Evaluating Ecosystem Service Trade-offs in Boreal Forest

by using a distance function approach

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Ecosystem Services Trade-offs

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Ecosystem Services Trade-offs

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- Supporting Service: biodiversity preservation, habitat protection;
- Cultural Service: Recreational hiking, fishing, picking and etc.

Categories of Ecosystem Services

Service	Explanation
Production and Provisioning	
Timber Production	Paper and Board
	Sawn Wood
	Pulp, Recovered Paper
	Paper Products
	Veneer, Plywood, Wood Products
	Roundwood, Chips, Sawdust
Biomass & Fuel	Branches & Tops(GROT)
	Fuelwood
Non-timber Production	Fish & Berry & Mushroom & Herbs & Fruits
Regulation and Regulating	
Air Quality	Aerosols & Chemicals Extraction
Water Quality	Water Infiltration & Storage
	Water Recharge & Discharge
	Water Purification
Climate Regulation	Greenhouse Gas Absorption
	Carbon Sequestration & Storage
Erosion Protection	Soil Maintenance & Fertility
	Soil Formation & Regeneration
Biological Regulation	Pest Control
	Disease Control
Habitat and Supporting	
Biodiversity & Habitat	Nursery Habitat
	Genepool Protection
Information and Cultural	
Spiritual & Inspirational	Referred as "Forest Spirituality"
	Religious attachment
Recreational	Hiking & Camping & Wildlife Observations
	Hunting & Fishing
	Berry & Mushroom Picking
Aesthetic&Educational	Aesthetic Values with Sightseeing
	Educational and Athlete Training

Source: Adapted from R. S. De Groot et al. (2010)

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- Production economics provide a framework to evaluate trade-offs between inputs or outputs, known as shadow pricing.
- To the best of our knowledge, there are none considering the problem in a production economic framework.

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Production Frontier Modeling

To describe the production technology of a forest:

$$T = \{(x, y) : x \text{ can produce } y\}, \text{ the technology set}$$

To involve non-marketed outputs:

$$T = \{(x, y, b) : x \text{ can produce } (y, b)\}$$

where b are non-marketed outputs (e.g. carbon sequestration, water filtration, biodiversity, recreation).

Assumptions

- We can conveniently impose conventional and standard economic assumptions to the output set $P(x) = (y, b)$, such as closedness, boundness, convexity.

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- Another important assumption is disposability. The marketed outputs by themselves are free (strong) disposable, meaning that a producer can freely choose not to produce given the undesirable market value of the outputs. The weak disposability models the idea that it is costly to increase non-marketed outputs. For instance, increasing carbon sequestration by harvesting fewer trees (profit loss).

(Directional) Distance Function and Shadow Pricing

- We use a distance function to specify a case of a multiple inputs and/or outputs. The distance function is a complete representation of the production technology.
- For example, an output distance function solves for a maximum proportional expansion of outputs, with given inputs.
- By estimating a distance function, we can calculate trade-offs of non-marketed goods, or the opportunity cost in production of a certain ecosystem service.

Trade-offs between Marketed and Non-marketed Goods

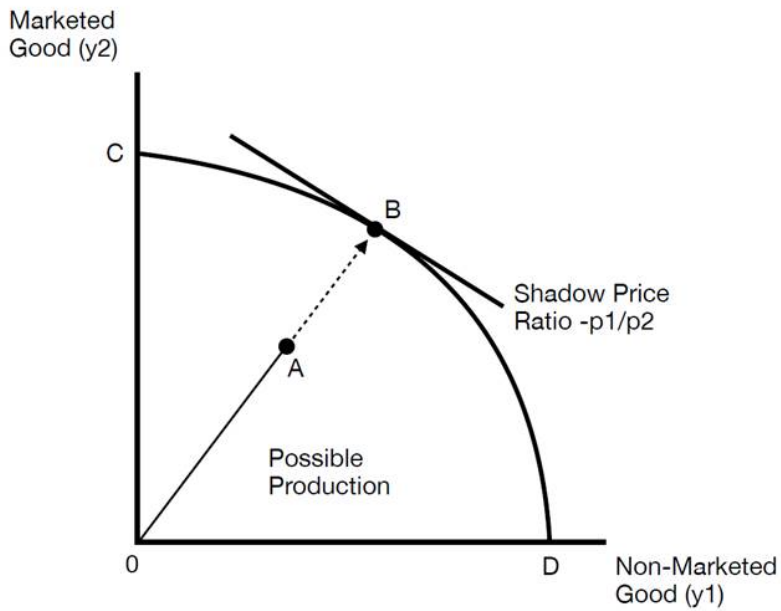

Figure: Trade-offs between Marketed and Non-marketed Goods

The shadow price implicitly values non-marketed good(y1) in terms of its corresponding trade-offs with marketed good(y2).

(Directional) Distance Function and Shadow Pricing

- Since a production involves multiple inputs and/or outputs, we introduce distance function to describe the frontier:

$$D_o(x, y, b; g_x, g_y, g_b) = \sup\{\beta > 0 : (y + \beta g_y, b \pm \beta g_b) \in P(x)\}$$

- If we are solving a revenue maximization problem, the distance function is the constraint. We can write down its Lagrangian form:

$$R(x, p) = \max_y py - \mu D_o(x, y, b; g_y, g_b)$$

- FOC shows that:

$$p - \mu \nabla_y D_o(x, y, b; g_y, g_b) = 0$$

- Shadow price of any outputs:

$$p_i = p_j \frac{\partial D_o(x, y; g_y)/\partial y_i}{\partial D_o(x, y; g_y)/\partial y_j}, i \neq j.$$

Estimation

- Typical functional form for distance function:

Function	Translog	Quadratic
Form	$lnD_o(x,y,b) = \alpha_0 + \sum_{n=1}^{N}\alpha_n lnx_n + \sum_{m=1}^{M}\beta_m lny_m + \sum_{j=1}^{J}\gamma_j lnb_j + \frac{1}{2}\sum_{n=1}^{N}\sum_{n'=1}^{N}\alpha_{nn'}lnx_n lnx_{n'} + \frac{1}{2}\sum_{m=1}^{M}\sum_{m'=1}^{M}\beta_{mm'}lny_m lny_{m'} + \frac{1}{2}\sum_{n=j}^{J}\sum_{j'=1}^{J}\gamma_{jj'}lnb_j lnb_{j'} + \sum_{n=1}^{N}\sum_{m=1}^{M}\delta_{nm}lnx_n lny_m + \sum_{n=1}^{N}\sum_{j=1}^{J}\nu_{nj}lnx_n lnb_j + \sum_{m=1}^{M}\sum_{j=1}^{J}\mu_{mj}lny_m lnb_j$	$D_o(x,y,b;g_x,g_y,g_b) = \alpha_0 + \sum_{n=1}^{N}\alpha_n x_n + \sum_{m=1}^{M}\beta_m y_m + \sum_{j=1}^{J}\gamma_j b_j + \frac{1}{2}\sum_{n=1}^{N}\sum_{n'=1}^{N}\alpha_{nn'}x_n x_{n'} + \frac{1}{2}\sum_{m=1}^{M}\sum_{m'=1}^{M}\beta_{mm'}y_m y_{m'} + \sum_{n=1}^{N}\sum_{m=1}^{M}\delta_{nm}x_n y_m + \sum_{n=1}^{N}\sum_{j=1}^{J}\nu_{nj}x_n b_j + \sum_{m=1}^{M}\sum_{j=1}^{J}\mu_{mj}y_m b_j$
Feasibility	$lnD_o(x,y,b) \leqslant 0$	$D_T(x,y,b;g_x,g_y,g_b) \geqslant 0$
Disposability	$\partial_y D_o(x,y,b) \geqslant 0$	$\partial_y D_o(x,y,b;g_x,g_y,g_b) \leqslant 0$
	$\partial_x D_o(x,y,b) \leqslant 0$	$\partial_x D_o(x,y,b;g_x,g_y,g_b) \geqslant 0$
	$\partial_b D_o(x,y,b) \leqslant 0$	$\partial_b D_o(x,y,b;g_x,g_y,g_b) \geqslant 0$
Homogeneity	$\sum_m^M \beta_m + \sum_j^J \gamma_j = 1$	-
	$\sum_m^M \sum_{m'}^M \beta_{mm'} + \sum_j^J \sum_{j'}^J \gamma_{jj'} + \sum_m^J \sum_{j'}^J \mu_{mj} = 0$	-
	$\sum_n^N \sum_m^M \delta_{nm} + \sum_n^N \sum_j^J \nu_{nj} = 0$	-
Translation	-	$-g_x \sum_{n=1}^N \alpha_n + g_y \sum_{m=1}^M \beta_n - g_j \sum_{j=1}^J \gamma_j = -1$
	-	$-g_x \sum_{n=1}^N \delta_{nm} + g_y \sum_{m'=1}^M \beta_{mm'} - g_j \sum_{j=1}^J \mu_{mj} = 0$
	-	$-g_x \sum_{n=1}^N \nu_{nj} + g_y \sum_{m=1}^M \mu_{mj} - g_j \sum_{j'=1}^J \gamma_{jj'} = 0$
	-	$-g_x \sum_{n'=1}^N \alpha_{nn'} + g_y \sum_{m=1}^M \delta_{nm} - g_j \sum_{j=1}^J \nu_{nj} = 0$
Symmetry	$\alpha_{nn'} = \alpha_{n'n}, \beta_{mm'} = \beta_{m'm}, \gamma_{jj'} = \gamma_{jj'}$	$\alpha_{nn'} = \alpha_{n'n}, \beta_{mm'} = \beta_{m'm}, \gamma_{jj'} = \gamma_{jj'}$

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- The parameters can be estimated by optimization techniques (linear programming) or econometrically (stochastic frontier analysis)

Remarks

- Distance function is a complete representation of multiple-output production frontier used to evaluate trade-offs between wood production and ecosystem services.
- The shadow pricing recovers the value of non-marketed goods (ecosystem services) in terms of opportunity costs of wood production.
- Thank you for the patience!

Assumptions (if b are bad outputs)

- By the basic setting, we can conveniently assume that the output set $P(x) = (y, b)$ is:
- *Closed and Bounded*: Given a fixed level inputs, it is not possible to produce unlimited outputs.
- *Convex*: Any combination of two outputs can be produced by x, given each of the outputs can be produced by x.
- *Weakly Disposable*: Bad outputs is not freely disposable, the producer must endure a cost to reduce bad outputs.
- Null-jointness of (y, b) indicates that if no bad output is produced, it must be the case no good output is produced, i.e. bad output is a by-product.

Directional Distance Function and Shadow Pricing

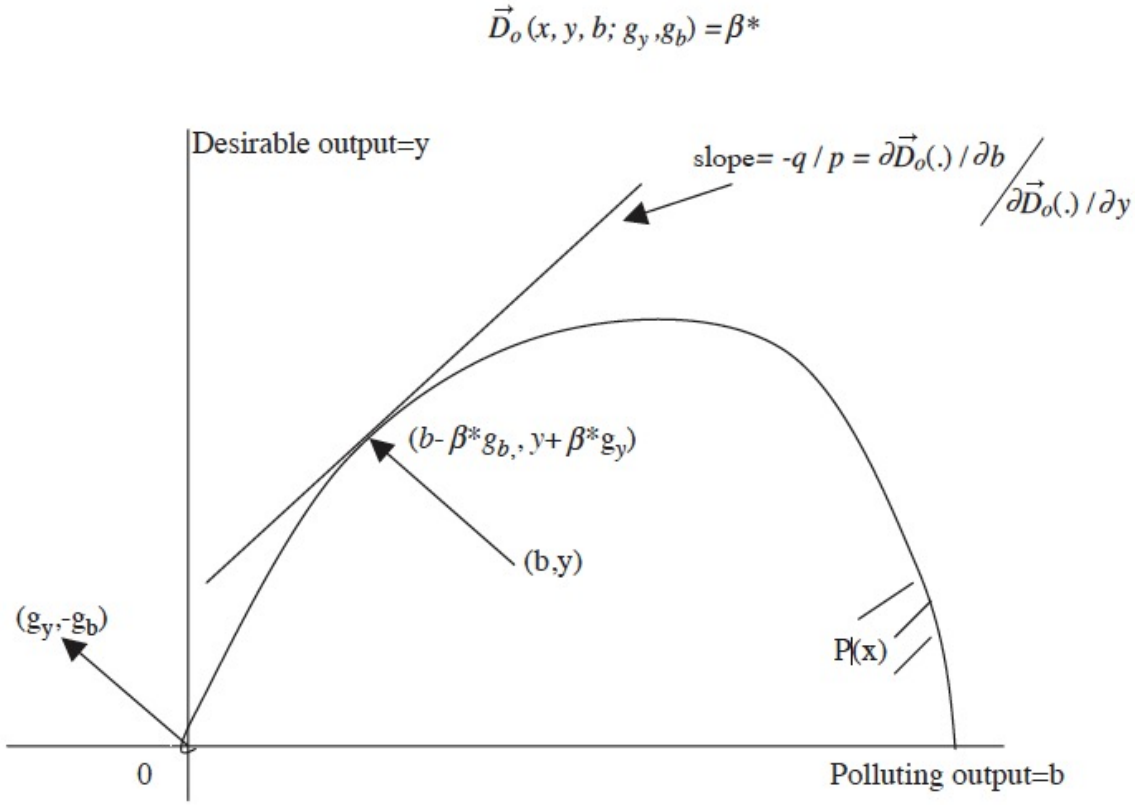

Figure: Distance Function and Shadow Pricing