ECN 275/375 Environmental and natural resource economics 2: Sustainability and ethics/welfare (ch. 2-3, Perman *et al.*)

Learning objectives and outline

Chapter 2 (things to emphasize when reading)

- What does sustainability imply (economic, social, environmental)
- Economy-environment interactions – environmental services and natural resources – why environmental services(excessive emissions) may be a more limiting factor (larger deviation for the social optimum) than natural resource scarcity
- Modifications of (the aggregate) production functions due to the environmental concerns
- Overview – but still important:
    - How economic growth and more equal distribution can solve some env. & resource issues
    - How economic growth threatens the environment – environmental impacts (key point – richer households usually consume more → produce more waste than poorer households)
    - Environmental impact (IPAT = Impact x Population x Technology)
    - Demographic transition
    - Environmental Kuznetz curve (medium rich societies (= early industrialization) have the largest per capita waste levels
    - Limits to growth (system dynamic approach (simulation) to map resource use and waste levels). Main problem: underestimate man's adaptive capabilities.

Chapter 3 (things to emphasize when reading)

- Overview
    - Philosophy: naturalis – libertarian (minium state) – utilitarian (where current economics belongs with *anthropocentric utilitarianism*).
- The utility function and maximization of individual welfare
    - Ordinal utility → utility not comparable across individuals
    - The impact of the budget constraint (not explicit in the textbook)
- Welfare – and the social welfare function.
    - Different forms of the social welfare function
    - Redistribution to increase welfare
- Intertemporal social welfare
    - exponential growth
    - discounting
    - social welfare over time, choice of the discount rate

Chapter 2 – Sustainability

The production function(s) for firm *i*

Ordinary production function without env. or res. $Q_i = f_i(L_i, K_i)$ || L_i= labor, K_i = capital. The production function is regular, that is:

partial first derivatives positive at a declining rate: , $f'_L = \frac{\partial f(L_i, K_i)}{\partial L_i} > 0$, and $f'_K = \frac{\partial f(L_i, K_i)}{\partial K_i} > 0$

all partial second derivatives are negative, i.e., $\frac{\partial^2 f(L_i, K_i)}{\partial L_i^2} < 0$, and $\frac{\partial^2 f(L_i, K_i)}{\partial K_i^2} < 0$ for profit max.

Additions:

- with natural resources R_i: $Q_i = f_i(L_i, K_i, R_i)$
- with environmental concerns *Mi* (waste): $Q_i = f_i(L_i, K_i, M_i)$

and with the same first and second order attributes in R_i and M_i.

Firms profit functions (p^* = product price, w^* = market wage rate, r^* = market interest rate):

- resources: $\pi_i = p^* f_i(L_i, K_i, R_i) - w^* L_i - r^* K_i - v_i' R_i' :: R_i' = R_i, v_i' < v^*$, *v'* and v^* private and optimal resource costs, R_i' = firm's resource use with the following most important first order condition (FOC) when resources are used as an input: $p f'_R(L_i, K_i, R_i) - v' R_i = 0$
- env. issues (waste): $\pi_i = p^* f_i(L_i, K_i, M_i) - w_i^* L_i - r^* K_i - c_i' M_i' :: M_i' \ll M_i, c_i \ll c_i^*$, c' and c* private and optimal costs of getting rid of waste, M_i' = firm's share of waste that is paid for. The most important FOC when emissions are an essential input (justification: without pollution, production cannot take place): $p f'_M(L_i, K_i, M_i) - c' M_i = 0$

Remark: from ECN 170 (or an equivalent intro course in natural resource economics) you know that you can correct both situations (= setting the actual resource use or emissions equal to the social optima) by introducing a resource tax (so that $v' = v^*$) or an emission tax (so that $c' = c^*$). On the emissions side, that requires that emissions are measurable. We'll return to that later in the course.

Limiting factors: Environmental services or natural resources

FOCs for natural resources (*R*) and waste (*M*) (from previous page) provides the insights:

- $p f'_R(L_i, K_i, R_i) - v' = 0$ with the resource price $v' < v^*$ (social optimal resource price) ==> more resources being used than what is socially optimal
- $p f'_M(L_i, K_i, M_i) - c' = 0$ with the price $c' << c^*$ (social optimal waste price) ==> more waste than what is socially optimal.

Most of the resources *R* used are measured, which means they have to be paid for (possibly at a lower price *v'* than the socially optimal price v^*) + those harvested (by someone) are charged for.

Contrast that with waste, where some waste (exept what is recycled) is not paid for or charged way too low a price ($c' << c^*$). Therefore, excessive emissions (M_i) are likely to be more common than excessive resource use (R_i).

Chapter 3 – Ethics and welfare

In economics it is the individual's (or household's) utility that is the basis for welfare calculations. Profits enter indirectly through money income (eases the budget constraint for the individual/household) as all firms are assumed owned by someone.

The natural extension to *anthropocentric utilitarianism* is

The utility function

Individuals (or households, hereafter I refer only to individuals) derive utility from consuming goods and services (hereafter only goods). Suppose that N goods and services are available, and denote these goods and services by the vector $\mathbf{x} = [x_1, x_2, \dots, x_{N-1}, x_N]$ containing all available goods, where x_i is element $n \in \{1,2,\dots,N-1,N\} = \{N\}$ in the choice set $\mathbf{x}$. The minimum amount to be consumed is zero of a particular good x_n, i.e., $x_n, \geq 0 \ \forall \ n \in \{N\}$.

The utility function for individual i is now described as $U_i = Ui(\mathbf{x}) = Ui(x_1, x_2, \dots, x_{N-1}, x_N)$.

Utility maximization

Let each individual, indexed by i, have money income Y_i. Individual i's utility is then maximized by solving the following constrained maximization problem:

$\left\{ \begin{matrix} MAX \\ \boldsymbol{x_i} \end{matrix} \right\} U(\boldsymbol{x_i}) \, s.t. \, Y_i = \boldsymbol{p}' \boldsymbol{x_i}$ (the individual spends all his income on consumption = saves none)

where the scalar product $\boldsymbol{p}' \boldsymbol{x_i} = \sum_{n=1}^{N} p_n x_n$, where the price vector $\mathbf{p}$ has N elements as does the goods and services vector. This yields the following Lagrangian:

$\mathscr{L}_i = U_i(\boldsymbol{x_i}) + \lambda_i (Y_i - \boldsymbol{p}' \boldsymbol{x_i})$, which has the following FOCs (for simplicity for two goods, i.e., N=2, and dropping the subscript i indicating this is for individual i):

market goods: $\frac{\partial \mathscr{L}}{x_1} = \frac{\partial U}{\partial x_1} + \lambda(-p_1) = U_{x1} - \lambda p_1 = 0$, $\frac{\partial \mathscr{L}}{x_2} = \frac{\partial U}{\partial x_2} + \lambda(-p_2) = U_{x2} - \lambda p_2 = 0$

budget constraint: $\frac{\partial \mathscr{L}}{\partial \lambda} = Y - p_1 - p_2 = 0$

This system of equations can the be solved to find the optimal consumption level of goods, $\mathbf{x^*}$, for this individual. Note that with positive prices for all consumer goods, the consumer will only consume goods where the marginal utility of consumption of good n is positive evaluated at the optimal amount of the good, i.e. $U'_n(x_n^*) > 0$.

Note that even if modern utility theory is ordinal, the FOC conditions imply that the marginal utility of consumption is higher the tighter the budget constraint $Y_i - \boldsymbol{p}' \boldsymbol{x_i}$ as the lagrangian mulitplier, λ_i, increases with a tighter budget constraint.

Remark: This is intermediate micro stuff. If you do not remember it, go back. There is an exercise to help you remember.

Utility maximization extended

We consider two cases, one where some goods are provided by the government (represented by the vector $\mathbf{g}$ and paid for through taxes T), and environmental goods and services (represented by the vector $\mathbf{z}$).

Extension 1: Governmental goods paid for via taxes

In this case the individual's disposable income is reduced by the extra taxes T_i to pay for the governmental delivered goods:

$\begin{Bmatrix} MAX \\ \mathbf{x}_i, g_i \end{Bmatrix} U(\mathbf{x}_i, g_i)\, s.t.\, Y_i - T_i = \mathbf{p}'\mathbf{x}_i$, (spends all his income on consumption = saves none)

which gives the following Lagrangian:

$$\mathscr{L}_i = U_i(\mathbf{x}_i, g_i) + \lambda_i(Y_i - T_i - \mathbf{p}'\mathbf{x}_i)$$

For two consumer goods and one governmentally provided good (and dropping *i* to simplify):

market goods: $\frac{\partial \mathscr{L}}{\partial x_1} = \frac{\partial U}{\partial x_1} + \lambda(-p_1) = U_{x1} - \lambda p_1 = 0$, $\frac{\partial \mathscr{L}}{\partial x_2} = \frac{\partial U}{\partial x_2} + \lambda(-p_2) = U'_2 - \lambda p_2 = 0$

government goods: $\frac{\partial \mathscr{L}}{\partial g} = \frac{\partial U}{\partial g} = U_g = 0$

budget constraint: $\frac{\partial \mathscr{L}}{\partial \lambda} = Y - T - p_1 - p_2 = 0$

This yields the same type of solution for the private goods **x*** as in the basic example with one exception: disposable income is less due to the taxes (see the budget constraint FOC equation). Note that with no payment (except for via the taxes), the marginal utility of the last unit of the governmental provide good is zero, i.e., $U_g(g^*) = 0$, which follows from the government FOC equation). This leads to high demand for goods provided by the government **g** (and the rationale for some own payments (egenandel) for such goods, for example medical visits). In reality this is not quite the case as individuals also spend some time going, for example, to the doctor's office.

Extension 2: Goods provided by the environment (ecosystem services)

In this case some environmental goods, $\mathbf{z}_i$, are provided for free. This gives the following optimization problem:

$\begin{Bmatrix} MAX \\ \mathbf{x}_i, z_i \end{Bmatrix} U(\mathbf{x}_i, z_i)\, s.t.\, Y_i = \mathbf{p}'\mathbf{x}_i$, (spends all his income on consumption = saves none)

which gives the following Lagrangian:

$$\mathscr{L}_i = U_i(\mathbf{x}_i, g_i) + \lambda_i(Y_i - \mathbf{p}'\mathbf{x}_i)$$

For two consumer goods and one environmental good (provided for free and again dropping *i* to simplify):

market goods: $\frac{\partial \mathscr{L}}{\partial x_1} = \frac{\partial U}{\partial x_1} + \lambda(-p_1) = U_{x1} - \lambda p_1 = 0$, $\frac{\partial \mathscr{L}}{\partial x_2} = \frac{\partial U}{\partial x_2} + \lambda(-p_2) = U_{x2} - \lambda p_2 = 0$

environmental good: $\frac{\partial \mathscr{L}}{\partial z} = \frac{\partial U}{\partial z} = U_z = 0$

budget constraint: $\frac{\partial L}{\partial \lambda} = Y - p_1 - p_2 = 0$

This yields the same type of solution for the private goods **x*** as in the basic example (same budget constraint FOC equation as in the base case). Note that with no payment for the environmental good, the marginal utility of the last unit of the environmental good is zero, i.e., $U_z(z^*) = 0$, which follows from the environmental good FOC equation). As in the previous example with governmental goods we get high demand for freely provided environmental goods **z**. In reality this is not quite the case as individuals also spend some time going, for example, to take a walk in the forest or experience a nice view from a mountain top.

Why is the environmental goods part of this utility maximization problem? Because utility is reduced for the individual if the supply of environmental goods and services is reduced, for example by environmental degradation.

Welfare (at the societal level)

The total welfare in a society should be a function (of some sort) of the individuals' utility in that society. Recall that utilities in modern microeconomic theory are ordinal (not cardinal). Therefore, we cannot compare utility among individuals. The most general way of describing welfare at the society level would therefore be some general function over the *I* individuals in an economy:

$W = W(U_1, U_2, \ldots, U_{I-1}, U_I)$

where U_i indicates the utlity for individual *i*, where $i \in \{1, 2, \ldots, I-1, I\} = \{I\}$, and total welfare in society increases if one individual is better off without someone else being worse off (*Pareto improvement*).

Politicians are free too chose more specific functional forms. Some candidates for the social welfare function:

- Welfare defined by the utility of the least happy person: $W = \text{MIN}(U_1, U_2, \ldots, U_{I-1}, U_I)$. This is an extremely egalitarian welfare function, as all resources should be spent making the least happy (proxy for utility/well-being) person happier until he/she is equally happy to the second most unhappy person, then these two individuals get all resources until their utility matches the third most unfortunate person. Such a policy implies welfare increases from below.
- Welfare is defined by a situation where nobody would like to trade places with someone else. From your childhood you may remember the "spliiting cake issue": I split and you choose.
- Samuleson-Bergson (1937) social welfare function: $W = \sum_{k=1}^{K} \beta_k U_k$ where *k* denotes income or some other variable that denotes social status. By assigning higher weights (the β's to certain groups, welfare is redistributed.

Recall that under modern micro economic utility theory (ordinal utilities), personal utilities (welfare levels) are not comparable between individuals. This may still imply that redistribution **could** lead to increases in social welfare. Reason: An increasing shadow price for the budget constraint (the λ's in the Lagrangian – poor people generally have a tighter budget) → by redistributing income from the richest to the poorest, the impact of the budget constraint (a high λ) is reduced (← market good FOCs).

Intertemporal social welfare

Exponential growth

Familiar to those having had ECN 120 / 122 (Intro macro courses)

Discrete exponential growth: $p_t = p_0 (1+\gamma)^t$ where γ*:* per-time-period growth rate, *t* : time index

Continuous exponential growth: $p(t) = p_0 e^{\gamma t}$ where γ*:* growth rate, *t* : time

Discrete time is easier to understand/use in practice as measurements of the state variable (here p_t) happens at discrete times (time intervals).

Continuous time is easier to work with, in particular in math (the exponential function with time is non-linear and not very handy to manipulate)

Doubling time: $0{,}7\,/\,\gamma$ (or multiply by 100 over and under divisor line: $70\,/\,(100\,\gamma)$)

Proof of doubling time: Set $p\ (t) = 2$ and p_0 to 1 → $2 = e^{\gamma t}$.

Take log on both sides → $\ln(2) = \ln(e^{\gamma t}) = \gamma t \ln(e) = \gamma t \rightarrow t = \frac{\ln(2)}{\gamma} \approx \frac{0{,}7}{\gamma}$

Discounting and the net present value

Discounting (constant interest rate r over time) reduces the value of benefits and costs into the future:

Discrete time:

- discounted value: $p_t = \frac{p_0}{(1+r)^t}$
- net present value: $NPV_T = \sum_{t=0}^{T} \frac{p_0}{(1+r)^t} = \sum_{t=0}^{T} \frac{p_0}{\beta^t}$ where $\beta = (1+r)$

Continuous time:

- discounted value: $p(t) = p_0 e^{-rt}$
- net present value: $NPV(T) = \int_{t=0}^{T} p_0 e^{-rt}\, dt$
  - infinite time: $NPV(\infty) = \int_{t=0}^{\infty} p_0 e^{-rt}\, dt = \frac{-p_0}{r}(e^{-r\infty} - e^{r0}) = \frac{p_0}{r}$ (remark: not appropriate math notation – should have taken the limit of T equal infinity, but notation would have become even more cluttered)

Social welfare over time, choice of the discount rate

Why discount? Income into the future is less worth because:

- benefits of investing today gives higher net benefits (provided the investment is profitable)
- one may not live tomorrow (= some risk consideration)

In welfare economic calculations, the government (policy maker) can decide which discount rate to use. r in the above formulas often replaced by δ (or some other symbol) to indicate that the chosen discount rate may differ from the market real interest rate r).

Exercises

Go to the exercises section on the course web page.

Discussion topics

1. Advantages and disadvantages of economic growth for environmental impacts? What is the net effect?
2. Advantages and disadvantages of economic growth and natural resource scarcity? What is the net effect?
3. In this note the impact on utility (and hence welfare) from environmental goods and services is indirect in the sense that environmental degradation may lead to a situation where $U_z > 0$, which contradicts the FOC for environmental goods and services. (i) Is this a relevant way of embedding (including) environmental aspects into a welfare economic framework? If so, why or why not. (ii) Which other ways of including environmental aspects in a welfare economic frame do you think exists. Justify your alternatives (and if you find none, justify that as well).