

Coordination problems and the control of epidemics affecting fruit trees

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Coordination problems and the control of epidemics affecting fruit trees

C.Martinez¹, P.Courtois¹, M.Tidball¹, G.Thébaud²

¹INRA, CEE-M; ²INRA, BGPI

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C. Martinez (INRA,CEE-M)

A complex management problem

- production by private owners distributed within a landscape
- economic losses due to the infection outbreak
- diffusion of pathogens intra and inter-patch
- finite horizon, multi-year production
- treatment by (partially inefficient) detection and removal of infected trees, (discrete binary choice)



Figure: Sharka example

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Objective: Understand the decentralized problem

Problem often studied under the centralized perspective.

Our objective: understand better the decentralized behavior. Emerging literature: [Atallah et al., 2017], [Fenichel et al., 2014], [Costello et al., 2017]

We analyze classical questions... coordination issues, inefficiency characterization... with specific modeling constraints

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Modeling: infection diffusion within a period

Management options: $\rho_i \in \{0, \rho_{max}\}; 0 < \rho_{max} < 1$

State variables:

 I_i Quantity of infected in patch i.

 S_i Quantity of uninfected trees.

Growth and diffusion of the infection: r_{ij} Evolutionary law (discrete time model), with $I \ll S$:

$$(I_i^{t+1}, S_i^{t+1}) = f(S^t, I^t, \rho^t)$$
$$I_i^{t+1} = I_i^t (1 - \rho_i) + \sum_{j=1}^N I_j^t (1 - \rho_j) r_{ji}$$
$$S_i^{t+1} = S_i^t - \sum_{j=1}^N I_j^t (1 - \rho_j) r_{ji}$$

Modeling: Infection diffusion, two patches model

Diffusion in a two patches model

$$I_{i}^{t+1} = I_{i}^{t}(1-\rho_{i}) + \sum_{j=1}^{N} I_{j}^{t}(1-\rho_{j})r_{ji}$$
patch 1 patch 2
$$\begin{array}{c} r_{12}I_{1}^{t}(1-\rho_{1}^{t}) \\ & \longrightarrow \\ (\bigcirc \\ r_{11}I_{1}^{t}(1-\rho_{1}^{t}) \end{array} & (\bigcirc \\ r_{21}I_{2}^{t}(1-\rho_{2}^{t}) \end{array} & (\bigcirc \\ r_{22}I_{2}^{t}(1-\rho_{2}^{t}) \end{array}$$

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Economic model: profit function

$$\pi_i^t(I^t, S^t, \rho^t) = \left(S_i^{t+1}v_i + I_i^{t+1}u_i - \frac{\rho_i^t}{\rho_{max}}(c_a + c_hA_i)\right)$$

subject to:

$$(I^{t+1}, S^{t+1}) = f(S^t, I^t, \rho^t).$$

 v_i production value by an uninfected tree in patch i

 u_i production value by an infected tree i

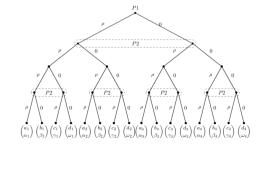
 c_a access cost

$$c_h$$
 per ha⁻¹ inspection cost

 A_i patch *i* surface

Conceptual framework

Framework



$$V_i^T(\rho^0, \rho^1, I^0, S^0) = \pi_i^0(I^0, S^0, \rho^0) + \beta \pi_i^1(I^1, S^1, \rho^1)$$
$$I^{t+1}, S^{t+1} = f(I^t, S^t, \rho^t).$$

Resolution for the closed loop feedback-Nash equilibrium concept. Comparison with the Pareto optimum.

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Results

Impact of the initial condition in the 2 patches 2 steps model:

- An example of analytical result: zone where $(\rho_{max}, \rho_{max}, \rho_{max}, \rho_{max})$ is the unique FNE
- Multiplicity of FNE
- Characterization of inefficiency

Maximal effort as a FNE

Proposition: Within the initial condition state space, there is a zone where initial infection is sufficiently high so that both players do maximal effort:

 $\begin{array}{l} (\rho_{max},\rho_{max},\rho_{max},\rho_{max}) \text{ is the unique Nash equilibrium if and only if} \\ (I_1^0,I_2^0) \in \Delta_{max}, \text{ where } \Delta_{max} \text{ is defined by the set of inequalities:} \\ \begin{cases} I_2^0 > \frac{\alpha_1 - I_1^0(1 - \rho_{max})(1 + r_{11})}{(1 - \rho_{max})r_{21}} \\ I_2^0 > \frac{\alpha_2 - I_1^0(1 - \rho_{max})r_{12}}{(1 - \rho_{max})(1 + r_{22})} \\ I_2^0 > k_2 \\ I_1^0 > k_1 \\ \end{cases} \\ \text{where } \alpha_i \equiv \frac{1}{F_i}(c_a + c_h \frac{1}{\rho_{max}}A_i) \text{ where } F_i \equiv (v_i - u_i)r_{ii} - u_i, \\ \text{ and } k_1 \text{ and } k_2 \text{ are some constants.} \end{cases}$

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Private efficiency in the case of maximal effort

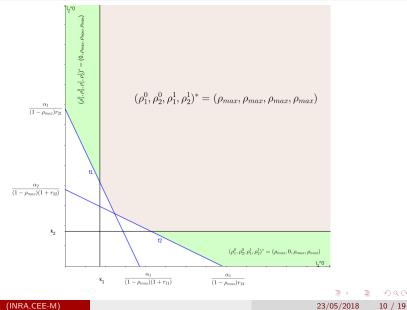
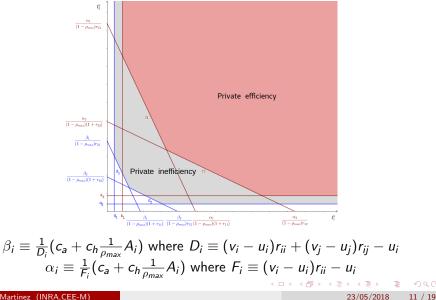


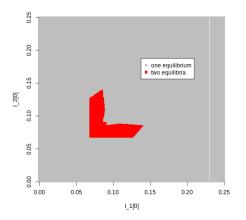
Illustration for ρ_{max} as a unique Nash equilibrium



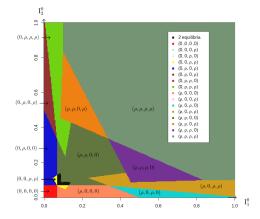
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Number of Nash equilibria

Proposition: Multiplicity might arise... even in a symmetric case (proof using an example).



Example, Nash equilibria according to the initial condition



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Symmetric example, inefficiency

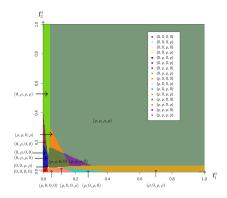


Figure: Pareto optimum, symmetric example

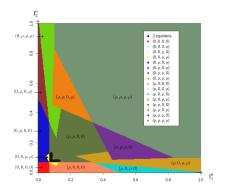


Figure: Nash equilibria, symmetric example

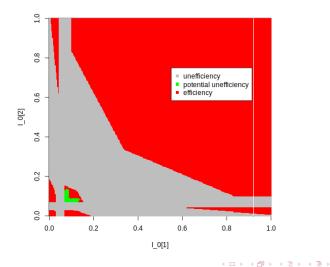
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Symmetric example, inefficiency



Conclusion

Main results

When infection is still small, ($I \ll S$), and detection imperfect, and given parameters (T, R, U, V...)

- Nash feedback resolution of the game shows equilibria depending on the initial infection level
- Geometric characterization of efficiency and inefficiency zones as a function of the initial infectious state
- Coordination issues: multiplicity of equilibria for some (I_1^0, I_2^0)

Conclusion

Perspectives

- Introduce asymmetry in the case study, look at the impact of other parameters
- Study de-synchronization of production cycles and longer time horizons
- Apply this framework to analyze real life problems (find some data); question large scale management programs using known parameters
- Work on the modeling: SI model, probabilistic framework...

Thanks for listening !

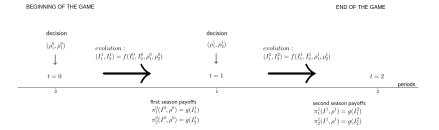
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Temporal structure



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