Economic inefficiencies in private management of epidemics spreading between farms

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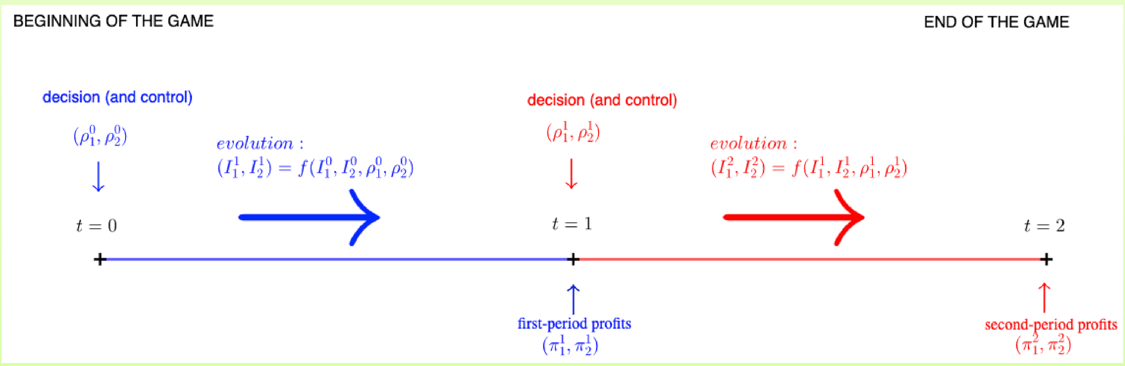
Gaël Thébaud[1], César Martinez[2,3], Mabel Tidball[2], Pierre Courtois[2]

[1] PHIM Plant Health Institute, INRAE, CIRAD, IRD, Institut Agro, Univ Montpellier, France; [2] CEE-M Center for Environmental Economics, Montpellier Univ., INRAE, CNRS, Institut Agro, Montpellier, France; [3] Ecodéveloppement, INRAE, Avignon, France

Most plant epidemics spread both within and between farms. However, in the absence of collective action, each farmer generally takes disease control decisions based on personal costs and benefits. It is important to identify under which conditions the combination of such private control decisions can have synergistic or antagonistic effects, can lead to collective economic inefficiency, and can be offset by a subsidy. We used a game theory framework to investigate these questions for sharka, an aphid-transmitted disease caused by the plum pox virus (PPV). In France, sharka control is presently regulated (and subsidized) by the State, with mandatory orchard inspections and removal of infected trees. However, the French government is organizing the devolution of sharka management and may end its subsidy policy, which requires a thorough examination of the potential implications.

The model

- *Assumptions:*
  - low disease incidence
  - 2 successive time periods
  - 2 neighboring farms onlydiffering in their initial incidence
  - full information and perfect self-profit maximization
  - simultaneous binary decisions: $\rho_k^t = \rho$ (Control) or $\rho_k^t = 0$ (No control)
- *Time structure:*



- *Epidemiology:*

$$\underbrace{I_k^{t+1}}_{\text{infectious}} = I_k^t(1-\rho_k^t) + \sum_{j=1}^{2} I_j^t(1-\rho_j^t)\underbrace{r_{jk}}_{\text{transmission}}$$

$$\underbrace{S_k^{t+1}}_{\text{susceptible}} = S_k^t - \sum_{j=1}^{2} I_j^t(1-\rho_j^t)r_{jk},$$

- *Economy:*

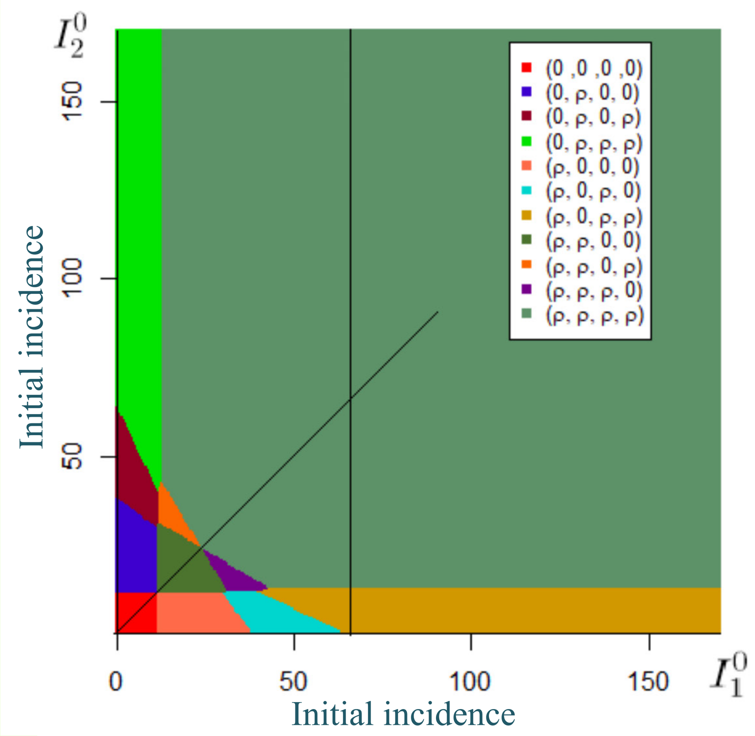
$$\underbrace{\pi_k^{t+1}(\boldsymbol{I^t},\boldsymbol{S^t},\boldsymbol{\rho^t})}_{\text{profit}} = \boxed{\underbrace{B_k^{t+1}}_{\text{benefits}}} - \underbrace{C_k^t}_{\text{costs}} = \boxed{I_k^{t+1}u_k + S_k^{t+1}v_k} - \underbrace{\frac{\rho_k^t}{\rho}c_f}_{\text{inspection}} - \underbrace{c_r\rho_k^t I_k^t}_{\text{removal}}$$

- *Parameters:*

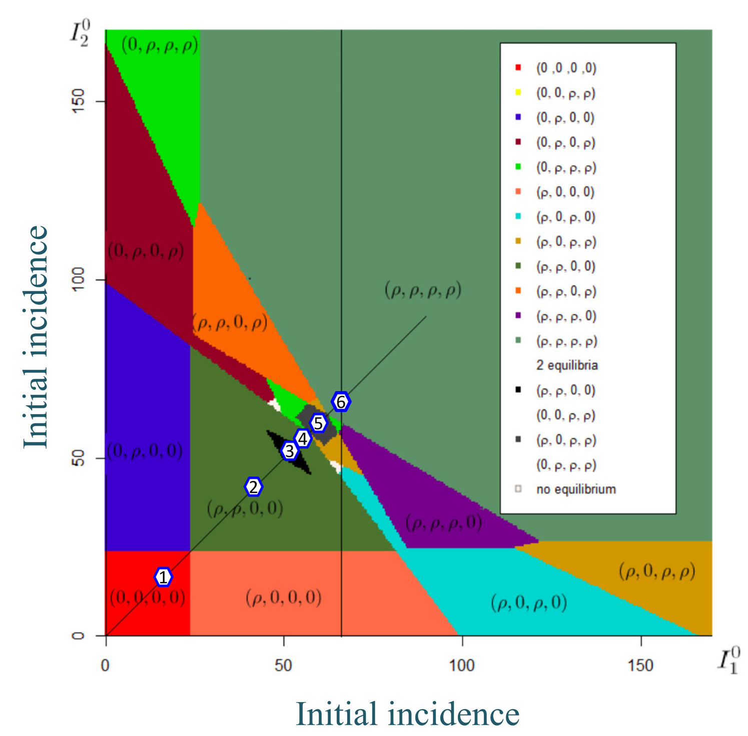
Parameter	Description	Value	Unit
Economic parameters			
c_f	Inspection cost for 10 hectares	1600	€
c_r	Removal cost per tree	15	€
u_1, u_2	Net benefit from an infected tree	10	€
v_1, v_2	Net benefit from a healthy tree	50	€
δ	Discount rate	0.96	–
Epidemiological parameters			
r_{12}, r_{21}	Interpatch transmission per infected tree	1.55	–
r_{11}, r_{22}	Intrapatch transmission per infected tree	1.6	–
ρ	Detection rate	0.20	–
N_1^0, N_2^0	Total number of trees per orchard	5330	Tree

Results of the profit-maximization problem

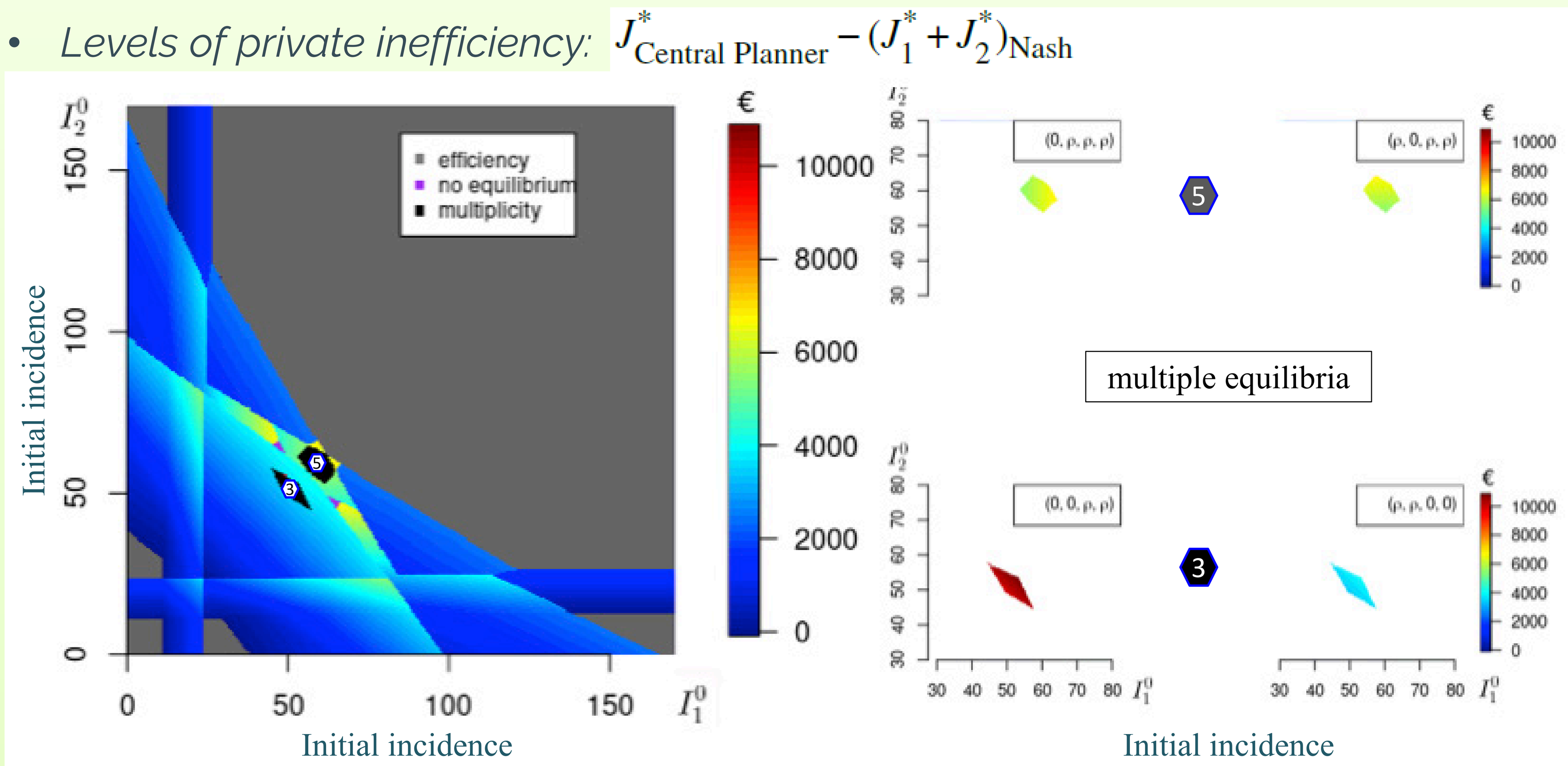
- *Socially optimal management*



- *Optimal private management (Nash)*



- *Levels of private inefficiency:* $J^*_{\text{Central Planner}} - (J_1^* + J_2^*)_{\text{Nash}}$



- *Equilibrium strategies:*

$$(\underbrace{\rho_1^0, \rho_2^0}_{\text{first period}}, \underbrace{\rho_1^1, \rho_2^1}_{\text{second period}})$$

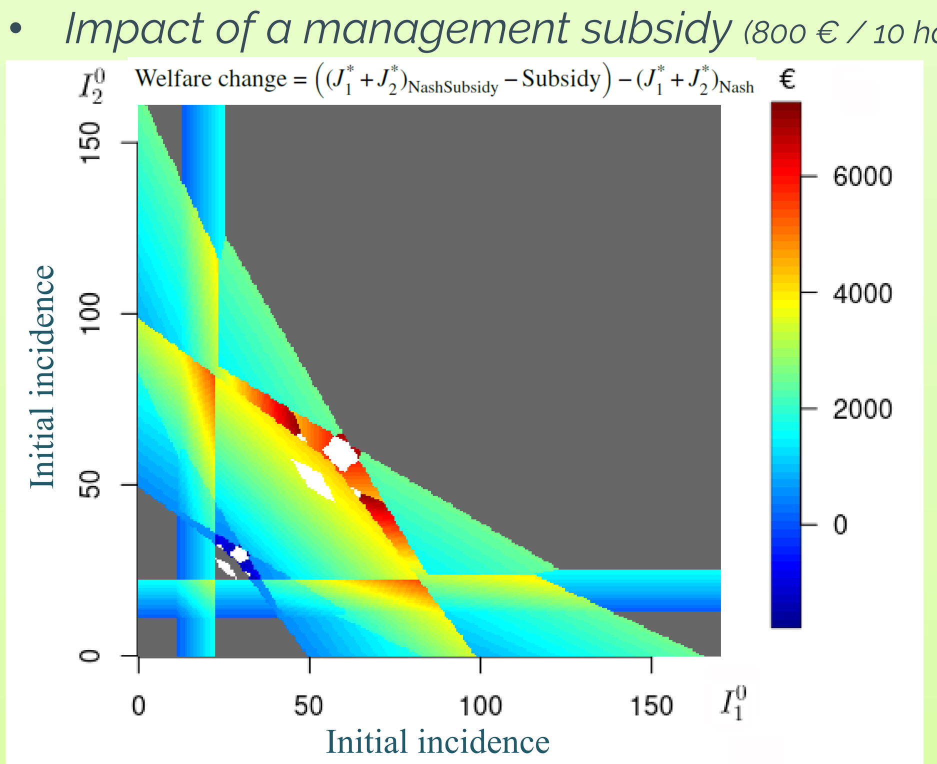
orchard 1, orchard 2

- ***Results - equilibria:***
  - Disease incidence affects the optimal strategies and the types of interactions
  - Private management increases:
    - strategic interactions
    - the diversity of equilibria
    - incidence thresholds for control (1) and full control (6)

- *Equilibria along the bisector*

	$I_1^0 = I_2^0$ range		0	ρ	Payoffs relations	Game number
full control	≥ 63	0	$(0,0,\rho,\rho)$ $(\underline{a},\underline{a})$	$(0,\rho,\rho,\rho)$ $(\underline{b},\underline{c})$	$a < c$	6
		ρ	$(\rho,0,\rho,\rho)$ $(\underline{c},\underline{b})$	(ρ,ρ,ρ,ρ) $(\underline{d},\underline{d})$	$b < d$	
anti-coordination	$57-62$	0	$(0,0,\rho,\rho)$	$(0,\rho,\rho,\rho)$	$a < c$	5
		ρ	$(\rho,0,\rho,\rho)$	$(\rho,\rho,0,0)$	$b > d$	
first-period control only	$54-56$	0	$(0,0,\rho,\rho)$	$(0,\rho,\rho,0)$	$a < c$	4
		ρ	$(\rho,0,0,\rho)$	$(\rho,\rho,0,0)$	$b < d$	
coordination	$50-53$	0	$(0,0,\rho,\rho)$	$(0,\rho,0,0)$	$a > c$	3
		ρ	$(\rho,0,0,0)$	$(\rho,\rho,0,0)$	$b < d$	
first-period control only	$24-49$	0	$(0,0,\rho,\rho)$	$(0,\rho,0,0)$	$a < c$	2
		ρ	$(\rho,0,0,0)$	$(\rho,\rho,0,0)$	$b < d$	
no control	$0-23$	0	$(0,0,0,0)$	$(0,\rho,0,0)$	$a > c$	1
		ρ	$(\rho,0,0,0)$	$(\rho,\rho,0,0)$	$b > d$	

- *Impact of a management subsidy* (800 € / 10 ha)



- ***Results - inefficiency & subsidy:***
  - For relatively high incidence, private disease management is efficient
  - Strategic interactions cause high levels of inefficiency, especially for multiple equilibria
  - A uniform subsidy on management costs:
    - generally offsets inefficiencies
    - can be unnecessary (grey) or counterproductive (dark blue)

Discussion

Sources of inefficiency:

- Ignoring negative impact on the neighbor
- Free-riding on the neighbor's effort
- Coordinating on late control in multiple equilibria

Consequences for sharka management:

- Transfer from public to private control may cause significant collective inefficiency in sharka control
- Mechanisms of coordination are necessary
- Well-designed subsidies may also be required

Model limitations:

- Simplistic spatiotemporal framework
- Simplistic sociological assumptions:
  - only incidence differs between farms
  - farmers solve a deterministic stategic game

=> Future work on simulations

For further information, see:
Martinez C., Courtois P., Thébaud G., Tidball M. (2024) The private management of plant disease epidemics: Infection levels and social inefficiencies. *European Review of Agricultural Economics* 51(2): 248-274.

Centre **Montpellier**

Cirad TA A-120/K
Campus de Baillarguet
34398 Montpellier cedex 5
Tél. : + 33 (0)4 99 62 48 55
gael.thebaud@inrae.fr
https://umr-phim.cirad.fr/

PHIM Plant Health Institute Montpellier

CAMEPI Characterisation And Modeling of Epidemics