Epidemics in markets with trade friction and imperfect transactions

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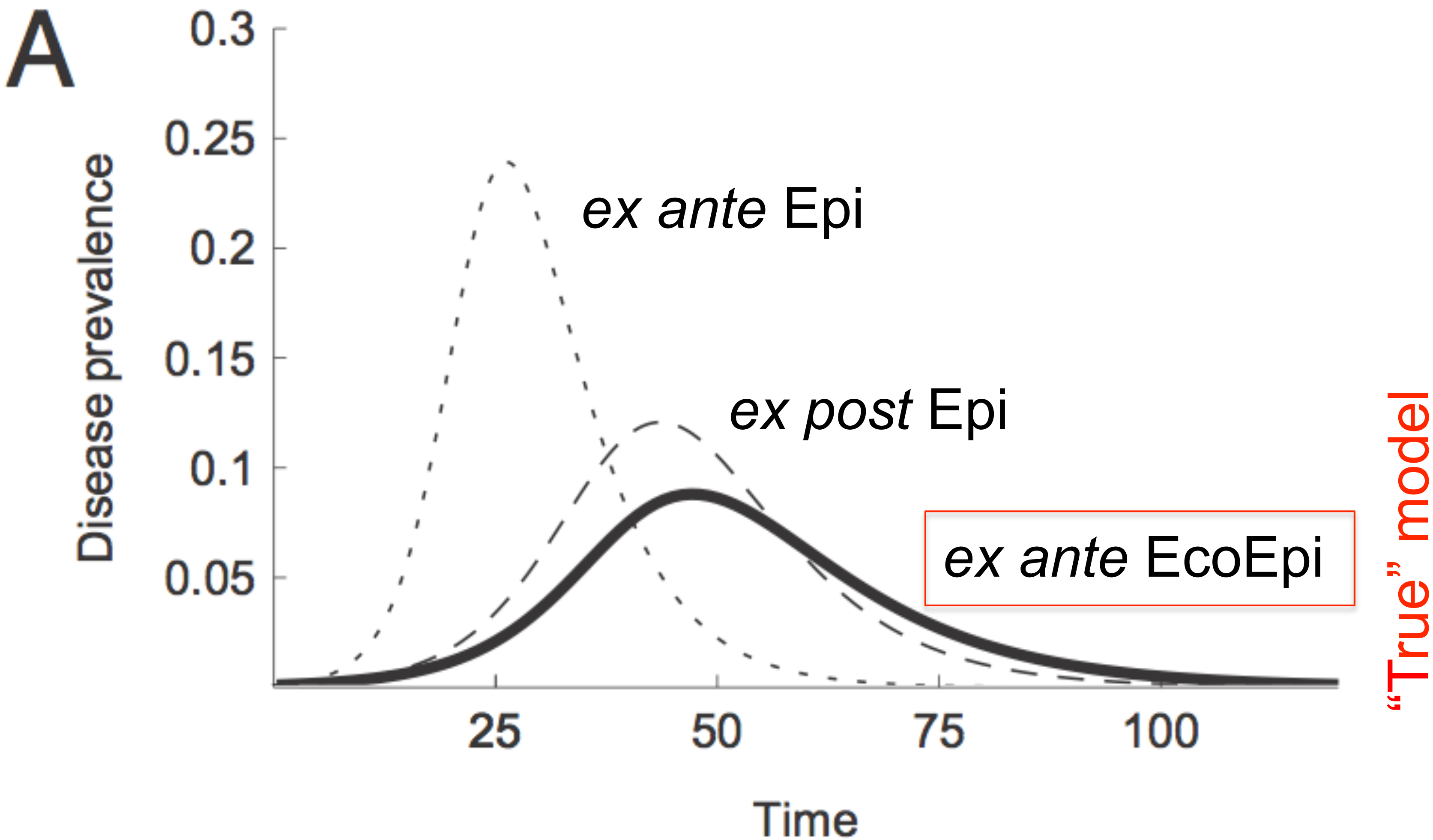
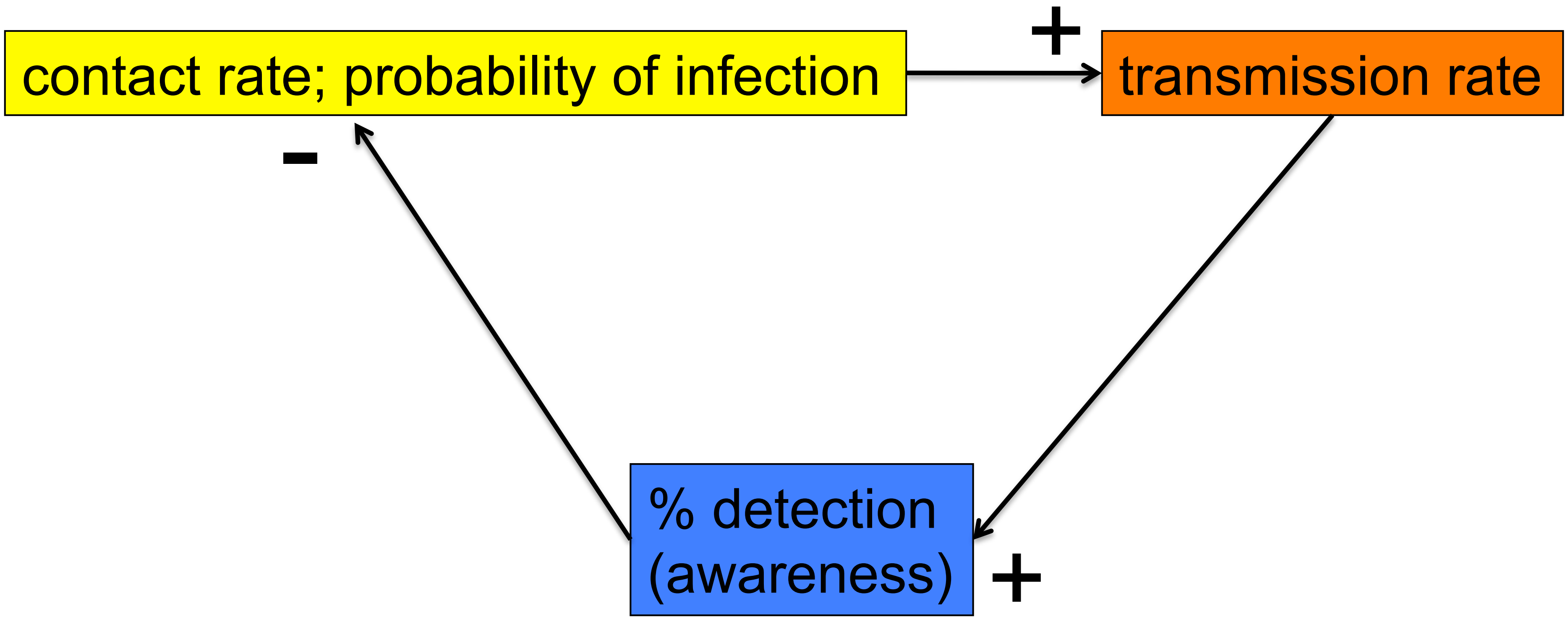
Motivation. Adaptive human behavior always seems to decrease the risk of infection…



Fenichel et al. (2011) *PNAS*

Motivation. This is because adaptive human behavior allegedly boils down to disease-risk-aversion (RA)!



Review: Funk et al (2010) *Interface*

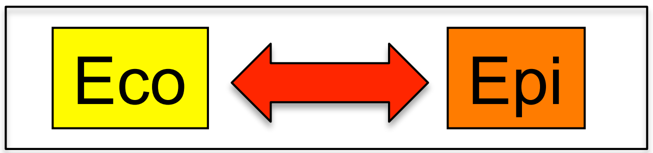
Motivation. Counter-example: complex human behaviour associated with markets.

- **[Eco] drives [Epi]** by propagating pathogens through trade routes and other transmission pathways. Examples: **livestock markets**; **plant nurseries**

- **[Epi] affects [Eco]** by altering:
  - economic agents (e.g. removal and re-entry);
  - agents' individual behaviours (e.g. decisions to sell and buy; RA);
  - collective coordination processes (e.g. actual exchanges and price).
  - **Conclusion: market-related behaviour is richer than RA.**

➢ **Key question:** trade can drive epidemics, but how and in which cases?

➢ **Our focus:** the *feedbacks* between [Eco] and [Epi]



Approach. Bottom-up construction and exploration of a novel [Eco]-[Epi] model.

A new framework

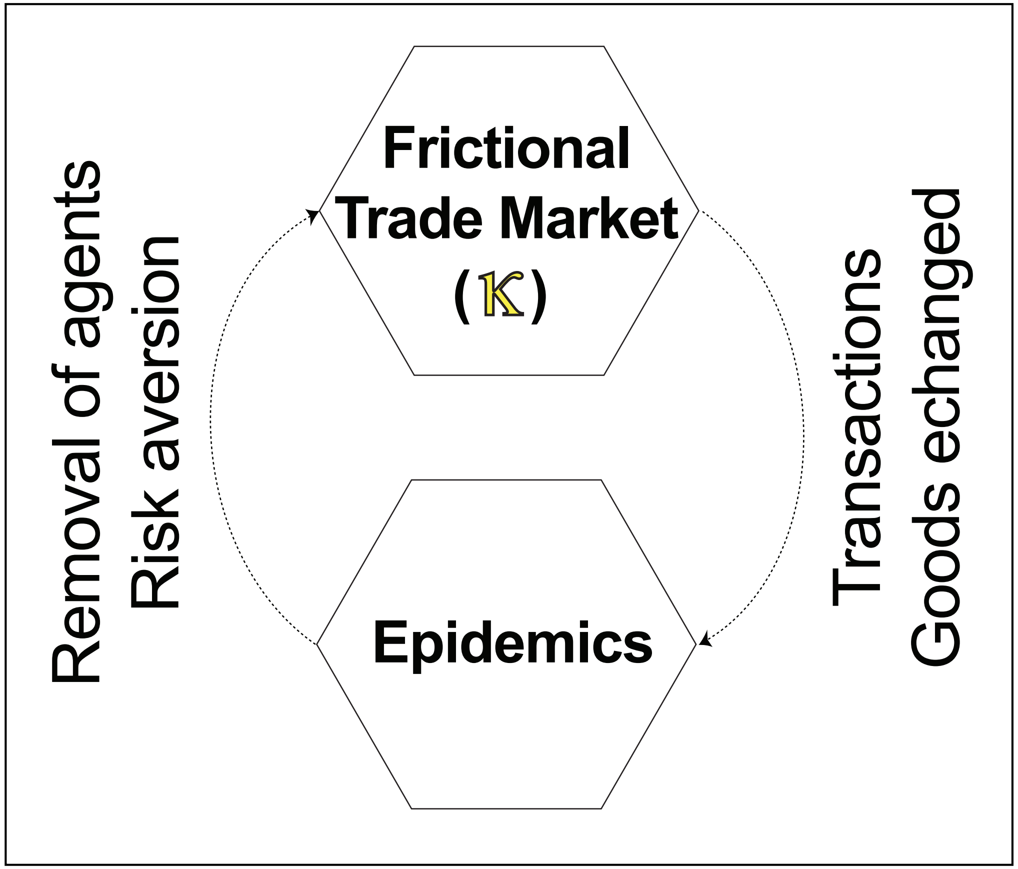
- **[Eco] The Frictional-Trade Market (FTM) model:**
    - mechanistic model of trade: sets the **contact** structure
    - non-equilibrium trade dynamics controlled by **friction**
- **[Eco]-[Epi] The Market-Epidemiological (ME) model:**
    - ME = FTM + Epidemics + RA

The methods

- **Formalism:** ODEs
- **Analytical approaches**:
    - equilibrium and stability analyses
    - bifurcations ($\mathbf{R_0}$)
- **Simulations**:
    - comparisons of contrasted scenarios
    - global sensitivity analysis (improved Morris)

Approach. Overview of the [Eco]-[Epi] model.

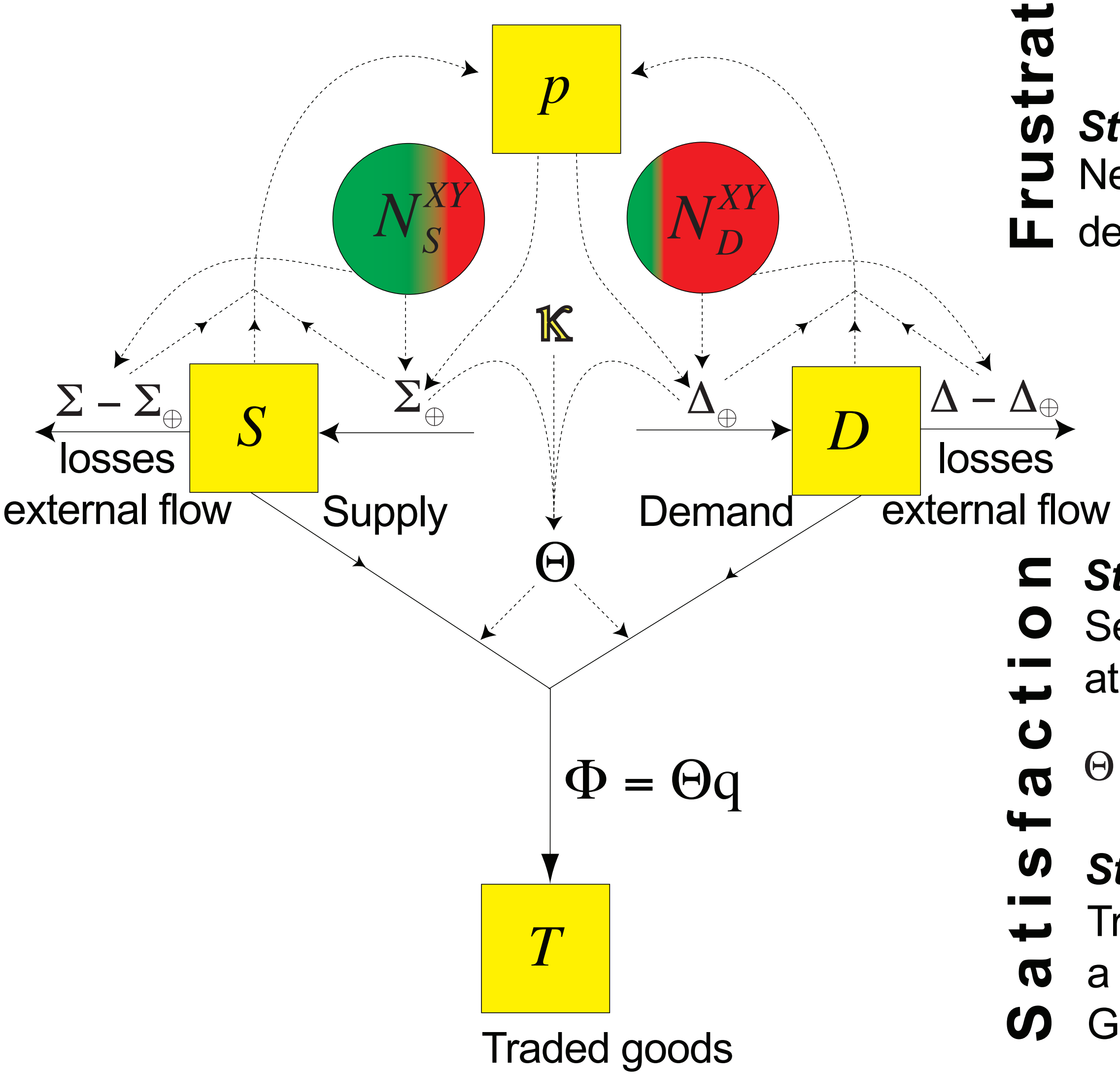
Epidemics impact hosts



The market sets the <u>contact structure</u> among hosts

𝕂 coefficient of friction

[Eco] The whole FTM model



Frustration

Step 1
Pricing at level *p*

Step 2
Net generation of supply and demand at rates Σ and Δ

Satisfaction

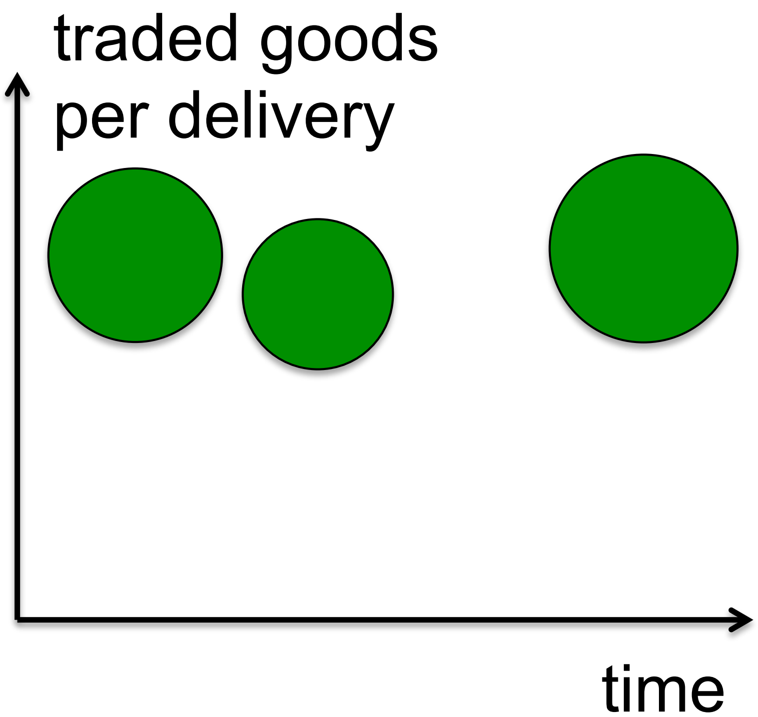
Step 3
Search and delivery processes at transaction rate Θ where:

$$\Theta = \frac{\min(\Sigma_\oplus, \Delta_\oplus)}{\mathbb{K}}$$

Step 4
Trading of q goods from a supplier to a client.
Generation of flows Φ

[Eco] Frictional versus Fluid Markets

A. Swine



B. Cattle

total # goods exchanged during Δt ≈ cte (at equ.)

Friction = *constraints* on agent satisfaction in trade transactions (underpinned here by search and delivery processes)
[Labour economics; papers by Diamond, Mortensen and Pissarides since 1970s]

[Eco] Frictional versus Fluid Markets

$\Phi = $ [trade flow] = [total # goods exchanged per time unit]

$\Phi = $ [transaction rate; Θ] $\times$ [# goods exchanged per transaction; q]

times per time step when suppliers deliver goods to demanders

goods exchanged from a supplier to a demander during a single delivery

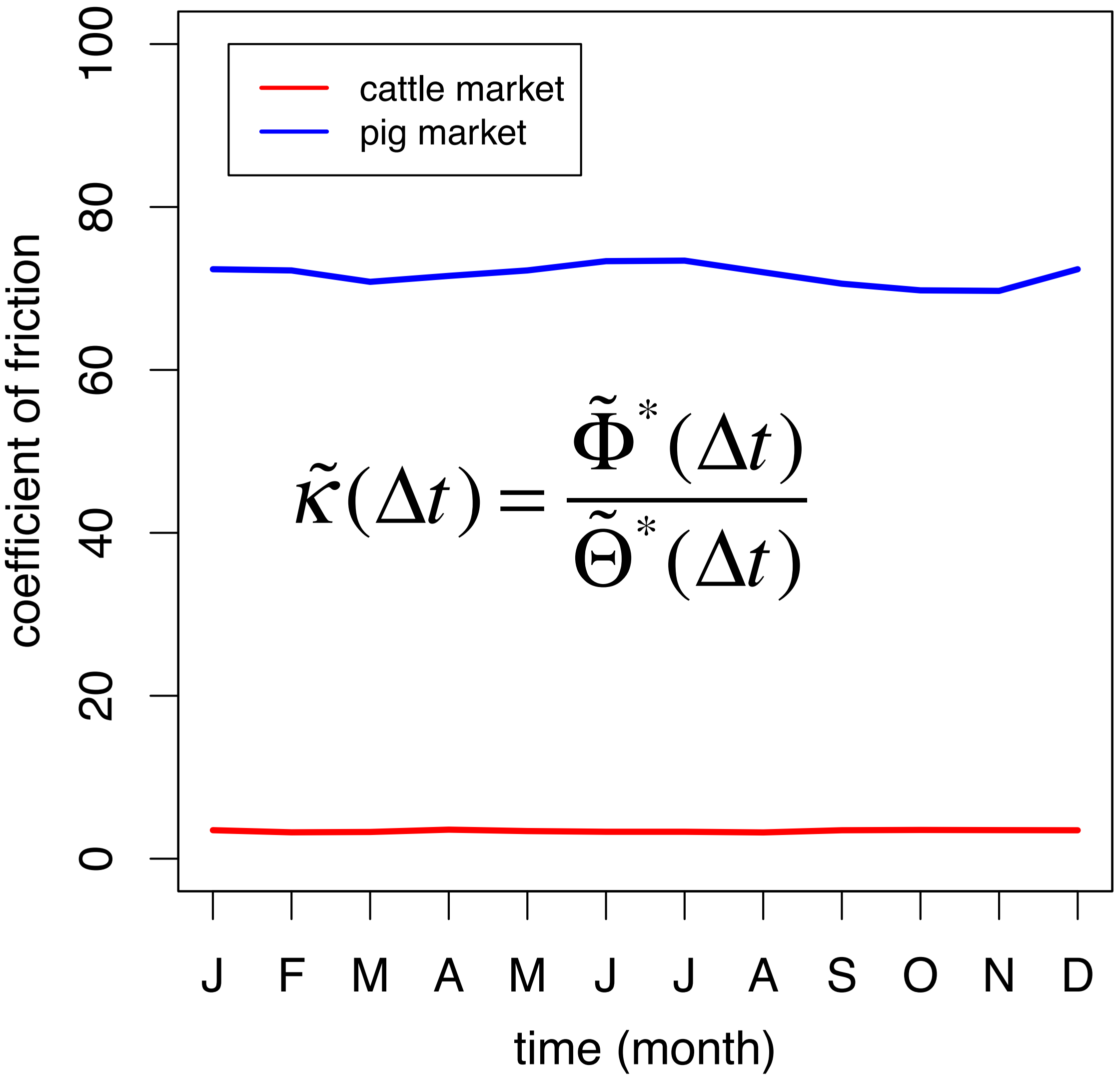
κ governs the trade-off with trade flow kept constant (at equ.)

– large κ (e.g. swine): small Θ but large q

– small κ (e.g. cattle): large Θ but small q

➢ Both transactions and goods can contribute to infection!

[Eco] Estimation of friction from trade flow data



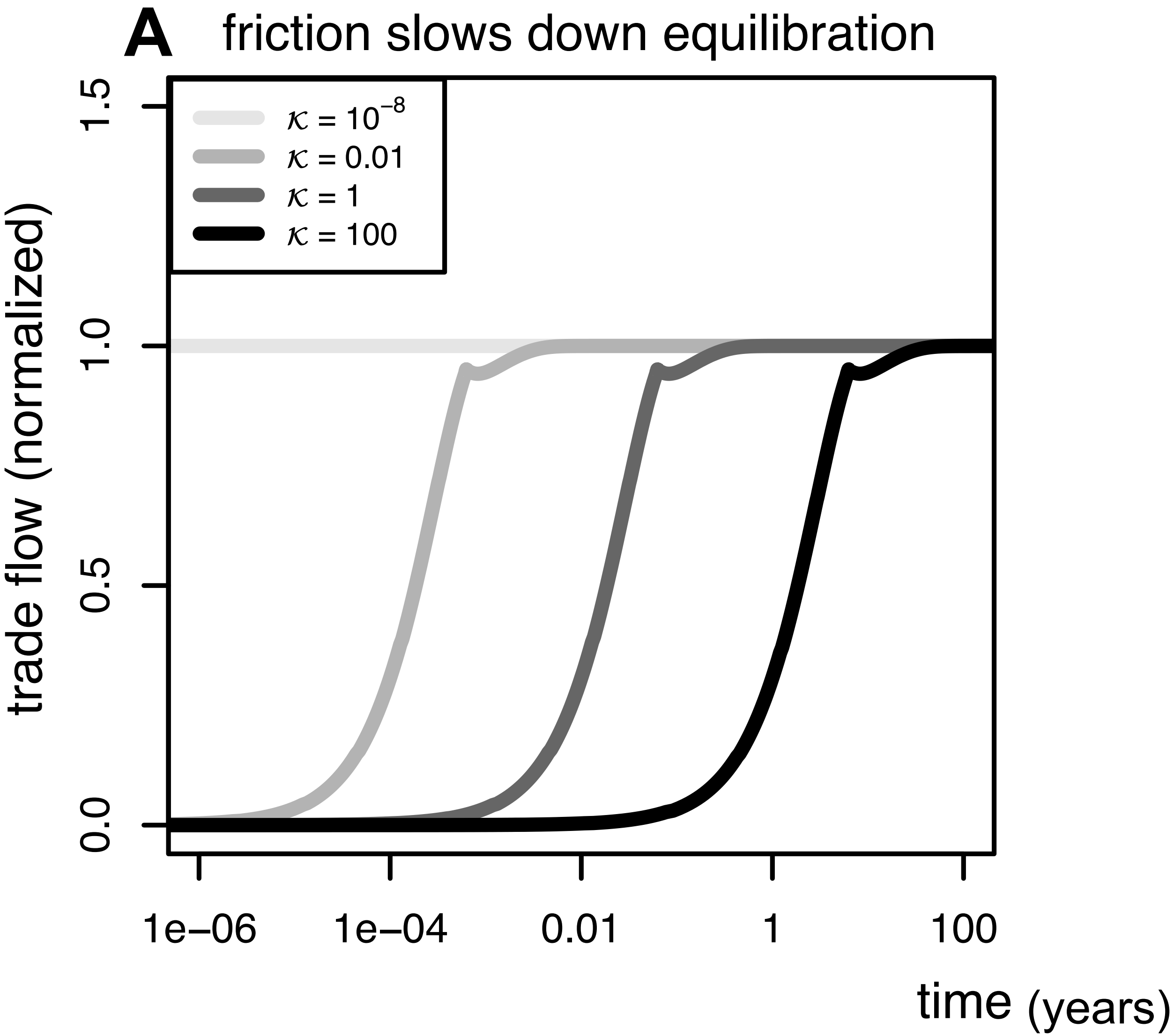
Pigs: $K = 72$

BDPorc dataset:
– *France, 2010*
– *Daily batch movements*

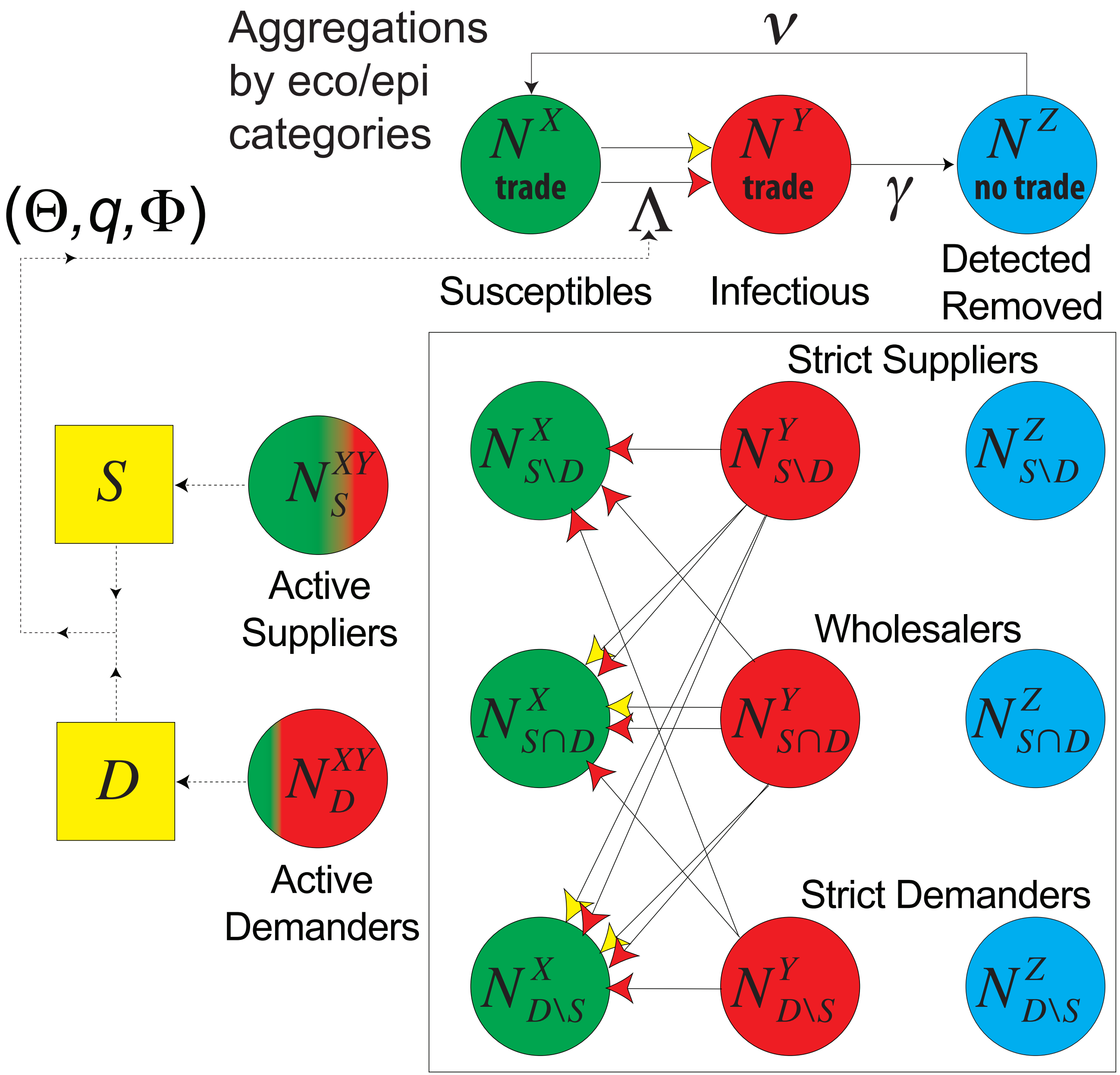
Cattle: $K = 3$

BDNI dataset:
– *France, 2009*
– *Daily individual movements*

[Eco] The influence of trade friction on market dynamics.



[Eco]-[Epi] Now we introduce epidemics…



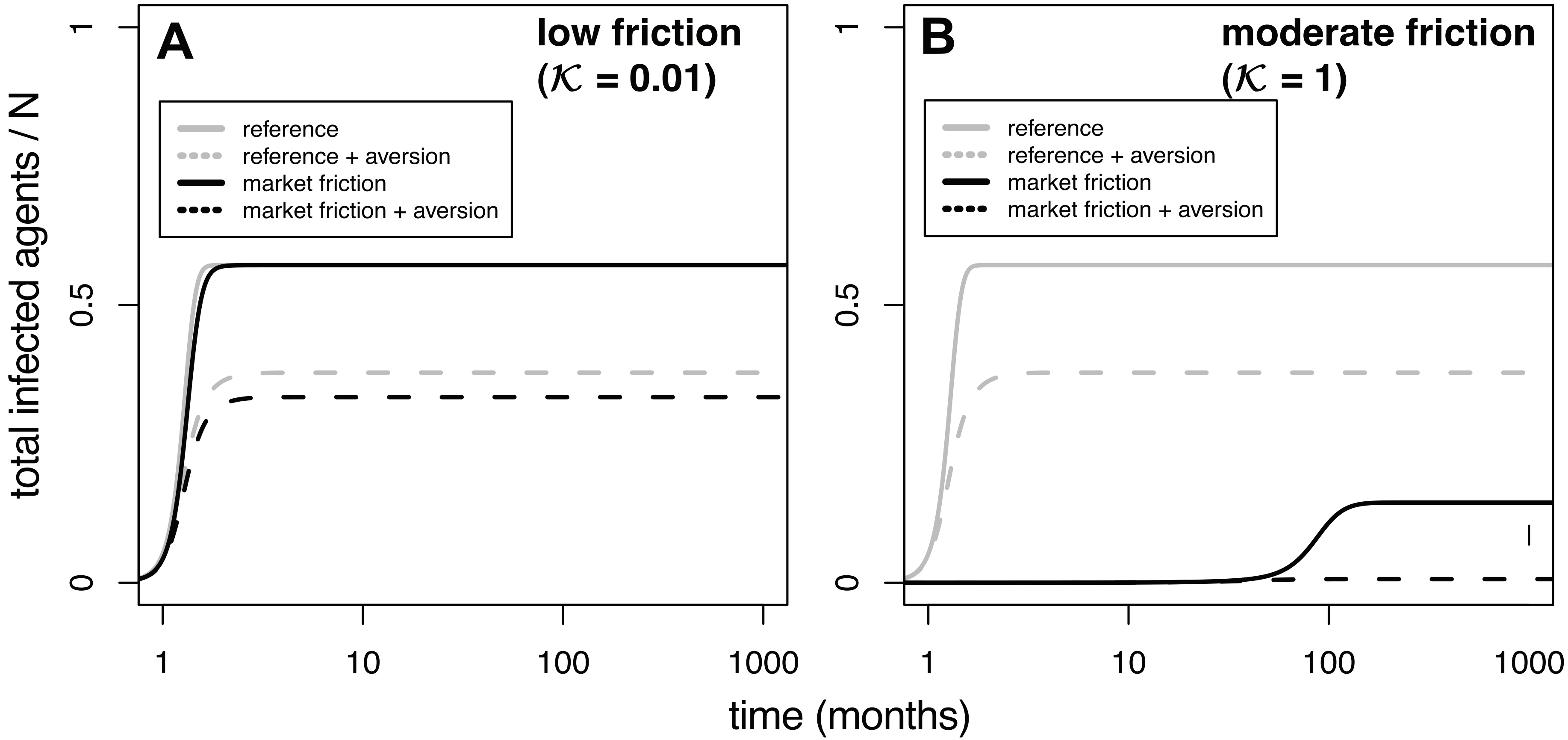
Force of infection for frictional-trade dynamics:

$$\Lambda_{tr} = \overbrace{[1-(1-\phi)^q]\frac{\Theta}{N_D^{XY}}}^{\beta_{tr}}\frac{N_S^Y}{N_S^{XY}}$$

Force of infection for reference dynamics (negligible friction and equilibrated market):

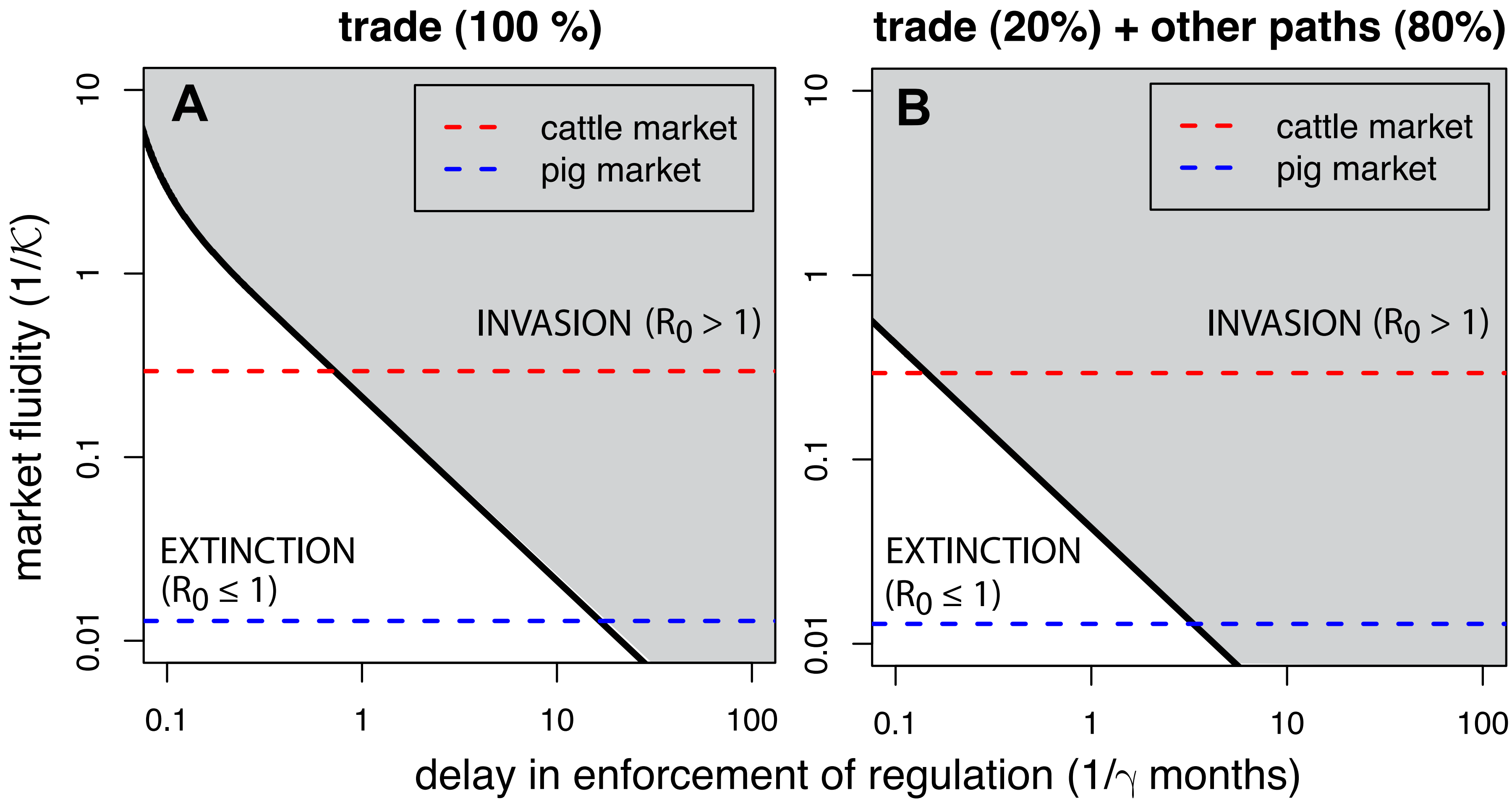
$$\Lambda_{tr}^0 = \overbrace{\ln\left(\frac{1}{1-\phi}\right)\frac{\Phi^*}{N_D^{XY}}}^{\beta_{tr}^0}\frac{N_S^Y}{N_S^{XY}}$$

[Eco]-[Epi] Impacts of frictional-trade with risk aversion on disease dynamics: trade friction outweighs risk-aversion (A-B)



Confirmation of the importance of friction with a global sensitivity analysis

[Eco]-[Epi] Maximal delay in enforcement of regulation that still allows prevention of epidemics: decreases with market fluidity (inverse friction; A) and inclusion of non-trade transmission pathways (B)



[Eco]-[Epi] Frictional versus Fluid Markets

A. Swine

B. Cattle

total # goods exchanged during Δt prior first detection ≈ cte (at equ.)

max # agents exposed = 2	**max # agents exposed = 8**

(likelihood for an exposed agent to become infected: the opposite trend)

Conclusions and perspectives

– Adaptive human behaviour does **not** boils down to risk aversion as shown by **market propagating epidemics**.

– **Trade friction** can be a key driver of the joint dynamics of trade and disease.

– To minimize contagion in markets, safety policies could generate incentives for larger-volume, less-frequent transactions, **increasing trade friction** without necessarily affecting overall trade flow.

– Knowledge gaps:

- further validation of the [Eco] model against **economic data** and further comparison with existing market models;

- extension to **heterogeneous** markets (conditions under which realistic levels of friction can mitigate epidemics).

Thank you!

For further details: Moslonka-Lefebvre et al. (2013) ***Epidemics in markets with trade friction and imperfect transactions.*** **arXiv:1310.6320**

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[Eco] The whole FTM model

unobservable

$$\dot S = \overbrace{\underbrace{N_S\sigma_0 p^{\varepsilon_S}}_{\Sigma_\oplus} - \underbrace{r_S S}_{\text{Losses}} + \underbrace{E_S}_{\text{External flows}}}^{\Sigma} - \overbrace{\underbrace{\frac{\min\{\Sigma_\oplus,\Delta_\oplus\}}{\kappa}}_{\Theta}\underbrace{\min\{\frac{S}{N_S},\frac{D}{N_D}\}}_{q}}^{\Phi}$$

$$\dot D = \overbrace{\underbrace{N_D\delta_0 p^{-\varepsilon_D}}_{\Delta_\oplus} - \underbrace{r_D D}_{\text{Losses}} + \underbrace{E_D}_{\text{External flows}}}^{\Delta} - \overbrace{\Theta q}^{\Phi}$$

observable

$$\dot T = \Phi$$

$$\dot p = \mu \frac{d(D-S)}{dt}\, p = \mu(\Delta-\Sigma)p$$

[Eco]-[Epi] The whole ME model

$$\frac{dS}{dt} = \overbrace{\underbrace{N_S^{XY}\sigma_0 p^{\varepsilon_S}}_{\Sigma_\oplus} - \gamma\frac{N_S^Y}{N_S^{XY}}S + E_S}^{\Sigma} - \overbrace{\underbrace{\frac{\min\{\Sigma_\oplus;\Delta_\oplus\}}{\kappa}}_{\Theta}\underbrace{\min\{\frac{S}{N_S^{XY}};\frac{D}{N_D^{XY}}\}}_{q}}^{\Phi}$$

$$\frac{dD}{dt} = \overbrace{\underbrace{N_D^{XY}\delta_0 p^{-\varepsilon_D}}_{\Delta_\oplus} - \gamma\frac{N_D^Y}{N_D^{XY}}D + E_D}^{\Delta} - \overbrace{\Theta q}^{\Phi}$$

$$\frac{dN_{S\cap D}^X}{dt} = \nu N_{S\cap D}^Z - \Lambda N_{S\cap D}^X$$

$$\frac{dN_{S\cap D}^Y}{dt} = \Lambda N_{S\cap D}^X - \gamma N_{S\cap D}^Y$$

$$\frac{dN_{S\cap D}^Z}{dt} = \gamma N_{S\cap D}^Y - \nu N_{S\cap D}^Z$$

$$\Lambda(t) = \left[\Lambda_{tr}(t) + \Lambda_{\overline{tr}}(t)\right]P_{RA}(t)$$

$$\Lambda_{tr} = \overbrace{\underbrace{[1-(1-\phi)^q]}_{P_{tr}(q)}\frac{\Theta}{N_D^{XY}}}^{\beta_{tr}}\frac{N_S^Y}{N_S^{XY}}$$

$$\Lambda_{\overline{tr}} = \beta_{\overline{tr}}\frac{N^Y}{N^{XY}}$$

$$P_{RA} = \left(1 - \frac{N^Z}{N}\right)^{\alpha}$$

[Eco]-[Epi] Impacts of epidemics on market dynamics: drop in trade flow (A,B) and price (C,D)