Optimal Allocation of Land for Conservation:
A General Equilibrium Analysis

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Abstract: This paper presents a general equilibrium analysis of the optimal allocation of land to be preserved as natural habitat for conservation and recreation. Following Anas (1988) we model the natural habitat as both a congestible public good due to recreation visits and a pure public good due to option and existence values. Following Fullerton and Kinnaman (1995) we analyze the use of tax instruments to achieve the first best outcome in a private competitive market. First we present the scenario where the public good, the environment, is provided by a government or conservation agency. We show that a per unit lump sum tax on the environment similar to Anas (1988) combined with a recreation tax or a wage subsidy can achieve the first best allocation. Given the difficulty of charging a lump sum tax we next show that combining the wage or recreation tax with a utility maximizing conservation agency achieves the first best outcome. Next we present the scenario where the public good, the environment, is privately provided. We show that a subsidy on the private land set aside for the environment combined with a recreation or wage tax can achieve the first best outcome. We then extend this scenario and show that alternate tax instruments on non-environmental sectors can be used to achieve the first best outcome. Given the growing interest in ecosystem service markets and in providing ecosystem services this analysis highlights that tax instruments can be used to provide the optimal amount of land devoted to the environment. More generally, this paper illustrates that environmental externalities can be addressed with carefully designed tax instruments placed on non-environmental sectors in the economy.

Keywords: Conservation, General Equilibrium Modeling, Optimal Land Allocation, Optimal Tax

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1. Introduction

Increasing human populations result in a growing demand for urban space and land for agricultural production. Over the last few centuries there has been an increasing conversion of many natural habitats for rare and endangered species to serve human needs. Costello and Polasky (2004) highlight these changes as “Only about fifty percent of the forest area that existed at the time of the rise of agriculture remains, of which less than half remains in large tracts capable of sustaining a full range of biological diversity.” Balmford et al. (2002) find that globally intact ecosystems are being converted to other uses at a rate of one percent per year. Closer to home, according to the Illinois Wildlife Action Plan (IDNR, 2005) Illinois has lost over 90 percent of its original wetlands, 99.9 percent of its original prairie, and over the past 30 years, populations of many wildlife species have fallen dramatically. The importance of preserving natural habitat is increasing daily as more and more species become extinct or endangered.

The importance of preserving natural habitats extends beyond conservation. Many natural habitats throughout the world provide a vast array of ecosystem services and also enable carbon sequestration. A study for the South African National Biodiversity Institute conservatively estimated the flow of ecosystem services in grasslands in South Africa to be in the order of 9.7 billion rand per year or 29,000 rand per square kilometer (De Wit and Blignaut 2006). Further, the carbon storage value for British Columbia’s grasslands is estimated at $21 million per year (Wilson 2009). Therefore, preserved natural habitat has the ability to mitigate the extent of climate change.

As the demand for land increases with increased demand for food and living space the task of preserving natural habitat becomes difficult. At the same time a growing literature on nonmarket valuations indicates that people have a significant willingness to pay for preserving natural habitat and consuming the environmental amenities. Loomis et al. (2000) conduct a contingent valuation survey on restoring the ecosystem in a river basin and find that households would pay an average of $21 per month or $252 annually for the additional ecosystem services, a total between $19 million to $70 million[1]. An Economic Research Service report by Sullivan et. al. (2004) finds a $300 million dollars per year increase in outdoor recreational expenditures due to

[1] The large spread due to whether those refusing to be interviewed have a zero value or not.

land enrolled in the Conservation Reserve Program. These studies are an example of many that highlight the direct recreation use value and existence value of the natural environment.

In this paper we ask the question "what is the optimal allocation of land for conservation?" and "what tax instruments can be used to achieve this optimal allocation?" We use a general equilibrium framework to study the use of tax instruments to achieve the first best allocation of land for conservation. The optimal allocation of land to be preserved as natural habitat should consider the consumers' use values and nonuse values for preserved natural habitat. Therefore, following Anas (1988), we construct a model in which the households obtain utility from direct use of the environment and indirectly from the existence and option value of the environment where the direct use results in congestion. We then analyze various tax instruments under public and private provision of the environmental good.

The paper is structured as follows. Section 2 presents a literature review of the general equilibrium land allocation models and the environmental tax literature. Section 3 introduces the general model based on Anas (1988). In section 4 we present the scenario where the public good, the environment, is provided by a government or a conservation agency. Section 4.1 presents the socials planner's first best outcome. Section 4.2 analyzes the private markets under various tax instruments. In section 4.2.1 we show that a per unit lump sum tax on the environment, similar to Anas (1988), along with a tax on recreation can achieve the first best outcome. A tax on the environment requires measuring the total value of the environment and we avoid this in section 4.2.2 and 4.2.3 by considering a utility maximizing government that provides the public good E. We show that the utility maximizing government combined with a tax on recreation or a tax on wages can internalize the externality caused by congestion leading to the first best outcome. In section 5, we present the scenario where the public good, the environment, is privately provided by households that purchase land to be set aside as environmental land. Section 5.1 presents the socials planner's first best outcome. In section5.2 we show that a subsidy on land set aside for the environment combined with a recreation or wage tax can achieve the first best outcome.

2. Literature Review (Still Incomplete)

Anas (1988) presented the first example of using a GE analysis to understand the optimal allocation of land for conservation. The author uses a static long-run land equilibrium model and specifies the natural environment as both a congestible public good due to recreation and pure public good due to existence and option value. He shows that a tax on recreation and a tax on the quality of the natural environment can achieve a first best allocation. Anas (1988) also presents a second best analysis and shows that in a Cobb-Douglas world visitation fees and visitation quotas are the only second-best instruments.

Giménez and González-Gómez (2003) present a static analysis similar to Anas (1988) where they extend the model to include heterogeneous agents and therefore use a rational general equilibrium model based on the microeconomic land use model by López, Shah, and Altobello (1994). Further they include an explicit time constraint (Anas (1988) does not specify a constraint on time). However, they ignore the impact of congestion, a fundamental reality of using the environment.

We extend Anas's model by explicitly including a time constraint. Further given that it is difficult to tax the environmental we present an alternative method to achieve the first best optimal. Our model differs from Giménez and González-Gómez (2003) since we include congestion and we present a general equilibrium analysis similar to Anas (1998). Further, in our last section we analyze the private provision of the public good where the households can sell their land to be used as environmental land. This differs from Giménez and González-Gómez (2003) where the Voluntary Contribution Mechanism assumes that the households voluntarily provide the land for the environment.

Perhaps the biggest contribution in our analysis is that we use the tools from the environmental tax literature (Fullerton and Kinnaman 1995, Fullerton 1997, Fullerton and Wonverton 1999; 2000) to understand how a multiple taxes can be used to achieve the optimum allocation of land for conservation. Our analysis, though based on the work by Fullerton and colleagues, differs from their work because we apply their insights to a public good as opposed to a public bad and we analyze a specific problem where the value of the public good depends on congestion caused by the use of the public good and the amount of land used for the public good. Therefore our results extend the environmental tax literature by highlighting the optimal taxation given a public good that has both positive and negative components. (NEED TO EXPAN THE TAX REVIEW HERE)

3. Model

We consider a competitive three-sector economy with a representative household that produce a composite good *C*, housing *H*, and environmental amenity *E*, using two factors of production, land *L* and labor (time) *M*. Labor is fully mobile and can be used by any sector. The composite good *C*, and housing *H*, is produced by a competitive firm. The environmental amenity *E* is provided by the government (or a private conservation agency) interested in increasing total welfare.

Notation Summary:

We consider a competitive three-sector economy with a representative household defined using the following notation.

Two factors of production

L	Land
M	Labor, fully mobile

Three goods

C	Composite good	$C = C(L_c, M_c)$
H	Housing	$H = \alpha L_h$
E	Environment	$E = E(NL_e, NM_e)$

Upper case subscripts denote partial derivatives, i.e.

$$C_{M_c} = \frac{\partial C(L_c, M_c)}{\partial M_c}$$

Lower case subscripts denote a factor of production being used in the production of a good, i.e. L_c is the land used in the production of good C.

The constant returns to scale production functions for the composite good and housing are:

$$C = C(L_c, M_c) \quad (1)$$

$$H = H(L_h) = \alpha L_h \quad (2)$$

where L_c is the land devoted to the production of good C and M_c is the amount of time used as labor in the production of good C, and L_h is the amount land devoted to housing.

The production function for the environmental amenity is:

$$E = E(L_e, M_e) \quad (3)$$

where L_e is the amount of land devoted to natural habitat, M_e is the total amount time spent in the environment (i.e. on hiking, fishing, hunting, and other forms of recreation). The production of the environmental good is increasing in the amount of land devoted to the environment and decreasing in the time spent in the environment due to congestion, i.e. $E_{M_e} < 0 < E_{L_e}$.

The resource constraint for time,

$$M_c + M_e = \overline{M} \quad (5)$$

where M_c is the amount of time spent working in the firm, and M_e is the amount of time spent on recreation.

The resource constraints for land is given by

$$L_c + L_h + L_e = \overline{L} \quad (6)$$

where L_c is the amount of land devoted to the production of C, L_h is the amount of land devoted for housing and L_e is the amount of land set aside as environmental land.

4. Public Provision of the Environmental Good

The utility of the representative household depends on the consumption of the composite good C, and housing H, and the natural habitat E. The natural habitat E enters the utility function in two forms, the direct use values are represented as $M_e E$ where M_e is the time spent in the environment, and the non-use option and existence values are represented by E.

$$U(X, H, M_e E; E) \qquad (4)$$

The representative household is endowed with M units of time and $\bar{L}$ units of land.

4.1 Social Planners' Problem

Given the above model the social planner's maximization problem can be solved to obtain the first best allocations. The social planner maximizes the aggregate utility given the resource constraints,

$$\underset{M_c, M_e, L_h, L_c, L_e}{Max} \; U(C, H, M_e E; E) = U(C(L_c, M_c), \alpha L_h, M_e E(NL_e, NM_e); E(NL_e, NM_e)) \qquad (7)$$

such that[2],

$$\text{(i) } L_c + L_h + L_e = \bar{L} \qquad (8)$$

$$\text{(ii) } M_c + M_e = \overline{M} \qquad (9)$$

The first order necessary conditions necessary for a maximum,

with respect to the decision variables

$$M_c \Rightarrow U_C C_{M_c} - \delta = 0 \qquad (10)$$

$$L_c \Rightarrow U_C C_{L_c} - \mu = 0 \qquad (11)$$

$$L_h \Rightarrow \alpha U_H - \mu = 0 \qquad (12)$$

$$M_e \Rightarrow U_{(M_e E)} E + NU_{(M_e E)} E_{NM_e} M_e + NU_E E_{NM_e} - \delta = 0 \qquad (13)$$

$$L_e \Rightarrow NU_{(M_e E)} E_{NL_e} M_e + NU_E E_{NL_e} - \mu = 0 \qquad (14)$$

with respect to the LaGrange multipliers

[2] The resource constraints can be substituted into the utility function to directly analyze the social planner's first best. We consider the resource constraints separately to be able to analyze the Lagrange multipliers.

$$\mu \Rightarrow L_c + L_h + L_e = \overline{L} \tag{15}$$

$$\delta \Rightarrow M_c + M_e = \overline{M} \tag{16}$$

Equations (10) and (11) indicate that the Lagrange multipliers δ and μ are the marginal benefits of using land and labor in the production of the composite commodity. Equation (12) indicates that μ is the marginal utility of using land for housing.

Equation (13) indicates that δ is the marginal utility gained by spending an additional unit of time on recreation (using the environment good E).[3] The first term is the marginally utility gained by the direct use which depends on the existing value of E and is positive. The second term is the marginal disutility from the marginal decrease in E due to the congestion created by the direct use and is negative. The third term is the marginal disutility from the marginal decrease in option and existence values due to congestion. Let $\Omega = NU_{(M_e E)} E_{NM_e} M_e + NU_E E_{NM_e}$.
Comparing (10) and (13) highlight that at the optimum, the marginal utility from using time (labor) for recreation or for the production of good C are equal. The marginal utility of spending an additional unit of time for production is equal to the total marginal utility obtained from spending an additional unit of time on recreation given the existing value of E.

Equation (14) indicates that μ is the marginal utility gained by setting aside an additional unit of land as environmental land. The first term is the marginal utility from the direct use due to the increase in E and the second term is the marginal utility from the existence and option value due to the increase in E. Let $\Psi = NU_{(M_e E)} E_{NL_e} M_e + NU_E E_{NL_e}$.
Comparing (11), (12) and (13) highlight that at the optimum, using land for either housing, or the production of good C or setting land aside for the environment has the same marginal utility.

The social planner's first best outcome can be obtained by substituting (15) and (16) in (12), (13), and (14):

[3] Since $\delta \geq 0$, at the optimum, the utility gained from directly using E has to be greater than the decrease in the utility caused by the decrease in E as a result of the direct use of E (i.e. congestion).

$$\alpha U_H - U_C C_{L_c} = 0 \tag{12*}$$

$$U_{(M_e E)} E + \Omega - U_C C_{M_c} = 0 \tag{13*}$$

$$\Psi - U_C C_{L_c} = 0 \tag{14*}$$

4.2 Private Markets

Next we consider a general equilibrium set up with a representative household, producers for the composite commodity and housing and a government/environmental sector and analyze the tax instruments to achieve a first best outcome. We assume the price of the composite commodity p_c = 1 and the price of housing is p_h. The price of land input is p_l, and the price of time is w, i.e. wage.

The producers of the composite commodity *C* solve

$$\text{Maximize } \pi_c = p_c C(L_c, M_c) - p_l L_c - w M_c \tag{17}$$

The resulting FOCs give

$$p_c C_{L_c} = p_l \Rightarrow p_l = C_{L_c} \tag{18}$$

$$p_c C_{M_c} = w \Rightarrow w = C_{M_c} \tag{19}$$

The producers of housing, *H*, solve,

$$\text{Maximize } \pi_h = p_h H(L_h) - p_l L_h = p_h \alpha L_h - p_l L_h \tag{20}$$

The resulting FOCs give

$$p_h = \frac{p_l}{\alpha} \tag{21}$$

Substituting from (18)

$$p_h = \frac{C_{L_c}}{\alpha} \tag{22}$$

We model the government/environment sector and the representative household using two alternate methods. In the first method, following Anas (1988), we assume that the government is able to charge a per unit tax on *E* and that *E* is provided by a profit maximizing conservation agency. This assumes that E is measurable and quantifiable. The second method relaxes the need for measuring the total value of the environment. In the second methods we assume that the government provides the environmental good and maximizes the net utility given the household's decision. In addition, we consider a tax on wage or a tax on time spent on recreation.

4.2.1 A Tax on the Existence Value of the Environment and a Tax on Recreation

Following Anas (1988) we assume the government collects a per unit tax τ for each unit of the environment good. In addition we introduce a per unit tax τ_m for each unit of time used for recreation[4]. The per unit tax on the environment, τ is implicitly a lump sum tax. Collecting a per unit tax on the total value of the environment is not unreasonable as might first appear. There is a growing literature aimed at valuing the ecosystem services and to create indices that value ecosystems. Costanza et al. (1997) estimated the total value of the biosphere to be in the range of US$16–54 trillion per year, with an average of US$33 trillion per year. The tax revenue is given to a conservation agency that maximizes the amount of the environment (or the government acts to maximize the quality of the environment) that provides the environmental amenity. At the optimum the conservation agency will have zero profit.

The providers of the environment good (either the government or an agency) purchase land for the environment.

$$\underset{L_e}{\text{Maximize}}\ \pi = \tau E(NL_e, NM_e) - p_l L_e \tag{23}$$

The FOCs,

$$p_l - \tau NE_{NL_e} = 0 \tag{24}$$

[4] Similar to the previous analysis, 4.2.1, a wage tax (subsidy) can be considered instead of the recreation tax τ_m.

Now the representative household pays a per unit tax or visitation fee, τ_m, for the time spend on recreation and a per unit tax τ for each unit of the environment. The household's maximization problem is given by,

$$\underset{C,H,M_e}{Max}\ U(C,H,M_eE;E)$$

s.t.

$$p_l\bar{L}+w(\bar{M}-M_e)=p_xC+p_hH+\tau_mM_e+\tau E \tag{25}$$

The corresponding Lagrangian is,

$$\underset{C,H,M_e}{Max}\ U(C,H,M_eE;E)+\lambda[p_l\bar{L}+w(\bar{M}-M_e)-p_xC-p_hH-\tau_mM_e-\tau E] \tag{26}$$

The consumers FOCs, with prices substituted with marginal products as in Fullerton and Kinnaman (1995), give,

$$C\Rightarrow U_C-\lambda=0 \tag{27}$$

$$H\Rightarrow U_H-\lambda(C_{L_c}/\alpha)=0 \tag{28}$$

$$M_e\Rightarrow U_{M_eE}E-\lambda C_{M_c}-\lambda\tau_m=0 \tag{29}$$

Substituting the value of λ from (27) into (28) gives,

$$\alpha U_H=U_CC_{L_c} \qquad (30^*)$$

Substituting the price of land (18) into (24) gives,

$$C_{L_c}-\tau NE_{NL_e}=0 \tag{31}$$

$$\text{Let}\ \tau=\frac{U_{M_eE}M_e+U_E}{\lambda}. \tag{32}$$

The numerator is the marginal utility gained from an increase in the environmental good E, $U_E=\dfrac{\partial U(C,H,M_eE;E)}{\partial E}=U_{M_eE}M_e+U_E$, the first term represents the change is utility due to the direct use, and the second term represents the change in utility due to the option and existence value. The denominator converts the change in utility to dollars.

Substituting τ from (32) into (31) gives,

$$U_C C_{L_c} = NU_{(M_e E)} E_{NL_e} M_e + NU_E E_{NL_e} \quad (33^*)$$

Let

$$\tau_m = -\frac{\Omega}{\lambda} \quad (34)$$

The numerator is the change in marginal social utility due to the marginal change in E from an increase in the time spent consuming the environment, M_e, $(NU_{M_e E} M_e + NU_E) E_{M_e}$, the first term represents the change in utility due to the direct use, and the second term represents the change in utility due to the option and existence value. The denominator converts the change in utility to dollars.

Substituting τ_m from (34) into (29) gives,

$$U_C C_{M_c} = U_{M_e E} E \quad + \quad \Omega \quad (35^*)$$

The private market's FOCs represented by equation (30*) (33*) and (35*) are identical to the social planners optimal FOCs (12*), (13*) and (14*). Therefore the recreation tax, τ_m and the "lump sum" environmental tax τ achieve the first best optimum.

4.2.2 Government Provides E and Maximizes Net Utility with a Tax on Wage

The above formulation requires a tax on the quantity/value of the environment presented by E. We next present an alternative formulation that does not require a direct tax on the environment. The government maximizes the net benefit from committing land for the environment given the household's decisions. The marginal utility of income is given by λ.

$$\underset{L_E}{Max}\, U(C, H, M_e E(NL_e, NM_e); E(NL_e, NM_e)) - \lambda p_L L_E \tag{36}$$

The resulting FOC gives $\lambda p_L = NU_{M_e E} E_{NL_E} M_e + NU_E E_{NL_E}$ or

$$p_L = \frac{\Psi}{\lambda} \tag{37}$$

The representative household sells the endowment of land, *L*, and part of the labor endowment, M_c in the market, and uses the remaining labor endowment for recreation, M_e. The wage earned is taxed with a tax, τ_w. The household purchases the consumption good, *C*, and housing, *H*. Then the household's maximization problem is given by,

$$\underset{C,H,M_e}{Max}\, U(C, H, M_e E; E)$$

s.t.

$$p_l L + (w + \tau_w)(1 - M_e) = p_x C + p_h H \tag{38}$$

The corresponding Lagrangian is,

$$\underset{C,H,M_e}{Max}\, U(C, H, M_e E; E) + \lambda[p_l \overline{L} + (w + \tau_w)(\overline{M} - M_e) - p_c C - p_h H] \tag{39}$$

The household's FOCs give,

$$C \Rightarrow U_C - \lambda = 0 \tag{40}$$

$$H \Rightarrow U_H - \lambda p_H = 0 \tag{41}$$

$$M_e \Rightarrow U_{M_e E} E - \lambda(w + \tau_w) = 0 \tag{42}$$

Equation (40) indicates that λ is the marginal utility of C, since C is the numeraire good, this implies that λ is the marginal utility of income.

Following Fullerton and Kinnaman (1995), replacing the prices with the marginal products give: Substituting p_h from (22) into (41)

$$U_H = \frac{\lambda C_{L_c}}{\alpha} \tag{43}$$

Substituting w from (19) into (42)

$$U_{M_e E} E - \lambda C_{M_c} - \lambda \tau_w = 0 \tag{44}$$

Substituting p_l from (18) into (37)

$$C_{L_c} = \frac{\Psi}{\lambda} \tag{45}$$

We can solve the FOCs for the Pigouvian taxes that will lead to the perfectly competitive private markets to match the socially optimal solution as follows. Substituting the value of λ from (40) into (43):

$$\alpha U_H = U_C C_{L_c} \tag{46*}$$

Equation (46*) is identical to (12*), therefore, the marginal utility gained from using the land either for housing or for the production of good *C* is equal for both the social planner and the private market.

Substituting $\lambda = U_C$ from (40) into (44)

$$U_{M_e E} E - U_C C_{M_c} - U_C \tau_w = 0 \tag{47}$$

Let

$$\tau_w = -\frac{\Omega}{\lambda}, \tag{48}$$

Substituting the value of τ_w from (48) to (47)

$$U_{M_e E} E + \Omega = U_C C_{M_c} \tag{49*}$$

Equation (49**) is identical to (13*). Therefore, for both the social planner and the private market, the marginal utility gained from using labor (time) for recreation equals the marginal utility gained from using labor for the production of good *C*.

Though the wage tax τ_w has a negative sign the value is positive[5] since $E_{NM_e} < 0$. In effect τ_w is a subsidy that increases the wage. The subsidy is necessary to achieve a first best solution since the household ignores the decrease in the value of the environment when making the household's consumption decision with regard to the environment. The subsidy internalizes this externality. The numerator of the subsidy, $(NU_{M_eE}M_e + NU_E)E_{M_e}$, is equal to the social marginal disutility due to the decrease in *E* from the household spending an additional unit of time on recreation. The denominator, the marginal utility of income, converts the utility to dollars.

Finally, the last FOC of the social planner, (14*), can be obtained from the private market by substituting the value of λ from (40) into (45) to get,

$$U_C C_{L_c} = U_{M_eE}E_{NL_E}M_e + U_E E_{NL_E} \qquad (50^*)$$

The private market's FOCs represented by equation (46*) (49*) and (50*) are identical to the social planners optimal FOCs (12*), (13*) and (14*). Therefore the wage subsidy, τ_w achieves the first best allocation. Though a wage subsidy might sound attractive to consumers it places a burden on the government budget. Therefore next, we consider an alternative recreation tax, i.e. a tax paid on the amount of time spent consuming the environmental good E.

4.2.3. Government Provides E and Maximizes Net Utility with a Tax on Recreation

The government still provides *E* by purchasing L_e and equations (36) and (37) remain unchanged.

The representative household sells the endowment of land, *L*, and part of the labor endowment, M_c in the market, and uses the remaining labor endowment for recreation, M_e. The time spent on recreation is taxed with a tax, τ_e. This tax can be equally viewed as an entrance fee charged

[5] As presented here a positive wage tax increases the wage, moving the household to allocate more time for work and less time for recreation.

per unit time spent in the environment. The individual purchases the consumption good, *C*, and housing, *H*. Then the household's maximization problem is given by,

$$\underset{C,H,M_e}{Max}\ U(C,H,M_eE;E)$$

s.t.

$$p_lL + w(1-M_e) = p_xC + p_hH + \tau_eM_e \tag{51}$$

The corresponding Lagrangian is,

$$\underset{C,H,M_e}{Max}\ U(C,H,M_eE;E) + \lambda[p_lL + w(1-M_e) - p_xC - p_hH - \tau_eM_e] \tag{52}$$

The household's FOCs for *C* and *H*, (40) and (41) remain unchanged. The FOC for M_e takes the form,

$$M_e \Rightarrow U_{M_eE}E - \lambda w - \lambda\tau_e = 0 \tag{53}$$

Equation (53) is identical to (42), therefore following the derivation in the previous section, an environmental tax or an entrance fee $\tau_e = -\dfrac{\Omega}{\lambda}$ will internalize the externality due to the congestion caused by using the environment and achieve the first best outcome.

As presented, the environmental good E is provided by a public entity. Given this setup, to achieve the first best in the private markets require either a government or the conservation agency to maximize the total utility as in (36) or for a tax on the environmental good E as in (26). An alternative method would be to allow private provision of the public good. The last section looks at the private provision of the public environmental good.

5. Private Provision of the Environmental Good

We extend the utility function to include a term that represents the private provision of the land for the environment. The households get utility from providing land for the environment. The household's utility function now takes the form

$$\underset{C,H,M_e,L_e}{Max}\; U(C, H, L_e, M_e E; E) \qquad (54)$$

5.1 Social Planners' Problem

The social planner maximizes the aggregate utility given the resource constraints,

$$\underset{M_c,M_e,L_h,L_c,L_e}{Max}\; U(C, H, L_e, M_e E; E) = U(C(L_c, M_c), \alpha L_h, L_e, M_e E(NL_e, NM_e); E(NL_e, NM_e))$$

such that,

(i) $L_c + L_h + L_e = \overline{L}$

(ii) $M_c + M_e = \overline{M}$

The resource constraints can be substituted into the objective function to get,

$$\underset{M_e,L_h,L_e}{Max}\; U(C(L - L_h + L_e, M - M_e), \alpha L_h, NL_e, M_e E(NL_e, NM_e); E(NL_e, NM_e)) \qquad (55)$$

The first order necessary conditions necessary for a maximum,

$$L_h \Rightarrow U_C C_{L_c} = \alpha U_H \qquad (56^*)$$

$$M_e \Rightarrow U_C C_{M_c} = U_{(M_e E)} E + \Omega \qquad (57^*)$$

$$L_e \Rightarrow U_C C_{L_c} = U_{L_e} + \Psi \qquad (58^*)$$

Interpretation of the FOCs is similar to that in section 4.1.

5.2 Private Markets

Next we consider a general equilibrium set up with a representative household, producers and a government/environmental sector and analyze the tax instruments to achieve a first best outcome. The producers' behavior remains unchanged from section 4 and the respective prices equal the marginal productivity. In this case, we substitute directly all the production functions in the household's problem, so that the choice variables are directly the input variables, i.e. land and time.

The representative household sells part of the endowment of land, L_c, for production of C, part of the endowment of land, L_H, for the production of housing H, and keeps the remainder of the land as wilderness. The household sells part of the labor endowment, M_c in the market, and uses the remaining labor endowment for recreation, M_e. Each unit of land L_c sold in the market is taxed with τ_l, and wage earned is taxed with a tax[6], τ_w. The household purchases the consumption good, *C*, and housing, *H* and pays a per unit tax for each unit of *C* and *H*, τ_C and τ_H respectively, and pays a per unit tax, τ_e, on the land set aside for the environment, L_e. Then the household's maximization problem is given by,[7]

$$\underset{L_C,M_C,L_H,M_e,L_e}{Max} \; U(C(L_C,M_C),\alpha L_H,L_e,M_eE;E)$$

s.t.

$$L_C+L_H+L_e=\bar{L}$$

$$M_C+M_e=\bar{M}$$

$$\tau_eL_e+(p_C+\tau_C)C+(p_H+\tau_H)H=(p_l+\tau_l)(\bar{L}-L_e)+(w+\tau_w)(\overline{M}-M_e)$$

Substituting the resource constraints and substituting prices by marginal production gives,

$$\underset{L_H,M_e,L_e}{Max} \; U(C(\bar{L}-L_H-L_e,\bar{M}-M_e),\alpha L_H,L_e,M_eE;E)$$

$$\begin{aligned} s.t.\ \tau_eL_e+(p_C+\tau_C)C(\bar{L}-L_H-L_e,\overline{M}-M_e)+(\frac{C_{L_C}}{\alpha}+\tau_H)\alpha L_H \\ =(C_{L_C}+\tau_l)(\bar{L}-L_e)+(C_{M_C}+\tau_w)(\overline{M}-M_e) \end{aligned} \tag{59}$$

The household's FOC are:

$$L_H \Rightarrow -U_CC_{L_C}+\alpha U_{\alpha L_H}+\eta\left[(1+\tau_C)C_{L_C}-(\frac{C_{L_C}}{\alpha}+\tau_H)\alpha\right]=0 \tag{60}$$

$$M_e \Rightarrow -U_CC_{M_C}+U_{M_eE}E+\eta\left[(1+\tau_C)C_{M_C}-(C_{M_C}+\tau_w)\right]=0 \tag{61}$$

$$L_e \Rightarrow -U_CC_{L_C}+U_{L_e}+\eta\left[(1+\tau_C)C_{L_C}-\tau_e-(C_{L_C}+\tau_l)\right]=0 \tag{62}$$

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[6] This will again be a subsidy

[7] Alternatively since the households choice variables are C, H, M_e and L_e the households problem can also be formulated as,

$$\underset{C,H,M_e,L_e}{Max} \; U(C,H,L_e,M_eE;E)$$

s.t.

$$\tau_mL_e+(p_C+\tau_C)C(L_C,M_C)+(\frac{C_{L_C}}{\alpha}+\tau_H)\alpha L_H=(C_{L_C}+\tau_l)(\bar{L}-L_e)+(C_{M_C}+\tau_w)(1-M_e)$$

5.2.1

First we show that two taxes can internalize the two externalities present.

Setting $\tau_C = \tau_H = \tau_l = 0$ and $\tau_e = -\frac{\psi}{\eta}$, recall $\Psi = NU_{(M_e E)} E_{NL_e} M_e + NU_E E_{NL_e}$, will internalize the externality caused by inadequate land being devoted to the environment and replicate the Social planner's FOC in (58*). Alternatively, we can set $\tau_C = \tau_e = 0$ and let $\tau_l = -\frac{\psi}{\eta}$, this is tax the input land for the composite good.

Setting $\tau_H = \tau_C = 0$ will result in replicating the social planners FOC in (56*).

Since $\tau_C = 0$ we can internalize the externality of excess recreation by a wage subsidy $\tau_w = \frac{\Omega}{\eta}$ recall $\Omega = NU_{(M_e E)} E_{NM_e} M_e + NU_E E_{NM_e}$ which will replicate the social planners FOC in (57*). Therefore directly taxing environmental land (or land for C and H production) and wage can achieve a first best outcome.

5.2.2

On the other hand, it is possible to achieve the first best outcome without directly taxing wage, based on the marginal rates of substitution between land and time in the production functions.

Set $\tau_w = 0$ in (61*), let $\tau_C = \frac{\Omega}{\eta}\frac{1}{C_{M_C}}$ and $\tau_H = \frac{\tau_C C_{L_C}}{\alpha} = \frac{\Omega}{\eta}\frac{C_{L_C}}{\alpha}\frac{1}{C_{M_C}}$ to get the social planners FOCs in (57*) and (56*). The first tax (on the composite commodity) is equal to the total marginal externality of a unit of time being used for recreation divided by the marginal product of a unit of time being used for the consumption good. The tax is effectively internalizing the externality of excess recreation. The tax on the composite commodity is a subsidy since the value of τ_C is negative given that. $E_{NM_e} \leq 0$. The subsidy increases the production of C and leads to an increase in the amount of time being used for the production of good C and therefore reduces the amount of recreation. At the same time, the increase in the production of good C increases the amount of land devoted to producing C and therefore distorts the land market. To fix this distortion in the housing sector the price of housing needs to be subsidized by τ_H. Since more land is being used for the production of good C, less land is devoted to the environment and this distortion can be fixed by setting $\tau_l = -\frac{\Omega}{\eta}\frac{C_{L_C}}{C_{M_C}}$. This tax does not address the externality of insufficient land being devoted to the environment given that households do not consider the externality of their environmental land on others. Setting $\tau_e = -\frac{\Psi}{\eta}$ will replicate the Social Planners FOC for the land sector (58*) and will optimally provide land for the environment while correcting the distortion in the land markets caused by tax on the composite commodity.[8]

5.2.3

Finally, we can correct the externality of insufficient land being provided for the environment by taxing the composite commodity and housing. This would then require the tax on wage to account for the externality of recreation but this tax would also need to fix the distortion in the labor market caused by the tax on the composite commodity. We let $\tau_e = \tau_l = 0$ and $\tau_C > 0$, then from (62*) allowing $\tau_C = \frac{\Psi}{\eta C_{L_C}}$, $\tau_H = \frac{\Psi}{\eta}$ and $\tau_w = \frac{\Psi}{\eta}\frac{C_{M_C}}{C_{L_C}} - \frac{\Omega}{\eta}$ achieve the first best outcome. The tax on the composite commodity and on housing internalizes the externality of not enough land being provided for the environment. The tax on wage addresses the distortion in the labor market created by the tax on the composite market, $\frac{\Psi}{\eta}\frac{C_{M_C}}{C_{L_C}}$, and simultaneously internalizes the externality of recreation, $\frac{\Omega}{\eta}$.

The tax placed on the composite commodity above consists of the externalities created by the total marginal use value and the total marginal non-use value. These two components of the

[8] Alternatively we can set $\tau_e = -\frac{\Omega}{\eta}\frac{C_{L_C}}{C_{M_C}}$, and $\tau_l = -\frac{\Psi}{\eta}$ or $\tau_e = -\frac{\Omega}{\eta}\frac{C_{L_C}}{C_{M_C}} - \frac{\Psi}{\eta}$ or $\tau_l = -\frac{\Omega}{\eta}\frac{C_{L_C}}{C_{M_C}} - \frac{\Psi}{\eta}$ to get the same result.

externality of insufficient land being provided for conservation can be fixed separately as below with a tax on the composite commodity and a tax on provision of private land for the environment: $\tau_C = \dfrac{U_{(M_e E)} E_{L_e} N M_e}{\eta C_{L_C}}$, $\tau_l = -\dfrac{U_E E_{L_e} N}{\eta C_{L_C}}$, $T_H = -U_{(M_e E)} E_{L_e} N M_e / \eta$, and $T_w = -\Omega / \eta + U_{(M_e E)} E_{L_e} N M_e C_{M_C} / C_{L_C} \eta$

Here the tax on the composite commodity, τ_C, accounts for the loss of recreation from not enough land being devoted to the environment, or the use value of the public good (or the sum of all the private marginal recreation benefits of the environmental land or public good). The tax on land sold for production, τ_l, accounts for the non-use value from not enough land being devoted to the environment, or the non-use value of the public good. The tax on the housing sector and wage can be interpreted as before.

6. Conclusion.

We analyze the tax instruments that can achieve a first best outcome in a world where households obtain utility from direct use of the environment and also from the existence and option value of the environment. First we analyze the case where the public good, the environment, is provided by a government or conservation agency. We show that a tax on recreation or a tax on wages can internalize the externality caused by congestion. Combining the wage or recreation tax with either a utility maximizing conservation agency or a profit maximizing conservation agency with a per unit lump sum tax on the environment achieves the first best outcome. Next we analyze the private provision of the environment good and show that a subsidy on the private land set aside for the environment combined with a recreation or wage tax can achieve the first best outcome. We then extend the scenario for the private provision of the environment good to analyze the use of alternate tax instruments to achieve the first best outcome. First, we show that a tax on the private land or a subsidy on the environmental land set aside for the environment combined with wage tax can achieve the first best outcome. Second, without directly taxing wage, we show that a subsidy on the composite commodity can be used to internalize the externality of excess recreation and the first best outcome can be achieved with a subsidy on the private and environmental land. Third, the tax on the composite commodity can be used to internalize the externality of insufficient provision of land for the environment. Combining this tax with a tax on wage and distortion correcting taxes on the housing sector will achieve a first best allocation. In this case the tax on wage is larger as it also needs to address the distortions in the labor market caused by the tax on the composite commodity. We finally show that separate taxes aimed at the use value and the non-use value along with a housing and wage tax can achieve the first best allocation.

The results from this paper illustrate that environmental externalities can be addressed with carefully designed tax instruments placed on non-environmental sectors in the economy, which are easier for the regulator to measure the use of resources and to ensure compliance rate.

As next steps it would be worthwhile to expand the model to have two types of agents, one that engages in recreation and one that does not engage in recreation or one that values the environment and one that doesn't value the environment and study the tax burdens. Further, it is often difficult to measure the use of resources and to ensure compliance rates that cause a market failure, thus implementing first best measures cannot be assumed. Therefore it would be useful to analyze optimal environmental taxes in the presence of other existing distortionary taxes. The general equilibrium framework presents here can also be used to study the optimal provision of ecosystem services and payment vehicles to sustain the services. Finally, the general equilibrium analysis presented here can be extended to see if the public provision of land for conservation decreases the private provision of land for conservation.

The importance of protecting the biodiversity in our ecosystems is crucial, at the same time many conservation agencies struggle to fund their conservation activities. The General Equilibrium analysis in this paper shows that it is possible to obtain the first best outcome in a world where households value the environment by using tax instruments to collect funds for conservation activities. The model as originally presented by Anas (1988) requires the measuring of the total environmental benefits to achieve an optimal allocation. The extensions that we present allow the optimal allocation to be achieved with a two part tax that avoids the need to directly tax the environmental sector.

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