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The Western Economics Forum

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Purpose

One of the consequences of regional associations nationalizing their journals is that professional agricultural economists in each region have lost one of their best forums for exchanging ideas unique to their area of the country. The purpose of this publication is to provide a forum for western issues.

Audience

The target audience is professional agricultural economists with a Masters degree, Ph.D. or equivalent understanding of the field that are working on agricultural and resource economic, business or policy issues in the West.

Subject

This publication is specifically targeted at informing professionals in the West about issues, methods, data, or other content addressing the following objectives:

- Summarize knowledge about issues of interest to western professionals
- To convey ideas and analysis techniques to non-academic, professional economists working on agricultural or resource issues
- To demonstrate methods and applications that can be adapted across fields in economics
- To facilitate open debate on western issues

Structure and Distribution

The *Western Economics Forum* is a peer reviewed publication. It usually contains three to five articles per issue, with approximately 2,500 words each (maximum 3,000), and as much diversity as possible across the following areas:

- Farm/ranch management and production
- Marketing and agribusiness
- Natural resources and the environment
- Institutions and policy
- Regional and community development

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Editor – Send submissions to:

Dr. Don McLeod
Editor, Western Economics Forum
Dept. of Ag & Applied Economics
University of Wyoming
Dept. 3354 1000 E. University Avenue
Laramie, WY 82071
Phone: 307-766-3116
Fax: 307-766-5544
email: dmcleod@uwyo.edu

Climate Change, Agriculture and the West: A Multifaceted Issue

Siyi J. Feng, Amy D. Hagerman, Bruce A. McCarl, Jianhong H. Mu and Wei Wei Wang[1,2]

Introduction

Climate change and associated issues have gained public and scientific prominence in recent years. Policy action is being debated with the past two years revealing US based discussions on cap and trade, policy on renewable fuel standards with greenhouse gas (GHG) emission features, Presidential level agreement to international accords regarding funding of adaptation efforts, the popular spread of the carbon footprint concept, and the release of major US and UN reports among others. Numerous outlets have published materials related to emerging evidence of climate change effects, mitigation of greenhouse gas (GHG) emissions, and adaptation to altered climatic conditions. Virtually every department or research group has a "climate change expert" and there are at least four journals that publish agricultural/resource economic pieces devoted to the subject (*Climatic Change*, *Mitigation and Adaptation Strategies for Global Change*, *Climate Research* and the soon to appear *Climate Change Economics*). The literature available on climate change topics is extensive and exhaustive. So what are the major components of the climate change issue that might stimulate work of an applied economist in the US West? This paper presents a condensed review of the issue, focusing on findings/deductions that are particularly relevant to agriculture in the Western US region. The purpose is to overview where climate change research is today, where it is going, and open questions. It is written from the perspective of an author who published his first climate change piece in the Western Journal of Agricultural Economics in the late 1980's and a group of graduate students just entering the field. It is certainly biased in coverage by the efforts and findings from the research group where they all work. Note, this paper is a companion to a more detailed book chapter[3].

Background

Climate change is already affecting agriculture, forestry, land use, water resources and biodiversity in the Western US and globally. Crops and pests are migrating toward the poles, and livestock grazing land is changing in carrying capacity (IPCC, 2007b; USCCSP, 2008) while water supplies and snowpack are being altered as is the hydrograph. Furthermore, atmospheric greenhouse gas concentrations shall soon attain dangerous levels (Fri et al., 2010). Real global action to manage GHGs seems to be over the horizon if it ever will occur. It is virtually inevitable that climate change will play an even larger role in the coming decades and beyond (Rose and McCarl, 2008) as well as a creating a need for a degree of adaptation. There are also likely to be increasing calls for mitigation efforts plus there is the emergence of state level GHG emissions reduction programs like that in California.

The Western US, being largely semi arid, is at risk to climate change. IPCC (2007a) indicates temperature is expected to increase by 3-4 degrees Fahrenheit by the 2030s and 8-11 degrees by the 2090s. Precipitation is expected to change but at a regionally differential rate. In the Southwest, a decrease is expected with average conditions reaching levels of today's drought of record by the latter part of the 2000's (Seager et al., 2007). Across most parts of the West, there

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[1] Seniority of authorship is shared

[2] The authors are Research Assistant, Post-Doctoral Research Associate, Distinguished Professor, Research Assistant, and Research Assistant respectively, Department of Agricultural Economics, Texas A&M University, College Station, Texas. We would like to thank John Reilly, Don McLeod and an anonymous reviewer all of whom made helpful comments and suggestions that aided in the development of this piece.

[3] Forthcoming book chapter, available at: http://agecon2.tamu.edu/people/faculty/mccarl-bruce/McCarlClimateChange.htm

is an expectation of wetter conditions due to increased evaporation, and increased precipitation in the form of rainfall in the winter. There is also the expectation of earlier runoff of mountain snowpack. Finally, the chance of changes in rainfall intensity, reduced snowpack, more tropical storms, more droughts and increased weather variability loom (IPCC, 2007a). (The precipitation projections are less reliable being substantially more variable across projections than are the temperature ones. For example, the 2001 US National Assessment was based on projections showing a wetter Southwest as opposed to the largely drier ones in the 2007 IPCC. Today the evidence from IPCC depends on the preponderance of the projections.)

A Multi Faceted Issue: Effects, Adaptation and Sequestration

The climate change issue has three major aspects:

- **Effects** of the changed climate;
- **Adaptation** to changed climate; and
- **Mitigation** of GHG emissions on the interest of reducing future climate change.

Each poses unique research challenges and has been the subject of research effort. These will be discussed sequentially.

Effects of climate change

Climate change has its main effects (as covered in IPCC, 2007a) in terms of altered temperature (generally higher), precipitation (generally higher but with sub tropical dryness plus intensity shifts and increased variability), carbon dioxide concentrations, and a mix of potential extreme event effects (possibly stronger El Nino's, more tropical storms, more droughts). Agriculture/forestry and ecosystems are highly vulnerable to changes in such factors due to the following:

- Their level of dependency on the environment.
- Dependency on similarly sensitive resources like water and forage.
- The fundamental relationship between plant photosynthesis and carbon dioxide.
- Vulnerability to pest incidence, forest fire incidence and disease spread plus, in some areas, sea level rise.

In turn, producers of goods may be impacted directly through increased resource scarcity or productivity changes. Markets, international trade, and technological development will all be shaped by climate change with shifts in comparative advantage and market prices. Sea level rise may also affect marketing facilities. This has been a dominant research topic with literature reviews on approaches and findings in Adams et al. (1998), Reilly et al. (2002, 2004), IPCC (2007b), USCCSP (2008) and Antle (2009).

Adaptation to climate change

A substantial degree of climate change appears to be inevitable (Rose and McCarl, 2008; Antle, 2009). Consequently, society will have to adapt activities to accommodate changes in climate. Agricultural producers have a long history of climate adaptation as seen by the variation in land use and cropping patterns across the globe. Western states producers have adapted by growing high value crops where irrigation water is available and climatic conditions are favorable. They then use those best adapted to local climatic conditions (Oranges in the South and Apples in the North). Livestock, however, predominate in arid regions without irrigation water supplies as well as in mountain alpine regions. A changing climate will stimulate adaptations including changes in varieties, breeds, stocking rates and land use patterns (McCarl, 2007; McCarl, Feng, and Wang, 2009; Antle, 2009).

A changing climate will increase the rate of obsolescence for many long-standing practices. Producers will need to adapt more quickly. Adaptation will also require investment in facilities for processing, handling and transporting crops and livestock commodities in volumes not previously produced in the region. Investments will be needed in research on new varieties better suited to the altered climate. Pest management and the movement of invasive species into new habitats will require practice changes, extension education and investment. This will increase the burden on research and extension units, who will play an important role in disseminating new technology and facilitating adaptation (McCarl, 2007). Adaptation will contribute to survivability of producers and agribusinesses but at the cost of diverting resources that could have been used in other ways. The adaptation investment will be accomplished in part by normal capital stock turnover in equipment and facilities; however, the remainder must be provided from other resources.

Mitigation of Net Emissions

Efforts to limit future climate change involve reducing net GHG emissions and will affect future agriculture and forestry. Agriculture and forestry can play a role in mitigation bylimiting rates of tropical deforestation, increasing rates of afforestation, reducing livestock related emissions, altering rice related emissions, increasing bioenergy feedstock production thereby offsetting fossil fuel use, and increasing sequestration in agricultural soils or forests along with pursuing a number of other strategies (McCarl and Schneider, 2001; IPCC, 2007c). These activities will have impacts on land use competition, water competition and market prices.

Price impacts and their consequences are also a factor. While climate change may lead to altered commodity prices, mitigation efforts divert key resources limiting production and raising prices. Higher market prices will likely lead to reductions in exports or expansions in imports. Environmentally, this will create pressure to bring sensitive lands around the globe into production (including rainforests and CRP) along with increasing agricultural pollution externalities and GHG leakage (Murray, McCarl and Lee, 2004; Searchinger et al., 2008; McCarl and Boadu, 2009). Mitigation activities in energy would also generally increase the cost of fossil fuel related inputs, potentially damaging economic growth and increasing costs of agricultural production (McCarl and Schneider, 2001). Though agriculture is shown to possibly benefit on the output side, the expectation is that the consumer losses will outweigh the benefits but that this would be offset by welfare gains from lessened climate change (Baker et al., 2009; Scheider and McCarl, 2005).

Western Agriculture Sensitivities

Climate change will alter the face of agriculture through longer term effects of the changed climate, shorter term mitigation activities and intermediate to longer term adaptations. A number of climate change related factors that will drive change in Western agriculture, forests and ecological characteristics are briefly discussed. These are presented in the following large groupings: (1) farm/forest productivity and prices; (2) agricultural and industrial water supply/ demand; (3) disturbances; (4) mitigation production and competition; (5) adaptation needs; and (6) ecological services.

Farm/Forest Productivity and Prices

Climate and climate change drivers have been shown to influence crops and livestock in diverse ways. The combination of hotter temperatures, possibly drier conditions, and a carbon dioxide richer atmosphere will have regionally heterogeneous effects on crops. Northern regions generally have larger, positive yield changes, whereas southern regions increase less and decline in some cases (Reilly et al, 2002; McCarl, 2006; Antle, 2009). Elsewhere livestock productivity has been affected directly through climate stress as well as indirectly through impacts on pasture, forage and grain availability and disease (Seo and Mendelsohn, 2008a; 2008b). Direct anticipated climate effects include reduced cold stress by rising temperatures in winter, but this effect will be offset by the negative effects of hotter summers. Reilly et al. (2002) suggests that productivity losses in the southern US could be in the order of 10 percent or more.Forage yield reductions will mean stocking rates will need to be reduced in drier areas. Furthermore there are likely to be changes as shown:

- *Yield Variability*: Largely projected to increase, as examined in McCarl, Villavicencio and Wu (2008).
- *Shifting Product Mixes and Management*: Crop mixes and management practices will shift to account for direct and indirect climate change impacts (e.g. northward migrations in crop mixes, or altered pest management regimes as discussed in Adams et al. (1998, 1999) or Reilly et al. (2002)).
- *Price Effects*: Market prices are likely to shift and stimulate production mix and other adjustments as shown in McCarl (2006).

Agricultural and Industrial Water Supply/Demand

Climate change is likely to alter water quantity, quality and demand in a variety of ways. Water quantity shortages, inappropriate timing of water availability (precipitation), and impaired water quality caused by drought are expected (Adams and Peck, 2008). Some parts of the western region are projected to have precipitation increases while other regions experience substantial reductions, particularly after adjusting for evapo-transpiration (Antle, 2009; Seager et al., 2007), although there is certainly a wide variance in the regional characteristics of the precipitation projections (IPCC, 2007a). For example, precipitation is expected to decrease up to 10% along the southern coast of Alaska and decline up to 25% in the Oklahoma panhandle, north Texas, eastern Colorado and western Kansas (NAST, 2000).

Water quality will be altered by changing precipitation patterns (Thompson, 2005). Water demand by plants would increase with hotter conditions increasing respiration and evapo-transpiration plus there will be increased demands stimulated by CO_2 effects (Adams et al., 1999) in turn increasing irrigation demands (see the data in McCarl, 2006). Water pricing mechanisms will be stressed, and the allocation of water rights will take on even greater importance (Reilly et al., 2002; Lund et al., 2006). A number of other factors merit discussion including the given changes:

- *Water Seasonality and Storage - Snow Pack:* Snow pack levels are expected to form later in winter, accumulate in smaller quantities, and melt earlier in spring. Rising temperatures increase the proportion of winter precipitation received as rain and decrease the proportion arriving in the form of snow (Adams and Peck, 2008). Earlier, melting of snow pack would shift the hydrograph away from midsummer flows toward spring and winter and perhaps increase storage needs (Gleick et al., 2000). Shifts in the timing of crops to accommodate earlier ends of winter will also alter the seasonal pattern of irrigation water demand.
- *Precipitation Intensity:* IPCC (2007a) summarizes data showing increases in precipitation intensity with larger contributions from the wettest days in a month. This signifies a shift in precipitation shares from gentle frontal rains to more intense storms (a pattern more typical in the sub tropics). The result is less suitable for plant growth and will cause greater erosion and changing runoff patterns, plus challenges for Western reservoir systems (USCCSP, 2008). Intensity increases are likely to become more pronounced as climate change proceeds.
- *Drought Incidence:* Observations show increased summer drought stress in the last 30 years (USCCSP, 2008; IPCC, 2007a). This trend can be expected to continue as

temperatures increase, plus there are projections that the future will contain more and longer lasting heat waves (IPCC, 2007a) as well as perhaps more frequent, stronger El Nino related events (Chen, McCarl, and Adams, 2001; Adams and Peck, 2002; 2008).

- *Non-agricultural Water Demand:* Climate change may increase demand for water resources from environmental, recreational, municipal and industrial uses. For example in a study in the San Antonio region Chen et al (2001) find increased demand from municipal, and ecological sources. (More on aspects of this appears in the Ecological Services section below).
- *Aquifer Depletion:* will likely be greater in many places due to increasing non-agricultural demands (Reilly et al., 2002).
- *Water Distributions Used in Planning:* Milley et al. (2007) argue that water supply distributions and concepts like the 100-year flood and drought are changing, thereby affecting water planning.

Disturbances

Climate change can create more favorable conditions for pests and fires, diminishing productivity as the following offers:

- *Fire Risk:* Increased spring and summer temperatures, earlier spring snowmelt and woodland growth have been associated with increased fire risk (Westerling et al., 2006; PNRS, 2004) and thus climate change will exacerbate this. New fire and fuels management strategies may be needed to manage such risks (Brown et al., 2004).
- *Crop Pest Incidence:* Empirical evidence shows climate conditions are expanding pest ranges and management costs (Chen and McCarl, 2001; Gan, 2004). Plant disease pressure may also increase (USCCSP, 2008).
- *Livestock Disease:* Diseases previously rarely observed may become more prevalent. For example, spread of vector borne diseases like Avian Influenza show positive correlation with increased temperatures (Mu, 2009).

Mitigation Production and Competition

Today one commonly hears words like carbon market, cap and trade, and climate bill. All involve limiting or mitigating GHG net emissions. McCarl and Schneider (2001) discuss four roles agriculture and forestry could play under such programs. They may(1) live with higher energy prices (note approximately 84% of emissions come from energy so an increased cost of using energy is an inevitable outcome of limiting GHGs); (2) reduce emissions from energy use, fertilizer, livestock and other sources; (3) increase sequestration or retention of sequestration through soil management, afforestation, forest management or reduced deforestation; and/or (4) replace of emission intensive products (though production of bioenergy feedstocks or building materials). When such actions are followed they tend to replace traditional production practices and generally reduce production. This implies higher prices. Two principal implications arise in the west:

- *Production Alterations:* Production practices could be altered, although the possible alternatives may be limited by moisture. Regionally manipulating feedlot diets and managing manure, are possibilities as well as forest management, afforestation and avoided deforestation. Bioenergy possibilities may play a role perhaps with the largest possibility involving fuels for electricity (see Murray et al. (2004)). However moisture and other factors may limit the possibilities as discussed by Young (2009).
- *Market Consequences:* Market prices would be impacted, not only for items directly used in mitigation (switchgrass, corn, soybeans etc.) but also for other commodities, due to substitution in consumption and competition for land (Baker et al., 2009). Evidence of this has been seen in commodity prices during the ethanol expansion, which does from

some viewpoints reduce GHG emissions (McCarl and Boadu, 2009) although this issue is complex involving many drivers (Abbott et al., 2009; Searchinger et al., 2008).

Adaptation Investment

Adaptation actions in the face of climate change will affect the West. There will be alterations in crop and livestock mixes, tree species, livestock breeds and land management practices plus a need for investments in infrastructure (McCarl, 2006; Antle, 2009; 2010). This will require additional research and extension efforts to adapt existing crops and livestock, move varieties of heat tolerant crops and livestock breeds into the region, and adapt management. Expanded investment may be needed for a sufficient food supply given the factor productivity implications of climate change as found by McCarl, Villavicencio and Wu (2009). Investment will be needed to facilitate new fire and pest management strategies.

Ecological Services

Large changes in climate and land use typically impact ecosystems, thereby altering the quantity and quality of the services that they provide. Economic value is generated through ecological service provision, biodiversity, and recreational benefits among others (Loomis and Richardson,2001). The items discussed in prior sections are agricultural, such as crop/pasture land use and water issues. Some other issues are relevant:

- *Water Usage:* climate change can create environmental conflicts between stream flows and consumptive usages (Chen, Gillig and McCarl, 2001). As populations increase competition increases for what may be a smaller available amount of water.
- *Biodiversity and Habitat Conservation:* Changes in regions suitable for pests can lead to large changes as evolving with the mountain pine bark beetle. Fisheries may also be affected, with an example being Salmon. Hibernating and migratory species, like marmots, are emerging a few weeks earlier, which may be due to the ongoing climate changes (USCCSP, 2008). Increased amounts of mitigation activity may lead to changes in land use with possible reductions in programs like CRP, but also the possibility of increased inventories of forest land.
- *Recreational Value:* the West has a wide range of ecosystems accommodating various recreation activities. Climate change adaptation and mitigation may involve change in the quantities and qualities of natural resources and thereby the recreational value of these resources. Whether the change is positive or negative depends on the type of the activities. Loomis and Crespi (1999) estimate that the effect of climate change on forest-based recreation is negative while that on stream recreation is positive. A recent more comprehensive review can be found in Shaw and Loomis (2008).

Concluding Comments

Climate change poses a substantial risk to the Western US. Issues arise as to the effects, how might we cope with them (Adaptation) and how can we limit the climate change effect (Mitigation). Climate change research is investigating these issues but it is a large and daunting task with a number of unresolved lines of inquiry. A few unresolved issues in this context are as follows:

- Climate change effects have, and will continue to, impact traditional production, water availability and ecological services with a number of these investigated. However, not much work has addressed the interaction of these areas.
- While extensive work has been done on the effects of climate change on crop yields and productivity, less work has been done on livestock productivity plus the implications of altered pests, and extreme events.

- Adaptation activities will be necessary and work on the economic alternatives and implications is only at its infancy.
- Mitigation is being widely discussed but program implementation and implications are in need of substantial work.
- Adaptation will alter the ability to mitigate GHG emissions, and vice versa plus will compete for resources that would otherwise be used in various ways such as promoting economy growth and combating hunger.

Overall, agricultural and resource economists will find much opportunity for research and outreach as society wrestles with these issues.

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Economic Sustainability in the Evolving World: Implications for American Agriculture and Economists

Steven C. Blank[*]

American agriculture continues to evolve in response to both natural and social change. Both natural and social scientists respond by evaluating "what is" at any point in time, but each group also contributes a unique piece to the eventual solution. In the simplest terms, natural scientists identify and/or create "what can be" while economists (as a subgroup of social scientists) help identify "what will be" by providing decision-makers with the information and analysis needed to select among the available alternatives. In agriculture, the last few decades have been astonishingly dynamic as science has greatly sped up the industry's evolution, thus creating the need for change in larger scale and scope. However, recent changes have brought agriculture into conflict with the environment in policy debates.

As natural and social scientists, agricultural producers, and policy-makers have become aware of the expanded scope of change, a new debate is focusing on an old issue: "sustainability." Both natural and social scientists are now focusing much attention on this issue, yet those efforts are rarely coordinated because the underlying problems and components are not yet well understood because they reflect complex systems and phenomena. As a result, progress toward sustainability has been very limited. This article offers a brief perspective on how agriculture evolved into its current status as a competitor with environmental conservation as alternatives for land and other resource uses. Suggestions how this conflict might be turned into a complementary coexistence is an important step toward sustainable agro-systems. It is argued here that economists need to take a leading role by working with other social scientists in defining the targets for natural scientists as the goal of sustainability is pursued.

Turning Different Perspectives Toward a Single Goal

The term "sustainability" itself has not been defined universally by natural and social scientists, thus each group has a unique perspective of what it means and, therefore, how it should be studied (Common and Perrings). In a natural science perspective, "sustainability" generally focuses research on identifying the balance and renewability of natural systems. In economics, however, "sustainability" is viewed as a temporal constraint on decision-making.

Economic studies of "sustainability" focus on the "fairness" of outcomes between time periods (Foy). For example, the simplest of these economic models evaluate outcomes between the present and future generations. One outcome of economic assessments of sustainability has been the development of the "sustainability criterion." The criterion suggests that, at a minimum, future generations should be left no worse off than current generations (Tietenberg, p 94). Combining the perspectives of natural and social scientists, and especially economists, means that, together, these groups must identify/create and help the industry select agricultural production systems that satisfy present and future needs.

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[*] Steve Blank is an extension economist in the Agricultural and Resource Economics Department at the University of California, Davis and a recipient of the WAEA's Distinguished Scholar Award.

What is Sustainable Agriculture?

The definition of the term "sustainable agriculture" is still evolving. A computer search for the definition generates at least one statement for each of the natural and social sciences trying to address the challenge. Even on the campuses of the numerous universities with "centers" or "institutes" or "programs" focusing on sustainable agriculture, there are multiple definitions being used by different groups or departments. Unfortunately, scientists tend to focus narrowly within their discipline and sustainability requires a broad, multidisciplinary view.

Congress tried to come to the rescue in 1990. They defined sustainable agriculture in the 1990 Farm Bill. Given that federal funding is a substantial source for agricultural research at present, it would be wise for all natural and social scientists to become familiar with the specifics of that definition. Under that law (U.S. Congress), "the term sustainable agriculture means an integrated system of plant and animal production practices having a site-specific application that will, over the long term:

- satisfy human food and fiber needs;
- enhance environmental quality and the natural resource base upon which the agricultural economy depends;
- make the most efficient use of nonrenewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls;
- sustain the economic viability of farm operations; and
- enhance the quality of life for farmers and society as a whole."

Two things should catch the eye about this definition of sustainable agriculture. First, the five bulleted points outline tasks that require both natural and social scientists to accomplish. The first point requires social scientists to identify the "needs" and natural scientists to create the systems necessary to produce the output sustainably. The second point is nearly all natural science, except that environmental and resource economists might contribute in the discussions of regulatory and market frameworks. The third point involves economists to identify "efficient" uses and natural scientists to fulfill the remainder of the tasks. The fourth point is all economics. The final point is again a combination of natural and social science tasks. Thus, no scientific discipline has a monopoly on finding a path to the goal, it must be a multidisciplinary effort.

The second theme is that "economic viability" (or sustainability) is a subset of the definition. Economic sustainability is key in identifying what *will* happen: it is a necessary, but not sufficient, condition for achieving the goal of a sustainable agriculture. This means a significant contribution to be made by economists is to evaluate the profitability of agricultural operations, not only in dollar amounts, but more importantly in terms of return on investment so as to facilitate comparisons between alternative systems developed by natural scientists. Part of this contribution will be analyzing the markets in which profitability is determined. The structure of markets for agricultural outputs is critical in the search for a sustainable agriculture, as explained later in this article.

Agriculture's Evolution, In Brief

A quick summary of the evolution of agriculture helps identify some of the key problems needing to be addressed to achieve a sustainable future. In general, Figure 1 illustrates that over the history of mankind there have been three general types of agriculture, with a sustainable agriculture being the next type to evolve. In the beginning man was a hunter-gatherer. Agriculture followed as a more-stable system for meeting the food needs of people and, as it became established, agriculture enabled people to develop villages and become less migratory. Traditional agriculture, the first type to develop, was "sustainable" in that people could use only what natural resources were available within a short distance and that system did not harm the environment over time. In essence it was a system of raising plants and animals in a convenient place. The only real improvements in this first type of production system compared to what was naturally occurring in the area was the human input that assured water availability and, gradually, the elimination of competing plants from the area being cultivated (although "slash and burn" systems prove not to be sustainable). Thus, productivity levels for traditional agriculture were only slightly higher than the yields offered by Nature. Eventually, the current total output capacity of an area would become insufficient to meet the demands of the expanding population, thus forcing a change in the production system in use.

Figure 1. The Evolution of Agriculture

Agriculture type	Description	Concerns forcing change
Sustainable ↑	An evolving goal	
Organic	Reduces some harmful inputs	Non-renewable resources, lower yields
Industrial	Higher productivity, inputs not sustainable (renewable)	Ecology, "quality of life"
Traditional	"Sustainable", low productivity	Total capacity within trade regions

For most of mankind's history the only real change needed to meet higher levels of demand was to expand the total area being cultivated. However, in the late 19th and early 20th centuries, population growth in many regions made it difficult to keep up with demand for food, even with trade between people within the region. As a result, people began to seek higher productivity levels from the available farmland by adopting "industrial" production methods. This involved applying many man-made inputs. This began the second type of agriculture, which was viewed as an improvement upon traditional production systems. (Hence, the vertical arrow in Figure 1 indicates an upward movement in the development of agriculture, as producers shifted from "traditional" to "industrial" methods – as shown on the bottom of Figure 1.) Industrial agriculture has included mechanical, chemical, biological, and managerial revolutions that continue, in varying degrees, to this day. The rate of industrialization in American agriculture increased rapidly during and immediately after World War II when, first, large numbers of men were pulled off farms for the war effort and, next, large amounts of capital flowed into farming. The third type of agriculture to evolve, "organic," has been slowly transitioning into favor as concerns over (1) industrial agriculture's effects on the environment and (2) "quality of life" have increased in recent decades. Whereas industrial production systems in agriculture have much higher levels of productivity than did earlier systems, they use many inputs that may be harmful and are certainly not sustainable. Organic production systems reduce the use of some harmful inputs, but many of the systems in use currently have lower yields than the industrial systems they are replacing (Blank and Thompson) and, thus, cannot sustain the world's population at current levels of demand for food. As a result, "organic" agriculture is viewed by many production scientists as an interim stage between "industrial" and "sustainable" production systems in wealthy nations only. The arrow in Figure 1 points upward to the ultimate goal of achieving a sustainable agriculture.

In this brief sketch of agriculture's evolution it is clear that the productive capacity of each system is the key concern causing society (including farmers, natural and social scientists, and policy-makers) to search for alternative systems. Traditional agriculture is sustainable with regards to its effects on the environment and it is still practiced in many less-developed parts of the world. It is being abandoned by those developing countries as soon as they can afford to shift to industrial production systems because additional volumes of food are needed for their growing populations. Thus, one reason developing countries move from traditional to industrial agricultural systems is in response to short-run needs for food. This is the first step up the simple development ladder depicted in Figure 1. Conversely, wealthy countries are moving up, slowly leaving some industrial systems for organic production methods, because of concerns for the long-run effects of industrial production on the environment and the health of their populations. Ultimately, both concerns must be faced by all countries and, it is being argued by increasing numbers of advocates, the final solution to both problems must combine the productivity of industrial systems and the environmental neutrality of organic systems to create a truly sustainable agriculture.

The Economics of American Agriculture

The current state of profitability in American agriculture is very mixed. Many producers across the country are quite profitable, so much so that the summary data published by the U.S. Department of Agriculture appears to indicate that production agriculture is a viable industry. However, a closer look finds that a majority of farmers and ranchers are not truly profitable and that the industry as a whole is far from sustainable (Hoppe and Banker).

In a detailed analysis of the many questions related to American agriculture's current level of profitability and its struggle for long-term sustainability, Blank (2008) presents three general results that illustrate the challenges facing the industry. First, he notes that economic theory clearly shows that perfectly competitive commodity markets average zero profits over time, thus agricultural producers are always struggling to find more profitable niches as competition squeezes agricultural investment returns below the levels offered by alternatives. Second, the "technological treadmill" (Cochrane) keeps American agriculture in the increasingly global markets for commodities by creating new technology that lowers unit costs, but the treadmill is not truly sustainable because it views Nature as a competitor to be overcome. And the third general result is that government agricultural policies try to help American producers, but most policies currently focus on subsidizing market profits – especially for Midwestern grains – rather than making those crops more competitive so as to *solve* the underlying problem.

The first of Blank's results can be summarized by saying that there is a profit squeeze on agricultural producers. Output has outpaced demand for most commodities over the past century, thus leading to falling real prices for the outputs of most producers. On the other hand, the prices of inputs used by agricultural producers have increased dramatically, especially in recent decades. The result is that profit margins are falling, making commodity production less profitable over time and, therefore, a less attractive investment for family farm owner-operators. The decline in profit margins over time is evident in Figure 2. The gross profit margin of American agriculture was about 50% from the beginning of the 20th century through World War II (the margin is the share of "total sales" represented by "net income", shown in Figure 2), but it gradually declined to about 10% by 2002. Additionally, Blank (2001) shows that average net returns on equity in American agriculture declined from 2.5% in 1960 to 1.5% in 2000.

Blank's (2008) second result is a natural response to the first result: farmers constantly strive to improve their incomes by adopting new technologies. As explained by Levins and Cochrane (p. 550), "early adopters make profits for a short while because of their low unit production costs. As more farmers adopt the technology, however, production goes up, prices go down, and profits are no longer possible even with the lower production costs." In this era of global markets for most commodities what is often driving the adoption of new technologies by American producers is the need to compete with foreign suppliers – especially those in less-developed countries – who have lower production input costs. This competition is resulting in increased output, but lower profit margins for producers as they continually search for a profitable niche. That search has mostly involved seeking production methods that give higher yields, despite the long-run effects on the environment – i.e., in the past the environment has been viewed by many as an obstacle to be overcome in the search for greater output.

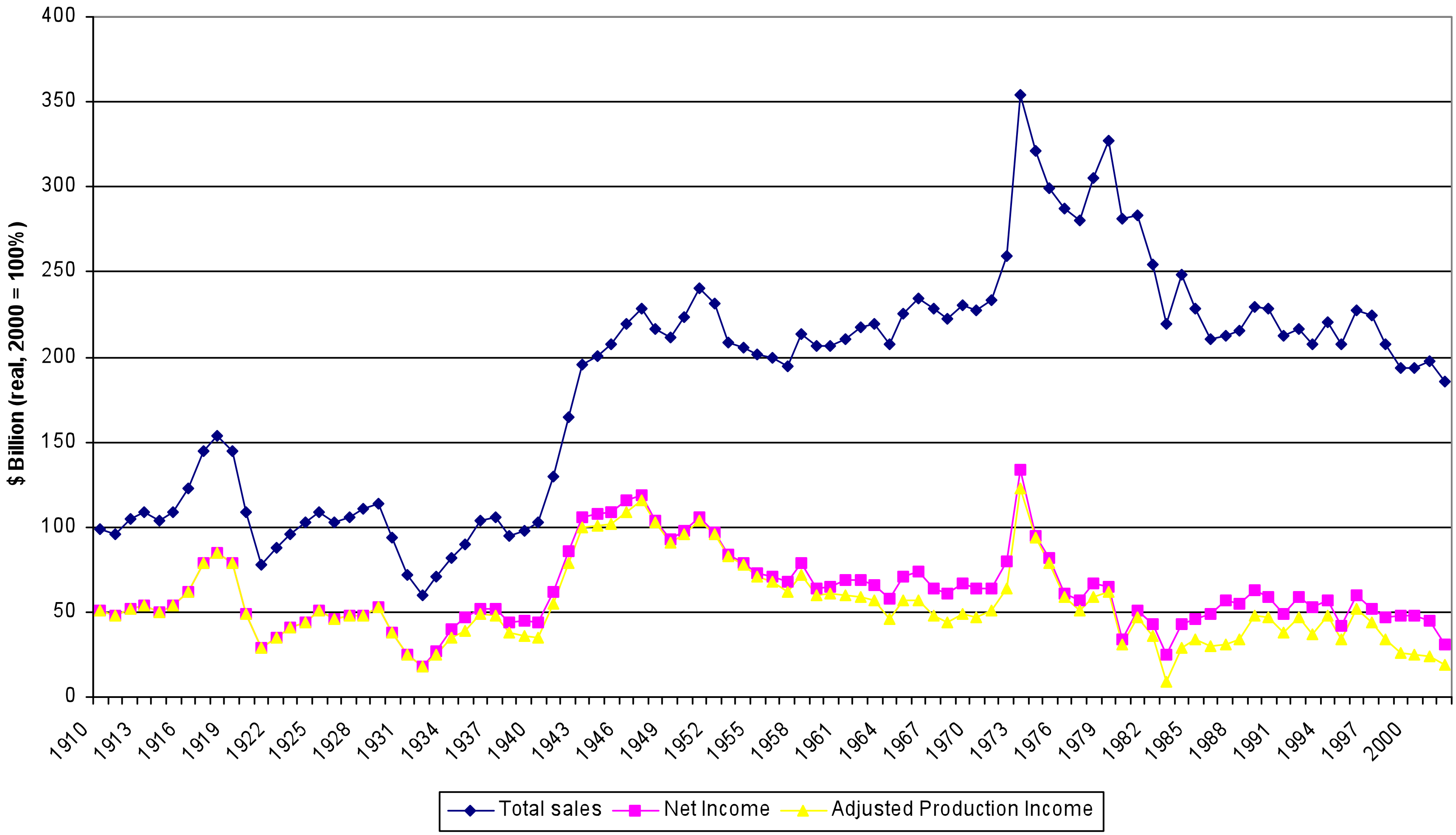
Blank's third result is spelled out (pp. 434-9) as he shows which farms receive government payments and where those farms are located. He argues that subsidizing market profits for commodities was a reasonable approach to achieving the goals of aiding the farm economy during the Great Depression of the 1930s and lowering food costs for consumers during the 1940s and 1950s. Unfortunately, those policies led directly to the surplus production that depressed commodity prices and profits over the last few decades thus hurting farmers to the benefit of domestic and foreign consumers of American agricultural commodities. Clearly, a change in focus is needed in American agricultural policy.

In light of these results concerning the profitability of American agriculture, the question arises: "how can economic viability be established so the sustainable agriculture goal can be achieved?" This is probably the most important question facing economists and the agricultural industry itself at this point in time. Natural scientists continue to work toward new alternative biological and production systems, but the value of their efforts is not fully recognized. It is economists who can and should lead the effort to help industry resolve this obstruction in the path to a sustainable agriculture, as explained below.

A Modest Proposal

Economists can help advance progress toward the goal of a sustainable agriculture by becoming more active in the pursuit of the piece of the goal's definition which has received almost no attention thus far. The fifth bulleted point in Congress's definition of sustainable agriculture asserts that agriculture affects "the quality of life for farmers and society as a whole" yet "quality of life" attributes have largely been ignored by economists. Although the help of other social scientists is needed to identify and define what those attributes might be (both negative externalities and positive amenities), economists can contribute by applying our understanding of markets. Specifically, the most likely answer to the question of how economic viability can be established for a sustainable agriculture is that government policies can assist markets in establishing the value of "quality of life" attributes, and the assistance of economists will be needed for that to happen.

Figure 2. Real U.S. Agricultural Sales and Income, 1910-2002



Quality of life attributes, such as agriculture's effects on health issues and environmental quality, do not yet have values determined in markets. This "market failure" justifies government intervention. Such interventions are beginning to happen in Europe and it is being discussed by some U.S. agricultural groups as a new approach to agricultural policy. Examples of indirect attempts to recognize agriculture's contributions to, and effects on, the quality of life in the U.S. include the Conservation Reserve Program, laws limiting agricultural pollution, and local ordinances recognizing and protecting the amenities provided by a rural landscape.[1]

"Multifunctionality" is the label being used for the new theme in agricultural policy debates. The term refers to the existence of multiple commodity and non-commodity outputs that are jointly produced by agriculture (Randall). Cahill (p. 36) noted that "food security, food safety, animal welfare, cultural and historic heritage values, environmental quality, landscape, biodiversity and rural development are just some of the outputs claimed to belong to the multifunctionality of the agricultural sector." Proponents argue that government intervention is needed because markets do not exist for all of these outputs, especially the non-commodity. If economists can work with policy makers to establish markets for all of the outputs of agriculture, and those markets can establish values for each output, the long-run economic viability of agriculture is sure to change for the better (Randall; Smith; Paarlberg, Bredahl, and Lee). For example, Bennett, van Bueren, and Whitten found Australian urban dwellers are willing to pay some positive amount to maintain rural populations because of the environmental stewardship function performed by rural residents.

Blank (2008, p. 450) suggests "America needs to shift the focus of policy from viewing 'agriculture as factory floor' to 'agriculture as neighborhood.' This change is needed because the farm factory is not always profitable, and taking the 'neighborhood' view helps us realize that agriculture affects everyone." With this new view, and a multifunctionality perspective, farmers and ranchers can be seen as "stewards of the land" that are performing a public good that should be valued because it is essential to achieving a sustainable future. Many farmers already view themselves as a steward in a limited sense. A broader notion of stewardship is based in Blank's call for a new policy perspective. A multifunctional view would encourage and empower farmers and ranchers as they are formally recognized as stewards of the land/environment, communities, human health, and rural vitality.

Such a policy shift would give market values to each alternative identified and/or created by natural scientists (which is not happening at present), such as plant varieties; production methods; systems for improving air, land, and/or water quality; to mention a few. This would point "what will be" toward an agriculture and an environment that are viewed as seamless components of a single world, rather than as competitors for attention and resources. As economists, we should probably argue to policy makers that this is a fair way to balance the needs of present and future generations in our evolving world.

[1] A host of environmental protection and/or conservation programs have been introduced in farm bills since Congress defined "sustainable agriculture" in 1990. The examples listed here demonstrate the wide range of issues addressed and approaches used by government.

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Invasive Alien Weeds and Western Cattle Ranching: Lessons Learned from Yellow Starthistle in New Mexico

Jennifer A. Thacher[1 2 3], Janie M. Chermak[4], Kristine M. Grimsrud[5], Kate Krause[1], James I. Price[6]

Introduction

Cattle remain an important feature of the Southwest's economic landscape. Arizona, Colorado, New Mexico, Texas, and Utah produce over 20 million head of cattle while total sales of cattle and dairy products within this region exceed $18 billion annually (U.S. Department of Agriculture, 2007). The majority of cattle in the Southwest are beef cows and consequently spend a substantial portion of their life grazing on rangeland.

Invasive alien weeds (IAW) have the potential to significantly affect the Western cattle industry. IAW alter rangeland vegetation by crowding out native grasses, increasing cattle management costs. Pimentel et al. (2005) estimates that invasive pastureland-weeds cost US agriculture $6 billion annually, consisting of $1 billion in forage losses and $5 billion in control costs.

Addressing the problem of IAW requires both studying the biology of IAW and understanding the economics of IAW management. Efficiently controlling an IAW is a complex management problem: private producers must take into account the trade-off between weed-control costs and future productivity of the land. This trade-off is complicated by interactions with neighboring lands. Even if one rancher efficiently controls the weed on her particular plot, there is the potential for increased weed infestation or re-infestation from neighboring plots. Thus, invasive species control is essentially a tragedy of the commons problem, where individual economic incentives (i.e., profit maximization) conflict with collective goals of land stewardship.

Despite the significant potential impact of IAW on the agricultural industry, limited research has been conducted on management strategy. This paper outlines some issues posed by IAW in the West by looking at the cattle industry in New Mexico (NM) and focusing on one specific IAW, Yellow Starthistle (YST). We briefly review state and federal policy, summarize some of our major findings, and suggest potential policy implications.

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[1] Associate Professor, University of New Mexico.
[2] Corresponding author: Department of Economics, University of New Mexico, MSC05 3060, Albuquerque NM 87131; jthacher@unm.edu; 505-277-1965.
[3]The authors wish to thank the Economic Research Service for partial financial support of this work through the USDA PREISM competitive grant program (Grant 43-3AEM-5-80065). The views expressed are not necessarily those of the USDA.
[4] Full Professor, University of New Mexico.
[5] Assistant Professor, University of New Mexico.
[6] PhD student, University of New Mexico.

Background

Federal and State Responses to IAW

In response to the environmental and economic costs imposed by invasive species, the federal government and several western state governments have drafted regulations to monitor and manage their spread.

Executive order 13112 (1999) specifies the duties of federal agencies concerning invasive species and established the National Invasive Species Council (NISC). NISC provides national leadership regarding invasive species, coordinates federal efforts, promotes action at state and local levels, identifies avenues for international cooperation, and facilitates efforts to monitor invasive species. NISC has identified nine priority areas for addressing invasive species problems: leadership and coordination, prevention, early detection and rapid response, control and management, restoration, international cooperation, research, information management, education and public awareness (National Invasive Species Council, 2001). A key activity in all areas is the coordination of federal, state, and international agencies already engaged with invasive species issues.

In 2005, NISC published a progress report on their management plan (National Invasive Species Council, 2005). Four actions relate directly to IAW. First, NISC encouraged federal, state, and local agencies to develop, and adequately fund, interagency rapid-response strike-teams. These teams were established within the National Park Service, the USDA Forest Service, and the U.S. Fish and Wildlife Service and were responsible for treating over 132,000 acres. Second, NISC called for legislation to provide federal funding for State-level initiatives. In 2004 the Noxious Weed Control and Eradication Act was passed. It requires the Secretary of Agriculture to establish a program for assisting states and other eligible organizations in managing noxious weeds. Third, NISC made recommendations to the Bureau of Land Management (BLM), subsequently adopted, that seeds from the BLM's Seed Warehouse be tested for IAW before being used for restoration purposes. Finally, NISC encouraged federal agencies to improve public awareness of invasive weeds. In response, the BLM expanded its environmental education program to provide IAW brochures and developed a volunteer-based outreach program aimed at educating communities on how to spot new infestations.

In addition to establishing NISC, Congress passed the Plant Protection Act (2000). The act empowers the Secretary of Agriculture to, 'prohibit or restrict the importation, entry, exportation or movement in interstate commerce of any plant, plant product, biological control organism, article, or means of conveyance, if the Secretary determines...it necessary to prevent the introduction...or dissemination of a noxious weed.'

Western states have also passed legislation aimed at reducing the impact of IAW. Colorado, for example, passed the Colorado Noxious Weed Act and developed a Strategic Plan to Stop the Spread of Noxious Weeds (Colorado Noxious Weed Act, 2003). This act makes it illegal to introduce, cultivate, sell, offer for sale, or knowingly allow the growth of any weeds classified as noxious. The act requires landowners to notify authorities when noxious weeds are found, manage the weed in an appropriate manner, and permit government officials to inspect their grounds for noxious weeds. The act empowers county commissioners to reimburse landowners for expenses due to eradication efforts. In 2000, NM passed the Noxious Weed Management Act (2000), which directed the Department of Agriculture to develop a noxious weed list, identify methods of control, and educate the public about noxious weeds. NM also published guidelines for managing noxious weeds (Nellessen, 2000).

Besides legislation, the federal government provides support for IAW research. In 2003 the USDA's Economic Research Service (ERS) launched the Program of Research on the Economics of Invasive Species Management (PREISM). PREISM's aim was to improve IAW management decisions through the funding and dissemination of IAW-related economic research by researchers outside of ERS. These projects included studies in bio-economic modeling, trade and invasive species, resource allocation and decision analysis, program and policy alternatives and design, institutions, and incentives (Blas-Rivera et al., 2009).

IAW and Western Ranching

Future impacts of IAW on western ranching could be substantial. Consider YST, which forms dense stands that displace other vegetation. Livestock avoid grazing in heavily infested areas due to the thorns; thus, the weed can highly increase the cost of managing livestock (DiTomaso, 2006). Cattle forced to feed on this plant can incur injury (Sheley et al, 1999). YST infested pastures also have less crude protein and digestible nutrients than uninfested pastures (Barry (1995) as reported in DiTomaso (2006)). Weed control cannot be accomplished with a single treatment or in a single year. Mowing, hand-pulling, prescribed burning, and the introduction of competitive plant species can be effective; for example, Jetter et al. (2003) found public biological control of YST was effective and had a positive impact on private lands. The most common treatments, however, are chemical.

In California between 1958 and 2002, the spread of YST increased from about one million infested acres to over 15 million acres (Pitcairn et al., 2006), with 85% of counties reporting YST (U.S. Department of Agriculture, 2006). Total losses of livestock forage are estimated at almost $8 million annually with additional out-of-pocket costs for YST control of almost $9.5 million (Eagle et al., 2007). Oregon, Washington and Idaho also have high levels of YST infestations: 72%, 66%, and 62% of counties, respectively, report occurrences. Julía et al. (2007) estimate the total annual economic impact of YST in Idaho to be $12.5 million. Other western states report lower levels of county sightings: Nevada (30%), NM (18%), Wyoming (8%), and Colorado (3%) (U.S. Department of Agriculture, 2006).

While the spread of YST may be slower in other western states than was seen in California, the economic impact could be considerable, making the management choices just as germane. Beef cattle account for over $570 million, or about 35% of the total value of NM livestock and their products sold. The value from this sector is second only to that of the dairy industry. The contribution of beef cattle in other western states is even higher. In Colorado, 77% of the total value of livestock and products sold is attributed to beef cattle, while in Wyoming the figure is 85% (U.S. Department of Agriculture, 2007).

IAW management by ranchers: findings from NM

Our research focuses on an IAW prior to economic impact and asks whether, and under what conditions, ranchers will manage a weed before it causes economic losses. We approach this problem with a series of numerical models, complemented by survey and experimental results.

In Grimsrud et al. (2009) and Chermak et al. (2010), we extend a bioeconomic model for a dispersing weed (developed in Grimsrud et al. 2007) to include strategic interaction between two profit-maximizing ranchers with feedback. These inquiries develop a non-cooperative, dynamic game between the ranchers but consider different synergies between their efforts. Grimsrud et al. (2009) derives a closed form solution with a linear effort-feedback between ranchers, while Chermak et al. (2010) permits non-linear effort-feedbacks and employs simulations to assess the problem. While the approaches are distinctive, the results are consistent. When ranchers are identical with low levels of infestation it is optimal to begin eradication efforts immediately. As the initial infestation levels increase, initial effort levels are lower, due to lower profitability of the land, resulting in a longer required planning horizon to eradicate the weed. When we allow for different initial infestation levels for the ranchers, the model results deviate somewhat. While both models find the high-infestation rancher benefits from being located next to a low-infestation rancher, the impacts on the low-infestation rancher diverge (due to the different dynamics in the two models). Grimsrud et al. (2009) find the low-infestation rancher is minimally affected, while Chermak et al. (2010) find that the impact on the low-infestation rancher is more substantial and requires higher effort levels (relative to the case where both ranchers start with the same initial infestation level) to manage the infestation. In Grimsrud et al. (2009) we also find that larger initial infestation levels can be economically controlled in the case of a longer management horizon. In Chermak et al. (2010) we also compare the noncooperative results to a socially-optimal cooperative-solution and find targeted subsidies to the high-infestation rancher can bring the noncooperative solution in line with the cooperative solution. By providing the incentive for the high-infestation rancher to manage the weed, the low-infestation rancher does not have to exert as high an effort, resulting in higher profits; thus, the low-infestation rancher experiences a positive spillover. The required subsidy depends on the specific characteristics of the problem.

In Krause et al. (2010) we report the results of experiments to investigate rancher-participant response to the level of infestation of IAW and neighbor eradication efforts. Seventy-two ranchers participated in five experiment sessions held in northern and eastern NM, where cattle ranches are prevalent. Our participants chose how much to spend on weed eradication in a multiple-round setting. Current round payoffs decreased by the amount spent on weed eradication, but payoffs in future rounds increased if the weed level fell. The round-to-round increase or decrease in weed level was determined by the participant’s and other experiment participants’ expenditures.

At each experiment, the initial level of weed infestation was set relatively low, and most neighbor-groups successfully reduced weed density in three to five rounds. In subsequent rounds, with higher levels of initial infestation, experiment participants were less successful. Many participants appeared to recognize the sub-optimality of fighting weeds that had been firmly established and chose to stop spending at all on weed eradication. Some were unable to lower the weed density because they did not spend enough. These results align with the theoretical predictions: early efforts can successfully eradicate IAW. But if a landowner waits until the weed is well-established it can be too late to cost-effectively manage.

Rancher eradication efforts were weakly negatively associated with neighbor efforts in prior rounds, suggesting some tendency to free ride. In other words, when the ranchers saw that significant money was being spent on weed eradication in early rounds, many decided to then reduce their own expenditures and rely on the weed eradication efforts of their neighbors. This is contrary to the reported tendency in the Rancher Survey results (reported in Thacher et al. (2010)), but is consistent with economic theory and Chermak et al. (2010). After the experiment rounds, participants completed an Experiment Survey. Two questions probed participants’ planning horizon and preference for immediate relative to future gains. Participants’ responses in the Experiment Survey were generally consistent with their experiment behavior: a preference for future gains and a long planning horizon were associated with higher weed-eradication expenditures.

In Thacher et al. (2010) we reports results from a Rancher Survey which focused on understanding and quantifying factors that affect weed-management decisions of ranchers outside of a controlled environment. We use choice-question data from a survey of 712 NM ranchers to examine whether ranchers' weed-management decisions are affected by the management decisions of other ranchers in the community and whether ranchers see light infestations as a management opportunity or a problem to defer. Ranchers chose between managing two types of IAW, managing one, or managing neither. The model estimates the relative importance of participation by other ranchers, the initial level of infestation, the externality impacts of no-management, the impact on carrying capacity, and the cost on weed management decisions.

The setup of the Rancher Survey differs from the theoretical work and experiments in ways that make an explicit comparison of results difficult. For example, in the choice questions, the focus is on the decision of whether or not to manage at all, rather than the level of effort expended on management. In addition, actual communities, composed of families who may have ranched together for generations, may differ fundamentally from experimental 'communities' of people who share an occupation and live in same area but do not share a history. Nonetheless, we consider how the two most striking results from the choice-question data - the timing of management and the importance of community effects - relate to the theoretical and experimental results.

First, while our numerical and experimental results find that early intervention is required for successful management of an IAW, the Rancher Survey results indicate that all else equal, ranchers are more likely to manage an IAW on their own land when local infestation rates are high, rather than when they are low. Note that while the Rancher Survey dealt with the degree of infestation in the area, the theoretical and experimental papers dealt with the degree of infestation on one's own land. However, this result highlights the importance of providing information to ranchers on the need to manage IAW before the infestation is widespread. In the experiments, such information was provided through the payoff matrix. Taken together, the experimental results and Rancher Survey results indicate that targeted information campaigns may, all else equal, lead ranchers to initiate management early on, before an IAW is fully established in an area.

Second, the choice-question data shows that ranchers are more likely to manage when a larger share of other ranchers are managing. This finding does not necessarily imply that ranchers would expend more effort on IAW as others ranchers in the community increase their IAW management. It does suggest, however, that if the goal is to encourage rapid response by ranchers to an initial infestation of an IAW, it may be important to publicize that other ranchers are managing this IAW. This information may help communicate the seriousness of the threat posed by the IAW. Advertising such information can help spread 'best practices'.

Policy Implications

Our results suggest that the effective management of a negative externality, IAW, will require a superior understanding not only of the biologic spread of the species, but also of the strategic economic choices of individual agents and the set of factors that frame the individual agent's choices. At least two policy implications stand out from this work.

First, consider the positive spillover effects of managment, where management by one rancher can reduce a second rancher's infestation level and consequently required management efforts. Because of these positive spillovers, there may be significant benefits for the largest land owner in the West, the federal government, in taking a lead in treating their own land for IAW. Specifically, by having large public landowners attack the IAW's on their land early, significant participation from private ranchers may not be required to contain the problem. This is similar to Jetter et al.'s (2003) findings, which suggest a public biological control program for YST allowed private landowners to focus on other IAW's. Given the size of public western land holdings, governmental agencies may see economies of scale, which would lower average cost to manage IAW, compared to costs of management by individual ranchers.

The existence of positive spillover effects could also suggest a role for incentives to manage. Consistent with Chermak et al. (2010), targeted incentives may be more efficient than a "one-size-fits-all" strategy. Optimal policy-design requires incorporating knowledge of the level of infestation at the time of the policy implementation with knowledge of the biologic spread of the weed and the strategic economic choices of the individual ranchers. While our research did not directly address the types of incentives, they could range from payments to ranchers to assistance with equipment and/or pesticides. Taken together, this raises the interesting policy question of whether increased initial control on public lands or direct federal subsidies for control on private lands is more cost-effective.

Second, while the theoretical work shows the importance of early management of an IAW, in the surveys, most New Mexico ranchers reported that they would not invest in weed management when the infestation level was 'low'. This potentially argues for the role of education or information programs regarding the importance of early treatment. When ranchers are confronted with a multitude of issues - drought, disease, weather, weeds and others - fighting weeds may not be a priority and the opportunity for early management may be lost. But when ranchers focused on the problem of weeds in isolation in an experimental setting, they successfully eradicated. Providing ranchers with clear information about how to identify emerging IAW, the physical and economic harm from spread, and the value of early management could have a large influence on mitigating the impact of IAW's on the Western cattle industry. This could reduce the uncertainty associated with impacts of management, providing ranchers with knowledge with which to make their management decisions.

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Bovine Brucellosis in the Greater Yellowstone Area: An Economic Diagnosis

Dannele E. Peck[1]

Introduction

Bovine brucellosis continues to frustrate livestock producers and wildlife managers in the Greater Yellowstone Area (GYA). The multifaceted nature of the issue makes it confusing and overwhelming. Economic principles, such as marginal analysis, externalities, imperfect information, incentives, and economic efficiency can bring clarity and focus to the situation. This paper uses economic principles to (1) identify the brucellosis issue's most important features, (2) diagnose their underlying causes, and (3) objectively discuss the following management questions: "What is the socially optimal level of brucellosis prevention?" "Are free markets capable of achieving this optimum?" "If not, what tools or policies will move us closer to it?" The purpose is to distill an overwhelmingly-complex issue down to its fundamental elements, and facilitate more objective discussion about potential solutions.

Background

1. Biology & epidemiology of brucellosis

Bovine brucellosis is a bacterial disease that causes abortions in domestic and wild ungulates. It is of concern because bison and elk in the GYA (the last known reservoir for the disease in the U.S.) occasionally transmit it to cattle, an event that triggers costly testing and movement restrictions. Susceptible animals contract brucellosis by ingesting objects contaminated with the causative organism (*Brucella abortus*), such as aborted fetuses, placental tissues and fluids, and forage (Meagher and Meyer 1994). Because brucellosis spreads primarily through abortions, testing and control policies focus primarily on sexually-intact cattle of reproductive age. Cow-calf operations are therefore more economically vulnerable to the disease than stocker or feedlot operations. Seventy percent of cow-calf producers in the West vaccinate some of their heifers against brucellosis (35% vaccinate all their heifers), but existing vaccines are only 65-75% effective (Cheville et al. 1996, Manthei 1959, USDA-APHIS-VS 2010).

2. Current brucellosis control policies

The few U.S. cases of bovine brucellosis that occur each decade are often detected in cull cows, sent to slaughter due to poor reproductive performance. A "test-positive" animal (i.e. an animal that has brucellosis antibodies, and *might* therefore be infected) triggers an epidemiologic investigation to identify the "index" herd (i.e. the animal's herd of origin) and all "contact" herds (i.e. herds that comingled or shared a fence line with the index herd). If brucellosis is successfully cultured from just one animal in the index herd, or if multiple animals in the herd test positive, the owner must decide whether to "depopulate" the entire herd, or attempt to "test-out" (Cook, personal communication); additionally, all contact herds are quarantined for testing.

[1/] Assistant Professor, Department of Agricultural and Applied Economics, University of Wyoming. The author thanks Dr. Ben Rashford for his insightful reviews of earlier drafts. Comments and suggestions from three anonymous reviewers and the editor also improved the paper tremendously.

Testing-out requires the infected herd to be quarantined for at least one year, during which time they undergo multiple brucellosis tests. If additional test-positive animals are detected, those individuals are slaughtered and the testing-out procedure repeats. It can be expensive to meet a herd's forage requirements during quarantine, so producers typically choose to depopulate. Producers might also choose depopulation because testing-out causes the federal government to downgrade the state's brucellosis-free status from "Class Free" to "Class A" status, which triggers state-wide testing and movement restrictions. If a producer depopulates their herd, the state maintains its brucellosis-free status (as long as no other infected herds are detected within the following two years). The United States Department of Agriculture's Animal and Plant Health Inspection Service (USDA-APHIS) is currently reviewing its state-level disease classification system. They will likely replace it in the near future with a "disease surveillance area" approach. These two approaches and their relative efficiency are discussed in more detail later.

Producers in the GYA have adopted a variety of brucellosis management practices to reduce the risk of outbreaks in cattle and associated financial and emotional repercussions. Management practices include fencing haystacks, modifying winter-feeding practices, and calling state wildlife agencies to haze elk off private property, all of which discourage elk from commingling with cattle during high-risk months. Adult-booster vaccination, spaying heifers (because spayed or castrated animals cannot spread the disease and are therefore not test-eligible), and delayed grazing on high-risk allotments are also being adopted. Although it is difficult to quantify the extent to which these practices reduce risk, they certainly contribute to USDA-APHIS's goal of eradicating brucellosis.

3. Outcomes of current policies

USDA-APHIS began a brucellosis eradication campaign in 1934. At that time, 11.5% of adult cattle were test-positive for the disease (USDA-APHIS-VS 2009). After investing more than $3.5 billion in the campaign (Cheville et al. 1998), national herd prevalence is now less than 0.0001% (USDA-APHIS-VS 2009). In February 2008, for the first time in history, cattle in all U.S. states were simultaneously declared "brucellosis-free." This notable moment in history was short-lived. Montana lost its Class Free status in 2008 after two infected herds were detected within 24-months; it regained its status in July 2009. Idaho and Wyoming also lost Class Free status in recent years (Idaho from 2006 to 2007; Wyoming from 2004 to 2006). Wyoming detected another case in 2008, but retained its Class Free status because a second case was not detected within the following two years. As of October 2010, all states were again Class Free; however, test-positive animals had again been detected in a Wyoming herd.

4. Hurdles for brucellosis eradication

Tremendous progress has been made towards the eradication of brucellosis in U.S. cattle. One hurdle remains though: infected elk and bison in the GYA. Brucellosis was first observed in Yellowstone National Park's bison in 1917 (Mohler 1917). They are thought to have contracted it from cattle kept within the Park as a food source for employees (Meagher and Meyer 1994), and to have later spread it to the Park's elk. Elk outside the Park are thought to have contracted the disease directly from cattle (Meagher and Meyer 1994).

Today, approximately 50% of the Park's bison, and 64% of the Jackson bison herd, have antibodies to brucellosis (i.e. are "seropositive"); recall however that antibodies indicate previous exposure to the bacteria but not necessarily infection (Rhyan et al. 2009, Scurlock and Edwards

2010). The proportion of seropositive bison actually infected (i.e. culture positive) is highly uncertain, with estimates ranging from 7 to 46% (Cheville et al. 1998, Roffe et al. 1999). Approximately 3% of the Park's elk and non-feedground elk outside the Park are seropositive (Barber-Meyer et al. 2007, Ferrari and Garrott 2002). Seroprevalence among elk that use supplemental winter feedgrounds is much higher, ranging from 18 to 28% (Scurlock and Edwards 2010). As with bison, the proportion of elk actually infected is highly variable and uncertain. In past sampling efforts, 35 to 63% of elk that tested seropositive were actually infected (Scurlock 2010).

The potential for disease transmission between bison, elk and cattle makes the epidemiology of brucellosis highly complex. The significance of bison, elk and cattle in the economics and culture of the GYA makes the management of brucellosis highly contentious. Uncertainty about current levels of risk; disagreement over acceptable levels of risk; and imperfect information about alternative management strategies' effectiveness, expense and equity exacerbate the issue. Given the brucellosis issue's enormity, people tend to tackle it one small piece at a time. Although this makes the problem feel more manageable, it also makes it easier to lose sight of the brucellosis forest for its trees. Economic principles demonstrate how individual pieces of the brucellosis issue collectively create the forest, and how they can be managed to benefit it as a whole.

An Economic Diagnosis

1. How much brucellosis prevention is socially optimal?

Define "brucellosis control" as a variable input, and "prevention of brucellosis in cattle" as an output (the latter is really only an intermediate good that is ultimately an input to calf production). Economic theory says prevention of additional cases of brucellosis in cattle should proceed if the marginal benefit outweighs the marginal cost.

In a simplified world (one without animal disease regulations such as compulsory culling of infected herds, and movement restrictions during outbreaks), the marginal benefit of preventing a case of brucellosis consists primarily of increased the value of increased calf production. The marginal benefit of preventing a case of brucellosis should be constant regardless of the number of cases already prevented. After all, one less infected cow (regardless of the number of infections already prevented) implies one less aborted fetus and hence one more viable calf. If the calf market is perfectly competitive, the value of an additional calf will be the same no matter how many calves you sell. Together, these two arguments imply a constant marginal benefit to brucellosis prevention, i.e. a horizontal marginal benefit curve.

Marginal cost of brucellosis prevention is more complex. Suppose inputs to brucellosis prevention, such as vaccination and delayed grazing, exhibit diminishing marginal returns. Prevention of an additional case of brucellosis will, in this case, require more additional input than did the previous case. This implies each additional case is more expensive to prevent than previous cases, and hence the marginal cost curve is upward sloping. Heterogeneity in the circumstances leading to infection could also cause the marginal cost curve to be upward sloping. Cattle-to-cattle transmission in a feedlot, for example, would be cheaper to prevent than elk-to-cattle transmission on a remote grazing allotment. Arranging individual cases of infection by their cost of prevention would create an upward-sloping marginal cost curve.

The infectious nature of brucellosis, in contrast, creates a downward-sloping marginal cost curve, or at least applies downward pressure on marginal cost as the number of prevented cases increases. Because one infected cow can spread the disease to many others in the herd, prevention of one infected animal contributes to prevention in others. It becomes increasingly easy to prevent an additional case of infection the more cases already prevented (this is similar conceptually to increasing marginal returns, but stems from disease dynamics between animals rather than input characteristics). Conversely, it becomes increasingly difficult to prevent a susceptible cow from becoming infected as an increasing proportion of its herd becomes infected.[2]

The marginal cost curve's overall shape depends on the relative strength of diminishing marginal returns, heterogeneity, and infectiousness. Its shape and position, relative to the marginal benefit curve, have important implications for the desirable level of brucellosis prevention. Suppose the marginal cost curve decreases at first (due to infectiousness) and then increases (due to heterogeneity and diminishing marginal returns), eventually rising above the marginal benefit curve (figure 1a). Then the marginal cost of prevention will eventually outweigh marginal benefit, and the optimal number of prevented cases will be something less than eradication. This scenario represents standard assumptions and conclusions in economics. In reality, marginal cost could take a variety of forms and relative positions, although some are more likely than others. When paired with a horizontal marginal benefit curve (which again assumes each prevented case of brucellosis increases the value of calf production by the same amount), some forms and positions imply eradication is optimal, and others do not (see Peck 2010 for examples).

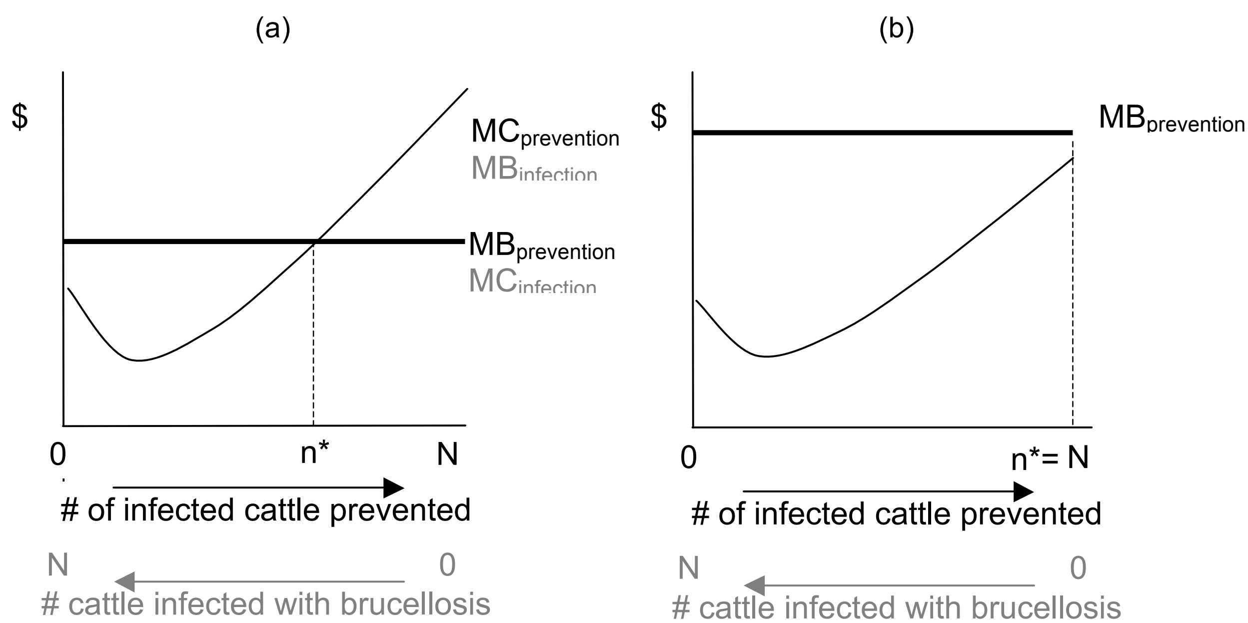
The exact shape and relative position of the marginal cost curve for brucellosis prevention is unknown. If we assume that diminishing marginal returns dominates infectiousness (i.e. the marginal cost curve is upward sloping) eradication would only be optimal if the marginal cost curve were located entirely below the marginal benefit curve (figure 1b). It is difficult to imagine increased calf production being sufficiently valuable to justify the resources necessary to prevent the last case of brucellosis, particularly if it arises from an elk-to-cattle transmission, which can be difficult to prevent. The point of this paper is not to determine the optimal number of cases to prevent, but rather to bring focus and objectivity to the eradication debate by framing it in terms of the marginal cost curve's most likely shape and position.

Those in favor of eradicating brucellosis sometimes take an alternative approach to answering the question "how much prevention is socially optimal?" They believe eradication is the best option because anything short of eradication imposes perpetual prevention and control costs that will eventually sum to infinity. This argument fails to consider two important points. First, even if brucellosis were eradicated in the U.S., we would still incur a perpetual cost to prevent its reintroduction (or incur a large up-front cost to help eradicate it globally). Second, it is incorrect to directly compare the total costs of eradication to the total costs of perpetual brucellosis management without first accounting for time preferences.

[2/] It may be tempting to capture infectiousness in the marginal benefit curve rather than the marginal cost curve. Marginal benefit is defined in this paper, however, as the additional benefit derived from preventing *one* additional case of brucellosis. Including infectiousness in the marginal benefit curve creates a situation in which the benefit of preventing one case is the prevention of *more* than one case. This is inconsistent with the definition of marginal benefit, or at the very least confusing. It is less confusing to capture infectiousness in the marginal cost curve instead.

Eradication will require relatively large upfront investments (e.g. in scientific labs and personnel to develop more effective vaccines). Perpetual brucellosis management, in contrast, will generate smaller annual costs, but they will be incurred every year into perpetuity (e.g. annual prevention and control costs punctuated by occasional large losses during outbreaks). Because people do not view costs incurred today equally to costs spread out over future years, the total cost (and benefits) of these two options cannot be directly compared without first accounting for time preferences. Even assuming a low social discount rate, e.g. 1 to 2%, perpetual management might be preferred over eradication, despite having a higher undiscounted total cost, because it pushes costs farther into the future (see Peck 2010 for a numerical example).

Figure 1. Marginal benefit (MB) and marginal cost (MC) of brucellosis prevention in an individual cattle herd containing N animals. The marginal cost curve' shape reflects increasing and then decreasing marginal returns to brucellosis prevention activities. Panel (a): MB is sufficiently low, or MC rises sufficiently fast, that MC eventually exceeds MB, so eradication is not optimal. Panel (b): MB is sufficiently high, or MC rises sufficiently slowly, that MB exceeds MC for each prevented case, so eradication is optimal.



2. Can markets achieve the social optimum?

If markets associated with brucellosis prevention worked perfectly, we would not need to anguish over the socially optimal number of cases to prevent (including whether eradication versus perpetual management is optimal), or how to prevent those cases as cheaply as possible. Individuals making decisions based on their private marginal benefits and costs would achieve the social optimum at least-cost. If free markets are imperfect, however, private decisions are unlikely to achieve the social optimum, and market interventions might be necessary. The market for brucellosis prevention suffers several imperfections, including incomplete markets, imperfect information, and externalities.

2.1 Incomplete Markets

Elk and bison play leading roles in the epidemiology of brucellosis in the GYA. Their abundance directly affects the probability of cattle becoming infected; population management is therefore an important and controversial element of the brucellosis debate. To identify the optimal elk, bison and cattle populations, we could construct a one-input, three-output social welfare maximization problem, in which the production possibilities curve captures biological and epidemiologic relationships between the species, and the isorevenue line captures their relative value. If free markets for these species were perfect, private management decisions would achieve the socially optimal combination of elk, bison and cattle.

Market prices unfortunately do not fully reflect society's value for these species because each species provides non-market goods and services (e.g. wildlife viewing, aesthetic appeal, cultural significance). When free markets are incomplete, stakeholders are unable to express, through mutually beneficial trades, all benefits they derive from elk, bison or cattle, or all costs they incur because of them. Suboptimal combinations of the three species are produced as a result.

2.2 Imperfect Information

Before producers can determine the optimal level of brucellosis prevention, they must first identify cost-minimizing combinations of management activities for achieving each prevention level. This requires information about the per-unit cost and technical effectiveness of alternative activities. Researchers at the University of Wyoming are currently estimating per-unit costs. Little is known, however, about the extent to which alternative management activities' reduce risk. Some management practices completely eliminate the risk, e.g. switching from cows to steers/spayed heifers. Most practices only partially reduce risk, however, and the extent to which they do so is highly uncertain and difficult to quantify. Imagine, for example, trying to quantify the extent to which fencing a haystack reduces the risk of elk-to-cattle transmission.

Producers face uncertainty not only about the extent to which various brucellosis management activities reduce risk, but also the underlying probability of their cattle contracting brucellosis prior to implementing preventive activities. They must therefore make brucellosis management decisions based on subjective beliefs about their underlying level of risk and alternative management activities' cost-effectiveness. This uncertainty makes it challenging for producers to identify cost-effective combinations of activities for alternative levels of prevention, and the privately optimal level of prevention.

Imperfect diagnostic tests are another source of uncertainty in the brucellosis issue. Infected cattle do not always immediately test positive following infection; animals that are actively incubating the bacteria can test negative (USDA-APHIS 2003). When a herd is known to be infected or exposed, imperfect diagnostic tests necessitate months of repeated testing to ensure all infected animals are detected. During this "testing-out" procedure, entire herds must be quarantined, including disease-free animals whose status cannot be immediately proven. Entire herds are therefore commonly culled to avoid quarantine costs. Quarantine and culling costs could be reduced significantly if brucellosis tests had greater sensitivity (the ability to detect all infected animals) and specificity (the ability to detect all uninfected animals) (Bercovich 1998).

2.3 Externalities in Cattle Production

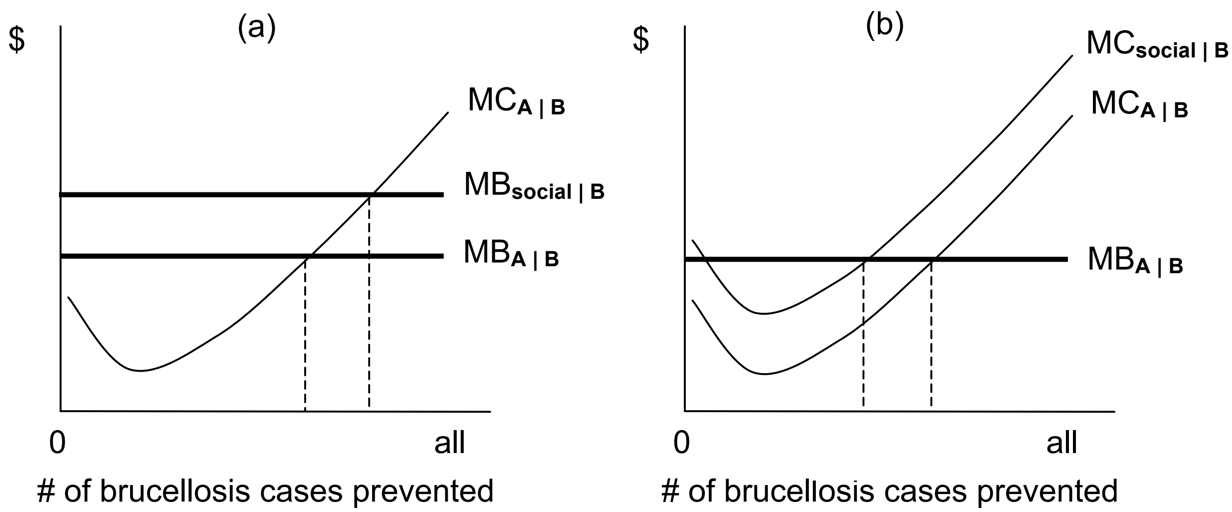
The infectious nature of brucellosis implies that an outbreak in one producer's herd generates costs not only for that producer (i.e. reduced calf production, and increased probability of other individuals in the herd becoming infected), but for neighboring producers as well. When a cow in one herd becomes infected with brucellosis, cattle in neighboring herds face a higher risk of contracting brucellosis, either directly from the infected cow itself, or indirectly from elk that contracted the disease from the infected cow (although the indirect route is theoretically possible, its empirical importance is thought to be quite limited).

Within-herd effects are reflected in the downward-sloping portion of the producer's private marginal cost curve (i.e. as more animals in the herd are prevented from becoming infected, it becomes easier to prevent the remaining cases). Cross-herd effects (i.e. as more animals in herd A are prevented from becoming infected, the cost of preventing cases in herd B changes) are captured instead as the difference between the social versus private marginal benefit (or cost) curve.

Suppose, for example, that producer A switches from a cow-calf to a stocker operation to reduce their brucellosis risk. This decision benefits producer B by eliminating the probability of their herd contracting brucellosis from herd A. Producer B can now achieve the same number of prevented cases with fewer resources (ignoring for now that their optimal prevention level might change, depending on how their total cost curve swings or shifts). Producer A's preventive activities, in this case, generate greater social benefit than private benefit (figure 2a). Producer A will therefore invest less in prevention than society would like them to.

Suppose instead that producer A fences haystacks to discourage elk from over-wintering on their property. This decision could potentially harm producer B by inadvertently causing more elk to over-winter on their property (particularly if their haystacks are unfenced). To achieve the same number of prevented cases, producer B must now invest more resources. The social cost of producer A's preventive activities, in this case, exceed private cost (figure 2b). Producer A will therefore invest more resources than is socially optimal, and prevent too many cases in herd A (and *cause* too many in herd B).

Figure 2. Private versus social marginal benefits and costs of producer A's brucellosis prevention activities (conditional on producer B's activities). Panel (a): producer A's activities positively affect producer B, so social marginal benefit exceeds producer A's private marginal benefit. Panel (b): producer A's activities negatively affect producer B, so social marginal cost exceeds producer A's private marginal cost.



The most direct means to correct a positive externality is to offer producers a subsidy for each prevented case of brucellosis. The subsidy would supplement the producer's marginal benefit from preventing a case of brucellosis. Ideally, it would supplement the producer's marginal benefit just enough to make it equal to society's marginal benefit. This would push the producer's level of prevention equal to the social optimum. Unfortunately, this policy cannot be implemented because the number of cases a producer prevents is unobservable. We observe the number of cases that occur in the presence of the activities, but can only speculate how many cases would have occurred in their absence. The opposite is true if a producer chooses not to adopt prevention activities.

An alternative means to increase the privately optimal level of prevention is to subsidize the cost of brucellosis management activities. This approach is easier to implement because we can more readily observe activity levels (e.g. the number of haystacks fenced). The marginal productivity of management activities would need to be known, however, to determine correct subsidy levels. Ideally, we would also only subsidize the most cost-effective activities, such that the socially optimal level of prevention is achieved as cheaply as possible. Again, uncertainty about the extent to which prevention activities reduce the risk of cattle contracting brucellosis would make it difficult to identify least-cost combinations.

2.4 Externalities in Wildlife Management

Externalities arise in another dimension of brucellosis: management of elk and bison that move relatively freely between public and private lands. If cattle were not present on the landscape, National Park Service (NPS) and state wildlife agencies would have little incentive to manage brucellosis in wildlife. Although the disease is exotic to North America (and some consider this adequate justification for control), it has not significantly impaired elk or bison populations, and is therefore not of great concern to wildlife managers. Furthermore, because some constituents disapprove of intensive brucellosis management activities, such as test-and-slaughter or vaccination, NPS and state wildlife agencies face a disincentive to take action.

Given cattle *are* present on the landscape, NPS and state wildlife agencies do have an incentive to manage brucellosis in wildlife. After all, for some portion of the year, elk and bison rely on habitat managed by private landowners (Coupal et al. 2004), many of whom own cattle. Reliance on private landowners for habitat provision therefore requires NPS and state wildlife agencies to engage in brucellosis management to help maintain goodwill. The Wyoming Game & Fish Department provides haystack fencing material and hazes elk from cattle feedlines. They also invested over $1 million in an elk test-and-slaughter program to reduce brucellosis seroprevalence in elk on supplemental winter feedgrounds. By maintaining good relationships with landowners, the agency ensures continued provision of elk habitat, and therefore larger elk populations (an important revenue source for the agency). Similarly, NPS has proposed a remote bison vaccination program within the Park (NPS 2010) in exchange for bison access to critical winter habitat north of Yellowstone National Park without compulsory brucellosis testing. The proposed vaccination program is currently under review (as required by the National Environmental Policy Act), and is expected to cost $9 million over a 30-year period if implemented (NPS 2010).

NPS and state wildlife agencies invest in brucellosis management presumably because it generates sufficient benefits for them to outweigh the costs. It is not clear whether their investment decisions consider benefits to cattle producers of preventing wildlife-to-cattle transmissions directly, or just the goodwill (i.e. wildlife habitat) generated when transmissions are prevented. If NPS and state wildlife agencies do not consider how their brucellosis management activities benefit cattle producers directly, they will invest too little in those activities relative to the socially optimal level, and too many wildlife-to-cattle transmissions will occur.

Incentives may be necessary to align the benefits and costs that NPS and state wildlife agencies derive from preventing brucellosis in elk and bison with society's. This could be accomplished by having society pay agencies for management actions that prevent wildlife-to-cattle transmission. Alternatively, society could require the agencies to pay some portion of losses generated when wildlife-to-cattle transmission occurs (a "polluter pays" approach). The second option is easier to implement, because outbreaks are easier to observe than prevented outbreaks (and it can be determined with some certainty whether elk or bison were the source). Regulatory approaches are a more politically popular means of correcting externalities. The court-mediated agreement between NPS, USDA-APHIS and the State of Montana requiring NPS to initiate a remote bison vaccination program serves as an example (NPS 2010). The agreement essentially forced NPS to internalize the costs brucellosis-infected bison impose on other stakeholders by legally requiring them to undertake management actions.

<u>What tools or policies move us towards the optimum?</u>

Now that we understand the market failures underlying the brucellosis debate, we can more objectively assess existing brucellosis policies and identify opportunities for improvement.

1. Incomplete markets

Incomplete markets are difficult to mitigate because they are often attributable to the underlying characteristics of the non-market good (which cannot be easily changed). It would be difficult, for example, to create a well-functioning market to capture people's existence value for bison. Nonetheless, we should continue to explore possibilities for new markets that (a) enable people to express their value for non-market goods, and (b) provide incentives for them to actually do so. In lieu of this, judicial venues (e.g. comment periods on proposed regulation) and collaborative forums (e.g. Wyoming's Brucellosis Coordination Team and the Interagency Bison Management Program) can help address incomplete markets by providing a means for people to express their non-market values.

2. Imperfect Information

Imperfect information about brucellosis may be one of the most difficult market failures to address. Little is known about the true prevalence of brucellosis in wildlife or the extent to which management activities reduce risk. Brucellosis tests and vaccines are also imperfect. As a result, (a) policymakers have only subjective notions of which prevention level is socially optimal; (b) their ability to identify least-cost management activities is limited, and (c) producers incurs additional costs because of prolonged quarantines and precautionary culling.

A few policies mitigate imperfect information, but more may be needed. USDA's current policy of quarantining and culling entire herds (not just test-positive individuals), for example, attempts to mitigate imperfect brucellosis tests by preventing undetected infected animals from transmitting brucellosis. This policy is accompanied, of course, by compensation to producer for culled herds (to increase their willingness to report suspected infections), but not for quarantine costs (which is the primary reason producers typically choose to depopulate infected herds rather than attempt to test out). Greater test sensitivity and specificity could dramatically reduce the cost of brucellosis control. Some state and federal dollars are dedicated to developing improving brucellosis tests and vaccines, but much more funding would be necessary for significant advancements to be made.

Research funds are also used to gather and analyze seroprevalence data for wildlife (e.g. Cross et al. 2010). Additional funds are needed, however, to determine the risk of cattle exposure to brucellosis at the livestock-wildlife interface, and the effectiveness of alternative management activities. This information would enable economists and epidemiologists to identify optimal management goals and the least-cost combination of prevention activities for achieving those goals. Many of the models needed to address such questions are already developed (e.g. Horan and Wolf 2005, Treanor et al. 2010, Xie and Horan 2009); however, they lack empirical parameter estimates necessary to prescribe specific policies. Care would be needed, however, to make sure the cost of data collection was less than the benefits it would generate.

3. Externalities

Current policies address externalities in the market for brucellosis prevention relatively well. Subsidies on brucellosis management activities (e.g. adult-booster vaccination) have narrowed the gap between private and social benefits of prevention. Collaborative processes have engaged state wildlife agencies and NPS, and raised awareness of the external costs of their inaction. This has pressured them to manage brucellosis in wildlife more actively (e.g.

vaccination and hazing). Additional policies to address externalities might be needed, but much has been accomplished already.

A few controversial policies that relate indirectly to externalities are currently being proposed. One such proposal is to close supplemental elk winter feedgrounds. People often assume closures would address externalities in the market for brucellosis prevention. More careful attention should be paid, however, when considering what market failures (if any) this would address. Elk winter feedgrounds were not created to address market failures in brucellosis prevention. They were created to prevent elk starvation and reduce depredation of private haystacks. Their creation addressed these problems, but generated unintended consequences (both negative and positive) for disease management. One negative consequence was higher rates of brucellosis in elk, and hence more infectious material in the environment for cattle to contact. One positive consequence was greater spatial separation of elk and cattle during the time of year in which abortions typically occur.

The potential effect of feedground closure on risk of transmission from elk to cattle is currently ambiguous. In the short-run, elk with relatively high rates of infection would likely migrate to private ranchlands in search of winter forage. Probability of transmission might increase as a result. In the long-run, more frequent elk-cattle interactions might become less problematic if infection rates in elk decrease due to lower population densities during high-risk months. Sportsmen and outfitters are concerned that native winter habitat is insufficient to support current elk populations and feedground closures might cause population decline.

The potential effects of feedground closure are sufficiently complex that a much broader analysis is required: one that examines market failures in the provision of elk and brucellosis prevention. Feedground closure would clearly affect brucellosis prevention, but many other effects would also need to be considered. While waiting for the feedground debate to be settled, Wyoming Game & Fish is exploring the potential for alternative feedground management activities (e.g. natural winter habitat improvement, a pilot elk test-and-slaughter project, low-density feeding, and shorter feeding seasons) to reduce the external costs of supplemental feeding. Cost-effectiveness is difficult to quantify for some activities (e.g. elk test-and-slaughter), which causes speculation and personal opinions, rather than objective comparison, to dominate management discussions.

Another controversial proposal is to replace USDA-APHIS's state-level brucellosis classification framework (i.e. if two or more infected herds are found in a two year period, the entire state loses its Class-A status) with a "disease surveillance area" framework, which would enforce testing and movement restrictions at the smaller "disease surveillance area" rather than the state level (USDA-APHIS-VS 2009). The World Organization for Animal Health already recognizes this "regionalization" approach, and uses it to minimize animal diseases' impacts on international trade.

USDA-APHIS is currently working with the states of Idaho, Montana and Wyoming to create a disease surveillance area in the GYA. Brucellosis outbreaks within the surveillance area would trigger the same epidemiologic investigations and farm-level control measures used currently. However, detection of multiple infected cattle herds within the surveillance area would not impose testing or movement restrictions on herds outside the area. To determine whether this disease surveillance area approach would address underlying failures in the market for brucellosis prevention, USDA's motivation for the original state-level classification system must first be understood. What market failures did policymakers design the system to address? Was it successful? How might the disease surveillance area approach improve upon it?

USDA's original motivation for a state-level brucellosis classification system is uncertain. One hypothesis is the federal government needed a way to increase state animal health officials' incentives to clean up infected herds (presumably to socially optimal levels). Intervention was justified because export of infected animals to other states imposes external costs by spreading the disease to previously uninfected areas. The state-level classification system punishes offending states by enforcing testing requirements (when two or more infected herds are detected within a two-year period), which makes moving animals across state boundaries more expensive. This forces offending states to internalize the costs they would otherwise impose on trade partners, and thereby increases their incentive to clean up infected herds.

Given the relatively high prevalence and widespread distribution of brucellosis in cattle when USDA-APHIS first initiated its eradication program, state-level enforcement probably seemed most appropriate and cost-effective, relative to regional or county-level enforcement. As the prevalence of brucellosis in U.S. cattle declined, and the disease became more geographically isolated, the system's ability to address externalities in a cost-effective manner diminished. Although it reduces externalities imposed on an offending state's trade partners, it achieves this by transferring external costs to producers within the infected state. Unfortunately, it transfers external costs to *all* producers in the state, not just those with infected herds, or those who knowingly put their cattle in risky situations. A portion of external costs previously imposed on "third-party" producers outside the state (i.e. those facing socially-acceptable levels of brucellosis risk) are simply transferred to third-party producers within the state.

The "disease surveillance area" approach improves on the state-classification system by transferring external costs to a smaller subset of producers, only those within the disease surveillance area, rather than in the entire state. A perfectly efficient surveillance area would include all producers whose herds face socially unacceptable levels of brucellosis risk (after accounting for risk-reducing management practices they adopt), but no third-party producers. Unfortunately, producers' brucellosis risks are uncertain, which prevents us from correctly identifying who belongs within versus outside the surveillance area. The surveillance area will therefore contain some producers whose cattle face socially acceptable levels of risk. Because these producers will be required to test animals before moving them across the surveillance area boundary, efficiency will be reduced. The disease surveillance area improves on the state classification system, however, by reducing the number of third-party producers subjected to brucellosis testing.

Although the surveillance area will include some third-party producers, they should not be worse off under the proposed approach than under the state classification system. Most producers in the proposed GYA disease surveillance area (or at least the Wyoming portion) sell cattle to buyers in other states, and are therefore already subject to brucellosis testing before test-eligible animals can be moved across state lines (if their state has lost Class-A status). Under the disease surveillance area approach, producers will simply have to test their cattle before moving them across the surveillance area boundary rather than the state boundary.

Producers in the GYA are rightfully concerned, however, that by eliminating state-level implications of brucellosis outbreak, political interest in the disease will wane and funding for research and management will disappear. From a social perspective though, investment in brucellosis should decrease if its consequences (i.e. potential gains from solving the problem) are somehow reduced (holding all else constant). Reduced funding of research and management causes the net welfare impacts of a disease surveillance area to be ambiguous for producers within it. Producers outside the surveillance area, however, will clearly be better off because they will no longer have to test cattle before moving them across state lines.

Conclusions

This article attempts to bring renewed clarity to the brucellosis debate by abstracting away from the issue's overwhelming details and focusing instead on its root causes. Economic principles, such as marginal analysis, discounting, missing markets, imperfect information, and externalities provide an objective means to diagnose the issue's root causes. This in turn enables us to better understand the fundamental nature of the conflict and identify more productive steps forward.

Economic principles indicate, first and foremost, that the control of brucellosis is not an end, but a means for improving society's well-being. Additional effort to control brucellosis should only be made if the additional benefit outweighs the additional cost. Economic principles also imply that because people tend to discount future benefits and costs, perpetual management might be preferred over eradication even if it is more expensive in the end.

Missing markets and externalities explain why private individuals, state wildlife agencies, and the National Park Service tend to invest too little in brucellosis prevention, relative to the social optimum. They clarify why government interventions and incentives might be justified (assuming their administrative costs do not exceed their benefits), and whether existing and proposed policies actually address underlying sources of market failure or simply transfer the costs of failure to a different subset of stakeholders.

Lastly, imperfect information makes it difficult to quantify all pieces of the economic puzzle necessary to identify the socially optimal quantities of elk, bison and cattle, the socially optimal level of brucellosis prevention, or the least-cost combination of activities to achieve it. Nonetheless, economic principles provide an intuitively-appealing framework that should enable stakeholders to engage in more objective discussions of the issue, and eventually identify an effective solution.

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