



A Bioeconomic Model to Predict Disease Movement

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Motivation

- TB eradication program experience
- Budget constraints mean targeted surveillance is important
- What can bioeconomic models do to improve surveillance efficiency?



Tuberculosis and Cattle Trade

- Bovine Tuberculosis (bTB)
 - An infectious disease caused by mycobacteria
- Cattle movement and disease transmission
 - Tens of millions of cattle are shipped yearly across the U.S. for feeding or breeding
 - Cattle movement is a key factor of bTB transmission
 - Epidemiology models need to account for economic behavior affecting transmission



Objectives

To develop a joint epidemiology/trade model to predict bTB transmission in US

- Develop an interstate cattle movement model
 - Based on market incentives, disease risks, and accompanying government interventions
- Develop an epidemiology model in which disease risks depend on human behavior
 - Disease transmitted via market interactions
- Predict regional disease risks



Gravity Models

- Economic application: to analyze trade patterns
 - Anderson 1979; Bergstrand 1985, 1989; Anderson and van Wincoop 2001, 2003; Eaton and Kortum 2002
 - Analogous to the physical theory of gravity
 - Trade flows depend positively on the economic sizes of two units, and negatively on distance between the units.
- Ecology application: to model invasive species risks
 - Bossenbroek et al. 2001, 2007
 - Estimate long-distance dispersal of zebra mussels between discrete points in heterogeneous landscapes
 - Gravity model used to model boat movements
 - No behavioral underpinnings



Gravity Model: Supply

(based on Eaton and Kortum, *Econometrica* 2002)

- Assumptions:
 - Cattle are homogenous and produced in each state
 - States differ according to relative location, input costs, and trade restrictions
 - Production efficiency varies within each state
 - Efficiency parameter (z_i) is random and follows a Frechet distribution function



Gravity Model: Supply

- Price for buyers in state j to buy one cattle produced in state i :

$$p_{ji} = c_i b_{ji} / z_i = \text{Effective MC of Production}$$

c_i : input costs

b_{ji} : trade cost

- Depends on distance and added trade costs arising from a bTB outbreak

- Buyers pay the lowest price across all sources:

$$p_j = \min\{p_{ji}, i = 1, \dots, N\}$$

- Pr(a cow from state i is sold into state j) is:
$$\phi_{ji} = \frac{x_{ji}}{x_j} = \frac{(c_i b_{ji})^{-\theta}}{\sum_{k=1}^N (c_k b_{jk})^{-\theta}}$$

where x_{ji} = supply of cattle from i to j



$$x_{ji} = \frac{(c_i b_{ji})^{-\theta} x_j}{\sum_{k=1}^N (c_k b_{jk})^{-\theta}}$$

Gravity Model: Demand

- Buyers in state j buy cattle and later resell for slaughter :

$$\max_{x_j} E[PROFIT] = (B_j - t_{sj} - c_j)x_j^{\alpha_j} - E[p_j]x_j$$

- The FOC yields total demand by j :

$$x_j = \left\{ \frac{E[p_j]}{\alpha_j(B_j - t_{sj} - c_j)} \right\}^{\alpha_j - 1}, \text{ where } E[p_j] = \Phi_j^{-1/\theta} \Gamma\left(1 + \frac{1}{\theta}\right)$$

$$\text{and } \Phi_j = \sum_{k=1}^N (c_k b_{jk})^{-\theta}$$

- Plug demand from j into previous supply relation solve for x_{ji} :

$$x_{ji} = \frac{[\Gamma(1 + \frac{1}{\theta})]^{\alpha_j - 1} (c_i b_{ji})^{-\theta}}{[\alpha_j (B_j - t_{sj} - c_j)]^{\alpha_j - 1} \Phi_j^{1 + \frac{\alpha_j - 1}{\theta}}}$$

Estimating the Gravity Model

- Take the natural log of both sides of x_{ji} :

$$\ln x_{ji} = \text{constant} - \theta \ln(c_i b_{ji}) - (\alpha_j - 1) \ln(\alpha_j (B_j - t_{sj} - c_j)) + \theta \left(1 + \frac{\alpha_j - 1}{\theta}\right) \ln P_j \quad (*)$$

$$P_j = \Phi_j^{-1/\theta} = \left[\sum_{k=1}^N (c_k b_{jk})^{-\theta} \right]^{-1/\theta}$$

- Anderson and van Wincoop (2004) suggest a technique provides consistent estimates of (*).
 - Replace $\ln P_j$ with a outward region dummy O_j , that indicates whether a state is a net importer or a net exporter of cattle.



Data to Estimate Gravity Model

- Cattle movement , x_{ji} , among 48 states
 - Source: interstate livestock movement data from the USDA Economic Research Service
- Input costs, c_i
 - Average feed prices in dollars per hundredweight
- Distance, d_{ji}
 - Distance between the center points of the two states



Data to Estimate Gravity Model

- Buyer's Transportation costs, t_{sj}
 - Calculated by multiplying average geographic distance from feedlot to major slaughterhouse with per mile cost \$0.0186.
- Cattle price received at slaughterhouse, B_j
 - Source: USDA Agricultural prices 2001
- Zero trade flow
 - “Ad Hoc” approach
 - Heckman's sample selection model
 - The inverse mills ratio significant at 1% level

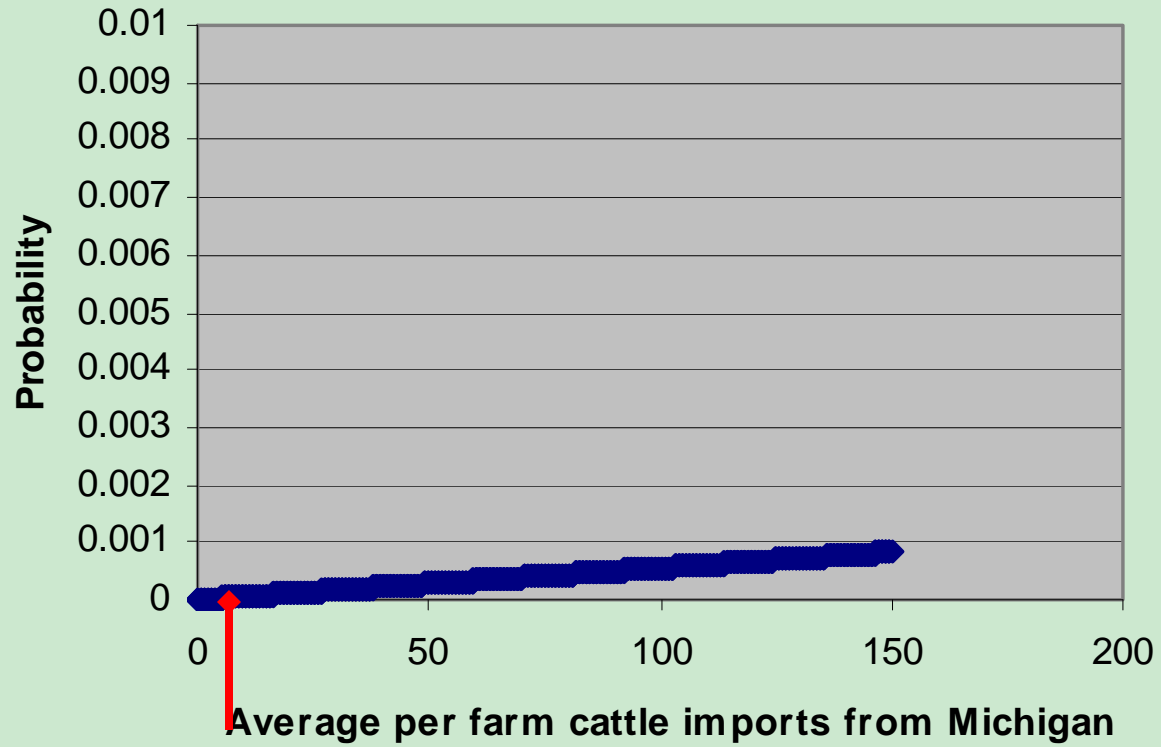


Estimation Results

	Coef.	Std. Error	P value	[95% Conf. Interval]	
Outward Dummy	0.50	0.23	0.029	-0.05	0.95
Input Cost	2.06	0.70	0.003	0.70	3.42
Distance	-1.29	0.12	<0.001	-1.53	-1.05
Disease status	-0.88	0.80	0.27	-2.44	0.69
Expected Profit	2.9	0.75	<0.001	1.44	4.37
Constant	-4.72	5.15	0.36	-14.8	5.39
Inverse Mills ratio	-3.57	0.15			

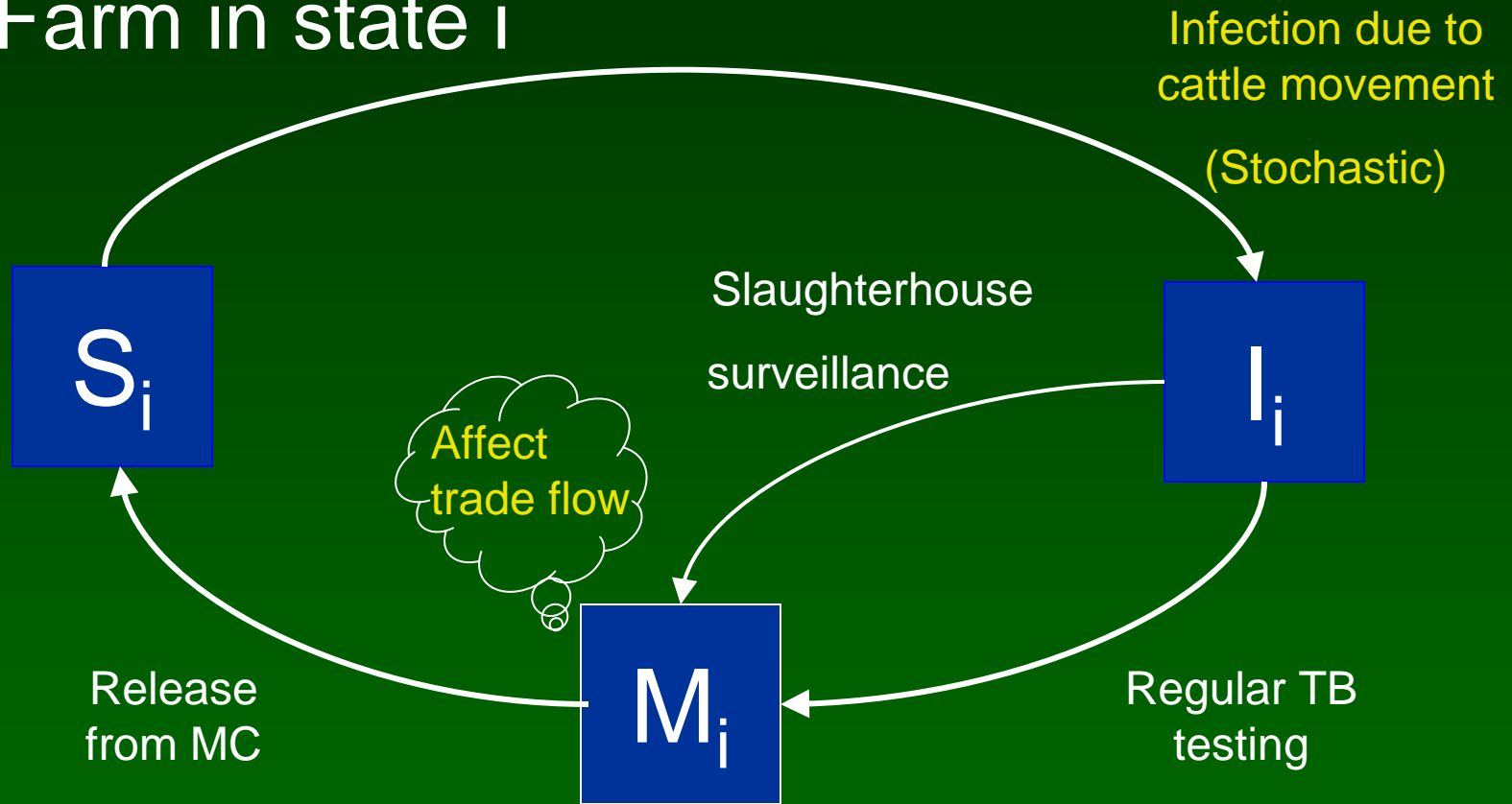


Probability of cattle infection for farms in Texas



Epidemiology Model

- Farm in state i



Epidemiology Model

- Stochastic force of infection
 - The probability that a farm becomes infected via cattle purchases follows a Bernoulli random process
 - Depends on the number of cattle traded from state j to state i .
- Feedback between the EPI model and the economic model
 - Trade flow affects the force of infection in the EPI model
 - Trade restrictions induced by detection of new TB infection also affects trade flow



Simulation (2001-2010)

- Initial Values

- Oregon, Kansas and Michigan initially have undetected infected herds

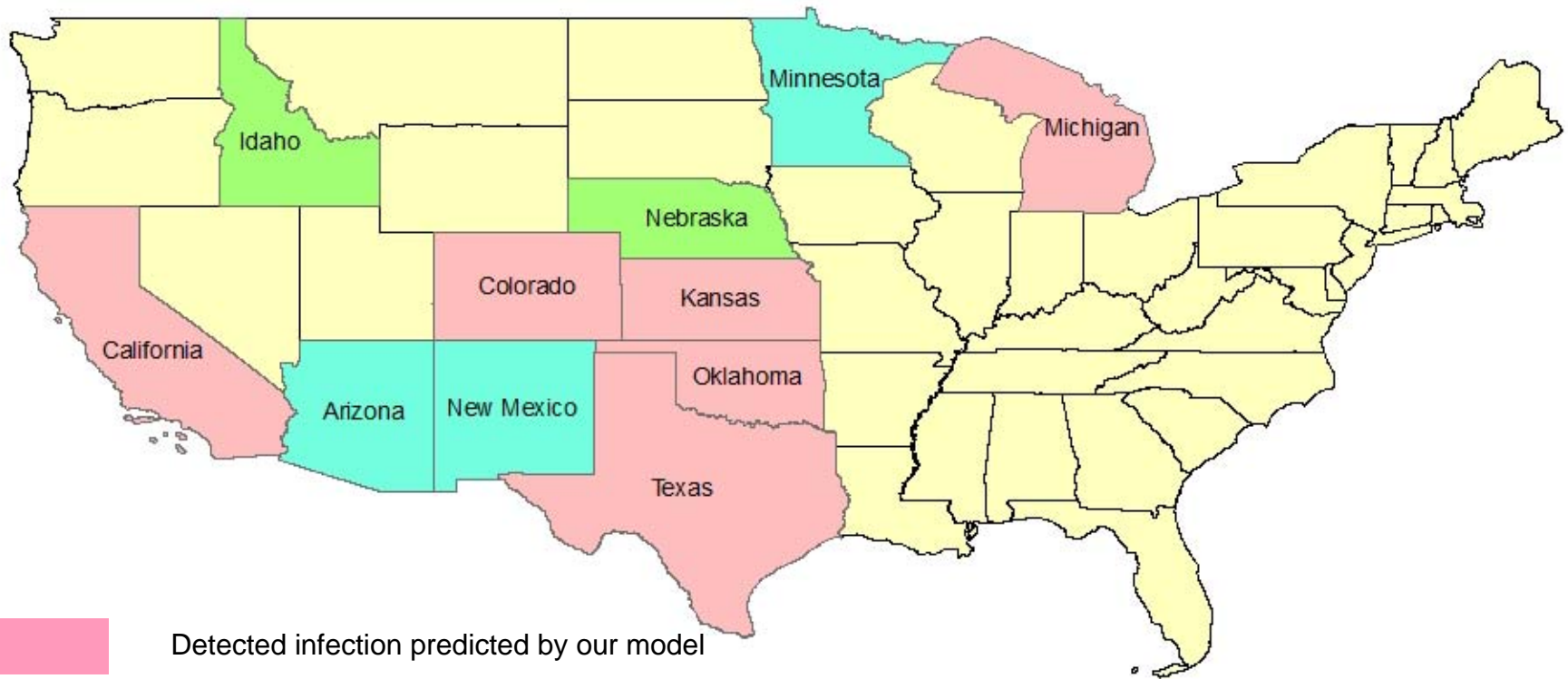
- $I(2001) = 1, 1, 8$ respectively (USDA-APHIS)

- No herds under movement control in 2001

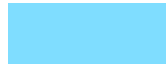
- No detected herds: $M(2001) = 0$



Predicted New Infection (2001-2010)



Detected infection predicted by our model



Detected infection not predicted by our model



Predicted infection, currently under investigation

- MN, AZ, and NM infection likely from Mexico

Conclusions

- No evidence that producers' market transactions are affected by social or private risks
 - Small infection risk for individual farms
 - Lack of data on actual disease risk
 - Only MI lacked disease free status in 2001
- Cattle trade affects disease dynamics
 - Biggest purchasers face largest risks
- Factors like input cost also affect trade flow, hence disease risks
- Predictions can be used to help target surveillance efforts

