Land use dynamics and the environment

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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** ⇒ 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 ⇒ 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.

Introduction: (cont.)

- Spatial Economics and land use: **lack of explicit modelling**.
- **Dynamic Spatial Theory:** spatial Ramsey model (Boucekkine *et al.*, 2009).
  - Forward-looking dimension of agents' decisions.
    - Policy maker who decides the trajectory for consumption at each location.
    - Technical problems: parabolic partial differential equations (PDE).
  - **Pragmatic approaches:** Desmet and Rossi-Hansberg (2009, 2010 and 2012): myopic agents + savings cooperative.
    - The structure of their framework ⇒ planner's problem is intractable (see also Desmet and Rossi-Hansberg, 2012).
  - **Our approach:** model to study **optimal land use** (social optimum), based on spatial Ramsey model.
    - 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 ⇒ local and global damages (Akimoto, 2003).

2.- The model:

- **Space:** a continuum of locations along a unidimensional region $R \subseteq \mathbb{R}$.
  - 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)

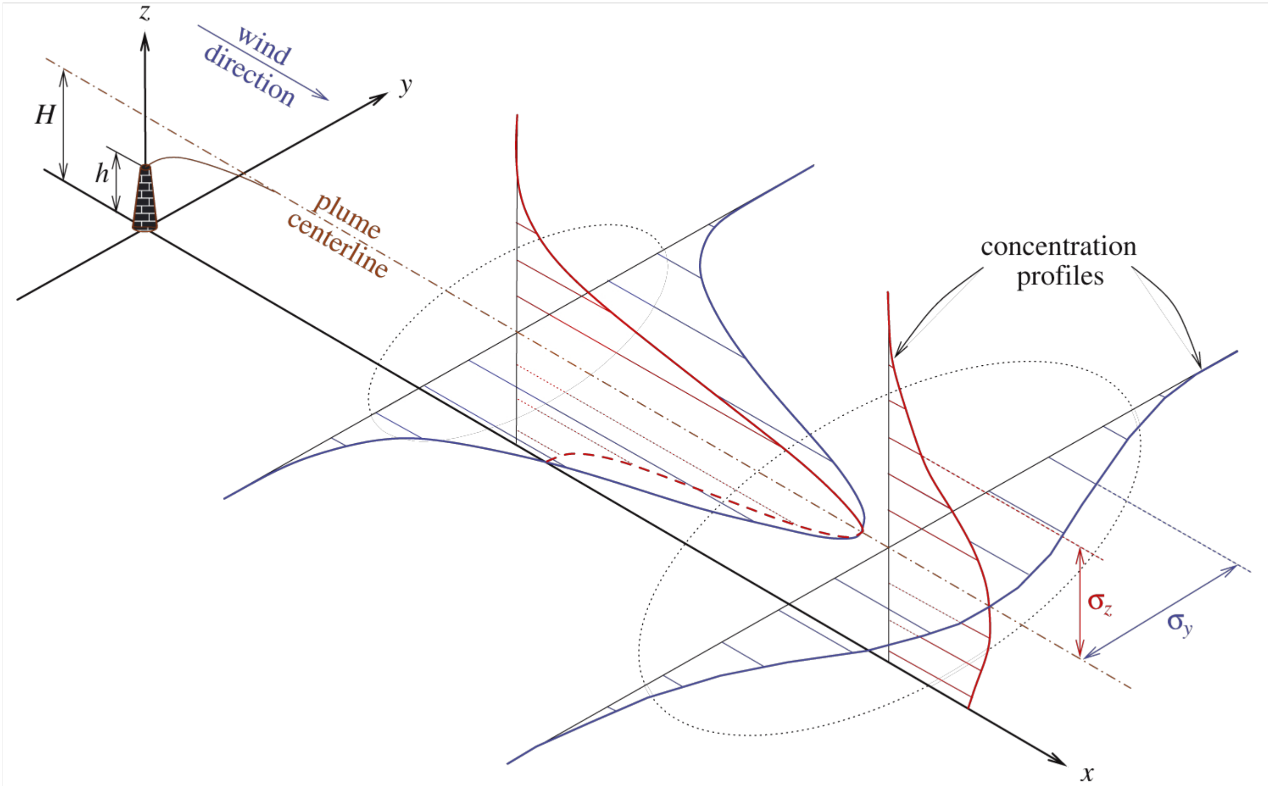
$$P(t) = \int_R p(x,t)dx.$$

  - 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
$$\int_R c(x, t) f(x) dx = \int_R \Omega(x, p, P)A(x, t)F(l)dx,$$
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:

$$\max_{\{c,l\}} \int_0^T \int_R u(c(x,t))f(x)e^{-\rho t}dxdt + \int_R \psi(p,P)(x,T)e^{-\rho T}dx \tag{4}$$

subject to

$$\mathcal{P} \begin{cases} p_t(x,t) - p_{xx}(x,t) = \Omega(x,p,P)A(x,t)F(l(x,t)) - G(1-l-f(x)), \\ \int_R c(x,t)f(x)dx = \int_R \Omega(x,p,P)A(x,t)F(l)dx, \\ P(t) = \int_R p(x,t)dx, \\ p(x,0) = p_0(x) \geq 0, \\ \lim_{x\to\delta R} p_x(x,t) = 0, \end{cases} \tag{5}$$

where $(x,t) \in R \times [0,T]$ and δ denotes R's boundaries.

3.- Analytical results:

- *Proposition*: **The policy maker's problem has at least a solution.**
- *Proposition*: **Pontryagin conditions** of problem (4)-(5)
  - We use the method of variations in Raymond and Zidani (1998 and 2000).
- *Corollary*: **Consumption per capita is spatially homogeneous**.
  - Due to production re-allocation.
- *Proposition*: There is a **unique time independent solution** ("steady-state").
  - Sufficient conditions: diminishing marginal damages.
- *Proposition (new paper)*: **The problem (4)-(5) is well posed**, *i.e.*, its solution exists and is unique in $(x,t) \in R \times [0,T]$, for every $T < \infty$
  - Banach fixed-point theorem (contraction mapping theorem).
- *Theorem (new paper)*: Under a sufficiently smooth damage function, the optimal trajectory **approaches to the "steady-state"** when the planning horizon T expands.

4.- Numerical exercises:

- To illustrate the richness of our model.

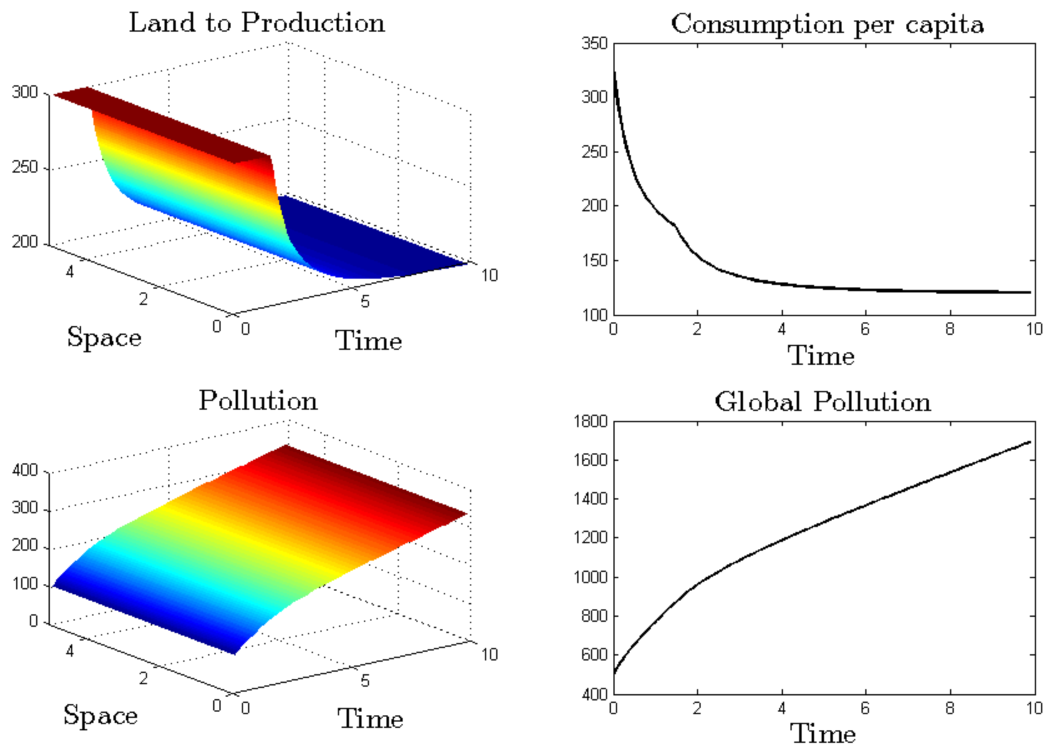
- Uniqueness of the simulated trajectories is ensured since our social optimum problem is well-posed (*new paper*).

- Brock and Xepapadeas (2008a,b and 2010) and Xepapadeas (2010): linear quadratic approximation. However, **our analysis is global**.

- **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.

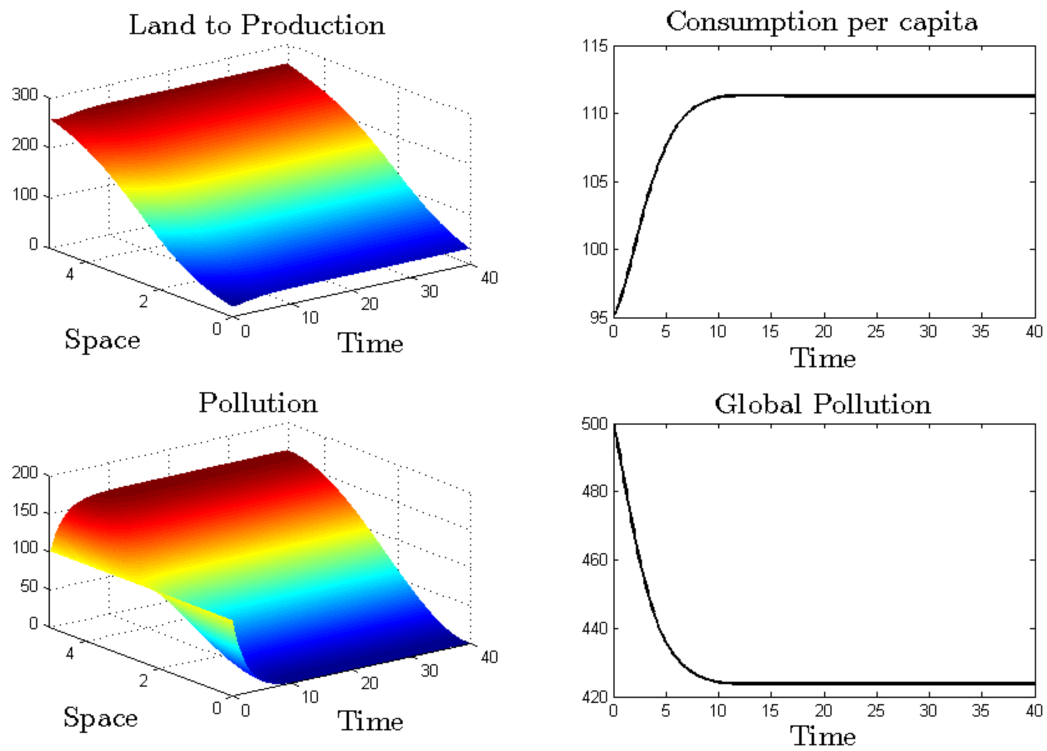
Numerical exercises: (cont.)

- **Benchmark scenario:**



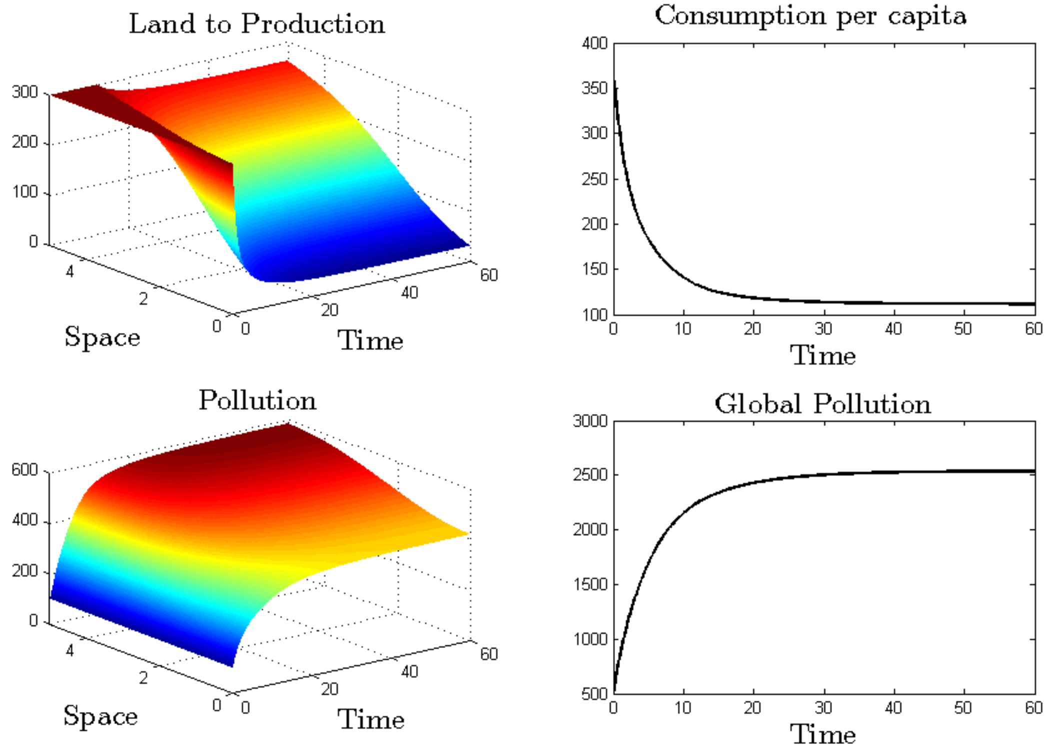
Numerical exercises: (cont.)

- **Role of abatement technology:** abatement efficiency parameter $\sigma(x)$
  - Logistic form: continuous representation of a step function.
  - $\sigma(x)$ monotonically decreases.



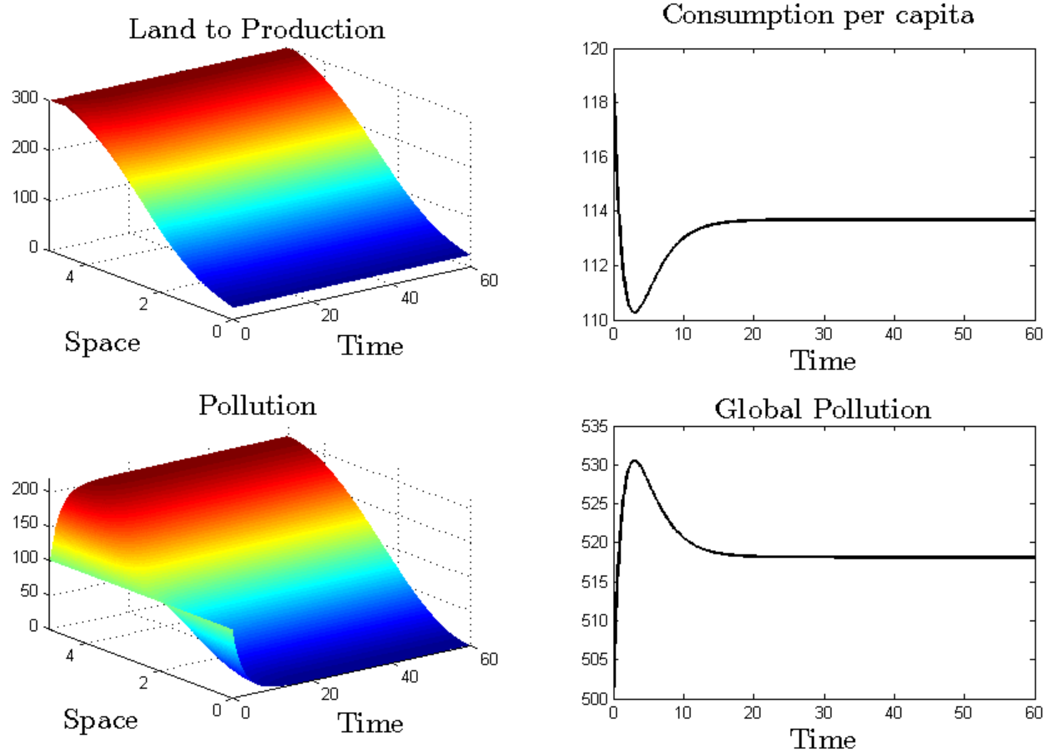
Numerical exercises: (cont.)

- **Role of abatement technology:** local ($\gamma_1 = 0$) damage.



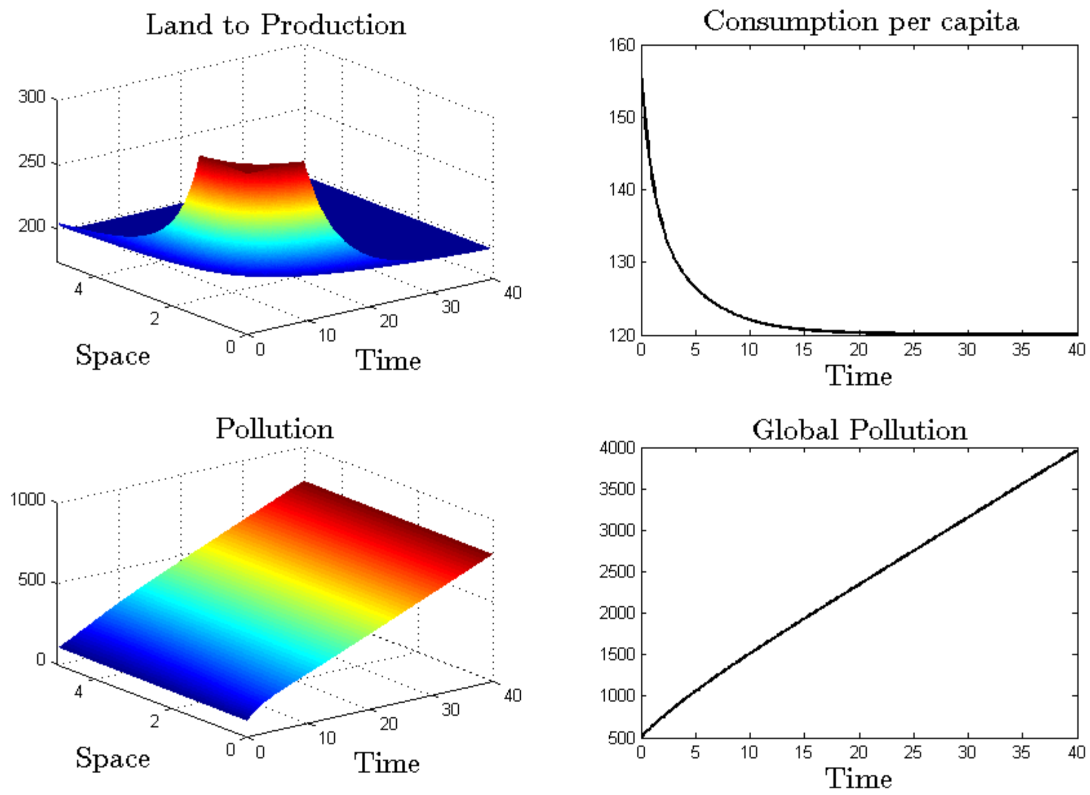
Numerical exercises: (cont.)

- **Role of abatement technology:** global ($\gamma_2 = 0$) damage.



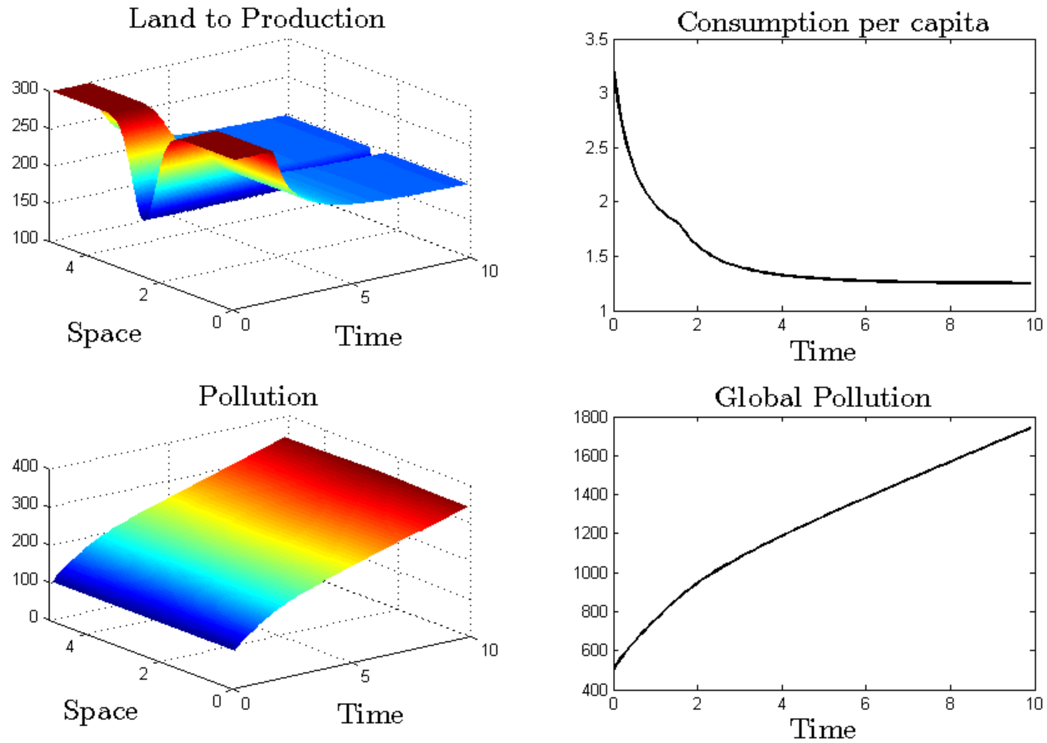
Numerical exercises: (cont.)

- **Spatially heterogeneous sensitivity to global pollution:** $s(x)$.
  - Logistic function: locations are more sensitive to global pollution as they get afar from $x = 0$.



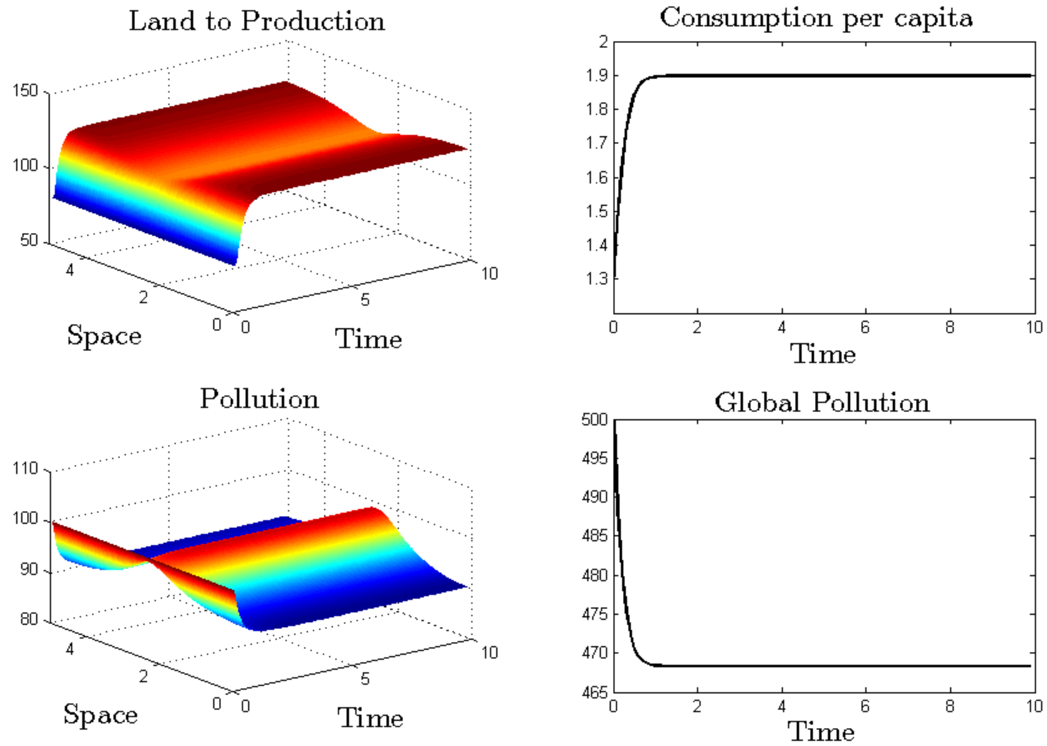
Numerical exercises: (cont.)

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



Numerical exercises: (cont.)

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



5.- Conclusions:

- Benchmark framework to study **optimal land use**, encompassing land use activities and pollution.
- Analytical results: the social optimum problem.
- Simple set-up: ample variety of **spatial heterogeneity** scenarios.

6.- Extensions:

- **Endogenously distributed population.**
- **Decentralisation of the social optimum:**
  - Optimal tax/subsidy schemes take spatial information into account (*e.g.*, Tietenberg, 1974; Henderson, 1977; and Hochman and Ofek, 1979).
- **Mobile spatial borders:**
  - Climate change can modify the shape of a region/country: *e.g.*, sea level rise or desertification.
  - Stefan problem (Cannon and Hill, 1967).