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Self-Protection, Strategic Interactions and the Relative Endogeneity of Disease Risks

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Selected Poster prepared for presentation at the Agricultural & Applied Economics Association's 2013 AAEA & CAES Joint Annual Meeting, Washington, DC, August 4-6, 2013.

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Self-Protection, Strategic Interactions, and the Relative Endogeneity of Disease Risks

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INTRODUCTION

- Infectious disease transmission is a filterable externality: private self-protection generates positive spillovers which reduce others' disease risks. These spillovers create strategic interactions between individuals.
- Prior work—which considers introduction and spread pathways separately—shows that self-protection efforts to prevent *introduction* of diseases into a region is a strategic complement (SC), while self-protection to prevent *spread* of an extant disease is a strategic substitute (SS).
- We extend prior work by modeling self-protection as simultaneously reducing the probability of pathogen introduction and spread.
- We find that self-protection can be either a SC or a SS. The relationship depends on the *relative endogeneity* of disease risk, or the degree to which an individual can manage his own disease risks (where self-protection is a SS) rather than being dependent on the protective actions of his neighbors (where self-protection is a SC).
- We frame the analysis in terms of livestock disease risk.

MODEL IN BRIEF

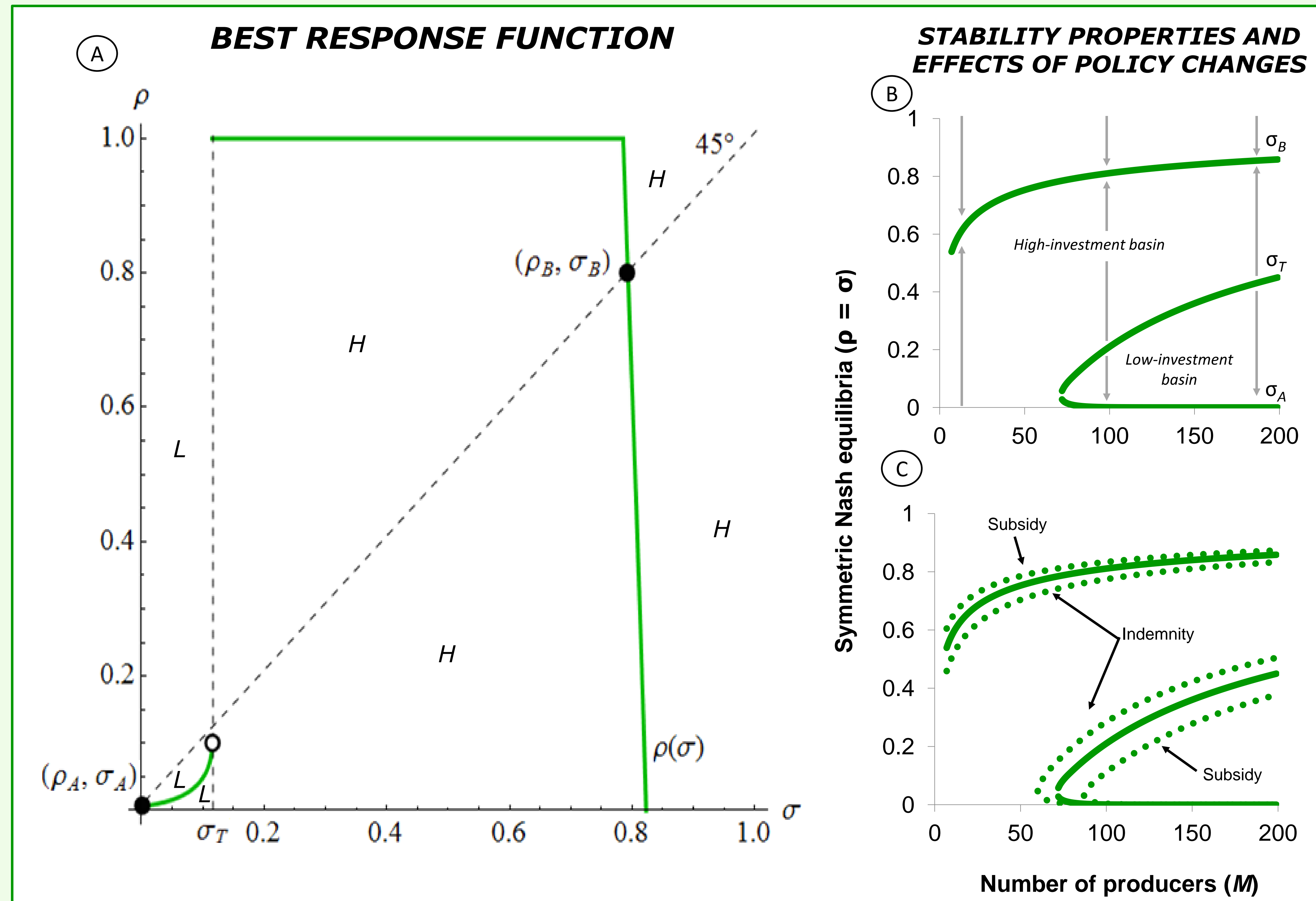
- A farmer's herd can become infected by (i) importing an infected animal, or (ii) via contacts with infected herds.
 - The risks of inter-herd contact and importing infected animals are both decreasing in biosecurity investment.
 - The number of contacts M_e between producers depends on the biosecurity of the farmer *and* his neighbors.
- A farmer maximizes his expected profit $E\pi$ by choosing his level of biosecurity investment $\rho \in [0,1]$, taking his neighbors' investment σ as given:

$$E\pi = \max_{\rho} \left\{ \underbrace{[1 - P(\rho, \sigma, M_e(\rho, \sigma))] R_s}_{\text{Expected revenue, not infected}} + \underbrace{P(\rho, \sigma, M_e(\rho, \sigma)) R_i}_{\text{Expected revenue, infected}} - \underbrace{c(\rho)}_{\text{Biosecurity cost}} \right\}$$

- From first-order conditions, we can solve for the farmer's best-response function $\rho = \rho(\sigma)$.
 - If $\partial \rho / \partial \sigma > 0$, then biosecurity is a SC: the farmer responds to decreases in neighbors' biosecurity by decreasing his own.
 - If $\partial \rho / \partial \sigma < 0$, then biosecurity is a SS: the farmer responds to decreases in neighbors' biosecurity by increasing his own.
- We find that $\partial \rho / \partial \sigma = \Psi_I + \Psi_C + \Psi_N \geq 0$. The Ψ terms are the effect of neighbors' biosecurity investments on the farmer's marginal incentives for reducing:
 - Import risks (Ψ_I);
 - Spread via contact, holding the number of contacts fixed (Ψ_C); and
 - Spread via contact by reducing the effective number of contacts (Ψ_N).
- Previous work that focuses on spread exclusively finds that $\partial \rho / \partial \sigma < 0$. We find that Ψ_C and Ψ_N are positive (negative)—and thus $\partial \rho / \partial \sigma > (<) 0$ —when the relative endogeneity of an individual's disease risk is low (high), i.e., their ability to manage disease risks depends heavily on their neighbors' (their own) actions.

EXAMPLE: THE 2001 UK FMD EPIDEMIC

- We highlight the model's features with a numerical example of the 2001 UK foot-and-mouth disease (FMD) outbreak.
- The epidemic began in Feb. 2001 and spread rapidly through the UK and other Western European countries.
- Over 6 million ungulates (e.g., cows, pigs, sheep) were culled. Total costs of the disease were over \$4.4 billion, with significant losses from tourism and exclusion from export markets.
- We examine producers' incentives for self-protection in the setting of Cumbria County in Northwestern England, the hardest-hit region during the epidemic.



RESULTS (letters refer to graphs at left)

- (A) The points where the best-response function $\rho(\sigma)$ intersects the 45° line are stable symmetric Nash equilibria. For $\sigma < \sigma_T$, neighbors invest little in biosecurity and the disease risks for the individual's herd are high without significant biosecurity investment. The relative endogeneity of their disease risk is low, and hence biosecurity is a SC. For $\sigma > \sigma_T$, neighbors make sufficient investments that disease risks are reduced and the relative endogeneity of the individual's disease risks are high, incentivizing full investment. Biosecurity is a SS. At high levels of σ , neighbors' investments are so effective in reducing disease risks that the individual can reduce their own investment. σ_T is thus an *expectational threshold* dividing the strategy space into high- and low-investment basins of attraction, denoted by the areas marked H and L, respectively. The equilibria can be ranked such that $(\rho_B, \sigma_B) > (\rho_A, \sigma_A)$. Expectations matter: a farmer's optimal investment depends on what he believes his neighbors are doing. Thus, coordination failure is a possibility.
- (B) When the number of at-risk producers M is low, relative risk endogeneity is high regardless of neighbors' actions, and biosecurity is a SS. The risk of coordination failure rises as M increases and multiple equilibria are formed. When multiple equilibria are present, σ_T increases with M , meaning the risk of coordination failure also increases.
- (C) Policies affect both the levels of the equilibria and also the size of the basins of attraction. When M is large, the bigger effect may be on the basin of attraction. For instance, biosecurity subsidies increase the full-investment basin (lowering the risk of coordination failure), whereas indemnities have the opposite effect.

CONCLUSIONS

- The strategic interactions among individuals self-protecting against disease are more complex than previously realized. The effect of biosecurity in preventing pathogen introduction promotes SC among producers, in line with prior results. However, the effect of biosecurity on disease spread can promote either SC or SS, in contrast to prior results that find controlling spread promotes SS only.
- Self-protection is more likely to be a SS when the relative endogeneity of disease risk is low, i.e., individuals can effectively protect themselves from infection. When the relative endogeneity is high, i.e., an individual's disease risks depend heavily on their neighbors' actions, self-protection is more likely to be a SC.
- When multiple equilibria exist, expectations matter and coordination failure can occur. Policies can both change Nash equilibrium self-protection levels and shift the expectational threshold to reduce the risk of coordination failure.

ACKNOWLEDGEMENTS

This work was funded by grant number 1R01GM100471-01 from the National Institute of General Medical Sciences (NIGMS) at the National Institutes of Health, and grant number 2011-67023-30872 from the National Institute of Food and Agriculture (NIFA), USDA. The work is solely the responsibility of the authors and do not necessarily represent the official views of NIGMS or USDA.

