{Bi}}$, $\rho_{Mi} = \frac{\sigma_{Mi} - 1}{\sigma_{Mi}}$. 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 numerical model and calibration process are described in Taheripour (2005) in detail. In the rest of this section the benchmark data and simulation results are presented.

4.1. The 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[20], 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[21]. 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

[20] See Sullivan et al. (1989)
[21] For example see Yen et al. (2003)

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.

4.2. Simulation results

The numerical model is solved for several values of nitrogen reduction targets (from 0 to 50 percent) under each of the alternative policies in the first and second best settings. Simulation results indicate that all policies can reduce consumption of nitrogen except for the land retirement. This policy fails to reduce consumption of nitrogen for two reasons. First, it fails to discourage consumption of the dirty good. Second, it encourages farmers to use more nitrogen per unit of output. Since nitrogen fertilizer and land are substitutable, imposing any restriction on land raises consumption of nitrogen fertilizer per unit of output. Therefore, the early conclusion is that the land retirement is the worst policy among alternative policies. The rest of this section considers the land retirement as an ineffective policy and emphasizes the welfare impacts of the remaining policies.

To facilitate the comparison among alternative policies, an *equivalent variation* measure (*EV*) with the following extended definition[22] is calculated[23] 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. The calculated *EV*s for the alternative policies in the first and second best settings are explained in the following subsections.

[22] This definition is designed based on the question 3.I.12 of Mas-Collel, Whinston, and Green (1995).

4.2.1. Costs of Policies in the First Best

The welfare impacts of the alternative policies for several values of nitrogen reduction targets in the first best setting are depicted in figure 1. This figure indicates that in the first best setting, the tax on nitrogen-run off and the nitrogen reduction subsidy are identical[24]. In addition, figure 1 indicates in the first best setting all policies generate some welfare gains at low levels of nitrogen reduction targets. That is, we observe gains for levels below 40 percent for the nitrogen run-off tax, below, 36 percent for the tax on production, and finally below 46 percent for the two part instrument. The maximum amounts of gains that these policies generate are about $470 million, $1600 million, and $550 million, respectively. These numbers appear at 22 percent, 20 percent, and 26 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. Recall from the analytical model, alternative policies generate two effects in the first best setting: the Pigouvian and trade effects. As it is explained in section 3, the Pigouvian effect reduces welfare and the trade effect improves it. The numerical results indicate that at lower levels of nitrogen reduction, the primary trade effect is larger than the primary Pigouvian effect. This relationship is reversed at higher levels of nitrogen reduction targets. This indicates that the Pigouvian effect grows faster than the trade effect as the level of nitrogen reduction target goes up. The extra gains at lower levels of nitrogen reduction generate a double dividend.

Figure 1 also reveals that the tax on the production of the dirty good is the most efficient policy at lower levels of nitrogen reduction targets, but is the worst one at higher levels. This policy is the most efficient policy at lower levels of nitrogen reduction targets because it raises the price of the dirty good sharply and generates a large trade effect at these levels. The trade effects of the other policies are not that large because they raise the price of the dirty good moderately. The tax on the production of the dirty good is the worst policy at higher levels of nitrogen reduction targets because unlike the other policies it does not encourage producers to use less nitrogen per unit of output. Reduction in consumption of nitrogen under this policy is due to substitution in consumption only. This imposes a considerable amount of cost at higher levels of nitrogen

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

[24] Note that there is no entry and exit in this economy.

reduction targets. Finally, figure 1 indicates that the two-part instrument is slightly more efficient than the nitrogen run-off tax.

4.2.2. Costs of Policies in the Second Best

To facilitate comparison between the first and second best results, the overall welfare impacts of the alternative policies in the second best world are depicted in figure 2. A comparison of the second best with the first best welfare impacts of the alternative policies reveals that:

- In the second best the tax on nitrogen run-off and the nitrogen run-off reduction subsidy are in their welfare impacts. In the second best setting the former policy is more efficient than the latter one.

- In the second best, similar to the first best, alternative policies enhance welfare until they reach some levels of nitrogen reduction targets, at which point they become costly. In the second best setting, 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.

- At low/high levels of nitrogen reduction targets, alternative policies generate more gains/costs in the second best than the first best.

- In the second best, similar to the first best, the tax on production of the dirty good is the most efficient policy until its turning point. After that, this policy is the worst one and the tax on nitrogen is the best policy.

- Regardless of the tax on production, the tax on nitrogen is the best and the nitrogen reduction subsidy is the worst policy at all levels of nitrogen reduction in the second best. The two part instrument is always placed in between these two policies.

At low levels of nitrogen reduction targets, the tax on production and the tax on nitrogen perform better than other policies in the second best. This is because of the following reasons. First, these policies raise government revenues and generate revenue recycling effect. Second, they reduce government expenditures due to reduction in costs of price support program and accelerate the revenue recycling effect. Third, they raise the price of the dirty good and reduce pre-existence distortionary effects of the price support programs. The last reason also explains why the tax on production generates considerable gains at lower levels of nitrogen reduction targets. The price support program which indeed is a negative tax on production is a distortionary policy by itself regardless of its impacts on the government budget constraint. The tax on production indeed eliminates all distortionary impacts of this program at lower levels of nitrogen reduction targets which makes this policy more efficient at lower levels of nitrogen reduction.

Finally, while the tax on nitrogen is more efficient than the two-part instrument at all levels of nitrogen reduction targets, the difference between the welfare impacts of these policies is not that large especially at the lower levels of nitrogen reduction targets. The difference between the welfare impacts of these policies is significant only at very high levels of nitrogen reduction targets. This means that the two-part instrument is an appropriate instrument when the tax on nitrogen run-off is not available.

5. 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.

6. Conclusion

This paper has considered the choice between alternative instrument policies for environmental regulation in agriculture in an open economy in the second best setting, where there exist distortionary factor taxes and distortionary agricultural support subsidies. It has developed analytical and numerical models to assess and compare welfare impacts of five policies: a nitrogen run-off tax, a nitrogen run-off reduction subsidy, a tax on the production of agricultural goods, land retirement, and a “two-part” instrument - a combination of the second and the third policies.

The paper finds that when nitrogen and other inputs, in particular land, are substitutable then the land retirement is the worst policy among alternative policies. The paper indicates that all alternative policies, except land retirement, may generate a double dividend because of agricultural support subsidies and exports of agricultural products.

The numerical results indicate that all alternative policies, except land retirement, generate some gains at lower levels of nitrogen reduction targets in the first and second best settings. Gains are higher in the second best. At higher levels of nitrogen reduction target all policies become costly and impose more costs in the second best. The relative efficiency of alternative policies is sensitive to the level of the nitrogen reduction target. For example, the tax on the production of the dirty agricultural good is the most efficient policy at lower levels of nitrogen reduction targets, but is the worst at higher levels.

Finally, the paper indicates that the difference between the welfare impacts of the tax on nitrogen run-off and the two-part instrument is insignificant, in particular at low levels of nitrogen reduction targets. This asserts that the government can use the two-part instrument to control non-observable nitrogen run-off in agriculture.

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)

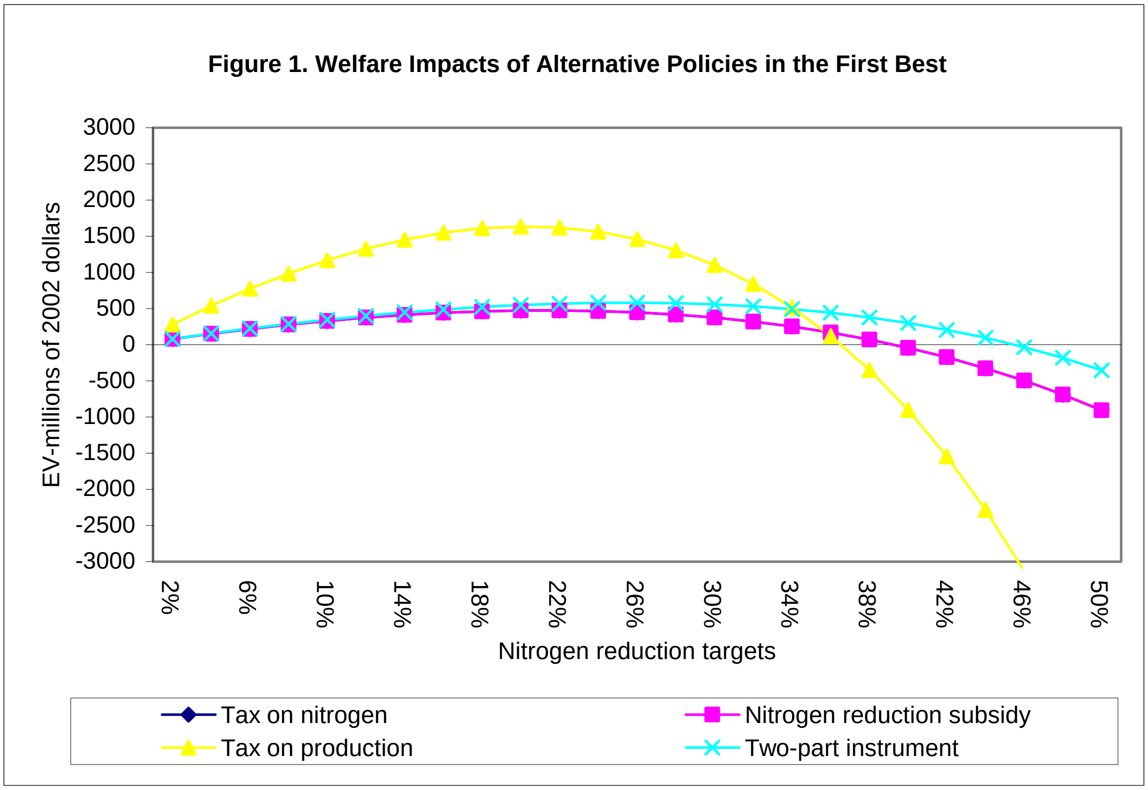
Figure 1. Welfare Impacts of Alternative Policies in the First Best
3000
2500
2000
1500
1000
500
0
-500
-1000
-1500
-2000
-2500
-3000
EV-millions of 2002 dollars
2%
6%
10%
14%
18%
22%
26%
30%
34%
38%
42%
46%
50%
Nitrogen reduction targets
Tax on nitrogen
Tax on production
Nitrogen reduction subsidy
Two-part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

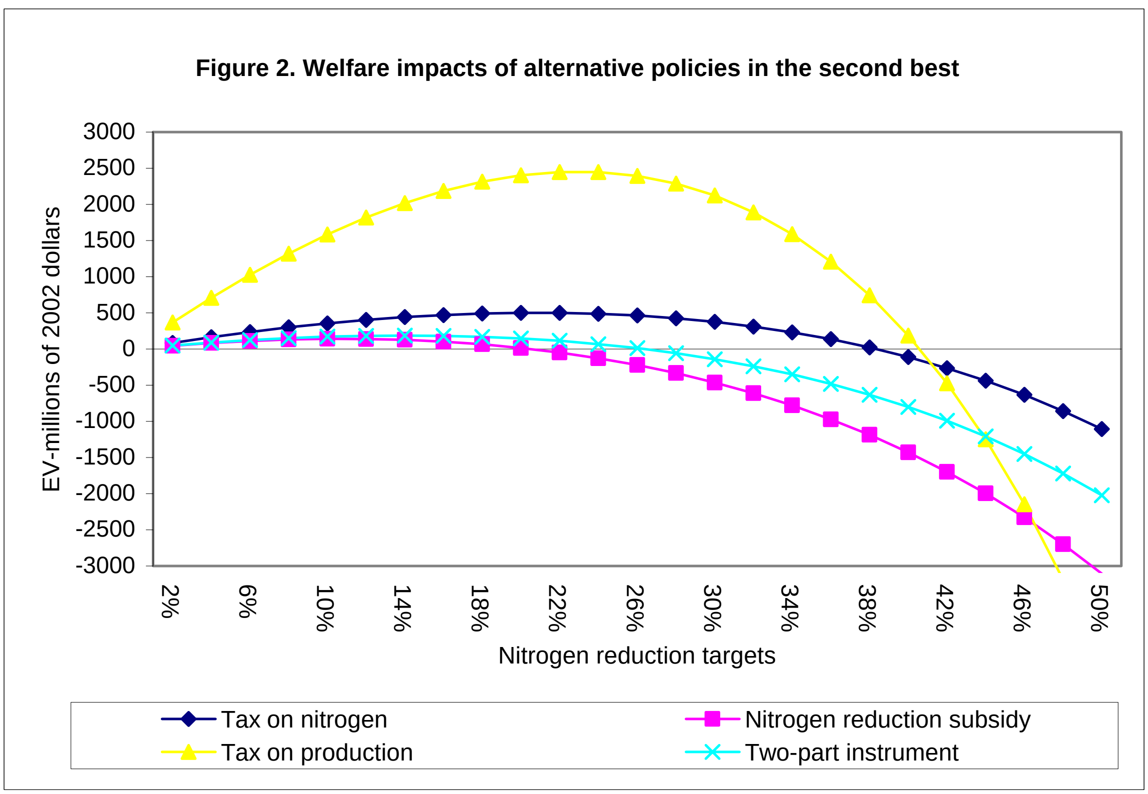
Figure 2. Welfare impacts of alternative policies in the second best
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