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Economics, Hysteresis and Agroterrorism

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whenever the availability of nutritionally adequate and safe foods or the ability to acquire foods in socially acceptable ways is limited or uncertain". Keenan et al provide a

1 Islam, M.Q and W. N. Shahin "Applying Economic Methodology to the War on Terrorism" Forum for Social Economics (2002):7-26 as reported on AOL News www.aol.com

2 Derrickson, J., and A.C. Brown "Food Security Stakeholders in Hawai'I: Perceptions of Food Security Monitoring" J. Nutrition and Educational Behaviour 34(2002):72-84

similar definition[3]. By 2002 food safety has become a key component of food security and insecurity. Likewise, the term food security has also evolved to include natural and unnatural threats to the food system including agro or bioterrorism[4].

If economic destruction is the goal of terrorist activity then it is critically important to fully comprehend the economic motives behind terrorism. This includes developing theoretical and empirical models in order to understand motives and opportunities. In other words, can economics be used as a tool by terrorists to optimize economic damage?; and if so, can an understanding of that economics be used to defend against economic terrorism? Yet the notion of using economics as a countermeasure to terrorist activities was not generally considered prior to 2001. Indeed, a search of economics, agricultural economics, and agricultural research indices provides only sparse reference to terrorism, bioterrorism, or agroterrorism. Yet, within the past year (2002/2003) two reports have emerged from the Academy of Sciences dealing with agriculture, food and terrorism. Both reports make an appeal to the social sciences to address issues of economics and human behavior. In "Countering Agricultural Terrorism"[5] the National Research Council identified four separate research needs;

1) Research to understand the perpetrators of agricultural bioterrorism as one approach to deter, prevent or thwart bioterrorist attacks,
2) Enhance understanding of the concerns of food producers and the public…to develop more effective and responsive communication strategies,
3) Support research on the social and psychological effects of bioterrorism, including identification of high risk groups and ways of assisting affected individuals, families and communities, and
4) Investigate methods of educating producers and consumers about plant and animal diseases and infestations.

3 Keenan, D. Palmer, C. Olson, J.C. Hersey, and S. M. Parmer "Measures of Food Insecurity/Security" " J. Nutrition and Educational Behaviour 33(2001):s49-s58.
4 Dilley, M. and T. E. Boudreau "Coming to terms with Vulnerability: A Critique of the F
Food Policy26(2001):229-247
5 National Research Council of the National Academies Countering Agricultural Terrorism prepublication copy The National Academies Press, Washington D.C. 2002

In another report entitled "Making the Nation Safer"[6], the Academy of Science implied (with less specificity than the above report), that the relationship between economics and terrorism should be explored. In particular the academy was concerned with the relationship between bioterrorism, human reactions and risk perceptions. It recommended that modeling tools for analyzing the health and economic impacts of bioterrorist attacks are needed in order to anticipate and prepare for these threats. Recognizing the relationship between fear and human behaviour the academy also recommended a communication strategy with accurate information to soothe and mitigate those fears. The academy recommends that historical research on the interrelated sequencing of reactions, interpretations, and memories of terrorist events be undertaken to deepen our theoretical and empirical understanding of those phenomena (Recommendation 9.8). Importantly, the Academy recognized the importance of path dependency which, from a foundation point of view, determines the overall impacts of risk perceptions and hysteresis in an economic system, as well as the significance of the theory of games, which allows for the investigation of dominating and second-best strategies for terrorist and counter-terrorist activities.

As a starting point to resolving issues raised by the Academy, an objective of this paper is to provide an economic framework that allows for the basic principles of how bioterrorism can impact the agricultural and food economy. The model introduces hysteresis, a consequence of fear and risk perceptions, on both the supply and demand functions of a simple economy. This allows us to examine, at least theoretically, the economic effects of hysteresis by consumers and producers. Understanding these issues satisfies, in part, the priorities established in both reports from the Academy. However, the framework also provides the means to explore strategies that would optimally be used by an intelligent terrorist. We argue that the optimal terrorist strategy is diametrically opposed to the economic strategy of a benevolent government. A benevolent government will choose those policies that show the maximum incremental gain in social (consumer + producer) welfare. In contrast, the intelligent terrorist seeking to cause economic harm will select activities that maximize the loss of social welfare.

6 National Research Council of the National Academies Making the Nation Safer: The Role of Science and technology in Countering Terrorism The National Academies Press, Washington D.C. 2002

Determining the economic criteria that optimizes the terrorist's strategy is a major goal of this paper. The terrorist plays two key roles. First, the purpose of imposing terror is to impose fear. If fear persists in an economy, how does that impact the economic system as a whole? Second, the terrorist can take actions to decrease supply and or demand, but if a terrorist were to choose from a range of possible targets, what would be the criteria ultimately used to maximize economic harm? The two roles are not independent. For example, by interrupting the physical supply chain, the terrorist can cause economic harm through an artificial price increase, but by creating fear, and ultimately hysteresis, the terrorist can exacerbate the economic losses by affecting human behavior. Our theoretical results show that the optimal target would be a product with a highly inelastic demand, and the impact of hysteresis makes that demand even more inelastic than its pre-terrorist state.

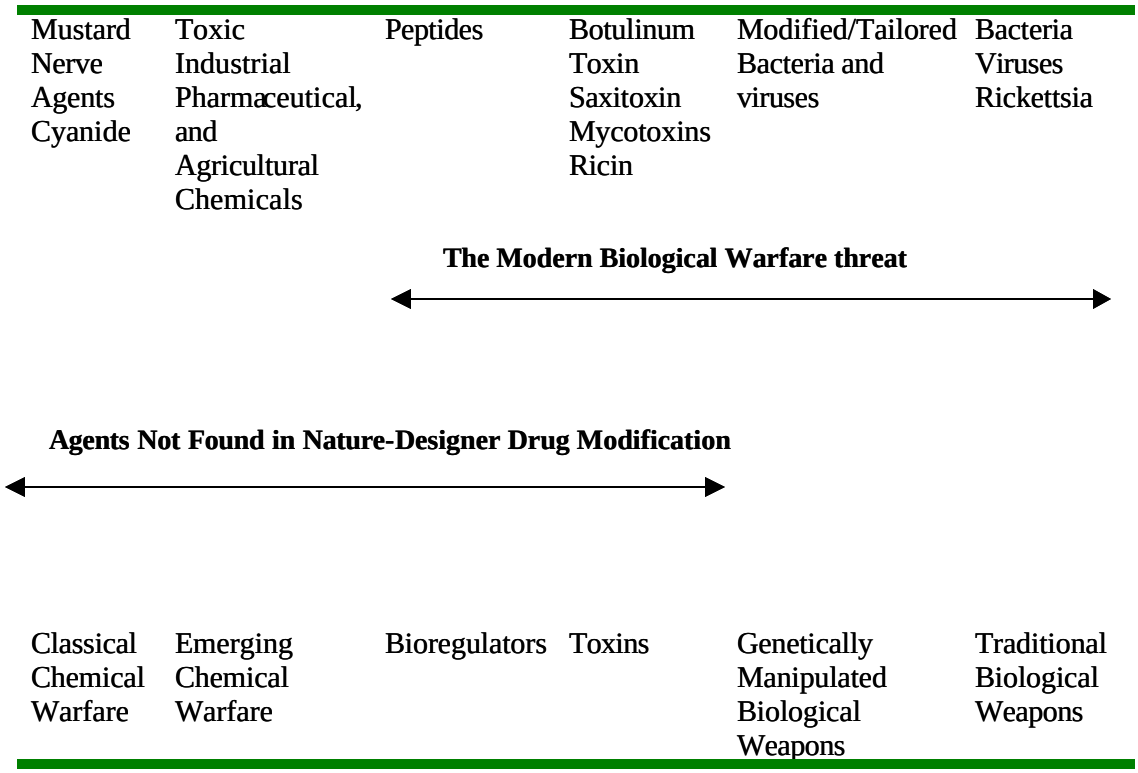

Figure 1:Chemical and Biological Warfare Spectrum (Source: Watson 1999)

Relationship to Food Security and Risk Perceptions

Figure 1 shows in a very general way the evolution of chemical and biological weapons over time. Progressively, the fear is that food borne illnesses can be purposefully inserted into the food system in a number of ways[7]. Appendix A has been compiled to illustrate a chronology of natural, military, and terrorist events including the use of food borne pathogens and attempts to affect agricultural crops. However from an economic and risk perception point of view there is a difference between historical artifacts and real behavior in a significant way. A threat of a bioterrorist attack on the food system will have significantly different attributes of perceived risk than an actual attack. It is entirely possible that a consumer, fully aware of the possibility of an attack does not perceive the threat as risky enough to challenge current buying behaviors. In contrast the perception of risk following an actual attack will be significantly different and can have a real economic impact.

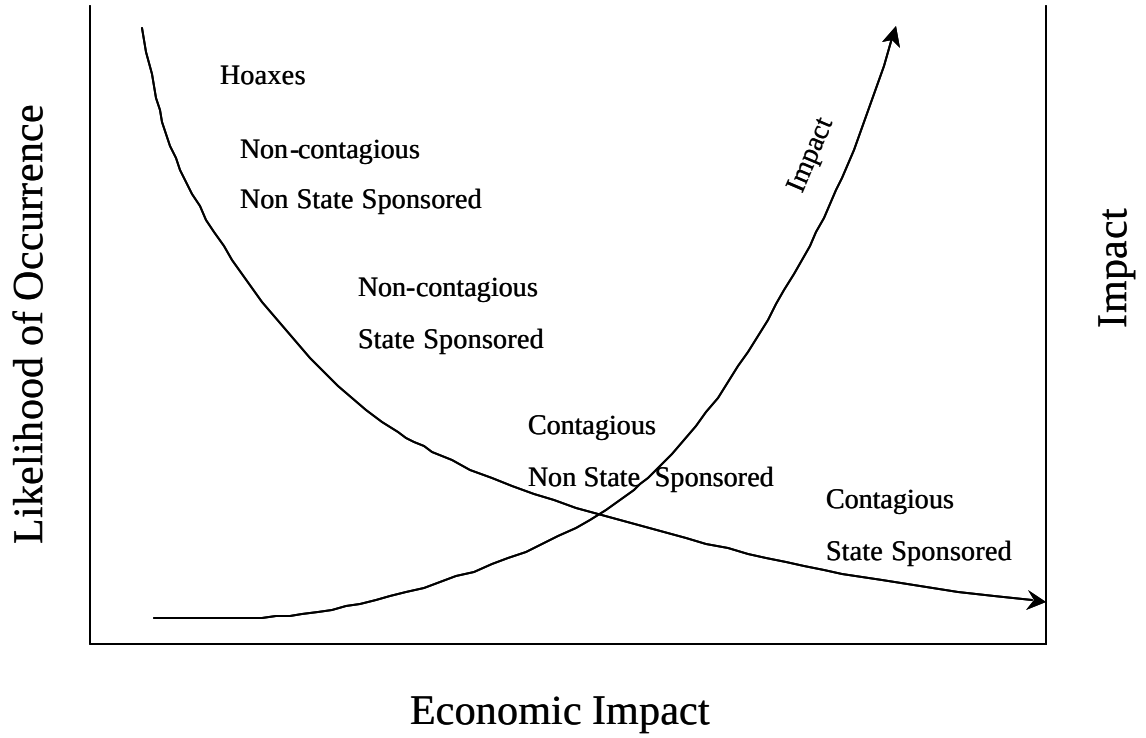

Figure 2: The Tradeoff Between Economic Impact and Likelihood of Terrorist Activities

7 Watson, S.A. "The Changing Biological Warfare Threat: Anti Crop and Anti Animal Agents" in Food and Agricultural Security: Guarding Against Natural Threats and Terrorist Attacks Affecting Health, National Food Supplies and Agricultural Economics T.W. Frazier and D.C. Richardson editors, Annals of the New York Academy of Sciences, Volume 894, NY,1999

We can hypothesize, as in figure 2, a relationship between economic damage and the chance of a threat[8]. In Figure 2 the downward sloping curve represents the likelihood of an event happening. The chance of a hoax is much higher in probabilistic terms than an attack using a contagious agent by a state, but the economic consequence of a state-sponsored attack (an inevitable consequence of which will be war) will ultimately come at a higher economic costs. Hoaxes will occur more frequently than any outcome, and while a hoax may have some economic impact, risk perceptions will dissipate quickly. Whether an attack is viewed as a contagion (widely dispersed) or not will also affect the economic impact, as will a determination that it is state-sponsored or not. A localized adulteration that is not state-sponsored will have a smaller effect because it will be perceived as localized and short lived. If it is state sponsored, risk perceptions would differ since the same event could be viewed as a sustained attack. As the perception of risk increases so will the economic impacts. The combined affects of a wide spread attack (contagion or contagious in the case of human disease) the perceptions of risk will be even higher and so will the economic impact.

Each of these elements are critical to the conceptual understanding of terrorism, and while the model is structured from theory, its calculus establishes a number of testable hypotheses on a broad range issues related to markets, trade, consumer perceptions, producer responses, and risk perception.

Hysteresis and Risk Perceptions

Terrorist attacks against the food system can occur in many ways and points across the food supply chain. Terrorist objectives can be confined to causing economic damage, sickness or death to animals, plants and humans or both. If the objective is to kill humans, then it is unlikely that the food system would be used as a vector since more powerful biological agents (e.g. anthrax, plague, small pox) than food-borne illnesses or zoonoses are available. In this regards, agroterrorism can be distinguished from bioterrorism in that the former is directed towards economic damage while the latter is a direct assault on human life. Agroterrorist attacks can be targeted towards a) production (supply) without causing a

8 Franz, D.R.. "Foreign Animal Disease Agents as Weapons in Biological Warfare" in Food and Agricultural Security: Guarding Against Natural Threats and Terrorist Attacks Affecting Health, National Food Supplies and Agricultural Economics T.W. Frazier and D.C. Richardson editors, Annals of the New York Academy of Sciences, Volume 894, NY,1999

behavioral or structural shift in demand, b) consumption (demand) without causing a behavioral or structural shift in supply, or c) both supply and demand. The welfare impacts are discussed further below.

An important problem in understanding the relationship between agricultural/food economics and terrorism is in identifying how terrorism, real or threatened, impacts economic behavior. Important elements to understanding this problem are risk perceptions and economic hysteresis since it is principally these elements of human behavior that cause shifts in, and changes to the structure of, demand systems. Risk perception relates to the cognitive ability of humans to perceive and judge risks. Its emergence as a field of study has often been described as a challenge to the rationality of the expected utility hypothesis (Arrow 1982)[9] in that it requires the consistent use of conditional probabilities to revise beliefs as new information evolves over time. The representativeness heuristic of Tversky and Kahneman (1974[10],1978[11]) for example stipulates that individuals judge future events by the similarity of the present evidence to it (Arrow, 1982). Bocker and Hanf (2000) [12] have explored this idea in the context of food safety. They present a model based on Baye's theory that allows individuals to revise their 'trust' in a food supplier after a food scare. They note that after a food scare demand drops, but then slowly builds as probabilistic assessments of food safety from the supplier increases. The mechanism is through reassurance, but Liu et al (1998)[13] have found that reassurance may not cause full restoration. In other words, simply removing the source of uncertainty is not sufficient to regain consumer confidence and a return to initial demand. This may be because food safety has a strong credence component due to the ambiguous causality between eating a food product and getting sick (Caswell and Mojduska, 1996)[14]. A consequence of credence is that individuals need more than personal experience to judge the safety of a food item, and rely on third party information (e.g. the supplier) to regain trust and reduce uncertainty (Bocker and Hanf, 2000). For example, Henson and

9 Arrow, K.J. "risk Perception in Psychology and Economics" Economic Inquiry 20 (January 1982):1-9.
10 Tversky, A. and D. Kahneman "Judgement Under Uncertainty:Heuristics and B Science 185 (1974):1124-1131
11 Tversky, A. and D. Kahneman "The Framing of Decisions and the Psychology of Choice" Science 211 (1981):453-458
12 Bocker, A and H. Claus-Hennig "Confidence Lost and –Partially-Regained: Consumer response to Food Scares" Journal of Economic Behavior and Organization 43(2000):471-485.
13 Liu, S, J.C. Huang and G.L. Brown "Information and Risk Perception: A Dynamic Adjustment Process" Risk Analysis 18(1998):689-699.

Northen[15] show that German respondents to a survey indicated that they would look at country of origin in order to qualify food safety. In a non-food example, Zikmund and Scott (1977)[16] provide evidence that a promoter/marketer can increase product demand by identifying product characteristics that potential buyers perceive as being risky, and advertising more positive attributes in order to encourage a revision of probabilities.

The evidence of risk perceptions has also manifested itself in larger food scares. For example worldwide bans imposed on British beef products contributed to the cutback of export markets worth at least $2.4 billion as the price of beef went to zero in the U.K. when the link between BSE and CJD was discovered (Brown 1999). In 2001/2 three cases of BSE in Japan caused a 50% drop in beef sales (Wheelis et al 2002, Watts 2001)[17]. After the lacing of grapes with cyanide, consumers refused to buy all types of Chilean fruit. Subsequent suspensions of Chilean fruit imports by US, Canada, Denmark, and Hong Kong cost Chile more than $210 million loss in profit and damaged its relationship between the United States (Casagrande, 2000). Even when adulteration is accidental, the economic effects can have long-standing economic consequences. For example, raspberries from Guatemala infected consumers in Canada and the U.S. with cyclosporiasis between 1996 and 1999. Despite best efforts by Guatemala to improve the image of food safety and to identify growers at-risk, it became evident that consumers were unable to identify individual brands as being safer than others and markets dwindled. In 1998, the FDA issued an import alert (a quarantine mechanism) while the Canadian Food Inspection Agency allowed imports from growers deemed as low risk. However, while no further reports of cyclosporia were found in the U.S., raspberries from medium risk growers were commingled with raspberries from low risk growers causing a further outbreak in Canada. Subsequent import restriction were modified in 1999, but by 2000 only 77 of the 369 Guatemalan farms growing raspberries in 1998 continued to produce. Despite controls placed by Guatemala, Canada, and the

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14 Caswell, J. and E. Mojduszka "Using Information Labeling to Influence the Market for Quality in Food Products" American Journal of Agricultural Economics 78(1996):1248-1253.

15 Henson, S.J. and J. Northen "ConsumerPerceptions of Beef Safetyand the Implications for the Quality Policy" Paper presented at the 56th EAAE-Seminar "Long Term Prospects of the Beef Industry" Paris france, Feb 26-27 1998.

16 Zikmund, W.G. and J.E. Scott "An Investigation of the Role of Product Characteristics in Risk Perception" review of Business and Economic Research 13(Fall 1977):19-34

17 Wheelis, M, R. Casangrande, and L.V. Madden "Biological Attack on Agriculture:Low Tech, High Impact BioScience 52(7)(July 2002):569-576

Watts, J. "Japan's Government Tries to Allay BSE Fears" Lancet 358(2001):2057

U.S. the perceived risk to reputation was too great for many importing firms to take, even when Guatemalan raspberries sold at a discount. Furthermore, the decline in demand for Guatemalan raspberries declined for all seasonal crops even though cylospora was never found in fall and winter crops (Calvin et al 2002)[18].

The issue is why consumer resistance persists either when the probabilities of harm are so low (e.g. BSE and Creutzfeld-Jacob Disease CJD), when terrorist activities were resolved (e.g. Chilean grapes) or safeguards put in place to protect the food supply (e.g. Guatemalan raspberries)? One argument is what we will refer to as consumer hysteresis. To paraphrase Dixit and Pindyck (1994)[19] consumer hysteresis is a phenomenon that causes consumers to fail to reverse their consumption habits when the underlying source of uncertainty or ambiguity has reversed itself. There is a time-dependency between what has occurred in the past and what is observed in the present. One of the definition provided by Katzner (1999)[20] is that hysteresis is brought about when changes in the state of a system by alterations in parameter values cannot be reversed by restoring those values to their original values. Gocke (2002)[21] adds to this the notion of permanence as a constituent characteristic of hysteresis, but in economic systems the notion of permanence is difficult to uphold. Rather, we weaken the definition of hysteresis to include short-term effects that may or may not persist in a time series. In other words, a weak-form hysteresis can permit a path dependency for which, ultimately, the (Bayesian) revision of probabilities is sufficient to restore equilibrium to its pre-shock levels, at least approximately or qualitatively.

As a case in point consider the data in figure 3, which was obtained from the U.S. Bureau of Economic Analyses (BEA). The data is from direct and indirect sales data from some of the sectors in the tourism and hospitality industry, indexed to the third quarter of 2000. The figure shows the transient and seemingly permanent effects of the September 11th 2001 terrorist attacks. The most striking response is the rapid decrease in air travel, which up until late 2002 still had not recovered, despite

18 Calvin. L., W. Foster, L.Solorzano, J.D. Mooney, L. Flores, and V. Barrios "Response to a Food Safety Problem in Produce: A Case Study of a Cyclosporiasis Outbreak" in Global Food Trade and Consumer Demand for Quality B. Krissoff, M. Bohman, and J.A. Caswell, editors, Kluwer Academic/Plenum Publishers New York, 2002
19 Dixit, A.K. and R.S. Pindyck Investment Under Uncertainty Princeton University Press, Princeton NJ, 1994.
20 Katzner, D.W. "Hysteresis and the Modelling of Economic Phenomena" Review of Political Economy 11(2)(1999): 171-181.

significant price reductions on some major routes. Likewise hotel stays also fell significantly and had only modestly returned to pre-September 11th levels. On the other hand, there is little evidence that restaurant services, at least outside of the NY area, were affected, and there seemed to have been a positive and persistent impact on movie-going. Qualitatively, the tourism industry has not fully recovered from the devastating impacts of the September 11th attacks even with significant efforts by government to provide physical security and reassurance.

The problem is in understanding what causes the path dependence of consumer hysteresis in the age of on-going terrorism and terrorist threats. Explanations of behavior are limited and empirical measurement of the effects of terrorism is rare. Fleischer and Buccola (2002)[22] examine the effects of terrorism on hotel stays in Israel. They employ a supply and demand framework that includes a terrorist index on the demand equations for domestic and foreign tourism. Foreign demand is price elastic and sensitive to terrorist events while domestic demand is price inelastic and quite insensitive to terrorist

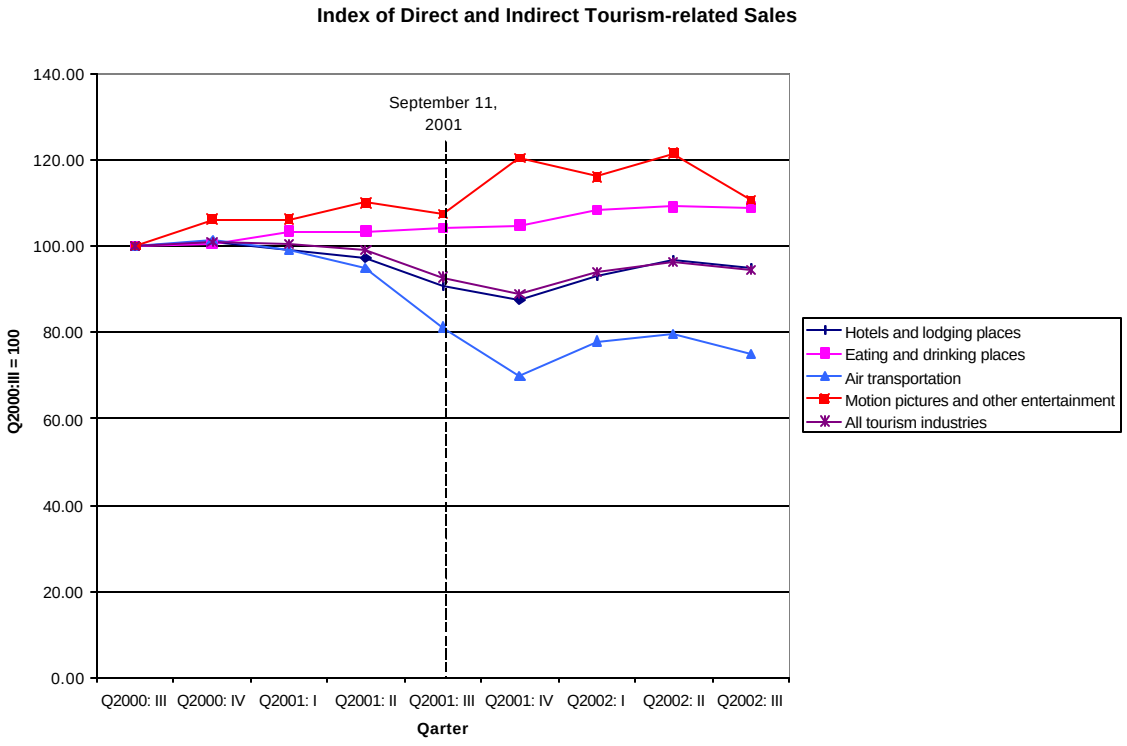


Figure 3: Index of Direct and Indirect Tourism-related Sales 2000 Q:III – 2002 Q:III

21 Go[illegible] 188.

22 Fleischer, A. and S. Buccola "War, Terror and the Tourism Market in Israel" Applied Economics 34(2002) 1335-1343

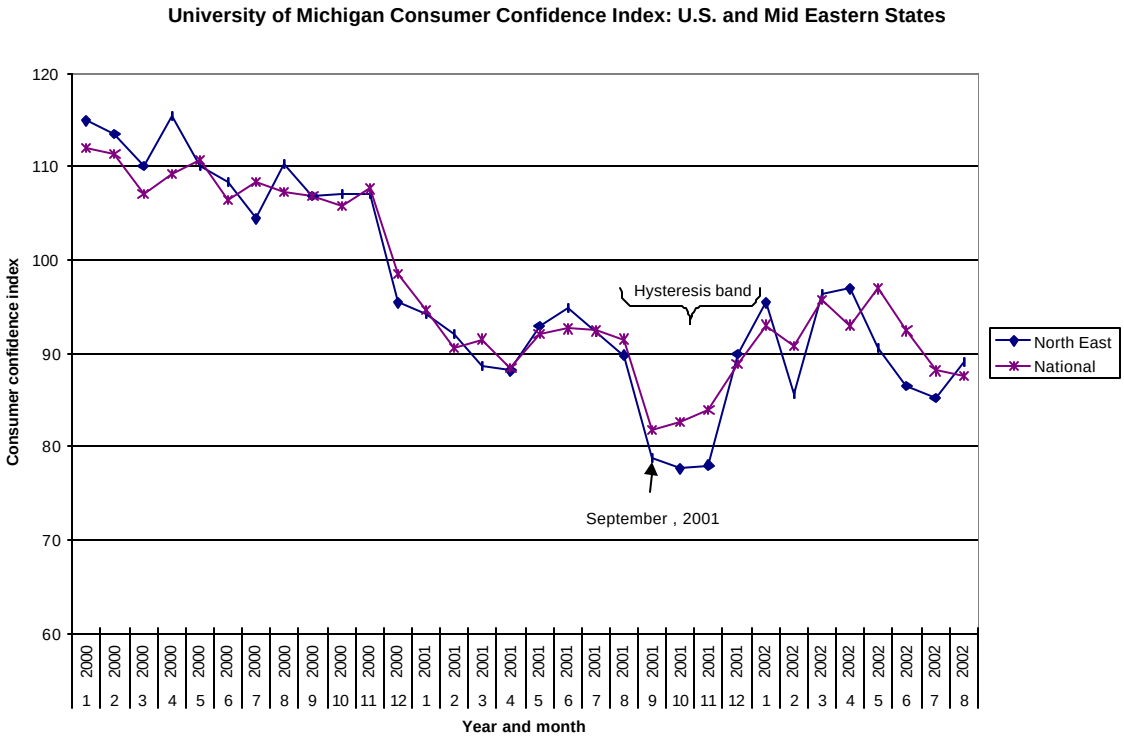


Figure 4: University of Michigan Consumer Confidence Index

effects. Fleisher and Buccolla (2002) found that the main reduction in hotel stays occurred nearly two months after a terrorist event. Apparently, fixities in planning would prohibit cancellation prior to two months, and for three months after the event, memory and risk perceptions faded. In this case hysteresis was short-lived.

As a case in point we can examine the consumer confidence index from the monthly survey of the University of Michigan. The index itself is a compilation of five factors relating to perceptions about the economy and how economic factors impact individual beliefs. Figure 4 illustrates the index for the Northeast United states as well as the U.S. average from January 2000 to August 2002. Although confidence was declining prior to September 11th 2001, there is a clear and marked decline, which is labeled the hysteresis band in the figure. It took four or five months for the events of September 11th to dissipate. What is notable, and expected is the difference in confidence between the North East and the U.S. in general. The loss of confidence was much higher for the North East, even though confidence in the North East mirrored the U.S. before this. Furthermore, consumer confidence index mirrors to a great extent the BEA data in figure 3, which also shows a rapid decline in some markets, followed by a rather precipitous recovery. However it is clear by the data that risk perceptions remained high enough in some markets for the impacts to be felt well into 2002, i.e. the airline industry, when the terrorist

attacks of 2001 used hijacked airplanes as a weapon. Qualitatively, consumer hysteresis can appear to be transient in some markets and persistent in others, but whether or not hysteresis is persistent in a hidden way, vis a vis a formal test for a unit root, requires a more detailed analysis.

So how does hysteresis manifest itself in an economic model? We argue that there are dual effects on the consumer side. First, the original shock causes a downward shift in the demand curve, lowering demand across the board. In an econometric model, this would be represented by a time dependant dummy variable that will eventually converge to zero in the limit. Second, we argue that the behavior itself is not simply linear, but there is also a nonlinear manifestation caused by enhanced risk perception that causes the demand to become more inelastic. By becoming more inelastic, consumers become more resistance to decreases in prices that could restore demand to its pre-terrorist level. In a classical economic framework, it is assumed that any disruption to an economic system is reversible through the ordinary mechanics of supply and demand, which could involve a deterministic path dependency through a cob-web cycle. However, when it comes to issues of food safety and security, an immediate response to resolution of a food security issue appears to be more of an exception than a rule.

In this section we present a deterministic model of hysteresis that illustrates how hysteresis can lead to welfare losses in the economy. Our approach is to define both the supply and demand as functions of hysteresis and to then define the equilibrium price accordingly. We step through the model examining demand effects first, assuming no hysteresis in supply, and then proceed to supply effects assuming no hysteresis in demand. We do not mathematically examine the possibility of hysteresis affecting both demand and supply simultaneously, but do discuss the effects in a more general and graphical way.

It is assumed that the demand function is defined by

(1) $$Q_d = A\,(1-h)^{\delta} P^{(-\varepsilon_d - \alpha h)}$$

and supply as

(2) $Q_s = B\,(1-h)^{\gamma}\,P^{(\varepsilon_s - \beta\, h)}$

where A and B are intercept constants, h is an index of hysteresis (1>h>0) with demand and supply intensity coefficients of δ and γ, price P, and elasticities ε_d, ε_s . The parameters α and β are multipliers that measure the sensitivity of the demand and supply elasticities to hysteresis. The general framework admits that there are dual impacts on supply and demand. The first is the possibility of a shift in the curves, while the second is a twist in the curves, making both more inelastic. Setting demand equal to supply and solving for the equilibrium price gives

(3) $P_e = \left(\frac{A\,(1-h)^{(\delta-\gamma)}}{B} \right)^{\left(\frac{1}{(-\beta+\alpha)\,h+\varepsilon_s+\varepsilon_d} \right)}$

The complexity of hysteresis can be seen by differentiating the equilibrium price with respect to h. It is

(4) $\frac{\partial}{\partial h} P_e = -P_e \left(\frac{(-\beta+\alpha)\ln\left(\frac{A\,(1-h)^{(\delta-\gamma)}}{B} \right)}{((-\beta+\alpha)\,h+\varepsilon_s+\varepsilon_d)^2} + \frac{\delta-\gamma}{((-\beta+\alpha)\,h+\varepsilon_s+\varepsilon_d)\,(1-h)} \right)$

and it is ambiguous in sign. Hysteresis will have a negative impact on the equilibrium price if the demand shift intensity exceeds the supply shift intensity $\alpha>\beta$ and the demand elasticity sensitivity exceeds the supply elasticity sensitivity, $\delta>\gamma$. The price will increase if $\alpha<\beta$ and $\delta<\gamma$ and $\frac{\varepsilon_s+\varepsilon_d}{-\beta+\alpha} \le h$.

To examine the economics in parts set $\gamma=0$ and $\beta=0$ so that hysteresis only impacts demand. Then

(5) $P_e = \left(\frac{A\,(1-h)^{\delta}}{B} \right)^{\left(\frac{1}{h\,\alpha+\varepsilon_s+\varepsilon_d} \right)}$

and

(6) $$\frac{\partial}{\partial \delta} P_e = \frac{P_e \ln(1-h)}{h\alpha + \varepsilon_s + \varepsilon_d}$$

which will be negative for h<1. That is the greater the intensity on A the lower will be the equilibrium price, all other things being equal. This effect establishes the shift impact of hysteresis. The twist impact of hysteresis can be established by taking the derivative of (5) with respect to the elasticity sensitivity parameter ;

(7) $$\frac{\partial}{\partial \alpha} P_e = -\frac{P_e\, h \ln\left(\frac{A(1-h)^{\delta}}{B}\right)}{(h\alpha + \varepsilon_s + \varepsilon_d)^2}$$

Assuming A> B, equation (7) will be negative for low values of h, but as h increases the term in logs could become negative so the ceterus paribus result could be an increase in prices as demand becomes more inelastic. However the combined effect of a negative shift and a more inelastic demand would most likely result in an overall net decrease in equilibrium prices.

The net effect of a change in the hysteresis is

(8) $$\frac{\partial}{\partial h} P_e = -P_e \left(\frac{\alpha \ln\left(\frac{A(1-h)^{\delta}}{B}\right)}{(h\alpha + \varepsilon_s + \varepsilon_d)^2} + \frac{\delta}{(h\alpha + \varepsilon_s + \varepsilon_d)(1-h)} \right)$$

Which will be negative as long as $0 \le \ln\left(\frac{A(1-h)^{\delta}}{B}\right)$.

The conditions of course are dependent on our choice of functional form and are not general, however the above model does provide the requisite insight into how hysteresis, at least in the short term, can move an equilibrium and affect economic welfare. However, equations (1)-(8) clearly shows the two distinct effects. The first right hand side element in the bracketed term represents the shift due to the intercept while the second shows the effect due to a change in elasticity. Relative to the initial state, the demand curve shifts towards the origin (zero) and becomes steeper. The net effect is that the quantity demanded falls. Without providing the mathematical detail, hysteresis will have the same effect on the

supply curve, namely it will shift to the left, decreasing supply and will, as a result of risk aversion and higher marginal costs, become more inelastic.

The demand shift will most likely be transitory. In reality the variable h will change over time. As with the events of September 11 2001, the fear dissipated in time for some markets, but persisted in others. Therefore the net welfare loss should not be considered permanent, but transitory with a path dependent return to equilibrium. The rate at which it returns to its pre-hysteresis state depends, politically on the preparedness of government and the resolve of society in general.

The welfare effects are illustrated in Figure 5 which illustrates an attack focusing on consumer demand. Given the supply, which we assume does not change in this scenario, and the original demand D1, the equilibrium is at consumption C1 and at price P1. Given an incident, the demand shifts and becomes more inelastic. The resulting consumption is at C2 and price P2. On the original demand, consumer surplus is a+b and producer surplus is c+d+e. After the event, consumer surplus falls to a+c and producer surplus is reduced to e. The net welfare loss is b+d.

In Figure 6, supply also shifts and become more inelastic. The shift is due to a reduction in quantity while the decreased elasticity is due to increased marginal costs and risk aversion. When both supply and demand are affected the welfare losses increase. In Figure 6, the net welfare loss due to reductions in consumer and producer surplus is b+c+f+j+k.

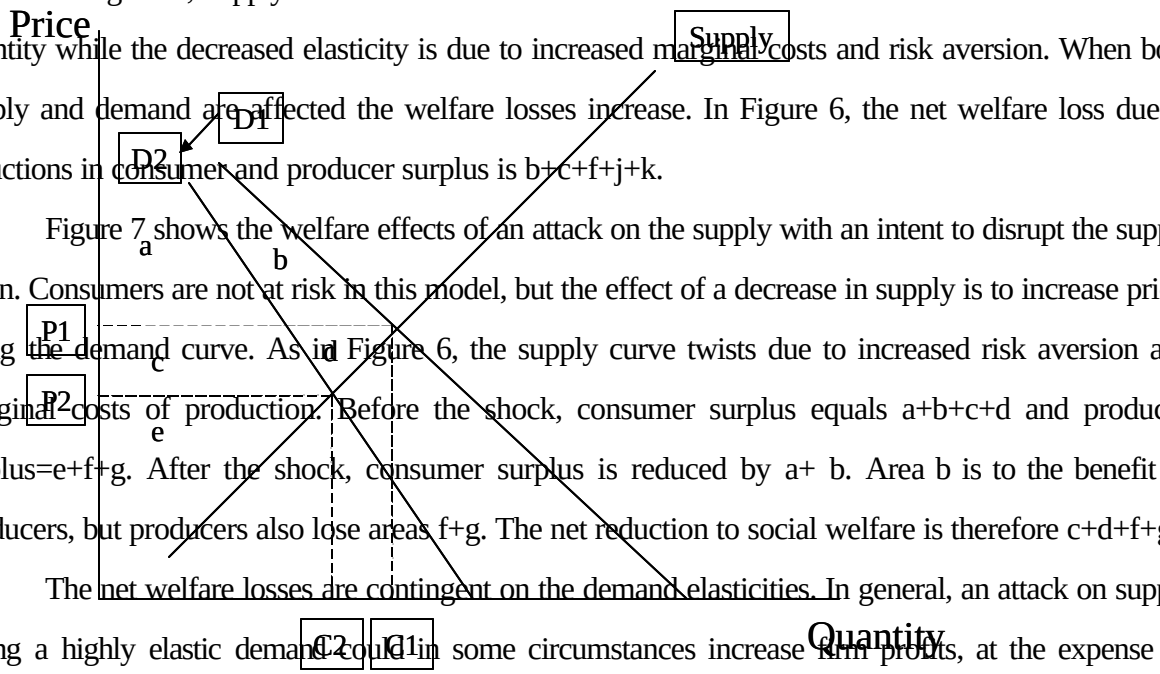
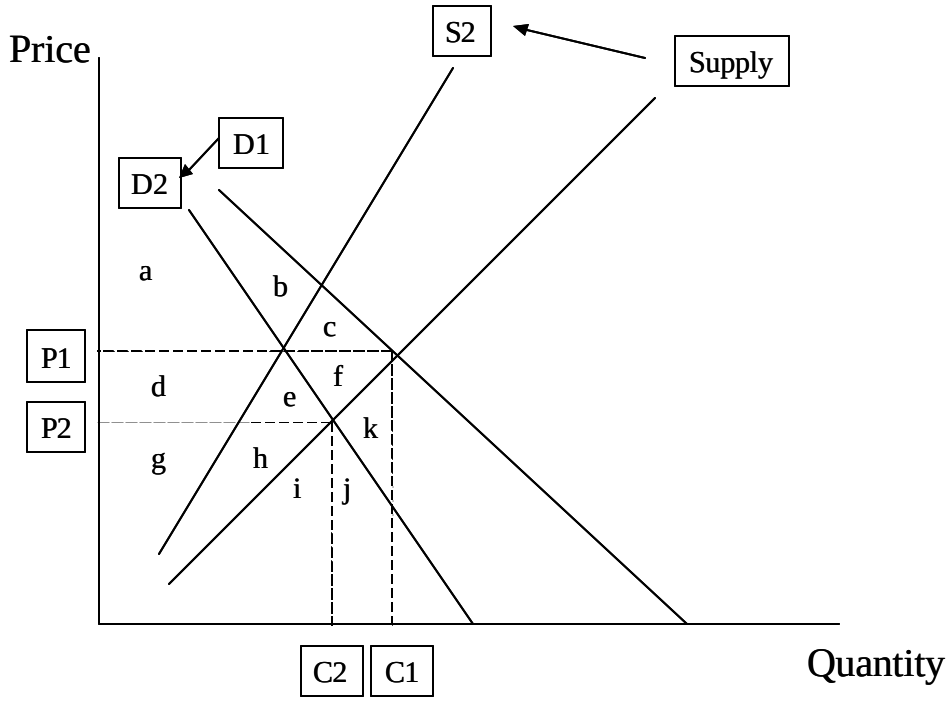


Figure 7 shows the welfare effects of an attack on the supply with an intent to disrupt the supply chain. Consumers are not at risk in this model, but the effect of a decrease in supply is to increase prices along the demand curve. As in Figure 6, the supply curve twists due to increased risk aversion and marginal costs of production. Before the shock, consumer surplus equals a+b+c+d and producer surplus=e+f+g. After the shock, consumer surplus is reduced by a+ b. Area b is to the benefit of producers, but producers also lose areas f+g. The net reduction to social welfare is therefore c+d+f+g.

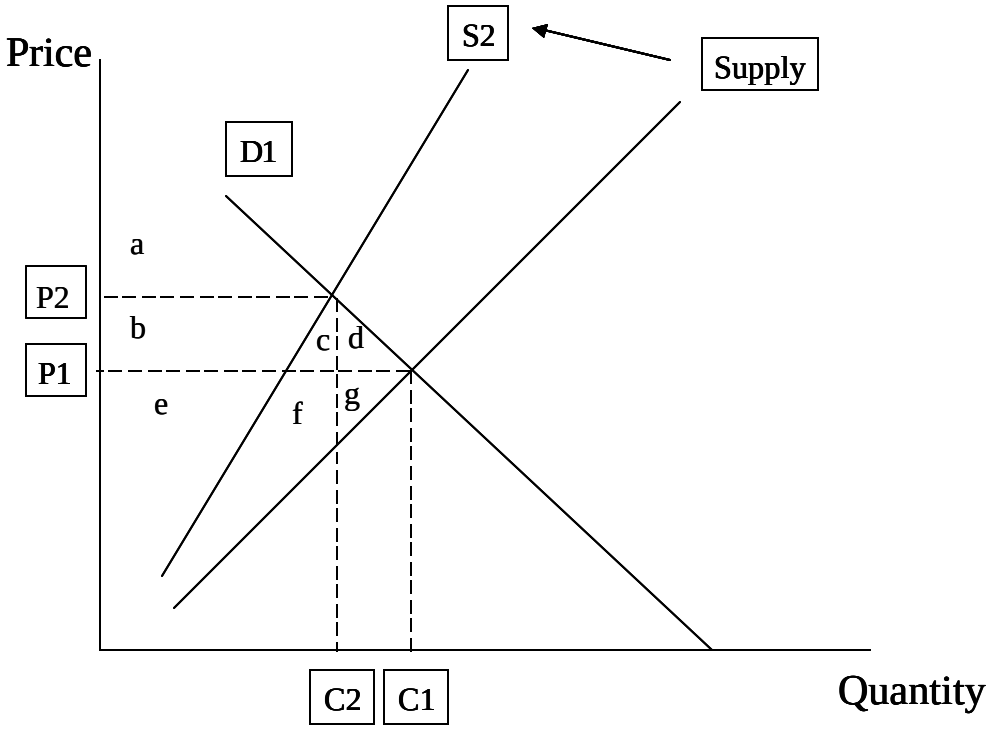
The net welfare losses are contingent on the demand elasticities. In general, an attack on supply facing a highly elastic demand could in some circumstances increase firm profits, at the expense of consumers. Likewise a reduction in demand will not have as great an impact, when the supply function is more elastic than demand. Consequently, from an economic point of view, an intelligent terrorist would mor

Figure 5:Welfare Effects due to Demand Shock



The Economic Impact of a Terrorist disruption to the Food Industry

Figure 6: Welfare Effect due to Demand and Supply Shocks



The Economic Impact of a Terrorist disruption to the Food Industry

Figure 7: Welfare Effects Due to Supply Shocks

Conclusions

The threat of a terrorist attacks against the agricultural and food system is believed by many to be imminent. However, there has been surprisingly little research to determine what the economic impacts of terrorism can be. This paper has discussed terrorism in many contexts and has illustrated the use of terrorism on the food sector over time. The paper argues that there are several behavioral characteristics that must be adjudicated before a complete understanding can be made. The difference between a threat versus an action will have different economic impacts. However, this paper argues that fear of a terrorist act upon the food system can linger in what we refer to as consumer hysteresis. We argue that hysteresis in an economic system is a path dependent process that removes economic equilibrium away from steady state for a prolonged period of time. Proof of hysteresis at this juncture is elusive, but there is sufficient anecdotal evidence that consumer hysteresis exists. The time response of consumers to regain trust in air travel following the September 11, 2001 attacks is a case in point, as is the University of Michigan Consumer confidence index, which showed a marked decline following 9/11, with at least four years to recovery. Our argument is that hysteresis is manifested in an economic system through a shift in the demand curve as well as a reduction in the elasticity of demand. Similar effects can also be argued for supply. Whether hysteresis is systemic in the economy is an empirical issue that will require a variety of econometric techniques such as partial adjustment models, that can include path-dependency in the model structure.

Date/ Period	Locale	Event	Cause	Comment
B.C.		Scythian archers dipped arrowheads in manure and rotting corpses to increase the deadliness of their arrows.23	Military	Some of the earliest recordings of bio warfare that indicates an early awareness of the biological relationship between bacteria and the transferability of disease.
1340	Ukraine	During the siege of Kaffa (modern day Ukraine) in the 1340s, invading tatars forces catapulted plague victims into the city. It is believed that retreating forces from the city contributed to the second plague epidemic in Europe.	Military	
14th century; 1665;1894	Europe United Kingdom China	In the 14th century nearly 25% of the population of Europe succumbed to bubonic plague in the Black Death. The Great Plague of London in 1665 was killing 7,000 people per week. The last bubonic plague pandemic started in China 19 1894, spreading around the world, including North America, killing over 12 million (Alibek 2000)	Natural	Caused by poor sanitary conditions and transferred by fleas, the pandemics are illustrative of the ferocity of a biological infection. Today outbreaks are still found, but treatment with antibiotics reduces mortality and the ability of the disease to spread. However (Alibek 2000) reports that the Russians were developing a super plague that was resistant to most antibiotics available in the late 20th century.
1711-1769 1857-1866 1889-1897	Western Europe And Africa	Following the many waves of military campaigns from Asia to Europe, rinderpest, or cattle plague, swept Western Europe killing over 200 million head of cattle. The 1857-1866 epidemic killed most cattle in Europe, and in 1889 the "Great Rinderpest Pandemic" was introduced to Africa by invading Italian troops. Over 90% mortality in	Accidental	The story as told by Torres (1999) shows how disease had shaped policy and cultures. Rinderpest epidemics led to the formation of the first biostrategies in 1741 which included quarantine and burial, as well as to the foundation of the first veterinary school in the UK . In Africa it caused the weakening of cattle keeping tribes in Africa and

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Date/ Period	Locale	Event	Cause	Comment
		cattle and oxen were found in some regions. Giraffe and African buffalo populations were also severely affected.		altered the ecological balance of game species of East Africa.24
1763	Pennsyl-vania	During the French and Indian War in 1763, British forces in Pennsylvania distributed blankets used by smallpox victims to the Delaware Indians in an effort to reduce the number of opposing forces. This resulted in a smallpox epidemic among the Native American population.	Military	With no natural protections to European diseases, this illustrates the deadly possibilities of taking an endemic disease from location to a region where the disease is non-existent (see the story about Ebola Reston in 1989 for a counter argument)
1917-1918	France	During World War I, German agents used anthrax and glanders as an equine disease to infect livestock and pack animals used for transporting supplies.	Military	It is unknown how effective these techniques were.
1940-1941	Manchuria / Siberia	Japan was involved in developing sophisticated techniques to deliver and spread fungi, bacteria, and nematodes on grains and vegetables in Manchuria and Siberia with airdrops of infected grains of wheat millet and cotton as well as anthrax and glanders (Runge, 2002).	Military	It is unknown how effective these techniques were.
1942	Stalingrad, Russia	In 1942 the Nazi campaign in southern Russia ground to a halt with a significant outbreak of	Military	This may or may not be true. According to Alibek (2000) the usual numbers of infection were 10,000.

24 Torres, A. "International Economic Considerations Concerning Agricultural Diseases and Human Health Costs of Zoonotic Diseases" in Food and Agricultural Security: Guarding Against Natural Threats and Terrorist Attacks Affecting Health, National food Supplies and Agricultural Economics Edited by T.W. Frazier and D.C. Richardson. Annals of the New York Academy of Sciences , Vol 894

Date/ Period	Locale	Event	Cause	Comment
		tularemia. Infection soon hit the Russian ranks, with over 100,000 troops infected.		Alibek suspects that the Germans were infected first, but then the wind shifted or rats carried tularemia back to the Russian lines. The story indicates how hard it would be to employ battleground bio-warfare when a sudden shift in wind can infect own troops. A tularemia weapon was developed in 1941 by the Russians.
1943	Europe	The Nazi regime experimented with dropping potato beetles from planes as well as the use of turnip weevils, antler moths, potato stalk rot, potato tuber decay and various weed.	Military	It is unknown how effective these techniques were.
1943	Germany	French focused on potato beetles and rinderpest virus in cattle directed at Germany25.	Military	It is unknown how effective these techniques were.
1944/1945	Great Britain	Britain stockpiled 5 million anthrax-laced cattle cakes to be dropped from aircraft, and had a program underway for the use of foot-and-mouth disease and plague.	Military	Planned but not employed
Post War	U.S.A	After World War II, the U.S. Army carried out at least 31 tests and stored rice and wheat blast fungus at Fort Detrick, Maryland, and at the Rocky Mountain, Colorado.	Military	
1950s/ 1960s	Brazil	Land speculators (reportedly) sent infected people into the Matto Grosso of Brazil in an effort to infect	Domestic Terrorism	This is reported in Wheelis et al (2001) following Davis (1977) in an effort to describe a low-tech

25 E. Geissler and J.E. Moon. "Biological Warfare from the Middle Ages to 1945." New York: Oxford University Press, 1999.

Date/ Period	Locale	Event	Cause	Comment
		native aboriginal tribes. The speculators could then buy inexpensive land once they were uninhabited		approach to spreading disease. A current concern is that terrorists, seeking martyr status, would infect themselves with small pox and then simply wander through airports and large U.S. cities.26
1960	U.S.A	U.S. Air Force produced anti-plant disease agents at Pine Bluff, Arkansas and tested wheat stem in North Dakota.	Military	Never applied in practice
1964-1965	U.S.A	U.S. Air Force tested anti-animal pathogens at stockyards in many states.	Military	Never applied in practice
1970	Alabama	The water supply of 1,000-acre farm near Ashville, Alabama, operated by a group of African American Muslims, was poisoned. This led to the death of thirty cows.	Domestic Terrorist	Perhaps the first recorded case of bioterrorism in the United States
1970-1990	USSR	Soviets used ticks to transmit foot-and-mouth disease. They also conducted experiments with rinderpest, African swine fever, bovine pleuropneumonia, mutant forms of avian flu, and ecthyma in sheep. They also experimented with wheat, barley and tobacco mosaic streak viruses, wheat funguses and brown leaf rust (Alibek, 1999; Runge, 2002) as well as wheat rust, rye blast, and rice blast (Alibek 1999).	Military	Never applied in practice, however since the democratization of the Soviet Union and the elimination of the Russian biopreparat program, Russian germ scientists were frequently invited to job fairs in Iran, Iraq and North Korea. The Iranians in particular were interested in bioweapons applied to livestock and crops.
1978	Israel	A Palestinian group used mercury to contaminate	Domestic	

26 Davis , S.H. Victims of the Miracle: Development and the Indians of Brazil Cambridge University Press, NY, 1977

Date/ Period	Locale	Event	Cause	Comment
		Israeli citrus exports to Europe.	Terrorist	
1979	USSR	anthrax spores accidentally released from a Soviet military lab in Sverdlovsk led to the death of 66 people.	Bioweapon/ Accidental	
1984	Oregon	Members of a religious cult led by Bagwan Shree Rajneesh poisoned salad bars with Salmonella in Dallas, Oregon in an effort to weaken residents and prevent them from voting in a local election. 751 people became ill. The Cult also experimented with typhoid, shigella, and tularemia27.	Domestic Terrorist	
1982-1984	Afghanis-tan	Soviet troops employed glanders against the Mujaheddin in the mountains of Afghanistan (Alibek 2000)	Military	Alibek (1999) points out that glanders would have had the dual effect of sickening the Afghan soldiers and killing their horses. The story was told to Alibek by a senior officer but has never been confirmed.
1985	Sri Lanka	A letter to the U.S. embassy claimed that tea exports to the United States was contaminated with cyanide (Runge, 2002).	Terrorist/prank	
1989	Chile	Anti-Pinochet movement laced grapes with cyanide (Casagrande, 2000).	Domestic Terrorist	after the lacing of grapes with cyanide, consumers refused to buy all types of Chilean fruit. Subsequent suspensions of Chilean fruit imports by US, Canada, Denmark, and Hong Kong cost Chile more than $210 million loss in profit and damaged its relationship between the United States

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Date/ Period	Locale	Event	Cause	Comment
				(Casagrande, 2000).
1982-1984	Afghanis-tan	Soviet troops employed glanders against the mujaheddin in the mountains of Afghanistan (Alibek 2000)	Military	Alibek (1999) points out that glanders would have had the dual effect of sickening the Afghan soldiers and killing their horses. The story was told to Alibek by a senior officer but has never been confirmed.
1986	UK	BSE was first diagnosed in 1986 and linked to human disease in the form of Creutzfeldt-Jakob Disease in 1995 making it one of the most debilitating zoonose viruses. By 1998 174,000 cattle had been reported infected with the disease, but estimates of actual diseased cattle exceed 1 million (Murphy 1999). It is believed that the disease morphed from sheep scrapies to BSE and then to CJD.28 In 1996 all cattle over the age of 30 months in the U.K. were ordered slaughtered (Brown 1999).	Natural / Food borne	A possible target for economic terrorism and therefore worthy of note.In the 1990s, the outbreak of BSE cost the UK government between $9 and $14 billion in compensation costs to farmers affected by the slaughter of their cattle, and employees laid off in the dairy and beef industries. In addition, worldwide bans imposed on British beef products contributed to the cutback of export markets worth at least $2.4 billion as the price of beef went to zero in the U.K. when the link between BSE and CJD was discovered (Brown 1999). In 2001/2 three cases of BSE in Japan caused a 50% drop in beef sales (Wheelis et al 2002, Watts 2001)29
1996	Arizona	a fungus disease called karnal bunt, a fungal disease of wheat that gives it an unpleasant odor and taste, was discovered in wheat seeds in	Natural/Accidental	A possible target for economic terrorism and therefore worthy of note. Following the discovery of karnal bunt, more than fifty U.S. trading partners,

28 Murphy, F.A. "The Threat Posed by the Global Emergence of Livestock, Food-Borne, and Zoonotic Pathogens" in Food and Agricultural Security: Guarding Against Natural Threats and Terrorist Attacks Affecting Health, National food Supplies and Agricultural Economics Edited by T.W. Frazier and D.C. Richardson. Annals of the New York Academy of Sciences , Vol 894

29 Wheelis, M, R. Casangrande, and L.V. Madden "Biological Attack on Agriculture:Low Tech, High Impact Bioterrorism" BioScience 52(7)(July 2002):569-576
Watts, J. "Japan's Government Tries to Allay BSE Fears" Lancet 358(2001):2057

Date/ Period	Locale	Event	Cause	Comment
		Arizona (Kohnen, 2000).		including China, the largest importer of U.S. wheat adopted phytosanitary trade restrictions against the United States. Control and clean up by the USDA's Animal and Plant Heath Inspection Service (APHIS) cost an estimated $45 million. The impact on exports was $250 million compared to the $6 billion total value of U.S. wheat exports (Kohnen, 2000). Horn and Breeze (1999) suggest that had international trading partners imposed border sanctions the loss could have exceeded $6 billion.30
1993	Milwaukee , Wisconsin	Cryptosporidium (an intestinal parasite) was found in the water supply. This contamination resulted in more than 400,000 illnesses and possibly 100 deaths.	Natural	While not terrorist related, the episode is illustrative of how a pathogen can be introduced in to the water system to cause harm to humans and animals. A possible target for economic terrorism and therefore worthy of note
1995	Intern-ational	Sorghum ergot pandemic started in Brazil in 1995v and spread to Australia (1996) and the U.S. and Mexico (1997). The rate of infection was swift with 800,000 sq km infected one month after identification in Brazil. Within a week of confirmation in Australia 16,000 sq km were infected and within a month 70,000 sq km. By	Natural	Bandyopadhyay and Frederiksen (1999) use this pandemic to illustrate the effects of introducing a new pathogen into the production system. From 1996-1998 APHIS spent over $60 Million in combating the disease, while growers in the affected areas lost over $100 million from lost sales and increased costs of production (Wheelis et al 2001)

30 Horn, F.P. and R.G. Breeze "Agriculture and Food Se Food and Agricultural Security: Guarding Against Natural Threats and Terrorist Attacks Affecting Health, National food Supplies and Agricultural Economics Edited by T.W. Frazier and D.C. Richardson. Annals of the New York Academy of Sciences , Vol 894

Date/ Period	Locale	Event	Cause	Comment
		1997 it had hit the sorghum growing regions of the U.S. (Bandyopadhyay and Frederiksen, 1999)31		
1995	Japan	The Aum Shinrikyo sect released sarin into a Japanese subway during morning rush hour and killed 12 people and sickened thousands.	Domestic Terrorism	
1996	Japan	A hospital worker introduced Shigella dysenteriae into food eaten by 13 co-workers. Nine of the individuals who ate the contaminated food required medical treatment.	Domestic Terrorism	
1996	Wisconsin	Brian Lea, an owner of an animal-food processing facility, deliberately contaminated with chlordane feed products at National By-Products Inc., a supplier for Purina Mills.	Domestic Terrorism	
1997 and 2001	Taiwan, U.K., Europe	Taiwan's livestock sector was deeply affected by the outbreak of FMD on its huge hog farms. From the time the disease was exposed on a single farm, to the time it was announced, 27 other farms were infected. Within a week, 717 farms were infected and within three months Taiwan was fully infected and 4 million hogs were destroyed (Casagrande 2002). The 2001 outbreak of the disease in Great Britain prompted the slaughter of more than 4 millions farm animals, out of herds of approximately	Accidental	While not terrorist related, the introduction of Foot and Mouth disease into the U.S. economy could be devastating. The Taiwan outbreak resulted in excess of 500,000 tons of pork meat being destroyed and in an indefinite ban on Taiwan's pork exports that caused Taiwan's GDP to drop by 2% (Chalk, 2000). It cost more than $5 billion, required to slaughter four million swine. Taiwan lost its principal export markets for pork particularly the Japanese market. Within one week of the outbreak, swine

31 Bandyopadhyay, R. and R. A. Frederiksen "Contemporary Global Movements of Plant Diseases" in Food and Agricultural Security: Guarding Against Natural Threats and Terrorist Attacks Affecting Health, National food Supplies and Agricultural Economics Edited by T.W. Frazier and D.C. Richardson. Annals of the New York Academy of Sciences , Vol 894

Date/ Period	Locale	Event	Cause	Comment
		60 million and caused billions of dollars in losses to farmers.		prices dropped by 60% and about 50,000 people became unemployed and $6.9 billion was lost in export revenue. Three years later Taiwan did not fully regain its exports markets. The 2001 outbreak in Great Britain caused billions of dollars in losses to farmers. It also lowered domestic consumption of beef in the U.K and reduce British beef exports that disrupted international trade. The ban imposed on British beef by European Union states severely strained London's relations with its major European allies, exacerbating tensions in bilateral and multilateral negotiations over closer EU integration.
1997-1998	Netherlands	An outbreak of classical swine fever infected 20 new herds every week, despite vigilant containment efforts (Casagrande 2002)	Accidental	The introduction of classical swine fever illustrates that FMD is not the only non endemic contagious disease to affect livestock in developed economies.
2001	U.S.A.	Unknown individual(s) distributed anthrax spores through the U.S. Postal Service and caused 5 deaths and many more exposures.	Domestic Terrorism	The anthrax incident illustrated just how strained and fragile the North American socio-economic base was. Buildings were closed, government shut down, postal service and other courier businesses were halted, and the anthrax vaccine was in limited supply.
2002		A shopkeeper, driven by jealousy and hatred of the owner of a rival business, spiked breakfast foods with rat poison "Dushuqiang" banned by the Chinese government and killed 38 people and sickened hundreds in the city of Nanjing.	Domestic Terrorism	