Environment in neoclassical growth models: Effects on growth, control, optimality.

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Plan of the lecture

- The beginning: Limits to growth and discussion around it;
- Pollution is an externality: Coase's Theory;
- Optimal control theory and pollution: Keeler, Spence, Zeckhauser (1972).

Club of Rome

- Organization founded in 1968
- The initial goal of the Club was to promote sustainability solutions
- Regularly publishes simulations reports on future of the humankind
- These reports contain different scenarios of development
- Data is updated in accordance with discovery of new oil deposits, etc.
- Majority of predictions is rather pessimistic.

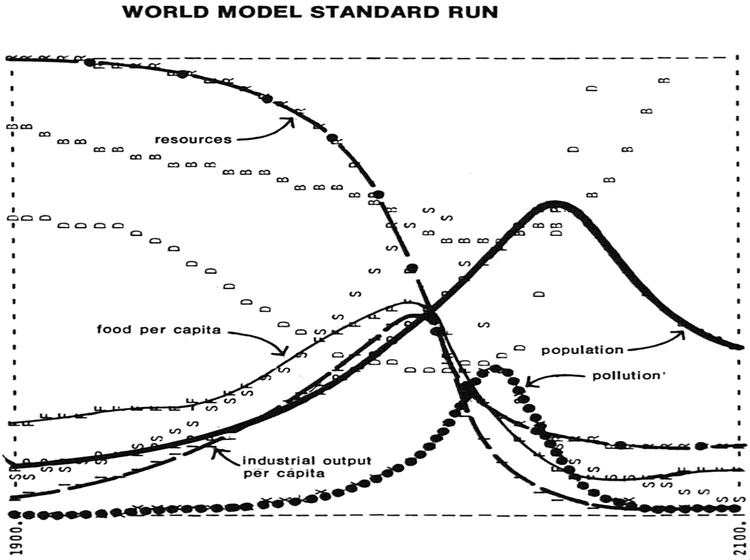
Result so far

"30 years of historical data compare favorably with key features of a business-as-usual scenario called the "standard run" scenario, which results in collapse of the global system midway through the 21st century."

Basic arguments

- Main modelled quantities:
    - Population
    - Industrial production
    - Resources usage

  are growing at exponential rates.
- This leads to:
    - Accelerating industrialization
    - Accelerating population growth
    - Widespread malnutrition
    - Depletion of natural resources
    - Deteriorating environment
- All these quantities are interrelated by some kind of positive feedback loops.


WORLD MODEL STANDARD RUN
resources
food per capita
population
pollution'
industrial output per capita
1900.
2100.

..

Solow

- Price of the resource should increase as much as the interest rate
- There is a ceiling for resource extraction
- **Backstop technologies** would prevent the resource from total exploitation
- **Technical change** will reduce resource costs
- Gradual substitution of resources by capital
- The only condition: sufficient initial capital

Nordhaus

- The set of assumptions in Limits to growth is not robust
- Changing any of them will change results to more optimistic
- Ongoing *costless* technical change
- Empirical arguments:
    - There are plenty of recoverable resources
    - These resources are used more and more
    - Technology will enable us unlimited time of operation
    - Nuclear power and fusion provides resources for indefinite time.

Environment

- This discussion does not touch environmental issues altogether
- Environment can be treated as:
  - Renewable resource
  - Public good
- Recipe for environmental catastrophe:

Growing production + **growing population** = **environmental degradation!**

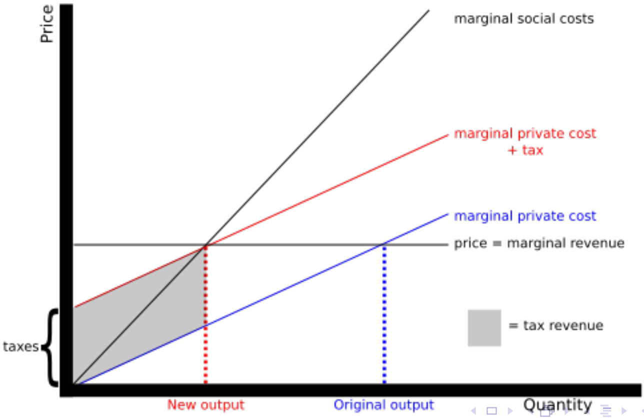
- Pollution is a consequence of production and negatively impacts environment.

Pollution

- Pollution is modeled as a **negative externality**
- It results from industrial activity of firms
- Profit maximization does not include this
- Households utility is decreased and they cannot affect this
- Pollution is not a public good (antigood)
- It is not controlled by any single agent in the economy
- Two options: market can care of itself vs. optimal management

Pigou and social welfare

- Pigou suggested the tax to be imposed on externalities;
- The tax is precisely in the size of externality and is **distortion-free**



Double-dividend hypothesis

- Idea: Pollution is an externality, treat it with pigouvian logic!
- Coined already in Tullock (1967) "Excess Benefit"
- Environmental pigouvian tax may lead to double gain:
  1. From social welfare increase since pollution decrease
  2. From substituting usual taxes by environmental (distortion-free)
- Widely discussed from 1960s onwards
- Depends on the underlying model.

Main idea of Coase's Theorem

- Negative externality affects others
- Thus the price for a good with externality would include the negative externality already
- No need of interventions: agents will set up proper prices by themselves
- Is a widely used argument (till today!) against any government regulation of markets
- Still is valid in a **very** specific setup

Coase's Theory: Origins

- Based on the paper *The Problem of Social Cost* (1960)
- Does not have anything to do with Coase himself
- First formulated in the book of G. Stigler in 1966
- Is used everywhere since then, although:
  1. It is not game-theoretically sustainable
  2. Applicable only under perfect information
  3. Assumes zero transaction costs
  4. Assumes fully defined property rights **for any potential asset, good or service**

Think of futures markets: they cannot be complete *by definition*.

Coase's Theorem

1. A clear delineation of private property rights is an essential prelude to market transactions.
2. As long as private property rights are well defined under **zero** transaction cost, exchange will eliminate divergence and lead to efficient use of resources or highest valued use of resources.
3. The allocation of resources is **invariant** to the assignment of private property rights under zero transaction cost and zero income effect.

Implications

- Regardless of the nature of externality, private contracts will rule them out in the most efficient way
- Initial property rights should be assigned to the agents, to whom associated externality costs are the lowest
- Government should create institutions which would minimize transaction costs
- There is no place for central planner and/or environmental taxation!
- Dynamic pollution call for optimal management

Basic points

- Pollution is a special type of externality: affects all
- It may have not specific source (thus Coase's theorem does not apply)
- May be a stream or a stock
- May be factor of production and/or social welfare

Overview

- Was the first model to include pollution as an argument of utility
- Later environmental models follow the same pattern
- Discusses two alternative ways of modeling pollution
- Makes use of optimal control technique (as many later models)
- **Controls** are abatement and investments into capital
- Optimization is carried out for the *social planner*.

General setup

- Lifetime utility includes pollution stock P and pollution flow, $\dot{P}$ as antigoods

$$\int_0^\infty \mathrm{e}^{-\rho t} u(c, P, \dot{P}) \tag{1}$$

- Production depends on capital and both types of pollution:

$$\dot{K} = F(K_1, P, \dot{P}) - c - \beta F - aK \tag{2}$$

- Pollution changes due to production and abatement:

$$\dot{P} = g(K_1) - h(K_2) - d\beta F - bP \tag{3}$$

Model I: Pollution is not productive

Objective is to maximize lifetime utility (social welfare):

$$W = \int_0^\infty \mathrm{e}^{-\rho t} u(c, P) \to \max_{\alpha,\beta}, \frac{\partial U}{\partial c} > 0, \frac{\partial U}{\partial P} < 0 \tag{4}$$

Production depends only on capital:

$$Y = f(K), f' > 0, f'' < 0 \tag{5}$$

Capital is accumulated due to investments:

$$\dot{K} = (1 - \alpha - \beta) f(K) - aK \tag{6}$$

Pollution grows proportional to output but slowly decreases:

$$\dot{P} = (1 - \beta d) f(K) - bP \tag{7}$$

Motivation

- Describes situations where environment does not play a productive role (water pollution)
- Combating pollution competes with output increase
- Technology may increase efficiency of abatement, d
- Environment regenerates itself (is renewable)
- Strong resemblance with R-C-K (previous lecture) economy corrected for pollution.

Steady states

Hamiltonian and FOCs Steady states are characterized by zero growth of state variables:

$$\dot{K} = 0 \rightarrow f(K)(1 - \alpha - \beta) = aK,$$
$$\dot{P} = 0 \rightarrow f(K)(1 - \beta d) = bP. \tag{8}$$

and constant co-states:

$$u_c(\alpha f(K), P) = \kappa,$$
$$\dot{\kappa} = 0 = \kappa(r + a - f') - \pi f' + \beta(\pi d - \kappa)f',$$
$$\dot{\pi} = 0 \rightarrow u_P = (r + b)\pi. \tag{9}$$

There are two possible steady states in this model:

- Golden Age equilibrium with $\alpha > 0, \beta > 0$,
- Murky Age equilibrium with $\alpha > 0, \beta = 0$.

For Golden Age equilibrium two equations are to be satisfied:

$$dc = bP - adK + (d-1)f(K),$$
$$(r+b)\pi = -u_c \frac{r+b}{d} \tag{10}$$

and capital is defined from

$$f'(K) = \frac{r+a}{1-1/d}. \tag{11}$$

Murky Age

Murky Age is defined as an equilibrium with no control on pollution ($\beta = 0$).
Capital is defined as:

$$f'(K) = \frac{r + a}{1 + \pi/\kappa} \tag{12}$$

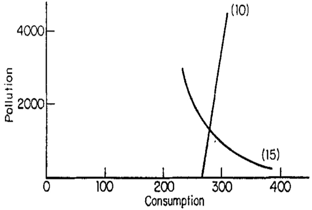
and pollution level from

$$P'(K) = \frac{C_1 f'' - C_2 \alpha f' [u_{cc} u_P - u_c u_{cP}]}{u_{cP} u_P - u_c u_{PP}} \tag{13}$$

together with (8) this defines unique no-depollution equilibrium.

Comparison

- In Golden Age pollution reduction efforts are non-zero;
- Golden Age equilibrium exists, if:
  1. The (11) is satisfied,
  2. Consumption defined by the pair (10) is between 0 and $f(K) - aK$.
- Murky Age equilibrium exists if:
  1. Capital defined by (12) is higher than golden age one.
- Only one equilibrium may exist at a time.



The Golden Age Equilibrium.

Model II: Pollution enters production

- Pollution enters both the utility and production;
- Utility is separable:

$$u(c, P) = g(c) - h(P), \tag{14}$$

- Labour has two competitive uses:
  1. Production with the use of pollutant, $j(L_1)$,
  2. And ordinary production with $L - L_1$:

$$c = F(L - L_1, j(L_1)) \to f(L_1), \tag{15}$$

- There is no capital.

Hamiltonian

Hamiltonian with dropped discount factor is then:

$$\mathcal{H} = g(f_1(L)) - h(P) + \pi(a(L_1 - bP) + q(L - L_1) + sL_1; \quad (16)$$

where q, s are nonnegativity lagrange multipliers.
F.O.C. for L_1 is:

$$\mathcal{H}_{L_1} = g'f' + \pi j' + s = 0,\ s \geq 0,\ sL_1 = 0. \quad (17)$$

Analysis

- First observe, that $L_1 < L$;
- As long as L_1 is positive, $s = 0$;
- There is a lower bound for π:

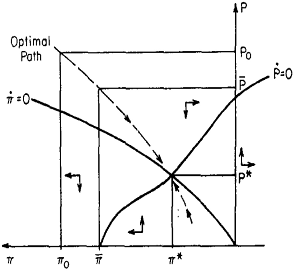
$$\bar{\pi} = \frac{g'(f(0))f'(0)}{j'(0)}; \tag{18}$$

- As long as $\pi < \bar{\pi}$ the usage of pollutant in production is zero, $L_1 = 0$.

Dynamics

The co-state evolution is

$$\dot{\pi} = (q + b)\pi + h'; \tag{19}$$



Phase diagram for Model II.

Implications

- It is not optimal to ignore pollution forever;
- However it is not optimal either to ban pollutant immediately and forever;
- Pollutant production is allowed below $\bar{P}$;
- If $P_0 > \bar{P}$, pollutant is banned until its concentration is lowered to $\bar{P}$;
- After reaching this point pollutant may be used while maintaining $\dot{P} < 0$.

Summary

- If pollution affects only utility but not production, policy depends on initial conditions:
  1. If initial capital is high enough, Golden Age policy may be realised;
  2. It has lower consumption and capital levels but lower pollution;
  3. Otherwise Murky Age policy is adopted granting higher consumption.
- This is the root of all "grow first clean up later" policies;
- If pollutant enters production function, then:
  1. Economy has always non-zero pollution levels;
  2. Optimal policy is to gradually reduce pollution by limited use of pollutant;
  3. Later models include feedback to pollutant stock from capital.

Summary on pollution

- Market economy cannot handle pollution problem properly;
- This is especially true for large-scale systems;
- Coase's theorem have a very limited application (local one);
- We need central planner;
- Depending on the structure of the model, optimal policy is different;
- There is no analogue for golden rule or etc.;
- The discussion on the proper way to include pollution into modelling is still ongoing;
- Today it is combined with exhaustible resources also (scarce);
- Still no technology influence.

Literature

- Nordhaus, W. D. (1974). Resources as a Constraint on Growth. *The American Economic Review, 64(2), pp. 2226* .
- Coase R. (1960) The Problem of Social Cost. *Journal of Law and Economics, 3, pp .1-44* ;
- Keeler E., Spence M., Zeckhauser R. (1971) The Optimal Control of Pollution. *Journal of Economic Theory, No. 4, pp. 19-34*.

What's next

Overall:

- Endogenous growth theory explicitly accounts for technical change;
- We consider ways to combine technical change *and* pollution control;
- These ways differ depending on the type of technical change and source of pollution!

Next lecture:

- Environmental Kuznets curve;
- Prototype examples of endogenous growth and pollution
- Paper: Gradus&Smulders (1993)

Hamiltonian

Back Hamiltonian is linear in controls:

$$\mathcal{H} = \mathrm{e}^{rt}[u(c,P) + \kappa[(1-\alpha-\beta)f - aK] + \pi[(1-\beta d)f - bP]] \quad (20)$$

co-state equations are:

$$\dot{\kappa} = -\mathcal{H}_\kappa + \kappa r = -u_c\alpha f' + \kappa[r + a - (1-\alpha-\beta)f'] - \pi(1-\beta d)f',$$
$$\dot{\pi} = -\mathcal{H}_\pi + \pi r = -u_P + (r+b)\pi. \quad (21)$$

and F.O.C.s are:

$$\mathcal{H}_\alpha = \mathrm{e}^{-rt}(u_c - \kappa)f,$$
$$\mathcal{H}_\beta = \mathrm{e}^{-rt}(-\kappa - d\pi)f. \quad (22)$$