Land use dynamics and the environment

Carmen Camacho

CNRS and Paris 1

Agustín Pérez-Barahona

INRA and École Polytechnique

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1.- Introduction:

- **Land use activities:** transformation of natural landscapes for human use or the change of management practices on human-dominated lands (Foley *et al.*, 2005).

- **Land use activities and the environment** $\Rightarrow$ existence and evolution of **spatial patterns** (Plantinga, 1996; Kalnay and Cai, 2003; and Chakir and Madignier, 2006).

- **Spatial Economics:**
  - Allocation of resources over space + location of economic activities $\Rightarrow$ spatial patterns.
  - Particular attention to: firms' location, transport costs, trade, and regional and urban development (Duranton, 2007).
  - However, the spatial drivers behind the interaction between land use and the environment are still far for being understood.

- **Objective:** theoretical model considering the interaction between land use activities and pollution. Focus on the **spatial externalities** of land use as drivers of spatial patterns.

- Spatial Economics and land use: **lack of explicit modelling**.
  - Bottom-up models of agricultural economics: *e.g.*, de Cara *et al.* (2005); and Havlík *et al.* (2011).

- **Dynamic Spatial Theory:** spatial generalization of Ramsey model (Brito, 2004; and Boucekkine *et al.*, 2009).
  - **Ill-posed** problem (Hadamard, 1923): one cannot ensure in general either existence or uniqueness of solutions.
  - **Pragmatic approaches:**
    * Desmet and Rossi-Hansberg (2009 and 2010): myopic agents and more structure.
      · Each location solves a static problem.
      · Savings are coordinated by a cooperative that invests along the space.
    * Brock and Xepapadeas (2008b): physical capital is spatially immobile.
      · Technological diffusion $\Rightarrow$ spatial externalities.
      · Diffusion-induced (local) instability.
  - Environmental context: Brock and Xepapadeas (2008a and 2010) and Xepapadeas (2010).

- **Our approach:** based on the Spatial Ramsey model (Boucekkine *et al.*, 2009)
  - Model in continuous time and space to study optimal land use (social optimum):
    * Each location: fixed amount of land, which is allocated among production, pollution abatement, and housing.
    * Land is spatially immobile by nature.
    * Locations' actions affect the whole space: pollution flows across locations $\Rightarrow$ local and global damages (Akimoto, 2003).
  - Main novelties:
    * In contrast to Boucekkine *et al.* (2009), Brock and Xepapadeas (2008a,b and 2010), and Xepapadeas (2010): our problem is **well-posed**.
      · We improve the spatial structure of the social optimum problem.
    * Pontryagin conditions: necessary and sufficient.
    * Numerical simulations:
      · Our algorithm uses a finite difference approximation of the Pontryagin conditions (Camacho *et al.*, 2008).
      · Brock and Xepapadeas (2008a,b and 2010) and Xepapadeas (2010): linear quadratic approximation. However, **our analysis is global**.

2.- The model:

- **Space:** real line $\mathbb{R} \Rightarrow$ continuum of locations.
  - Each location has 1 unit of land, which is devoted to three different activities:
    - Production: $F(l)$.
    - Housing: equal to location's population density $f(x)$ (simplification).
    - Abatement: $G(1 - l - f(x))$.

- **Pollution:** travels across space following the Gaussian plume (*).
  - Local: local productivity harm (*e.g.*, individuals health and/or land).
  - Global: effect of global pollution $P(t)$ (*e.g.*, anthropogenic GHGs)

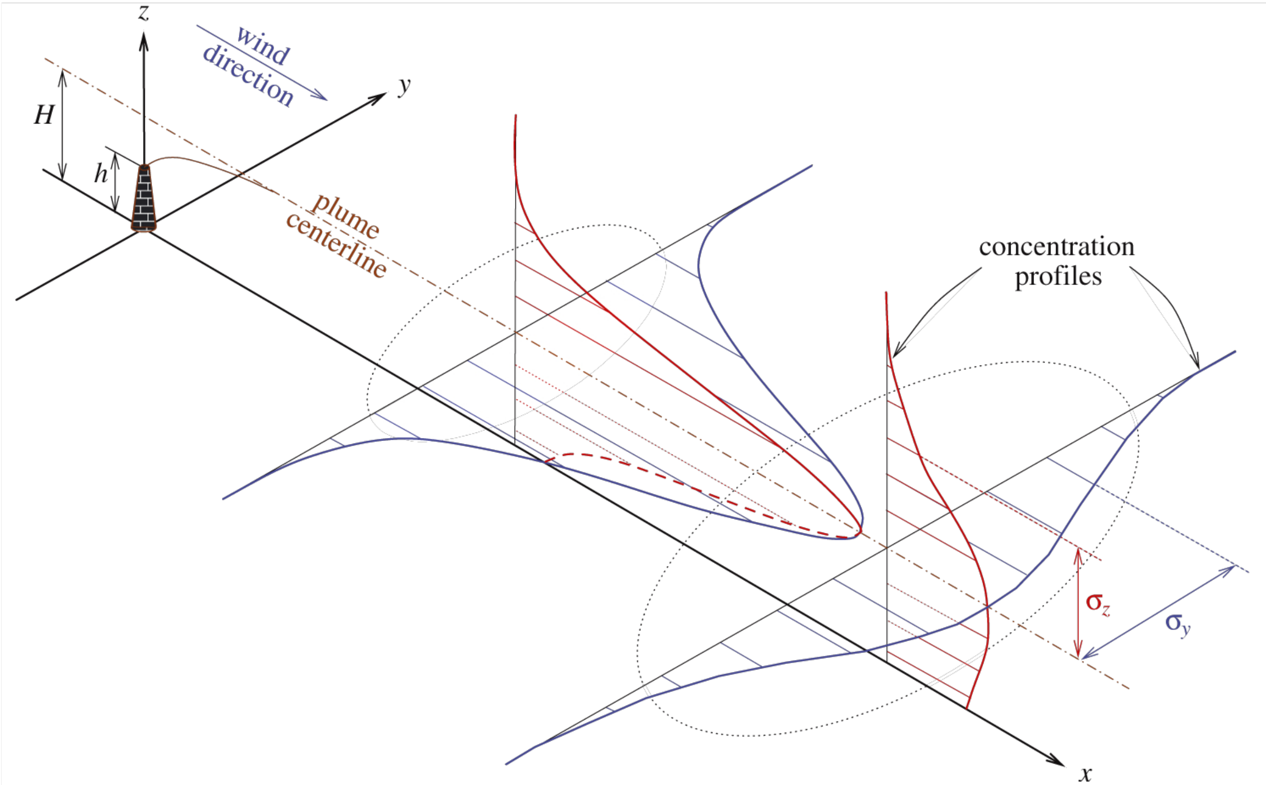
$$P(t) = \int_{\mathbb{R}} p(x,t)dx.$$

  - Some examples (Nordhaus, 1977; and Akimoto, 2003):
    - Local effect: air pollutants (tropospheric ozone, NO_x, and CO_2 plumes).
    - Global effect: CO_2 and anthropogenic GHGs.
    - Local and global effect: methane and CO.

(*) The Gaussian plume:

- Pollutant emitted by a single source located at $x \in \mathbb{R}^3$: $p(x,t)$

$$p_t(x,t) + \nabla \cdot J(x,t) = E(x,t)$$



The model: (cont.)

- **Damage** function $\Omega(p, P) \in [0, 1]$: share of foregone production
$$y(t) = \Omega(p, P)A(x, t)F(l),$$
where $A(x, t)$ is the total factor productivity at location x at time t.

- **Social optimum:**
  - The policy maker maximizes the discounted welfare of the entire population.
  - She chooses consumption per capita and the use of land at each location.

- **Consumption:** the policy maker collects all production and re-allocates it across locations at no cost
$$\int_{\mathbb{R}} c(x, t)f(x)dx = \int_{\mathbb{R}} \Omega(x, p, P)A(x, t)F(l)dx,$$
where $c(x, t)$ denotes consumption per capita at location x and time t.

- **Discount functions:** (Boucekkine *et al.*, 2009)
  - Spatial discount function: population density function $f(x)$.
  - Temporal discount function (as in the standard Ramsey model): $g(t)$.

The model: (cont.)

The policy maker maximizes:

$$\max_{\{c,l\}} \int_0^\infty \int_{\mathbb{R}} u(c(x,t))f(x)g(t)dxdt \tag{1}$$

subject to

$$\mathcal{P} \begin{cases} p_t(x,t) - p_{xx}(x,t) = \Omega(x,p,P)A(x,t)F(l(x,t)) - G(1-l-f(x)), \\ \int_{\mathbb{R}} c(x,t)f(x)dx = \int_{\mathbb{R}} \Omega(x,p,P)A(x,t)F(l)dx, \\ P(t) = \int_{\mathbb{R}} p(x,t)dx, \\ p(x,0) = p_0(x) \geq 0, \\ \lim_{x\to\{\pm\infty\}} p_x(x,t) = 0, \end{cases} \tag{2}$$

where $(x,t) \in \mathbb{R} \times [0,\infty)$.

3.- Analytical results:

- *Proposition 1*: **The policy maker's problem has at least a solution.**
- *Proposition 2*: **Pontryagin conditions** of problem (1)-(2)
  - We use the method of variations in Raymond and Zidani (1998 and 2000).
- *Corollary 1*: **Consumption per capita is spatially homogeneous**.
  - Due to production re-allocation.
- *Proposition 3*: **The problem (1)-(2) is well posed**, *i.e.*, its solution exists and is unique.
  - Spatial Ramsey model $\Rightarrow$ infinite possibilities for q_0 $\Rightarrow$ ill-posed problem.
  - Improving the spatial structure of the social planner problem can overcome ill-posedness:
    * Spatially fixed production factor l with spatial externality (pollution flows across locations) + consumption "imports".
  - Proposition 3 $\Rightarrow$ **Pontryagin conditions are necessary and sufficient**.

4.- Numerical exercises:

- To illustrate the richness of our model.

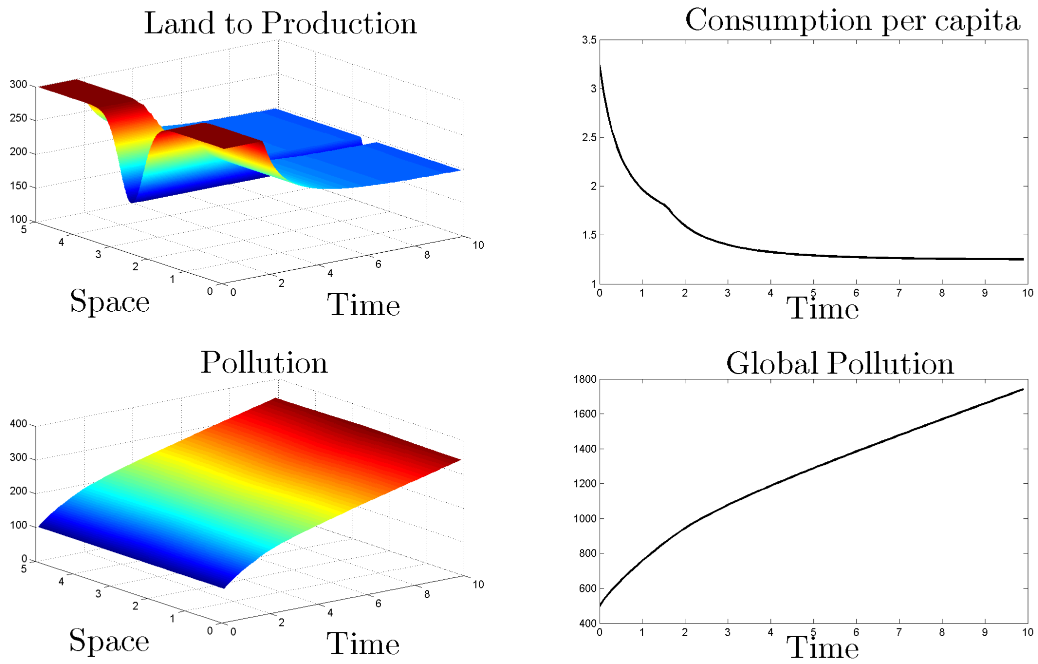
- Uniqueness of the simulated trajectories is ensured since our social optimum problem is well-posed.

- **Emergence of spatial patterns**:
  - Benchmark set-up: already reproduces an ample variety of spatial heterogeneity scenarios.
  - Persistence in time of spatial heterogeneity:
    * We study if spatial disparities are equally persistent and if they vanish with time.
    * We see if spatial differences may arise in an initially equally endowed world.
  - **Abatement technology**: fundamental ingredient to achieve steady state solutions, which are compatible with the formation of long run spatial patterns.

Numerical exercises: example

- **Population agglomeration:**

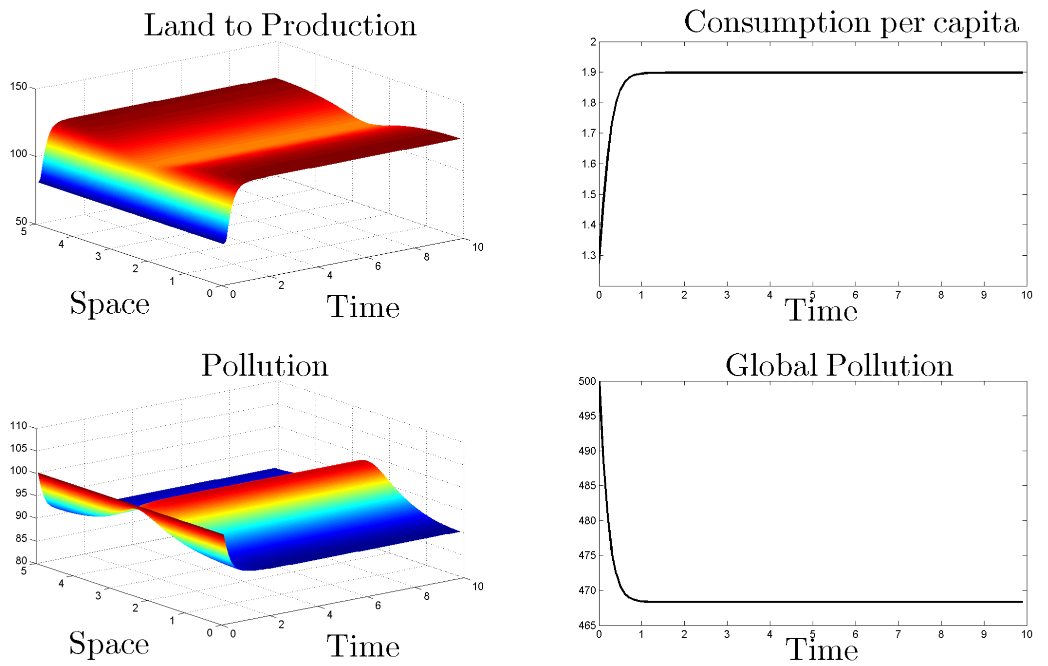
  Population: Gaussian function over $[0, 5]$, *i.e.*, it agglomerates around $x = 2.5$



Numerical exercises: example (cont.)

- **Population agglomeration: abatement efficiency doubling.**

  Population: Gaussian function over $[0,5]$ + $D(x) = 0.2$



5.- Conclusions:

- Benchmark framework to study **optimal land use**, encompassing land use activities and pollution.
- Spatial drivers behind the interaction between land use and the environment: **spatial externalities** of land use activities.
  - Land is spatially immobile by nature.
  - Dynamics of pollution (Gaussian plume) $\Rightarrow$ location's actions affect the whole space.
- Analytical results:
  - The social optimum problem is **well-posed**: improving the spatial structure of the social planner problem can overcome ill-posedness.
  - Pontryagin conditions: not only **necessary but also sufficient**.
- To illustrate the richness of our model: numerical simulations
  - Brock and Xepapadeas (2008a,b and 2010) and Xepapadeas (2010): linear quadratic approximation.
  - Our analysis is **global**.

6.- Extentions:

- Theoretical perspective:
  - **Endogenously distributed population:**
    - ∗ Papageorgiou and Smith (1983): spatial externalities can induce population agglomerations.
    - ∗ Migration flows induced by climate change (see, for instance, Marchiori and Schumacher, 2011).
  - **Explicit modelling of climate change:** non-monotonicities in the environmental degradation (Deschênes and Greenstone, 2007).
  - **Decentralisation of the social optimum:** optimal tax/subsidy schemes that will evolve with time but also across the space.
    - ∗ Optimal corrective policies take spatial information into account (*e.g.*, Tietenberg, 1974; Henderson, 1977; and Hochman and Ofek, 1979)
- Empirical perspective:
  - Pertinence of our **damage function** (Weitzman, 2009).
  - Role of local and global pollution.
  - Spatial sensitiveness.