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Essays on Externalities and Agriculture in the United States and Brazil

by

Maria Susannah Bowman

A dissertation submitted in partial satisfaction

of the requirements for the degree of

Doctor of Philosophy

in

Agricultural and Resource Economics

in the

Graduate Division

of the

University of California, Berkeley

Committee in charge:

Professor David Zilberman, Chair

Professor Peter Berck

Professor Matthew Potts

Spring 2013

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Abstract

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In these three essays collectively entitled "Essays on Externalities and Agriculture in the United States and Brazil", I discuss three topics. In the first essay, I review the economic literature on diversification in farming systems and comment on the economic incentives and disincentives for diversification in 21st century agriculture. In the second essay, I focus on deforestation in Brazil, which is an externality associated with the expansion of agricultural production at forest frontiers. Using a natural experiment (changes in international Foot-and-Mouth Disease certification), I identify the portion of annual deforestation that can be attributed to changes in disease status, and suggest that the mechanism for new deforestation may be due to increased prices when beef is considered to be safe for export. In my third essay, I discuss the production economics behind the use of sub-therapeutic antibiotics in U.S. pork and poultry production, and comment in detail on the potential for heterogeneity in the returns to antibiotic use (and costs of regulation). A more detailed summary of each essay follows.

Chapter 1: Economic Factors Affecting Diversified Farming Systems

In response to a shift toward specialization and mechanization during the 20th century, there has been momentum on the part of a vocal contingent of consumers, producers, researchers, and policy makers who call for a transition toward a new model of agriculture. This model employs fewer synthetic inputs, incorporates practices which enhance biodiversity and environmental services at local, regional, and global scales, and takes into account the social implications of production practices, market dynamics, and product mixes. Within this vision, diversified farming systems (DFS) have emerged as a model that incorporates functional biodiversity at multiple temporal and spatial scales to maintain ecosystem services critical to agricultural production. This essay's aim is to provide an economists' perspective on the factors which make diversified farming systems (DFS) economically attractive, or not-so-attractive, to farmers, and to discuss the potential for and roadblocks to widespread adoption. The essay focuses on how a range of existing and emerging factors drive profitability and adoption of DFS, and suggests that, in order for DFS

to thrive, a number of structural changes are needed. These include: 1) public and private investment in the development of low-cost, practical technologies that reduce the costs of production in DFS, 2) support for and coordination of evolving markets for ecosystem services and products from DFS and 3) the elimination of subsidies and crop insurance programs that perpetuate the unsustainable production of staple crops. This work suggests that subsidies and funding be directed, instead, toward points 1) and 2), as well as toward incentives for consumption of nutritious food.

Chapter 2: Foot-and-Mouth Disease and Deforestation in the Brazilian Amazon

Deforestation in the Brazilian Amazon released approximately 5.7 billion tons of CO_2 to the atmosphere between 2000 and 2010, and 50-80% of this deforestation was for pasture. Most assume that increasing demand for cattle products produced in Brazil caused this deforestation, but the empirical work to-date on cattle documents only correlations between cattle herd size, pasture expansion, cattle prices, and deforestation. This essay uses panel data on deforestation and Foot-and-Mouth Disease (FMD) status—an exogenous demand shifter—to estimate whether changes in FMD status caused new deforestation in municipalities in the Brazilian Amazon and *cerrado* biomes during the 2000-2010 period. Becoming certified as FMD-free caused annual deforestation to be 42% to 85% higher than deforestation rates in infected municipalities, on average, during the 2000-2010 period.

Chapter 3: Potential for heterogeneity in the returns to sub-therapeutic antibiotics in U.S. pork and poultry operations

Each year, more than 50,000 people in the U.S. die from hospital-acquired bacterial infections, millions experience episodes of foodborne illness, and reported cases of "superbugs" such as Methicillin-resistant *Staphylococcus aureus* (MRSA) and vancomycin-resistant enterococci (VRE) are on the rise. For those who acquire a resistant infection in their food, in their community, or in a hospital, resistance is associated with a longer duration of treatment, the use of more potent antibiotics, and longer hospital stays. This, in turn, means increased health care costs and costs to society due to antibiotic-resistant infections. Antibiotic resistance is contributing to the scope and severity of this health care crisis, and at least some of the responsibility for antibiotic resistance sits on the shoulders of industrial livestock production. In livestock operations, low or sub-therapeutic doses of antibiotics (STAs) are used to promote growth, in addition to their use to prevent and control disease. Today, more antibiotics are used in livestock production and the production of milk and eggs than in humans. While the use of sub-therapeutic doses of antibiotics is regulated less stringently in the United States than in the European Union, there is movement toward and potential for such regulation. Beginning in the 1970s, economic researchers began to study the potential impacts of bans on the use of sub-therapeutic antibiotics on the pork, poultry, and beef sectors and on U.S. consumers, but there has been little study of how heterogeneity impacts antibiotic use, and in turn, how it impacts returns to using antibiotics in U.S. livestock operations. I concentrate on U.S. pork and poultry operations since they are the largest users of sub-therapeutic antibiotics by volume in the U.S., and explore the existing

literature on the economics of sub-therapeutic antibiotic use for glimpses of heterogeneity in the returns to antibiotic use. Perhaps the most interesting source of heterogeneity in returns to antibiotic use may be heterogeneity in management and/or the use of potential substitutes for antibiotics, such as improved sanitation practices and more modern facilities. Productivity and use of technologies that substitute for STA use vary amongst producers, and likely by region and farm size. Thus, the marginal abatement costs of reducing STA use vary across industries, producers, production systems, and regions.

To James, my partner—

and to Floyd, our dog.

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Chapter 1: Economic Factors Affecting Diversified Farming Systems[1]

Introduction

The 20th century brought significant changes to the economics of global agriculture. In more developed countries such as the United States, the face of agriculture was once that of the small family farmer. Today, the agricultural landscape in developed—and to some extent developing—countries is dominated by agribusiness and large farming operations. While many of these operations are still family-owned and farm size, management, and production methods remain diverse, on the whole, farms are larger and more mechanized and specialized than ever before (Schmitt 1991, Chavas 2001, Sumner and Wolf 2002). This transition is a direct result of the increase in relative price of labor and changes in domestic and global agricultural policies (Ruttan and Binswanger 1978, Kislev and Peterson 1982), and was spurred by dramatic improvements in agricultural productivity, and a shift from more labor-intensive agriculture to more capital- and technology-intensive agricultural practices that employed new varieties, synthetic inputs, and irrigation (Griliches, 1963; van Zanden, 1991; Antle, 1999; Chavas, 2001; Paul et al., 2004; Dimitri et al., 2005; Hoppe et al., 2007; Chavas et al., 2010). While agricultural production in much of Asia, Africa, and Latin America is more heterogeneous and more labor-intensive in general, specialization, mechanization, and technological change have increased productivity of agricultural commodity crops such as soybeans and sugarcane in Brazil, wheat and rice in China and India, palm oil in Indonesia and Malaysia, and others (Feder et al., 1985, Jayasuriya and Shand, 1986; Pingali, 2007). Incorporating and disseminating technological advances that improve productivity and incomes in smallholder farming systems remains a challenge throughout the developing world (Barlow and Jayasuriya, 1984).

In spite of—or perhaps in response to—this shift toward specialization and mechanization, there has been renewed momentum on the part of a vocal contingent of consumers, producers, researchers, and policy makers who draw attention to the social, environmental, and economic implications of this transition (Ikerd, 1993; McCann et al., 1997; Timmer, 1997; Webster, 1997; Antle, 1999; Seyfang, 2006). They envision a new model of agriculture that employs fewer synthetic inputs, incorporates practices which enhance biodiversity and environmental services, and takes into account the social implications of production practices, market dynamics, and product mixes. Components of this movement are taking hold in the economic and cultural mainstream in the United States, Europe and other countries. Evidence of this shift includes the rise of organic, "fair trade", and other production and certification schemes, and the growth of consumer willingness-to-pay for these differentiated food products. The prevalence of local

[1] This chapter, co-authored with David Zilberman, was previously published as part of a Special Feature in the journal Ecology and Society entitled: A Social-Ecological Analysis of Diversified Farming Systems: Benefits, Costs, Obstacles, and Enabling Policy Frameworks. See Bowman and Zilberman (2013) for the full citation.

farmers' markets and slow and local food movements, and the emergence of Payments for Ecosystem Services (PES) and multifunctional agriculture (MFA) within agricultural landscapes are also supporting this change (Thompson, 1998; Hinrichs, 2000; Heal and Small, 2002; Loureiro and Hine, 2002; Weatherell et al., 2003; Loureiro and Lotade, 2005; Antle and Stoorvogel, 2006; Swinton et al., 2006; Heiman et al., 2009).

While closely related to the concepts of sustainable, multifunctional and organic agriculture, diversified farming systems (DFS) have emerged as a separate agricultural model (Chambers and Conway, 1991). Diversified farming systems share much in common with sustainable, multifunctional, organic and local farming systems, but are unique because they emphasize incorporating functional biodiversity at multiple temporal and spatial scales to maintain ecosystem services critical to agricultural production. These ecosystem services include but are not limited to pollination services, water quality and availability, and soil conservation (see Kremen et al., 2012). Our aim is to provide an economists' perspective on how a range of existing and emerging factors drive profitability of DFS at the farm level and how these relate to the adoption and emergence of diversified farming systems at larger scales. We begin with an overview of the factors that impact the profitability of agricultural systems, follow with a discussion of the economic factors that support and run counter to diversified farming systems, and conclude with our thoughts on how technological innovation and market trends must continue to evolve if DFS are to become economically sustainable and widespread.

Economic factors that impact the profitability of agricultural systems: an overview

How profitable is it to farm? The answer depends upon the choices a farmer makes about what crops to grow and where, what technologies to use, and many other short- and long-term management decisions. Economists assume that farmers make choices so as to improve their utility, or well-being. In particular, farmers tend to pursue activities that increase their income, reduce their financial and physical risk, reduce labor requirements, and are convenient or enjoyable. A variety of constraints play into farmers' decisions, including constraints with respect to available production technologies, biophysical or geophysical constraints, labor and input market constraints, financial and credit constraints, social norms, intertemporal tradeoffs, policy constraints, and constraints to knowledge or skills (Stoorvogel et al., 2004).

The literature on technology adoption at the farm level tells us that many factors—in particular, variables that vary across farms and are sources of heterogeneity—influence farmers' choices about what crops to grow, whether to use a new technology, and how to manage their land. Just as individual consumers have different preferences about products they consume, farmer characteristics, asset endowments, risk preferences, and intertemporal considerations affect their choices. Farmer attitudes, resource availability, and education and knowledge are especially important; farmers may be risk-averse toward making changes in cropping decisions or adopting new agricultural practices, or might have very conservative attitudes toward technology or lower

or higher levels of concern for the natural environment (McCann, 1997; Hanson et al., 2004; Musshoff and Hirschauer, 2008; Serra et al., 2008). A farmer's income or resource base and ability to obtain credit will also influence his/her choice of crops, farming systems, and willingness to invest in new crops, systems, or technologies (McCann, 1997; Knowler and Bradshaw, 2007). A risk-averse farmer or one who is credit or income-constrained (which often is the norm rather than the exception, particularly in developing countries) may be less likely to adopt new technologies, even if they are likely to reduce his susceptibility to risk or increase productivity or income over the long-run (Nerlove et al., 1996; Hanson et al., 2004). Lack of knowledge and information about the costs and benefits of adopting new technologies or conservation practices *or* lack of knowledge about how to implement such technologies or practices will also affect a farmer's propensity to adopt them (Chavas et al., 2010; Chavas and Kim, 2010). Even if farmers have full information and can implement new technologies efficiently and at low cost, differences in intertemporal preferences or credit constraints may mean that farmers are unwilling to sacrifice current profits or income for long-term improvements in soil fertility, risk-reductions, or improved yields (Shively, 2001; Sunding and Zilberman, 2001; Coxhead and Shively, 2002).

Biological and geophysical factors and input and output market conditions are important variables that also impact farmer decision-making and adoption of land use practices or technologies. Biological and geophysical factors that influence production can include water availability, soil fertility, and risks of floods, droughts, frost, or pest or weed infestations, and the importance of each of these factors varies with the types of crops planted (Loomis et al., 1971; Leemans and Born, 1994). Input market conditions can shape farmer production decisions in a number of ways; dynamics of local and seasonal labor availability may mean that it is not profitable to grow a crop with a very narrow harvesting window in a month where the overall demand for agricultural labor is high in the region (Fisher, 1951; Binswanger and Rosenzweig, 1986). Input price volatility and economies of scale with respect to inputs or technologies can also contribute to farmers planting different mixes of crops, or planting more land in one crop than another (Zilberman et al., 2012). Similarly, output market conditions including prices, price variability, transportation costs, and supply chain transactions costs are important determinants of how profitable it is for farmers to grow a crop. Many of these variables are influenced by location; Rogers (2003) notes that communities closer to urban centers are likely to adopt new technologies more quickly. Consumer attitudes and willingness to pay (i.e., the maximum amount a consumer would be willing to pay for a good or attribute) for differentiated crops or particular attributes, such as organic or local production or pesticide-free varieties, also affect the agricultural systems that emerge in response to the demands of a changing market.

Finally, policies and regulations can impact the profitability and evolution of different agricultural systems by facilitating or hindering trade in particular types of agricultural products, by influencing farmer decisions about what crops to grow or how much land to farm using policies such as price supports or set-aside programs, or by making different types of production or land-use relatively more or less "expensive" via regulations, taxes and subsidies, or standards (Hardie et al., 2004; Goetz and Zilberman, 2007). In addition, many policies that do not specifically target

agriculture, such as labor and immigration or water policies, have a significant effect on the costs of agricultural production. For example, laws such as those that regulate pesticide usage and application or limit water use can make it more costly to produce using synthetic pesticides or inefficient irrigation systems (Lichtenberg et al., 1988; Lichtenberg, 2002). While in the short-run such regulations may have a negative impact on farmer welfare, they also serve to stimulate innovation and adoption of new technologies in order to comply with regulations and reduce the costs of production (Lichtenberg, 2002).

How can we describe trends in adoption and diffusion of agricultural technologies at landscape, regional, or global scales? Early studies on adoption noticed that the number of adopters, or the cropped area of using the new technology, were S-shaped (or followed a logistic curve) as a function of time. They explained this pattern by imitation behavior among farmers; adoption is slow until enough farmers begin using the technology, and then rates of adoption speed up rapidly before they plateau (Rogers, 2003). The more profitable the new technology, the faster the rate of adoption and the higher the level of adoption after the diffusion process has played out (Griliches, 1957). Farmers are heterogeneous, however, which impacts how and when they make decisions. In light of this heterogeneity, David (1975) and Feder et al. (1985) introduced the threshold model of adoption which characterized adoption within a community as a dynamic process whereby farmers make decisions according to explicit economic decision rules. Differences in when and how farmers adopt new technologies, then, arise due to heterogeneity among farmers and differences in other factors, such as their location and land quality. Larger farmers, for example, are often early adopters of mechanized technologies that exhibit increasing returns to scale.

There is an interplay between farmer heterogeneity and the biological and geophysical factors that influence adoption that we mentioned earlier in this section; farmers in areas with soils with lower water-holding capacity will reap greater benefits from adopting irrigation technologies, and pest control strategies are adopted first in regions with high pest pressures. Over time, technologies and practices diffuse as producers gain knowledge and experience, or "learning by doing," and as more and more farmers begin to use the technology, or "learning by using." More and more farmers will adopt a technology as the fixed costs of adoption decline with time, and for some technologies, the gains from adoption *increase* with time as the network of producers using the technology increases in size (i.e., technologies that exhibit network externalities, such as cell phones) (Sunding and Zilberman, 2001). These basic principles that guide producer adoption choices provide a background for analyzing the factors that will affect whether farmers adopt diversified farming systems.

Economic factors that support diversification

Within the context of farmer decision making, there are a number of ways that diversified farming systems can help farmers maximize their utility, including through their roles in

mitigating different types of risks, providing complementary inputs and optimizing production in the face of different biophysical or input and output market constraints, and through providing income or nonpecuniary benefits from ecosystem services or other benefits of using DFS practices. In this section, we focus on how these factors might make diversification an economically optimal choice for the farmer.

Farmers are typically risk-averse (where risk implies, for example, that the farmer knows that the price of their outputs will vary with some known probability). They face many different types of risk including price risk (e.g., the risk that the price that they receive for their output will be higher or lower than average in a given year), yield risk (e.g., the risk that a pest infestation or drought will cause yields to be lower than average), input supply risk (e.g., the risk of a water shortage or a labor shortage at a critical point in the production process) and other types of risks (e.g., the risk of a family member getting sick or a tractor breaking down) (Mcnamara and Weiss, 2005). Many of these types of risk (e.g., price risk, yield risk) contribute directly to profit risk, which is ultimately most important to the producer. Farmers and their families can respond to risks in many ways, and can respond ex ante (before the event) in precautionary ways, or ex post (after the event) to try and minimize their losses. Strategies for coping with risk include finding off-farm employment (Mcnamara and Weiss, 2005; Ito and Kurosaki, 2009), saving or using credit markets, informal borrowing (e.g., loans between family members), adopting risk-reducing technologies such as seed varieties with properties such as drought or herbicide resistance that emerged during the green revolution (Feder et al., 1985), engaging in contracts such as those that ensure that the farmer will have a buyer for his product at the end of the season at a set price (Goodhue and Hoffmann, 2006), and diversification of production.

Diversification of crops that the farmer produces may be an effective tool to help farmers deal with several types of risk including price and yield risk, risk in input markets (e.g., in labor markets), and other output market risks (i.e., the risk that you might not be able to find a buyer for your product). In the case of price risk, because the markets for different crops are characterized by different degrees of risk (in the simplest treatment of price risk, each price for each crop is characterized by a different mean and variance), the farmer can use what he knows about the means and variances of the prices for each crop to choose a mix of crops that have a low correlation of profitability (Coyle, 1992). If the price risks for two crops are poorly-correlated, the farmer can use diversification and choose an optimal portfolio of crops to help insure against drops in profit or utility that occur if the price for one crop is lower than average in a given year (Bromley and Chavas, 1989). Farmers' cropping choices, degree of diversification, and allocation of land amongst different crops will be direct reflections of their weighing these diverse risks (Dorjee et al., 2007).

The types of risk and constraints the farmer faces are not just macroeconomic; they often take the form of limited availability of inputs, such as fertilizer, water, labor, or capital. Using diversification, farmers can respond to input-related risks by choosing to farm a combination of crops with different characteristics (i.e., crops that are more or less drought-resistant, or crops

that are harvested in different seasons to mitigate labor risks). One of the most important types of input constraints and risks the farmer may face is labor or capital constraints and risks associated with harvesting. The labor and capital requirements for many agricultural crops vary seasonally and are often far higher at the time of harvest than at any other point in time during production. In the case where farmers are labor constrained and rely mainly on family labor, or require timely availability of costly, hired labor, farmers may diversify and grow several different crops for which the labor requirements peak at different points throughout the year so as to not leave fruit rotting on the tree or vegetables withering on the stalk (Musser and Patrick, 2002).

Biological constraints or risks to production are also important drivers of diversification, and can contribute to both input and output risk. Limited water or nutrient availability may cause farmers to plant a mix of crops that minimize surface water runoff or that take advantage of the nitrogen fixing abilities of particular crops in order to restore the soil nutrient balance through practices such as crop rotation (e.g., corn and soybean rotations). Crop rotation also plays a major role in pest and disease control (see e.g. El-Nazer and McCarl, 1986; Kremen and Miles, 2012). Although these biological factors favor crop rotation in many cases and contribute to the allocation of production of different crops over the landscape, land shares in different crops will still respond to prices and to new cultivation, irrigation, or harvesting technologies. In a similar way to crop rotation, integrated crop-with-livestock systems can harness biological synergies by meeting feed input needs for livestock (through crop silage) at the same time as the livestock provide necessary nutrients to crop agriculture (through manure). Pest pressures may also spur diversification by encouraging farmers to plant different varieties of crops, to intercrop on the landscape to encourage resilience to pests, or enhance biodiversity of agricultural systems as farmers adopt techniques such as integrated pest management (IPM) to deal with pest problems (Feder et al., 1985; Mahmoud and Shively, 2004).

Yet another economic incentive for farmers to adopt DFS is the potential to market products grown in DFS as specialty goods that appeal to a growing contingent of consumers concerned about the impacts of their food choices on their health and on the health of the environment. With modern agribusiness has emerged a transition from the idea of producing commodities to producing differentiated products with particular attributes, such as being "local," "organic," "pesticide-free," or "sustainable," that are desirable to consumers (Boehlje, 1999). This transition began in developed countries, and is now underway in the developing world (Rearden and Timmer, 2012). While DFS may not always be strictly local or organic, the synergies between DFS production methods and many of these existing, marketable labels that consumers are familiar with imply that DFS producers might capture price premiums associated with these attributes in the marketplace (Raynolds, 2004; Oberholtzer et al., 2005). Through different marketing channels such as community-supported agriculture (CSA), consumers can commit in advance to buy bundles of products, rather than a particular type of fruit or vegetable, as part of a weekly or bimonthly share of diverse and seasonal produce (Brown and Miller, 2008). This particular model helps producers deal with potential output market risk.

Policies and regulations can be important drivers of adoption of different types of farming systems. For the past 25 years, scientists have warned of climate change and of the need for conservation in order to maintain the quantity and quality of natural resource stocks as global populations rise (Stern, 2007). Though the implications of climate change at local, regional, and global scales are still uncertain, climate change will certainly have implications for the changing face of global agriculture (Rosenzweig and Parry, 1994; Howden et al., 2007). Inherent in human-driven climate change is the role of fossil-fuel intensive practices and technologies. Agriculture that relies heavily upon mechanization, fossil-fuel inputs and clearing of new land is now acknowledged to be "costly" both from a greenhouse gas perspective as well as due to its consumption and degradation of land, water, and biodiversity resources (Robertson et al., 2000; Tomich et al., 2011). The role of modern agriculture and agricultural policies in contributing to nutrition deficits and obesity epidemics worldwide is also becoming an important concern, particularly for more developed countries (Cash et al., 2005; Alston et al., 2006) Thus, there is an important role for policies and regulations to drive a suite of initiatives that aim to internalize the environmental and health externalities associated with industrial agriculture.

These policies may include establishing and expanding existing public (nonmarket) payments for ecosystem services, or creating regulations that give rise to private markets that support biodiversity in agricultural landscapes. Above and beyond PES, there are three categories of policies that are likely to emerge in the next decade which may lend support to DFS: carbon tax or trading systems that penalize carbon-intensive agricultural or transportation practices; pollution control regulations that address pesticides, herbicides, animal waste, or agricultural runoff; and taxes or subsidies for producers and/or consumers that are designed to make consuming cheap calories (such as those from high-fructose corn syrup; see Cash et al., 2005) more expensive or consuming nutrient-rich foods cheaper in order to affect consumption patterns that contribute to global obesity epidemics and malnutrition.

Public and private payments for ecosystem services are a final important set of economic drivers that may support diversified farming systems. In the context of agriculture, payments for ecosystem services are usually payments to landowners for leaving high-value conservation land uncultivated or payments that arise from an understanding that a working agricultural landscape, while not an undisturbed ecosystem, can perform a diverse array of services that go above and beyond producing food (Randall, 2002; Sandhu et al., 2008). These services include but are not limited to soil conservation and carbon sequestration through no-till agriculture or planting of hedgerows (Antle and Diagana, 2003; Knowler and Bradshaw, 2007), water conservation or quality improvement, and maintenance or conservation of biodiversity through practices such as active promotion of pollinators, intercropping to promote both plant and animal biodiversity, and establishing planting of native plant species (Babcock et al., 1996; DiFalco, 2012). Above and beyond the multifunctionality or ecosystem service benefits provided by these practices, they can also generate indirect benefits for farmer well-being through nonpecuniary externalities such as improved health through reduced exposure to pesticides (Huang et al., 2003).

Public (nonmarket) payments for ecosystem services include examples of federal programs such as the Conservation Reserve Program (CRP) and EQIP (Environmental Quality Incentives Program) in the U.S., payments provided as part of Rural Farming Contracts in France, the 1999 Basic Law of Food Agriculture and Rural Areas in Japan (Smith, 2006), the Grain-for-Green program in China (Uchida et al., 2009), and Costa Rica's PES programs for carbon sequestration via forestry, afforestation, forest conservation, and agroforestry (Montagnini and Nair, 2004). Beyond PES schemes, other public incentives to adopt environmentally sustainable production methods can help farmers to offset the fixed costs of adopting a new technology; in 2006, the Northern Constitutional Finance Fund of Brazil (a federal credit institution) established the "Sustainable Amazon" credit line to fund sustainable agriculture and investment in sustainable infrastructure in the Amazon region of the country, and gave out more than 1 billion USD in loans during 2010 (Banco da Amazônia, 2011). Subsidized credit and PES schemes acknowledge that there are positive externalities—including the ecosystem services being provided by agricultural landscapes or multifunctional landscapes—that are not being priced appropriately in a market context. In other words, these services have a net benefit to society, but there is no corresponding market income for the individual farmers providing such services, which constitutes a "market failure." Because society derives some benefit when the government steps in and establishes policies that encourage farmers to adopt management practices which generate ecosystem services, these types of public payments can be welfare-improving for farmers and society as a whole if done correctly (Just and Antle, 1990; Randall, 2002; Smith, 2006; Swinton, 2006).

Private payments for ecosystem services occur in a market context, and can arise from direct willingness to pay for ecosystem services (e.g., when a bottling company that relies on a high level of water quality in order to produce a quality product pays farmers to implement land management practices which reduce sedimentation in local waterways or reduce nitrate leaching into the groundwater), or via demand for mitigation or compensation activities mandated by regulation. In the United States, laws such as Section 404 of the Clean Water Act of 1972 and Section 9 of the Endangered Species Act of 1973 require compensatory action if the statutes in the sections are not met. For example, in the case of the Endangered Species Act, the construction of a new office building in an area that is considered to be prime habitat for an endangered species requires the purchase of an offset of an equivalent unit of habitat within a designated compensation area (Sohn and Cohen, 1996; Fox and Nino-Murcia, 2005; Bowman, 2011). Agricultural landscapes do not always naturally provide habitat for endangered species, but in some cases, plantings of native vegetation or committing to particular cropping mixes can turn an agricultural landscape into a multifunctional landscape that can serve as a species "bank" accompanied by credits to be sold in private markets. Biodiversity offset markets are emerging as a result of legislation in the United States, Brazil, Europe, and Canada (Burgin, 2008).

To the extent that DFS by definition maintain ecosystem services critical to agricultural production, public and private PES schemes could provide economic benefits to DFS if there is private or public willingness to pay for ecosystem services being maintained through diversified farming methods. If DFS use fewer pesticides than conventional systems or incorporate other

practices that improve surface or groundwater quality, there may be future willingness to pay on the part of municipal or state governments or water boards for improved water quality from DFS due to the associated human health benefits or reduced costs of water treatment. Similarly, if DFS maintain pollination services or other ecosystem services as part of a working agricultural landscape (i.e., support higher levels of bird biodiversity or provide soil conservation benefits), DFS may be able to obtain payments through PES programs.

Economic factors that run counter to diversification

Just as there are economic reasons for a farmer to diversify production in response to risk, biophysical or input constraints, or market conditions, there are many reasons it may be economically efficient for a farmer to specialize in the production of a particular crop. Throughout history, agro-climatic conditions have contributed to both diversification and specialization of agricultural production. Studies suggest that most regions employed diversified farming systems that concentrated on the production of a few key staples (e.g., rice, wheat, or barley) together with complementary fruit and vegetable crops and livestock production (for its flexibility, and for fertilizer production) (Timmer, 1997; Diamond, 1998). However, even in regions with a more diverse crop portfolio, such as the Mediterranean, there was some degree of specialization within subregions (e.g., Greece and olive oil; France and wine) due to trade. Today, technological innovation has made some factors that previously limited agricultural production (such as climatic or biological constraints to production) less relevant. Together with trade, these trends have magnified regional specialization. For example, in the Central Valley of California, water projects have effectively transformed vast deserts into a 3-season greenhouse for the rest of the country. In turn, California's carefully-constructed comparative advantage in fruit and vegetable production has meant that growers in other states struggle to compete in these markets if consumers value an array of product choice on the shelves over quality or location attributes (Timmer, 1997). Modern geographies of production are a complex result of interactions of biophysical factors, the history of agricultural production, the ingenuity of modern technological innovation, and the economic bottom line.

Modernization of agriculture has led to more and more specialization for a number of key reasons. The introduction of synthetic fertilizers and chemicals decoupled the need for livestock waste as a complementary input to agricultural production. Economies of scale in the production, harvesting and processing of agricultural products have also contributed to this trend toward specialization and mechanization. Staple commodities were mechanized first because they were lower-value and therefore exhibited the largest gains for farmers of reductions in harvesting costs due to mechanization (Raup, 1969; Rosset, 1991; D'Souza and Ikerd, 1996; Paul et al., 2004). The ability to store commodities also means that they can be sold and stored strategically according to current and expected market conditions. Among crops that are produced as monocultures, breeding of crops for a few key traits has also contributed to reduced genetic diversity and increased specialization (Heal et al., 2004). Increased opportunity costs of time for farmers and

laborers (higher wages in industries other than agriculture) have led to increases in farm size to reduce labor costs (Kislev and Peterson, 1991).

The consumer's desire to have an array of cheap produce available, no matter the season, and decreased long-distance transportation costs due to improved infrastructure have also had important implications for regional specialization. Even in markets where some consumers are demanding food that is produced more locally, sustainably, organically, and diversely, the high costs of certification and marketing (Hardesty and Leff, 2010) and risks associated with pests commonly controlled by synthetic pesticides, in the case of organics or pesticide-free varieties, can make these varieties more expensive than conventional varieties, and make consumer demand (and therefore farmer revenues) unpredictable (Lohr and Salomonsson, 2000; Regmi and Gehlhar, 2005). Farmers marketing locally-grown food also face the challenges of transporting small volumes of goods to local markets (Pretty et al., 2005). Finally, variation in regional agricultural suitability and length of growing seasons mean that diverse, local production systems may not provide the same consistent product variety that consumers have become accustomed to. When large volumes of conventional produce varieties can be shipped cheaply and provide a consistent (if possibly inferior-tasting) product year-round, so long as consumers choose low prices over quality, specialization will thrive.

In addition to these economic factors that have driven specialized rather than diversified production, agricultural commodity programs have sustained the specialization of production of a few global agricultural commodities such as corn, rice and wheat, in some regions (Pingali and Rosegrant, 1995). In the United States, such programs arose during the Great Depression as increasing yields of these globally-traded commodities (with mostly inelastic demand, or demand that varies little with an increase or decrease in price) contributed to falling prices and, in turn, reduced farm incomes. Although these programs are not directly responsible for increased specialization in the countries where they were implemented, they required production of program crops to receive program payments, and thereby disincentivized diversification. Furthermore, overproduction of commodity crops in countries where they were subsidized led to depressed global food prices, and adversely affected terms-of-trade for developing countries and—in-turn—likely affected their investment in domestic agricultural production as they began to import more food (Mellor, 1988; Anderson, 1992). In the last decade, commodity prices have increased and the initial logic behind commodity programs has become less relevant; farms are larger and incomes are higher than ever before in the developed countries (Gardner, 1992). Even as commodity programs are slowly being eliminated, however, the emergence of crop insurance programs for commodity crops serves as an effective subsidy-in-disguise with questionable social welfare implications (Sproul, 2010) and little-to-no benefit for DFS; O'Donoghue et al. (2009) showed that U.S. farmers responded to the 1994 Federal Crop Insurance Reform Act with increased specialization.

How, then, do these factors continue to affect the proliferation of diversified farming systems? Because DFS often employ intercropping or multicropping systems in order to take advantage of

complementarities between crops, prevent soil erosion, and foster biodiversity, they are also less-easily mechanized and therefore are more labor-intensive than planting monocultures. In the same way, the use of chemical pesticides and fertilizers and GMOs is often cheaper than manual weeding or biological pest control or IPM technologies (Dobbs et al., 1988). In more developed countries where the costs of labor are high, in developing countries where labor markets are incomplete (i.e., where transactions costs of matching willing workers with employers are high) (Binswanger and Deininger, 1997), and wherever local and regional labor shortages are a key limiting factor for agricultural production (as is becoming the case in the United States; see Devadoss and Luckstead, 2008), farmers will require developments in precision agricultural technologies that allow for more efficient intercropping and planting on smaller scales if they are to adopt DFS systems. Although labor surpluses exist in developing countries and DFS may provide new opportunities for rural employment, there is a tradeoff between keeping labor costs low to make labor-intensive agricultural production economically viable, and retaining agricultural workers through higher incomes in order to compete with urban migration (Binswanger and Deininger, 1997; Hu, 2002). Because precision farming uses information technology to vary application of inputs by location, input use efficiency improves and is highly adaptable to bio-ecological conditions. The technology is expensive and faces many challenges in the development of new harvesting technologies and production management, but (in particular) the application of precision farming to harvesting technologies will be necessary if multicropping or intercropping is to become widespread in regions where mechanized monocultures prevail. In general, pest and input management techniques, harvesting technologies, and flexible physical capital that can be employed in diverse agricultural systems may help balance the increased labor requirements relative to other systems where labor costs are the most important factor limiting the profitability of DFS. Thus, though the productivity and sustainability of DFS may be high, the high labor costs and requirements associated with such systems are a major barrier to adoption.

The potential for DFS to cash in on public or private payments for ecosystem service schemes represents both a potentially significant economic benefit to such systems, as well as a great challenge. In spite of growth in emerging markets for PES in developed and developing countries, the degree to which PES will provide financial support for DFS is unclear. Valuation of the economic benefits associated with the ecosystem services provided via DFS production methods is still in its early stages, and even if ecosystem services are identified, questions remain: to whom are the services valuable…and how much are they willing to pay for them? Critically, even if demand for these ecosystem services exists on the part of consumers, governments, or private firms, the mechanisms and markets to make these exchanges work are still missing in many cases. Below, we discuss several key sticking points associated with linking PES to DFS, including: lack of research on and valuation of environmental services provided in DFS, transaction costs, heterogeneity in benefit provision and the costs of provision of benefits, landowner coordination problems associated with engaging in PES markets, and lukewarm political and financial support for publicly-funded PES programs.

Because DFS by definition focus on providing crucial ES for agricultural production (and therefore

reducing costs associated with synthetic pesticides or fertilizers, waste treatment, or pollination services), identifying and quantifying WTP for ES beyond those critical to agricultural production at the single farm/single landowner level may be a key component in making these systems economically sustainable. Identifying the exact direct, indirect, or existence benefit provided by DFS methods is a first step, and combining rigorous evaluation of ES with evaluations of willingness to pay for these services is crucial (see Glebe (2007) for a discussion on the environmental benefits of agriculture in the European context). For example, in the case of pollination services, neighboring farmers may receive a direct benefit from increased production due to improved pollination from a landowner who maintains a healthy native bee community as part of a DFS (Brosi et al., 2008; Lonsdorf et al., 2009). Understanding the production functions associated with environmental services (e.g., how much one landowner maintaining a healthy native bee community contributes to other landowners' production) is absolutely critical to understanding how PES schemes will support DFS.

Knowing who benefits from what services is a starting point for rigorous economic research on the value of or WTP for environmental services from DFS, but even if we knew who benefited from DFS and how much, creating and adapting existing markets to correctly link provision of environmental services in DFS to existing WTP for such services is a challenge (Daily and Matson, 2008). Tepid political and financial support for expansion of publicly-funded PES programs has limited the supply of such services, and privately-funded PES programs have been limited in large part to payments for watershed protection (Los Negros program in Bolivia, Pirampiro in Ecuador), payments for improvements in water quality (Nestlé-sponsored Vittel in France), and payments for carbon sequestration (Wunder et al., 2008). Finally, the transactions costs for farmers to enter into existing PES schemes as well as for private or public entities to develop new PES schemes are often quite high (Bulte et al., 2008; Engel et al., 2008).

Finally, in many cases, the level and costs of provision of environmental services (ES) at the local or regional scale are heterogeneous (Antle et al., 2003; Engel et al., 2008), as well as in some cases dependent upon the coordinated actions of a large group of landowners (e.g., water quality, regional biodiversity) (Parkhurst and Shogren, 2007; Drechsler et al., 2010). In most cases, heterogeneity in the marginal cost of provision of benefits makes PES a more economically-efficient and lower-cost mechanism for providing environmental services than less flexible policy alternatives, such as command-and-control regulation (Engel et al., 2008; Wünscher et al., 2008). Heterogeneity in the marginal benefit of provision of ES, in contrast, makes designing efficient and effective PES schemes more complicated. Consider the case where habitat for an endangered species the ES to be provided. In this case, benefits only exist above and beyond the conservation of a critical (and sometimes contiguous) area of habitat, and the marginal benefit of conserving a unit of habitat will depend upon the location of the property, as well as upon the total amount of existing suitable habitat. In cases such as this, targeting PES schemes for optimal ES provision is complex and costly (Babcock et al., 1997; Wu et al., 2001; Claassen et al., 2008), and there is a tradeoff between making programs more context-specific and efficient, and costs of implementation (Jack et al., 2008). Designing and expanding such programs will require public

and private funding for research, program implementation, enforcement and monitoring, as well as funding for outreach and extension that minimize the costs to farmers of engaging with PES mechanisms.

Providing ES via landowner coordination is a special case where the marginal benefit of providing an environmental service is not constant. Almost all existing PES programs pay landowners to engage in behaviors or management practices on their property, and pay landowners independent of what other landowners in the region are doing. The provision of many environmental services, however, occurs at scales larger than that of the property boundary. Goldman et al. (2007) discuss three examples of types of benefits for which landowner coordination and landscape-level coordination for provision of benefits are critical: pollination services, hydrologic services, and carbon sequestration. Despite a number of papers that make the theoretical case for programs such as "cooperation bonus" programs that take this into account (Parkhurst et al., 2002; Shogren et al., 2003; Parkhurst and Shogren, 2007), they are largely absent in practice. This is, in part, due to high transactions costs which increase with the number of landowners (Jack et al., 2008).

Conclusions

The expansion and adoption of DFS is limited by a number of factors, including still-limited demand for products produced via DFS, supply-side constraints such as high costs of tilling or harvest in multiple crop systems, and policies such as subsidies and crop insurance which discourage diversification. The supply-side constraints to adopting DFS such as high costs of tilling or harvest in multiple crop systems, pest damage or disease in crops where current alternative pest management strategies are costly or have little impact (Zilberman et al., 1991, National Research Council, 2000), and limited supply channels and capacity for storage of diversified products. One key innovation that will be necessary to improve the productivity of DFS is the introduction and adoption of technologies that reduce the costs of harvesting in diversified systems, and the adoption of precision agriculture that helps farmers manage and optimize input allocation in multiple crop systems. These technologies are costly, however, and the development of innovative low-cost, practical strategies that reduce the costs of production in DFS in the developing world will be necessary if they are to become widespread.

Importantly, public investment in research and development for such technologies, in expanding the markets for ecosystem services and products from DFS systems, and in educating and spreading awareness about the benefits of DFS is justified and necessary; DFS provide important public goods, and public funding will be necessary if they are to become a profitable choice for farmers and a central part of global agriculture in the future. Finally, regional or global market-based incentives that incorporate the social costs of industrial agricultural models could help tip the balance toward diversified production models. Beyond carbon regulation, more stringent regulation of agricultural runoff, agricultural water use, pesticide safety, and water quality will have significant impacts on the face of agricultural production in the developing and developed

world; to the extent that DFS rely less on fertilizer and pesticide application and inefficient water use and work to control soil erosion and runoff, these systems may be better positioned than other forms of agriculture to comply with evolving regulations, and at lower cost.

In summary, we envision several paths to overcoming the sticking points to the expansion of DFS. First, in order for consumers to be willing to pay for products produced in DFS, there is a need for education and public awareness campaigns that lay out the ecological benefits of DFS and the establishment of new market channels for consumers to gain access to products produced in DFS. Public incentives also need to align to provide support for DFS; this will require establishment and expansion of PES programs that pay farmers for the production of environmental benefits produced via DFS, as well as the substantial redirection of funds currently allocated toward subsidies and crop insurance toward PES programs, incentives for improved nutrition, and funding for research and development of technologies that can be applied in diversified systems.

Chapter 2: Foot-and-Mouth Disease and deforestation in the Brazilian Amazon

Introduction

One-third of the world's remaining rainforests are in Brazil, and it is the world's most biodiverse country (Lewinsohn and Prado, 2005). It is also the 3rd largest exporter of global agricultural commodities, ranking 1st in sugar exports and 2nd in exports of both beef and soybeans (FAS, 2012). Between 2000 and 2005, Brazil deforested approximately 0.4%-0.6% of its Legal Amazon region every year (INPE, 2012)—an area larger than Belize—and 50-80% of these forests were replaced by pasture (Simon and Garagorry, 2005; Morton et al., 2006; Wassenaar et al., 2007; Espindola et al., 2012). Although deforestation rates have slowed since 2005, deforestation in the Brazilian Amazon released approximately 5.7 billion tons of CO_2 to the atmosphere between 2000 and 2010[1]. Bustamante et al. estimate that cattle ranching accounted for more than half of Brazil's total GHG emissions for the 2003-2008 period (Bustamante et al., 2009). Beyond the effects on global climate, the local and regional consequences of deforestation in Brazil include drought, perpetuation of the fire regime, and loss of biodiversity and local ecosystem services (Kirby et al., 2006; Nepstad et al., 2008; Nepstad et al., 2009; Martinelli et al., 2010).

Policy makers and scientists alike have been more-than-willing to assume that cattle ranching causes more than half of new deforestation since more than half of the forest that is cleared is converted to pasture (Comitê Interministerial Sobre Mudança do Clima, 2008; Zaks et al., 2009; Cerri et al., 2010). They cite increasing beef consumption in Brazil (Faminow, 1997; Levy-Costa et al., 2005) and the dramatic increase in exports from roughly 5% to 20% of production between 1990 and 2010 (Secretaria de Comércio Exterior, 2012) as the forces driving this expansion. Empirical work to-date shows that deforestation is correlated with cattle prices (da Silva and Kis-Katos, 2010; Faria and Almeida, 2011), and that growth in cattle herds or pasture area at the municipality or state levels is significantly correlated with deforestation (Garcia et al., 2007; Rivero et al., 2009; Barona et al., 2010). While these studies suggest that cattle production is associated with deforestation in Brazil, they do not establish whether increased demand for beef causes deforestation, or how much.

For years, scholars of land use change in the Brazilian Amazon have suggested there may be reasons other than increased demand for beef that forests are cleared for pasture. These include land speculation (Hecht, 1993; Faminow, 1998; Bowman et al., 2012), land rent capture as transportation costs decrease with investments in infrastructure (Walker et al., 2008), timber sales (Margulis, 2004; Arima et al., 2005), or the desire to establish property rights legally through "productive use" (Faminow, 1998; Margulis, 2004; Arima et al., 2005; Walker et al., 2008). In these

[1]Using data from the INPE PRODES database (www.obt.inpe.br/prodes), CO_2 emissions were calculated using a conversion factor of 100 tons C committed to the atmosphere per hectare deforested, which is the (conservative) factor official used by Brazil's Amazon Fund. The conversion factor from C to CO_2 is 3.66.

stories, the conversion of forest to pasture is the observed outcome, but cattle are mere placeholders on land that was deforested for other reasons. Others suggest that cattle ranching is at least partially a scapegoat for indirect land use change that occurs as other agricultural activities expand in southern and central Brazil and cattle ranching is displaced northward and westward (Walker et al., 2008; Barona et al., 2010). Arima et al. found that a 10% reduction in conversion from pasture to soybeans would have decreased deforestation by as much as 40% in heavily-forested municipalities between 2003 and 2008 (Arima et al., 2011).

In this paper, I use data on deforestation and Foot-and-Mouth Disease status for municipalities in the Brazilian Amazon and cerrado biomes to empirically test whether changes in FMD-status—an exogenous shifter of demand for beef—caused new deforestation during the 2000-2010 period. In Brazil, endemic Foot-and-Mouth disease historically limited the degree to which Brazilian beef was exported to international markets, and recent progress toward its control is associated with an expansion of beef exports since the late nineties (Walker et al., 2008, Kaimowitz et al., 2004; Cattaneo, 2008; Cederberg et al., 2011). In 1992, the World Organization for Animal Health (OIE) of the United Nations implemented a new protocol whereby *regions* of countries (rather than whole countries) could become certified as FMD-free. By 1993, Brazil had implemented a country-wide, mandatory vaccination policy, and established protocols for vaccination and outbreak procedures (Ministerio de Agricultura, do Abastecimento e da Reforma Agrária, 1993).

Not long after, the Ministry of Agriculture planned how and when to expand the FMD-free area conditional on location. They delineated different "circuits" of the country that would be sequentially certified provided they were outbreak-free for two years prior to submission for approval by the OIE. Mandatory buffer zones were established around FMD-free regions (Ministerio de Agricultura e do Abastecimento , 1997; Mayen, 2003; Lima et al., 2005). This certification plan began in the south with the states of Paraná and Santa Catarina in 1997, and moved northward and westward. During the time period of this study (2000-2010), Brazil saw large expansions in the area considered FMD-free, and exports grew from 9% to 22% of production during the same period (Secretaria de Comércio Exterior, 2012). An FMD outbreak also affected central and central western Brazil in 2005 and subsequent years (Fig. 2.1).

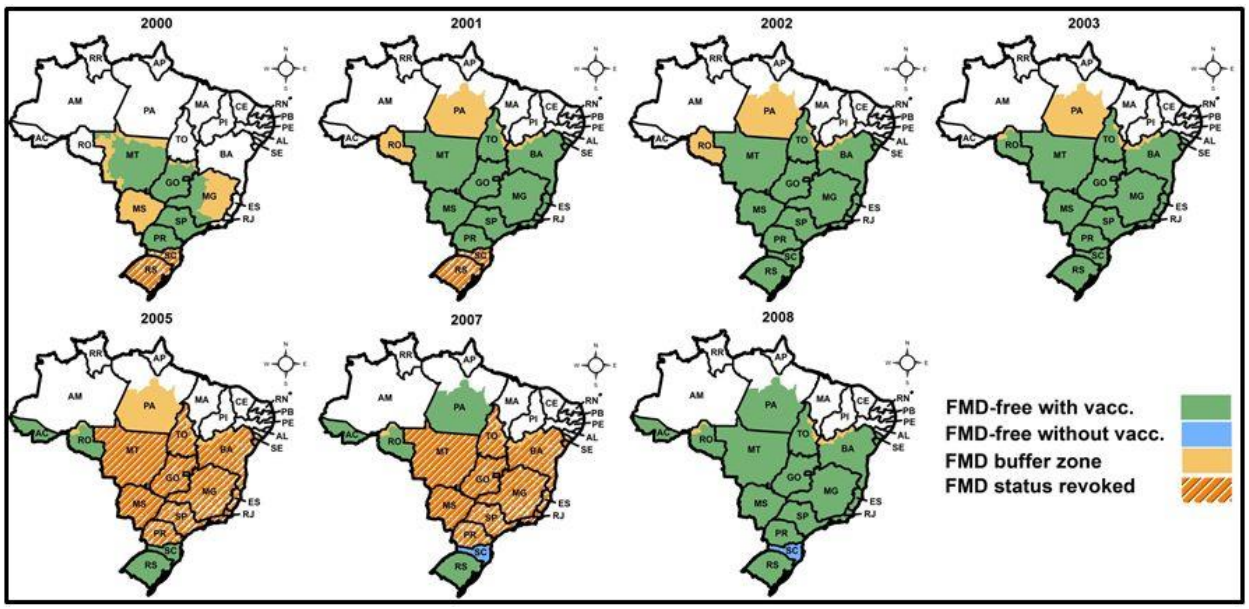


Fig. 2.1. Changes in Foot-and-Mouth disease status in Brazil between 2000 and 2010. Data for omitted maps (2004, 2006, 2009, and 2010) are identical to the previous year. Source data were compiled using the SISLEGIS system of the Brazilian Ministry of Agriculture (http://www.agricultura.gov.br/legislacao/sislegis) and digitized and geo-referenced by the author.

In order to investigate the impact of changes in municipality-year FMD status during the 2000-2010 period, I assume they are exogenous shifters of demand for beef produced in the municipality (see Empirical Strategy and Identification for more about underlying assumptions), and test the following hypotheses: 1. being certified as FMD-free caused a significant increase in deforestation at the municipality level when compared to infected municipalities, and 2. outbreaks of Foot-and-Mouth disease caused a significant decrease in deforestation at the municipality level when compared to municipalities that are FMD-free. In the first hypothesis, a potential mechanism is that the certified municipality was able to export more beef products to more countries. Because the price of beef for export is higher than the domestic price, average producer prices for beef increased and deforestation increased as a result. Applying the same logic to the second hypothesis, a municipality that experienced an outbreak may have been subject to decreased demand for beef and lower producer prices.

Empirical Strategy and Identification

I use changes in Foot-and-Mouth Disease (FMD) status for municipalities in the Brazilian Amazon and cerrado biomes to empirically test whether these changes in FMD-status caused new deforestation during the 2000-2010 period.

The causal interpretation of the effect of FMD-status on deforestation relies upon the following key points:

1. The Brazilian Ministry of Agriculture's (MMA) plan for expanding the area free of FMD and, in turn, the "treatment" whereby municipalities are classified as FMD-free is *as good as randomly assigned, conditional on municipality location*. This assumption is reasonable, as the MMA set out a location-dependent plan for declaring whole circuits of the country successively free of FMD. This plan began with declaring the two southern-most states FMD-free in 1997, and designations of successive areas moved northward and westward with time. According to Mayen (2003):

   > *"The Ministry of Agriculture divided the country into five circuits, conforming to their geographical positions: Southern Circuit, Eastern Circuit, Centre and Western Circuit, Northeastern Circuit, and Northern Circuit."*

   Because this treatment follows a selection on observables design, the inclusion of municipality fixed effects in my empirical specification allows for a causal interpretation if these assumptions hold.

2. The incidence of FMD-outbreaks during the period of the study was idiosyncratic, and therefore exogenous to deforestation rates. While not completely analogous, several papers in the literature treat disease events that affect cattle as exogenous shifters of demand for or supply of beef. Jarvis et al. (2005) assume that FMD-status of individual countries is an exogenous shifter of demand that is a determinant of the probability of trade between countries. Marsh (2008) and Schlenker and Villas-Boas (2009) also treat incidence of BSE as an idiosyncratic event that allows them to estimate the impact on cattle prices and consumer and market responses, respectively.

Another relevant limitation to the identification is that the assumption that changes in FMD status shift only demand but not supply may not hold in the case of outbreaks, where culling of animals is standard outbreak response protocol. How this affects estimates of the impact of an inward shift in demand for beef on deforestation at the municipality level is not totally clear; if beef production in parts of Brazil is high enough as to impact prices, an inward shift in supply will cause prices to go up, and will therefore introduce a bias toward zero on the magnitude of the coefficient of the impact of decreased demand on deforestation, and produce an underestimate.

Materials and Methods

I combined data on deforestation, Foot-and-Mouth Disease status, and other variables to create an unbalanced panel dataset of 1356 municipalities in the Amazon and cerrado biomes of Brazil

that exhibited any new deforestation between 2000 and 2010. Deforestation and land cover data come from the PRODES dataset at the Instituto Nacional de Pesquisas Espaciais (Instituto Nacional de Pesquisas Espaciais, 2012) for the Amazon (667 municipalities; 2000-2010), and from the Laboratório de Processamento de Imagens e Geoprocessamento (LAPIG) at the Universidade Federal de Goiás (Laboratório de Processamento de Imagens e Geoprocessamento, Universidade Federal de Goiás, 2012) for the cerrado biome (689 municipalities; 2002-2008) (see Fig. 2.2). Data on Foot-and-Mouth Disease status at the municipality level were compiled using legislation (including Portarias, Instruções de Servício, and Instruções Nomativas) relevant to the prevention and control of Foot and Mouth Disease in Brazil from 1995 to present (Table 2.1) using the Sistema de Legislação Agrícola Federal (SISLEGIS) of the Ministério da Agricultura, Pecuária e Abastecimento (Ministerio da Agricultura do Brasil, 2011), and were entered by hand in ArcMap into a georeferenced map of Brazilian municipalities obtained from the Instituto Brasileiro de Geografia e Estatística (Instituto Brasileiro de Geografia e Estatística, 2011).

My regression equation directly relates annual deforestation in municipality i in year t to FMD-status at the municipality level.

$$\text{Log Deforestation}_{it} = \alpha_i + \gamma_t + \beta_1 \text{FMD-free}_{it} + \beta_2 \text{log years FMD-free}_{it} + \beta_3 \text{affected by FMD outbreak}_{it} + \beta_4 \text{FMD buffer zone}_{it} + \beta_5 \text{log years in buffer zone}_{it} + \epsilon_{it}$$

Variables of interest include whether the municipality was FMD-free in a given year, was previously FMD-free but saw a drop in exports as a result of an FMD-outbreak, or is in an FMD buffer zone, as well as variables representing the length of time since the municipality was first declared FMD-free, and the number of years the municipality has been in a buffer zone. Year and municipality fixed effects (α_i and γ_t, respectively) are included to control for factors common across municipalities that vary with time, such as commodity prices, overall trends in political, macroeconomic, or socioeconomic variables affecting deforestation; and to control for time-invariant characteristics unique to the municipality such as location, local institutions, differences in deforestation enforcement at the municipality level, and other characteristics. In order to correct for spatial and serial correlation, I use the standard error correction method employed by Hsiang (Hsiang, 2010) that combines GMM methods to correct for spatial autocorrelation with a non-parametric correction for serial correlation.

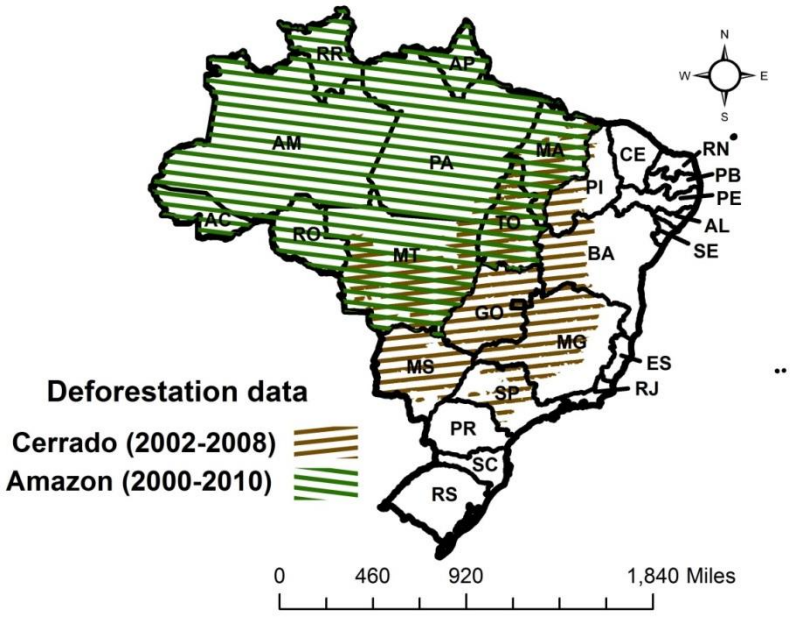


Fig. 2.2. Data coverage of deforestation for the Brazilian Amazon and *cerrado* biomes, in green and brown, respectively.

Table 2.1. List of federal declarations and laws relevant to Foot-and-Mouth Disease status of Brazilian municipalities.

Date	Legislation	Action
August 28, 1997	Portaria Nº 91	Established procedures for the entry of potentially infected animals and their products and derivatives into the states of Rio Grande do Sul and Santa Catarina.
December 28, 1999	Portaria Nº 618	Created a buffer zone that separates the area considered FMD-free with vaccination from infected areas in the listed municipalities in the states of Paraná, São Paulo, Minas Gerais, Goiás and Mato Grosso.
April 27, 2000	Portaria Nº 153	Declared the states of Rio Grande do Sul and Santa Catarina as an FMD-free zone, without vaccination.
August 25, 2000	Instrução de Serviço Nº 8	Limited the transportation of animals and products of animal origin due to an outbreak of FMD in Rio Grande do Sul.
December 28, 2000	Portaria Nº 582	Created a buffer zone that separates the area considered FMD-free with vaccination from infected areas in the listed municipalities in the states of Tocantins and Bahia.
December 10, 2002	Instrução de Serviço Nº 29	Clarifies the location of the internationally-recognized FMD-free zone, and defines the procedure for the entry and passage through the state of Santa Catarina of animals that are susceptible to FMD and their products and derivatives.
June 11, 2003	Instrução Normativa Nº 7	Added the state of Rondônia to the FMD-free zone constituted by the states of Bahia, Espírito Santo, Goiás, Mato Grosso, Mato Grosso do Sul, Minas Gerais, Paraná, Rio de Janeiro, Rio Grande do Sul, Santa Catarina, São Paulo, Sergipe, Tocantins and the Distrito Federal.
July 6, 2005	Instrução Normativa Nº 14	Included the state of Acre and the municípios of Boca do Acre and Guajará in the state of Amazonas in the FMD-free zone constituted by the states of Bahia, Espírito Santo, Goiás, Mato Grosso, Mato Grosso do Sul, Minas Gerais, Paraná, Rio de Janeiro, Rio Grande do Sul, Rondônia, Santa Catarina, São Paulo, Sergipe, Tocantins and the Distrito Federal.
November 24, 2005	Instrução Normativa Nº 36	Reduced the area subject to restrictions due to sanitary risked posed by the outbreak earlier in the year for specified regions.
February 10, 2006	Portaria Nº 43	Declared the municipalities of the center-south region of the state of Pará as FMD-free with vaccination.
June 28, 2007	Instrução Normativa Nº 25	Included the municipalities of the center-south region of the state of Pará as part of the internationally-recognized FMD-free zone.
November 23, 2007	Instrução Normativa Nº 53	Recognized and consolidated the situation with respect to FMD in the 27 Brazilian states.
All documents downloaded from: Ministerio da Agricultura do Brasil. Sistema de Consulta à Legislação (*SISLEGIS)*. Available at: http://www.agricultura.gov.br/legislacao/sislegis. Accessed November 1, 2011		

Results

Regression results show that, on average, being classified as Foot-and-Mouth disease free caused municipality-level deforestation to increase relative to municipalities not yet classified as FMD-free when controlling for time- and municipality-specific trends (Table 2.2). Though the effect varies with the number of years since the municipality had been declared FMD-free, my results suggest that being FMD-free caused annual deforestation at the municipality level to be 42% to 85% higher, on average, during the 2000-2010 period. Deforestation was highest relative to infected municipalities for municipalities that were newly declared FMD-free (85% higher), but decreased with the number of years since the municipality had first been declared FMD-free to an average of 42% higher after 11 years. In addition, although the results for municipalities in FMD-buffer zones or experiencing FMD outbreaks were not robust to correction for spatial correlation, they suggest that being in an FMD buffer zone may cause a significant increase in deforestation, and that FMD outbreaks may cause deforestation rates to decline.

Table 2.2 Regression coefficients for Foot-and-Mouth Disease export status, with log hectares deforested per year as the dependent variable

Municipality is FMD-free	0.77***
	(0.27)
Log number of years since municipality first became FMD-free	-0.54***
	(0.15)
Exports affected by FMD-outbreak in 2006/2007	-0.23
	(0.20)
Municipality lies in an FMD buffer zone	0.35
	(0.40)
Log number of years municipality has been in an FMD buffer zone	0.14
	(0.26)

Coefficients (with standard errors in parentheses) represent the impact of changes in Foot and Mouth Disease (FMD) status on log deforestation in 1356 municipalities in the Brazilian Amazon and *cerrado* biomes. Panel is unbalanced, and mean log deforested hectares per year is 4.81. The model specification includes year and municipality fixed-effects, and the standard errors are robust to spatial correlation up to 180 km and autocorrelation for two periods. Asterisks indicate two-tailed significance levels: *<0.10, **<0.05, ***<0.01.

Discussion

My results suggest that the expansion of Foot-and-Mouth Disease-free areas in Brazil caused some deforestation during the 2000-2010 period. While these results are agnostic with respect to how changes in FMD status cause deforestation, one plausible explanation is that being FMD-free and obtaining greater access to export markets raises the average producer price, which in turn

drives expansion of beef production at the extensive margin. Several studies and reports within Brazil add credence to this explanation; Carvalho et al. show that the wedge between producer beef prices in the state of Rondônia when compared to São Paulo was significantly higher prior to the state being certified as FMD-free (Carvalho et al., 2009), and Teixeira et al. (2008) and Costa et al. (2011) document depressed producer prices due to the 2005 FMD outbreak. My results also suggest that FMD outbreaks may cause a drop in deforestation, though this result is not robust when I correct for spatially correlated errors. One factor that may be complicating my ability to robustly estimate the effect of outbreaks on deforestation is that the shift in demand in response to an FMD outbreak is accompanied by a concurrent inward shift in supply due to "stamping out", or culling, of animals that are suspected to be infected or vulnerable to infection. In response to the FMD outbreak in 2005, Brazil slaughtered or destroyed 84,676 animals, more than half of which were in the state of Mato Grosso do Sul (World Organization for Animal Health, 2007). This effect would likely produce an underestimate of the impact of FMD-outbreaks on deforestation (see Empirical Strategy and Identification).

Independent of the mechanism by which becoming FMD-free caused deforestation in Brazil, these results have strong implications for the debate on whether increasing demand for cattle products produced in Brazil will continue to cause deforestation, and for how Brazil can continue to reduce deforestation rates. Prompted by several influential reports (Steinfeld et al., 2006; Greenpeace International, 2009; de Gouvello et al., 2010), the Brazilian government developed a plan for the mitigation of greenhouse gas emissions. In their National Plan for Climate Change (Comitê Interministerial Sobre Mudança do Clima, 2008), Brazil proposed Nationally Appropriate Mitigation Actions (Embassy of Brazil, 2010) which focus on reducing emissions by constraining the land area occupied by extensive cattle ranching, and intensifying cattle ranching in areas already used for ranching. In doing so, they hope to kill several birds with one stone by conserving standing forests, expanding the area available for crop production, and reducing greenhouse gas emissions from ranching.

The cattle sector is, on average, using land more intensively in Brazil and adopting more productive management techniques (Polaquini et al., 2006; Steiger, 2006; Euclides et al., 2010; Millen et al., 2011; Martha et al., 2012; Pacheco and Poccard-Chapuis, 2012). In spite of this fact, the land base in pasture has continued to expand in the Amazon, and many believe that facilitating producer adoption of more intensive production systems—for example through credit programs or government investment in research and development—is the solution to saving forests, curbing GHG emissions, and minimizing the industry's footprint on the landscape. Whether such programs will ultimately decrease the demand for land at the forest margin, however, is uncertain at best (Kaimowitz and Angelsen, 2008; Angelsen, 2010).

My results suggest that changing access to beef export markets during the last decade caused new deforestation in Brazil, even as the industry intensified overall and adopted more productive management techniques. These findings bring into question what combination of policies will be successful in curbing new deforestation for pasture. They also emphasize the importance of

combining policies designed to directly increase the cost of deforestation—such as establishment and enforcement of a revised version of the Forest Code—with policies that are conducive to more intensive and productive land management if Brazil hopes to simultaneously constrain the amount of land used for cattle ranching, curb deforestation for new pastures, and intensify production in areas already dedicated to cattle ranching.

Chapter 3: Potential for heterogeneity in the returns to sub-therapeutic antibiotics in U.S. pork and poultry operations

Introduction

Antibiotics are one of the greatest discoveries of the 20th century in terms of their impact on the quality of human life. Though they were hardly a new concept when penicillin was discovered by Alexander Fleming in 1928[3], the ability to mass-produce, store, and administer antibiotics (such as penicillin) revolutionized health care. Diseases that were formerly major public health problems—such as pneumonia and tuberculosis, gonorrhea and syphilis—suddenly became curable, and early antibiotics such as penicillin and streptomycin were soon hailed as "miracle drugs" for their live-saving properties. Despite these remarkable properties, Fleming himself urged early-on that antibiotics be used prudently due to the potential that resistance would develop with over- or mis-use (Levy, 2002).

Indeed, by the mid-1940s, antibiotic resistance to penicillin was already becoming widespread, and medical experts warned that the trend would only get worse (Levy, 2002). This early evidence of antibiotic resistance foreshadowed the scope and magnitude of the potential problem (Laxminarayan and Malani, 2007). Even so, antibiotic use continued globally in both human and animal medicine while, at the same time, farmers began using low or sub-therapeutic doses of antibiotics in livestock operations to promote growth in addition to using them to prevent and control disease. Today, more antibiotics are used in livestock production and the production of milk and eggs than in humans (Silbergeld et al., 2008). In the United States, roughly 80% of all antibiotics sold are used in animals, though some classes of antibiotics used in livestock production are not used in humans[4].

Each year, more than 50,000 people in the U.S. die from hospital-acquired bacterial infections, and reported cases of "superbugs" such as Methicillin-resistant *Staphylococcus aureus* (MRSA) and vancomycin-resistant enterococci (VRE) are on the rise (Laxminarayan and Malani, 2007). At the same time, millions of episodes of foodborne illness occur in the U.S. each year resulting in, on average, 55,961 hospitalizations and 1,351 deaths (Scallan et al., 2011), most of which are acquired from consumption of produce (though most deaths are attributable to poultry consumption) (Painter et al., 2013)[5]. More than half of ground beef, ground turkey, and pork chop

[3] and had likely been used for centuries prior in many different forms; see Levy (2002), pages 32-35.
[4] FDA reports from 2011 estimated that 3.29 million kg. of antibiotics were sold for human use (FDA, 2012), and 13.5 million kg. of antibiotics were sold for use in animals (FDA, 2011). Of the 13.5 million kg. used in animals, 4.1 million kg. are in the ionophore class which is largely used to treat coccidiosis in poultry (a class not used in human medicine; but many argue that the potential for cross-resistance may still exist).
[5] Scallan et al. (2011) report that more than half of reported cases in the U.S. were caused by norovirus, and the most common patogens after that were Salmonella, Clostridium, and Campylobacter, respectively. The most common causes of hospitalization (ranked from most to less common) were Salmonella, norovirus, Campylobacter, and toxoplasmosis.

samples collected as part of the National Antimicrobial Resistance Monitoring System were contaminated with resistant bacteria in 2011 (NARMS, 2011). There is also evidence that other routine infections, such as urinary tract infections, could arise from bacteria acquired through the food chain (Manges et al., 2007). For people who acquire a resistant infection in their food, in their community, or in a hospital, resistance is associated with a longer duration of treatment and the use of more potent antibiotics, and longer hospital stays for those who wind up in or acquire their infection in a hospital. Increased length of treatment, use of rarer antibiotics, and longer hospital stays mean increased costs to society and to our health care system due to antibiotic-resistant infections (Howard and Rask, 2002; McDonald, 2006; Laxminarayan and Malani, 2007; Roberts et al., 2009; Schaffer et al., 2008). It's still not clear, however, to what degree using antibiotics to promote human health *vs.* using antibiotics in livestock operations bears responsibility for causing resistance or clinical incidence of antibiotic-resistant infections, as well as how different levels of antibiotic use produce differing degrees of resistance in these two uses (McEwen and Fedorka-Cray, 2002; Smith et al., 2002; Phillips et al., 2004; Smith et al., 2005; Marshall and Levy, 2011)[6].

Farm-level or regional data on how antibiotics are used in U.S. livestock operations are virtually non-existent, but as authorized by the ADUFA (Animal Drug User Fee Act), we do collect data on the aggregate volume of sales of antibiotics by pharmaceutical companies that are destined for animal feed. These data tell us that large quantities of antibiotics are used in livestock feed each year (see footnote 4), but little else[7]. There is no information collected or made publicly available on the geographic distribution of their use, on how the production of resistance relates to the level of antibiotic use in livestock operations, or what proportion of clinical cases of antibiotic resistance might be caused by bacteria that originated in livestock or whose resistance gene was produced by the use of antibiotics in livestock operations. What we do know, however, is that veterinary scientists, epidemiologists, and public health researchers have documented the rise of antibiotic resistant bacteria in livestock and on livestock operations (Harper et al., 2010; Larson et al., 2011; Davis et al., 2011; Marshall and Levy, 2011; Price et al., 2012), the transmission of resistant bacteria between livestock of the same species, to other species, and to humans (Harper et al., 2010; Marshall and Levy, 2011; Smith and Pearson, 2011; Feingold et al., 2012; Harrison et al., 2013), and the presence of resistant bacteria in the environment and in retail meat destined for human consumption (Kumar et al., 2005; Price et al., 2005; Sapkota et al., 2007; Hanson et al., 2011; NARMS, 2011; O'Brien et al., 2012).

[6] see Barza (2002) for an excellent summary of the mechanisms by which causality could be established in order to determine an "attributable fraction" of disease incidence, and Salisbury et al. (2002) for a comprehensive framework for risk-assessment.

[7] Prior to the release of data under ADUFA, Mellon et al. (2001) produced one of the first estimates of antibiotic use in U.S. livestock operations. The Environmental Defense Fund also attempted to extrapolate the data from Mellon et al. to generate a geographic distribution of use, but this is based on sweeping assumptions (Florini et al., 2005).

Policy makers in developed countries have approached the threat of antibiotic resistance in dramatically different ways. Operating on the precautionary principle, countries in the European Union have progressively banned the use of over-the-counter antibiotics in livestock, beginning with Sweden in 1986, and followed by Denmark (1998), Poland (1999), and Switzerland (1999), among others. The Danish experience has been closely watched by U.S. animal scientists and producers. While there were challenges in the short term for pork production (due to increases in *Lawsonia intracellularis* and post-weaning multisystemic wasting syndrome *(*PMWS) in pigs) that were met by increased therapeutic use of antibiotics, overall antibiotic use has declined by 90% and the prevalence of resistant bacteria seems to be falling as a result (though there was some debate about whether this was happening early-on in the ban) (Stein, 2002; Hayes and Jensen, 2003; Cogliani et al., 2011).

While the U.S. has never brought legislation calling for a complete federal ban on the use of sub-therapeutic antibiotics in livestock operations before the U.S. House of Representatives or the Senate, the use of flouroquinolones was banned in poultry production in 2005 due to its role in the rise of flouroquinolone-resistant campylobacter (Love et al., 2012)[8]. There have been calls by researchers, doctors, and advocacy groups for the U.S. to follow the lead of the European Union and ban the use of sub-therapeutic antibiotics in livestock operations, but at present, the most important regulations that directly affect the use of antibiotics in livestock operations are the Federal Food, Drug, and Cosmetic Act (FFDCA) which gives the FDA the authority to regulate feed additives and residues in food, and an amendment to the FFDCA, the Animal Drug Fee User Act, which requires antimicrobial drug sponsors to report antibiotics sold or distributed for use in food-producing animals (FDA, 2013a)[9]. The U.S. Food and Drug Administration has also recently issued non-binding guidelines in the form of "The Judicious Use of Medically Important Antimicrobial Drugs in Food-Producing Animals", which recommends that farmers limit the use of antibiotics that are important to human medicine, and the Veterinary Feed Directive, which suggests that some feed additives be used only under the supervision of a veterinarian (FDA, 2013b). There have also been recent attempts to introduce versions of two bills: the Preservation of Antibiotics for Metical Treatment Act (PAMPTA), which would curb use of sub-therapeutic antibiotics and toughen the approval process for use of drugs in food animals, and the Delivering Antimicrobial Transparency in Animals (DATA) Act, which would require the FDA to collect and report antibiotic use by industry, type of use (growth promotion, therapeutic etc.), and by state (Bottemiller, 2013; Slaughter, 2013). Prompted by economists and lawyers who suggest that antibiotics are under-priced and overused and that pharmaceutical companies have little-to-no incentive to invest in the development of newer, more effective antibiotics (Coast et al., 1998; Ellison, 1998; Laxminarayan, 2002; Horowitz and Moehring, 2004; Kades, 2005; Katz et al., 2006; Herrmann, 2010; Herrmann and Laxminarayan, 2010; Fox, 2011), there has been some political

[8] Love et al. (2012) also show evidence of flouroquinolone use in U.S. poultry operations, in spite of the 2005 ban.

[9] The Animal Drug Availability Act of 1996 also amends the FFDCA to give the FDA additional flexibility in approving drugs for use in animals.

momentum behind the idea of issuing patent extensions for antibiotics or wildcard patents to pharmaceutical companies that invest in antibiotic development.

Therefore, despite the fact that no regulations have been passed that directly limit or regulate the routine or sub-therapeutic use of antibiotics in U.S. livestock operations (other than flouroquinolones), there is the movement toward and potential for such regulation. Beginning in the 1970s, economic researchers began to study the potential impacts of such a ban on the pork, poultry, and beef sectors and on U.S. consumers, but there has been little study of how heterogeneity impacts antibiotic use, and in turn, how it impacts returns to using antibiotics in U.S. livestock operations. In this chapter, I concentrate on U.S. pork and poultry operations since they are the largest users of sub-therapeutic antibiotics by volume in the U.S. I begin by summarizing how and why antibiotics are used in pork and poultry production, and then summarize the existing literature on the economics of sub-therapeutic antibiotic use in the U.S.. I then take the few papers that comment on heterogeneity in antibiotic use, and explore them in detail. Only through understanding the benefits producers gain by using antibiotics and how these benefits vary from producer to producer will we be able to weigh the potential cost of regulating the use of sub-therapeutic antibiotics against the potential benefits.

Summary of antibiotic use in U.S. pork and poultry operations

The U.S. FDA first approved the use of antibiotics in livestock feeds in 1951. For both pork and poultry operations in the U.S., antibiotics are used for distinct purposes at different stages of the animal growing cycle, and can be used prophylactically to prevent disease, therapeutically to treat disease, and for growth promotion. Both prophylactic and growth promotion uses of antibiotics, depending upon their application, can be considered sub-therapeutic use. In the case of poultry, antibiotics are first used prior to hatch in order to minimize the transmission of bacteria (such as *Mycoplasma sp.*) from mother hen to unhatched chick. These antibiotics are sometimes administered by dipping the egg in such a way that the antimicrobial penetrates the shell, but more recently, are administered via injection or vacuum techniques. Antibiotics are then commonly used prophylactically to reduce mortality among young chicks, and to prevent infection when chicks are especially vulnerable to infections (such as *E. coli*) in the post-vaccination period. In general, antibiotics are used prophylactically on adult birds to control infections such as colibacillosis, airsacculitis, *Staphylococcus sp.,* omphailitis, and *Mycoplasma sp.*, and to combat Coccidiosis, which is most commonly controlled by ionophore use (among other coccidiostats) (Burbee et al., 1985; NRC, 1999; Prescott et al., 2000). Of the 32 antimicrobials that were FDA-approved for use without a prescription in broiler feed in 2002, 15 were listed as treatments for coccidiosis, 11 as growth promotants, and 6 for other purposes (Jones

and Ricke, 2003). Among those used to control disease but less frequently for growth promotion are floroquinolines[10], gentamicin, cetiofur, and others (McEwen and Fedorka-Cray, 2002).

The use of antibiotics to promote growth in poultry operations has been shown to increase rate of weight gain, increase feed conversion, and decrease mortality (NRC, 1999; Emborg et al., 2001; MacDonald and Wang, 2011). The effect of sub-therapeutic antimicrobials on feed conversion rates and weight gain is thought to be primarily due to the control of enteric bacteria in the gut and intestine of birds, with possible secondary effects on the weight, length, and width of epithelial wall in the animal's intestines, both of which increase nutrient absorption and reduce the potential for necrotic enteritis caused by bacteria such as *Clostridium sp.*(NRC, 1999; Dibner and Richards, 2005; Ferket, 2007; Graham et al., 2007). The drugs most commonly used as feed additives for growth promotion in poultry are bacitracins, bambermycin, lincomycin, and virginiamycin (NRC, 1999).

For U.S. pork producers, like poultry producers, antibiotics are used for three purposes: disease prevention, disease treatment, and growth promotion. When used in treating disease, antimicrobials are typically used at higher doses and for shorter periods of time (weeks), while sub-therapeutic doses are given prophylactically or for growth promotion purposes (months) (Dewey et al., 1999). Data from the National Animal Health Monitory Survey (NAHMS) between 1989 and 1991 suggested that antimicrobials were most frequently used continuously (51% of feeds contained antimicrobials that were fed continuously), whereas only 4% of feeds contained antimicrobials being used to treat disease (Dewey et al., 1999). Data from the 2004 Agricultural Resource Management Survey (ARMS) of the USDA suggest that more than 40% of producers in farrow-to-finish and feeder-to-finish operations use antibiotics for growth promotion during finishing, and that more than 80% of producers use antibiotics for disease prevention and disease treatment for nursery pigs on wean-to-feeder operations (McBride et al., 2008). These data support the consensus in the literature that the use of antibiotics and sub-therapeutic levels of antibiotics is most critical during the weaning of piglets and the early growing stages; during this time piglets are more vulnerable to disease, and also respond more quickly to lower doses of antibiotics (Burbee et al., 1985; Cromwell, 2002). Some of the most problematic diseases in swine operations are pneumonia, bacterial diarrhea (caused by bacteria such as *E. coli* and *Clostridium perfringens*), and swine dysentery, and the most important antimicrobials used are tetracyclines, tylosin, and sulfa-based antibiotics (McEwen and Fedorka-Cray, 2002).

Using antibiotics as growth promoters in pork operations also increases weight gain, improves feed efficiency, and decreases mortality, and this is likely via the same mechanisms hypothesized for poultry (Wade and Barkley, 1992; NRC, 1999; Cromwell, 2002; Dritz et al., 2002). Estimated increases in weight gain in experimental settings are between 4.2% for the growing-finishing stage and 16% for the starting phase, and (experimental) estimates of increased feed efficiency are between 2.2% for finishing pigs and 6.9% for starter pigs (Matthews, 2001; Cromwell, 2002).

[10]Floroquinolones were banned in the U.S. in 2005, but were used prior.

Cromwell (2002) suggests that these numbers may be even higher in actual pork operations when compared to experimental settings, especially when the animals are under additional stress, but Miller et al. (2003) use the National Animal Health Monitoring System (NAHMS) data to estimate that improved weight gain and feed efficiency during the finishing phase are only about 1.1% and 0.5%, respectively, for U.S. farms between 1990 and 1995. Miller et al. (2005) also apply econometric methods to the 2000 NAHMS data to look at whether sub-therapeutic antibiotics had significant impacts on average daily gain, feed conversion, and mortality, but find that they only have a significant impact on daily gain (see next section).

Economics of antibiotic use: quantifying the potential benefits to production

In the previous section, I presented a summary of the types of benefits that antibiotic use conveys to pork and poultry production systems in the U.S. In this section, I review the literature that attempts to translate these potential benefits—improved weight gain and feed efficiency, and reduced mortality, morbidity, and sort loss—into economic terms. I focus on research from the last two decades, with emphasis on more recent research. Methodologically, these studies fall into several categories:

(1) Studies that make assumptions about how production parameters would change if the use of antibiotics were partially or fully banned, and make back-of-the-envelope calculations based upon their assumptions to calculate the total impact on U.S. pork or poultry producers and/or consumers (e.g. Gilliam and Martin, 1975; Hayes et al., 1999; Hayes et al., 2001; Hayes et al., 2002).
(2) Studies that use industry data or data from experimental research at land-grant university experiment stations to develop estimates of average, total, or differential impacts of antimicrobials on production parameters, and translate these into economic terms (e.g. Engster et al., 2002; Graham et al., 2007; Hogberg et al., 2009).
(3) Studies that use statistical or econometric methods to analyze data from representative national surveys of pork or poultry producers, such as the USDA's Agricultural Resource Management Surveys (ARMS) or the USDA's National Animal Health Monitoring System (NAHMS). These surveys often include data on antibiotic use, costs of production, and other information that help get at the relationship between how using antibiotics affects production costs or economic profit (e.g. Miller et al., 2003; Liu et al., 2005; Miller et al., 2005; McBride et al., 2008; MacDonald and Wang, 2011).
(4) Studies that use partial equilibrium models of the meat industry to simulate impacts of antibiotics bans on producer and consumer welfare (e.g. Mann and Paulsen, 1976).

In the next two sections, I divide several relevant studies by sector (pork and poultry) and discuss their findings.

Economics of antibiotic use in U.S. Pork operations

How do we quantify, in economic terms, the net benefit of routine use of sub-therapeutic antibiotics to pork producers? Several early studies on the impacts of eliminating antibiotic use in animal feed were prompted by the establishment of the FDA of a task force of scientists to review the science of the use of antibiotics in animal feed (and the potential economic impact on livestock producers and consumers). Two early studies that followed this request used a partial-budgeting approach (Gilliam and Martin, 1975) and a partial-equilibrium simulation model (Mann and Paulsen, 1976) to evaluate the impact of restricting or eliminating antibiotic use on supply of and demand for pork. Gilliam and Martin (1975) assume that, in the case that antibiotics were banned completely in animal feeds, producers would do one of two things: maintain supply at previous levels by increasing the number of animals fed, or allow supply to decline while the number of fed animals remained constant. In the first scenario, they estimate the total net increase in production costs for the additional hogs at $533 million, which would translate into an increase in cost of $2.88 per hundredweight or a $0.057/lb increase in the average retail price of pork in 1973. When they include an estimate of increased mortality, the expected impact on the retail price of pork is an additional third of a cent per pound. For the second scenario, when supply declines (without mortality effects), they estimated that retail prices would increase by $0.19 cents/lb., and that producer profits would increase by $15.69/head. Clearly, this study would fit in category (1) from our methods typology, and considers only the *short-term* impacts on producer profits and retail pork prices.

Mann and Paulsen (1976) simulate demand and supply in U.S. meat markets (beef, hogs, lamb, broilers, and turkeys) between 1962 and 1972 to estimate the potential (future) impact of banning antibiotics in animal feeds on prices, meat consumption, returns to production, and consumer welfare[11]. Assuming certain changes in production efficiency following a ban[12], their results suggested that the most significant changes would happen in the pork industry. In the short run, they estimated that supply would decline and lead to a 4.5% increase in both the price of pork and average profit for pork producers. After several years, their simulation suggested that returns-per-head would have changed little for livestock and poultry producers, but that consumer welfare would have declined due to increased prices.

Following bans on over-the-counter use of antibiotics in animal feed in Sweden, Norway, Finland, and Denmark in 1986-1998, Hayes et al. (1999), Hayes et al. (2001), Hayes et al. (2002) and Hayes and Jensen (2003) apply some changes in production parameters in Sweden and Denmark to look

[11] The authors detail their methods for the pork sector, and use both short- and long- run adjustment equations that incorporate the quantity of barrows and gilts slaughtered, sow farrowings, pigs saved per litter, hog price, change in hog price, quarter dummies, and input prices.

[12] "Three biological responses were explicitly acknowledged for each livestock and poultry class: first, lower daily rate of gain; second, increased feed and other input requirements per unit of meat; third, higher mortality and lower reproduction rates. Stock-to-slaughter coefficients and reproduction variables like pigs saved per litter were reduced to reflect increased livestock and poultry mortality." (Mann and Paulsen, 1976; pp. 49)

at the potential impacts of a ban on feed-grade antibiotics in U.S. pork production. Using the changes in production parameters before and after the ban, Hayes et al. (1999), Hayes et al. (2001), and Hayes et al. (2002) develop three scenarios (Best, Most Likely and Worst Case) to simulate the potential impacts of the ban on production in the U.S.. The "Best" scenario assumes that the only impact of such a ban would be on piglet mortality (increase by 1.5%) with some additional capital investment in nursery and finishing spaces, whereas the most significant differences in the "Worst" scenario are that the authors assume that piglet mortality would be much higher (+4% when compared to +1.5%) when compared to the Best or Most Likely scenarios, and that the number of days needed from weaning for the piglet to reach a weight of 25kg would increase by 12. Under the "Most Likely" scenario, the authors calculate that the costs per head[13] would increase by between $6.05 (short-run) and $5.24 (long-run; after 10 years), but that profit would only decline by $0.79 per head (long-run) due to increased prices. Consumer prices increase by $0.05/lb under this scenario. Hayes et al. (2003) modify these numbers slightly; they estimate that costs per head would increase by $4.50 in the first year, of which increased costs in the finishing stage account for $1.50, increased costs in the weaning stage account for $1.25, and increased veterinary and vaccination costs account for $0.25 and $0.75; sort loss accounts for $0.65 and capital costs for $0.55. They estimate that these increased production costs would result in a 2% increase in retail pork prices. Hayes et al. (2002) present the same results, but discuss the implications for marketing technologies and supply chains, and the impact of heterogeneity in management and production technologies on the impacts of a ban.

Brorsen et al. (2002) model supply and demand for pork using production and elasticity values from the literature to estimate distributions of potential benefits to producers of using STAs (impacts of STAs on feed to gain ratio, mortality, and sort-loss). They assume that a ban on sub-therapeutic antibiotics can be modeled as an inward shift in supply, and their general results support the results from the Hayes et al. (1999, 2001, 2002) studies; they find that producers bear the largest portion of the cost of adjustment in the short-run, but that after an adjustment period, the burden falls upon consumers. Unlike many of the other studies mentioned here that use a partial equilibrium approach, they allow poultry and beef to be substitutes for pork.

In the last 10 years, the USDA has begun to collect some data on animal health, antibiotic use, production practices, and costs of production in U.S. pork operations as part of the National Animal Health Monitoring System (NAHMS) survey and Agricultural Resource Management Survey (ARMS). Miller et al. (2003) and Miller et al. (2005) use farm-level data from the NAHMS survey to estimate the relationships between the use of antibiotic growth promoters (AGPs) and productivity (Miller et al., 2003), and to then evaluate the impacts of a full ban and partial ban[14] (between 61 and 90 days) on U.S. pork grower/finishers (Miller et al., 2005). In order to estimate

[13] These costs include reduced productivity due to changes in growth, feed conversion, and mortality; investments in capital (troughs and additional space); and sort-loss.

[14] Because the majority of the benefits of antibiotic use to pork producers happen during the early growing phases, the idea is that a full and partial ban might have significantly different impacts on costs and productivity (i.e. if antibiotic use were banned only in the finishing phase).

the impacts of AGP use on productivity, Miller et al. (2003) use NAHMS data from 1990 and 1995 and estimate relationships between AGP use and productivity measures (feed conversion ratio, average daily gain, and mortality rate) using backward stepwise maximum likelihood regression where the feed conversion ratio and average daily gain were estimated jointly via seemingly-unrelated regression. They found significant associations between AGP use and improved (lower) feed conversion (estimated at 1.1%), and AGP use and higher average daily gain (estimated at 0.5%), though using more than one antibiotic had the opposite effect on feed conversion. Mortality was also significantly lower when AGPs were fed for longer periods of time (estimated at 0.2% lower). Using these estimates, the authors calculate that, on average, using AGPs conveys an additional $0.59 net return per pig, which they contextualize as being approximately 9% of the total net return per pig in Illinois in 2000.

In a second study using data from the 2000 NAHMS swine survey, Miller et al. (2005) update their previous (2003) study of the impact of AGPs on productivity, as measured by average daily gain, feed conversion ratio, mortality rate, and a new measure: stunted rate. They then run OLS regressions for each, and seemingly unrelated regressions for all four dependent variables, with independent variables that addressed antibiotic use, animal health and disease prevention, management and biosecurity, and feeding practices. In this analysis, they were able to evaluate the impact of feeding AGPs at different times, and found that average daily gain was highest when AGPs were fed between 61 and 90 days (5.6% higher than no AGP use). When controlling for confinement, all-in all-out production, number and variety of rations, and regional variability, the authors found that AGP use did not have a significant effect on feed conversion. AGPs did not generally have a significant impact on mortality, but the stunted rate was significantly lower when AGPs were used between 61 and 90 days. In order to estimate the economic impacts of improved productivity due to AGP use, Miller et al. (2005) model two scenarios using a partial budgeting approach: a complete ban on AGPs and a partial ban on AGP use after 90 days. Importantly, they also assume that producers not currently using AGPs *use AGPs between 61 and 90 days but discontinue use after that period.* In the first scenario, they estimate that banning AGPs decreases the net return per pig by $1.37, but that a partial ban combined with increased use during the 61-90 period would increase the net return per pig by $1.95.

The most recent study that uses producer data to look at the impact of feed antibiotics on hog productivity is McBride et al. (2008). Using data from the Agricultural Resource Management Survey (ARMS) of the USDA , the authors use a two-stage Heckman model to first estimate the farmer's decision to use sub-therapeutic antibiotics (STAs) via Probit, and then use predicted antibiotic use in OLS estimation of the determinants of productivity (where the dependent variable is $\frac{\text{cwt of hog production}}{\$ \text{ of total factor cost} \cdot 10^{-2}}$). Surprisingly, they found that STA use had a negative and significant relationship with productivity during finishing, but found a significant and positive impact of STA use on productivity during the nursery stage of production. The authors do not directly extrapolate from their results to estimate how producer profits or retail prices would be affected by discontinuing STA use, but do discuss how some of their results imply that

heterogeneity amongst producers will cause the effects of a ban to vary widely from farm to farm. I discuss this study in greater detail in the section on heterogeneity.

At least a few studies discuss the potential relationship between the use of sub-therapeutic antibiotics and risk-reduction in pork production. This relationship could, in theory, take at least two forms: 1) use of STAs reduces output/profit risk by reducing variability in finishing weight of live animals and 2) use of STAs reduces output/profit risk by reducing the risk of mortality in the herd or risk related to veterinary costs due to a disease event. To date, the existing literature mainly addresses the first of these. Liu et al. (2005) econometrically estimate the relationship between use of antibiotic growth promoters (AGP) and mean live market weight, and the relationship between use of antibiotic growth promoters and the standard deviation of live market weight. Both fitted models are quadratic, and suggest that use of AGP increases live market weight up to 77 days of use, and decreases variation in live market weight up to 64 days of use. Assuming no market price risk, they then estimate stochastic budget models based on mean weight and variations in live weight, and compare and rank one set of profit distributions using 1st, 2nd, and 3rd order stochastic dominance analysis. The stochastic dominance analysis suggests that risk-averse producers would prefer to administer AGP up to 65-75 days, and that all producers (independent of risk preferences) would prefer AGP use to no-use. According to their model, increased mean weight and decreased weight variability due to AGP use in the 65-75 day range translates into increased profit of approximately $2.99/pig relative to no AGP use. Results from McBride et al. (2008) support Liu et al. (2005); they find that variance in estimated total factor productivity was significantly lower for STA users when compared to non-users.

Economics of antibiotic use in U.S. poultry operations

Fewer studies have targeted the economic benefits of sub-therapeutic antibiotic use in poultry operations or estimated the costs of discontinuing use, perhaps because the benefits are assumed to be greater for pork producers. Mann and Paulsen (1976), as mentioned in the previous section, simulate demand and supply in U.S. meat markets (beef, hogs, lamb, broilers, and turkeys) between 1962 and 1972 to estimate the potential (future) impact of banning antibiotics in animal feeds on prices, meat consumption, returns to production, and consumer welfare. While their results suggested that the most significant changes would happen in the pork industry, they estimate a short-term peak in broiler prices at 2.2% higher than the baseline price, and estimate that returns over the long-run return to roughly pre-ban levels.

Within the last decade, Engster et al. (2002) and Graham et al. (2007) use the same data from a randomized trial conducted by the Perdue company between 1998 and 2001 to evaluate the impact of AGPs on mortality, weight, feed conversion, and potential costs of production. Engster et al. (2002) report that mortality increased by 0.14% in North Carolina, on average, over the 3 year trial, and by 0.2% on the Delmarva peninsula, while body weights decreased by 0.04 and 0.03 and feed conversion ratios increased by 0.012 and 0.016 in NC and on the Delmarva peninsula,

respectively. Variability in weights increased in both locations. Using these data, Graham et al. (2007) apply average feed costs, AGP costs, liveweights, feed conversion ratios, mortality rates, and payments paid to growers obtained from various sources to develop estimates of the differences in costs to producers that result from AGP removal, as determined by the Engster et al. (2002) estimated productivity changes. They estimate that a negative net return to AGPs of about 0.45% of total cost, or $0.00093 per chicken, though these estimates exclude potential impacts to net returns of any changes in veterinary costs or reduced variability in bird weights, and are based upon estimated average grower fees (see MacDonald and Wang (2011), footnote 7 on page 83 for why this may matter).

In the most recent and thorough look at the use of STAs in U.S. poultry production, MacDonald and Wang (2011) use data from a sample of U.S. poultry producers from the 2006 Agricultural Resource Management Survey to estimate the determinants of STA use in poultry production, and then estimate a production function. They use a nearly identical estimation approach to McBride et al. (2008), and first estimate the producer's decision to use STAs without a Hazard Analysis and Critical Control Point Plan (HACCP plan), or to not use STAs and use an HACCP plan[15]. They then estimate production models (where the dependent variable is log annual liveweight pounds removed). They find no statistically significant differences in production given inputs, operator characteristics, and operation characteristics for STA users and non-users, but do find that contract fees paid to growers that do not use STAs are approximately 2.1% higher when controlling for contract features and other variables, which the authors attribute to higher costs of production when STAs are not used (though, they also note that it could be due to improved performance/higher quality). I discuss some of the authors' findings and how they relate to potential heterogeneity in production and costs of eliminating STA use in the next section.

Use of sub-therapeutic antibiotics and producer heterogeneity

There are few papers that explicitly discuss how producer heterogeneity might impact which producers choose to use antibiotics, and how this, in turn, might have implications for the costs of reducing antibiotic use in U.S. pork and poultry systems. There is, however, a rich literature within economics that looks at how heterogeneity impacts the adoption of other agricultural technologies, such as irrigation technologies or improved seed varieties, and agricultural technology in general (Feder et al., 1985; Caswell and Zilberman, 1986; Khanna and Zilberman, 1997; Wu, 2000; Sunding and Zilberman, 2001; Chavas et al., 2010).

There are also glimpses of factors that might generate heterogeneity in returns to antibiotic use within the existing literature on the economics of antibiotic use in U.S. pork and poultry

[15] According to ARMS data, 42.4% of operations (44.3% of production) reported that their contractor/buyer required that broilers were raised without antibiotics in their feed or water. This is consistent with more recent estimates of STA use in U.S. poultry operations; Chapman and Johnson (2002) reported that 33% of operations used no STAs in the year 2000.

operations. These factors include spatial/geographic heterogeneity; heterogeneity in farm size, returns to scale, and contracting arrangements; and heterogeneity in farmer characteristics, management ability, production practices, and input use.

Spatial heterogeneity in the returns to sub-therapeutic antibiotic use could arise for a number of reasons, including geography of input or processing markets (it might be cheaper to obtain medicated feeds in some locations vs. others, or via particular integrators), and geographic factors that might affect the epidemiology of particular diseases or prevalence of sub-clinical levels of potentially harmful bacteria (such as temperature, moisture/humidity, endemic disease). Jones et al. (2005), in a controlled experiment, demonstrate the importance of temperature and humidity for bird welfare and overall stress (which is a risk factor for infection). The association between livestock and wild animals or rodent populations also affects disease risk and is related to geographic variables; Garber et al. (2003) found more *Salmonella enterica* in poultry houses with higher rodent populations, and found the highest prevalence in the Great Lakes region (much lower in the southeast). See Collins and Wall (2004) for an overview of some of the factors that affect disease prevalence and zoonotic risk in poultry production.

There is some evidence to support the existence of regional differences in antibiotic use and production parameters within the U.S. for pork operations; Miller et al. (2005) found associations between farms being located in the South and higher mortality rates and lower feed conversion rates in pork operations when compared to other regions (and controlling for antibiotic use), and an association between being located in the West/Central U.S. and lower stunted rates when controlling for other factors (including antibiotic use). Descriptive statistics from McBride et al. (2008) suggest that use of STAs for finishing and in nursery operations is highest in the Midwest and lowest in the East (NC, VA, PA) and in the West (CO, KS, NE, OK). In their selection equation for AGP use, being located in the West was negatively and significantly associated with use when controlling for other factors, and in their second stage estimates of productivity, being in the East was significantly and negatively associated with factor productivity.

For poultry production, MacDonald and Wang (2011) found that location in California was a significant and negative contributor to production in broiler operations when controlling for other factors, though they note that this may have something to do with limited observations, high mortality, and antiquated production systems in the California sample. In a controlled trial that looked at changes in mortality rates, feed conversion, and body weight when AGPs were removed from poultry operations on the Delmarva Peninsula and in North Carolina, Engster et al. (2002) found that the effect of AGP removal on body weight differed in the two locations. In North Carolina, the effect of AGP removal on bird weight was larger and more immediate, but then improved over time—whereas on the Delmarva peninsula, there was less of an immediate impact in the short term, but a longer-term consistent, negative impact.

There doesn't appear to be any speculation in the literature about how the possible existence of regional monopsonists/monopolists in the pork or poultry processing industries may impact STA

use[16]. It seems reasonable to assume, if integrators are making many of the decisions about STA use and specifying them as part of a contract, that STA use will vary regionally just as the market share of different integrators or processors likely varies by region. The question of how (regional) market power (if it exists) relates to STA use is worthy of further study.

During the last century, agriculture in the U.S. has become more and more concentrated and specialized, and the pork and poultry industries exemplify this trend, especially through the use of contracting. Use of sub-therapeutic antibiotics has increased, though there are hints of a decline in average use in the last decade (Dimitri et al., 2005; MacDonald and McBride, 2009). To what degree, then, are farm size (and potential for returns to scale) and concentration in production associated with antibiotic use, and how could potential heterogeneity in these variables relate to the benefits/costs of STA use or the removal of STAs? Results from Miller et al. (2005) suggest that "confinement," rather than antibiotic use per-se[17] is associated with improved feed conversion on pork operations, but is also associated with a higher stunted rate. McBride et al. (2008) show descriptive statistics that indicate that, for the smallest size class(less than 500 hogs), a significantly larger proportion of producers do not use STAs vs. use STAs in finishing; similarly, for all other size classes, a significantly larger proportion of producers use STAs for finishing compared to those that don't. Of the producers who use closed confinement finishing facilities, significantly more use STAs (84% compared to 49%); and of producers with a contracting arrangement, more use STAs, though the difference is not statistically significant. The differences in means are similar for nursery operations.

When the same authors estimate the determinants of the decision to use STAs, they find that closed confinement and specialization are positively and significantly associated with the decision to use STAs in feeder-pig-to-finish operations when controlling for other factors, but that size is not significant (no scale bias for STA selection). Confinement is also positively and significantly associated with the decision to use STAs in farrow-to-finish operations. In the productivity equations, however, all three size classes that are larger than 500 hogs are positively and significantly associated with total factor productivity, as is having a production contract for finishing (in the feeder-to-finish operations)[18]. Thus, while larger pork operations may be more likely to use STAs, the work of McBride et al. (2009) suggests this effect is not due to any economy of scale associated with antibiotic use, but rather due to other factors, such as larger farms being more likely to use confinement facilities where conditions are more stressful for animals and it is more difficult to control disease without antibiotic use. Heterogeneity in farm size, returns to scale in antibiotic use, and confinement are less relevant for poultry operations as

[16] Four-firm concentration ratios from the U.S. Census Bureau indicate moderate concentration in processing in the livestock industry (see: http://www.census.gov/econ/concentration.html).
[17] The authors drop non-significant variables from the estimation in a procedure similar to step-wise regression. Thus, it could be that antibiotic use variables and confinement variables have a large covariance.
[18] Once again, McBride et al. (2008) found that STA use was negatively and significantly associated with productivity during finishing; interestingly, they don't include any interaction terms between STA use and other variables in any of their productivity regressions.

production is more standardized and decisions about antibiotic use are often made by the integrator. Still, MacDonald and Wang (2011) find modest returns to scale that they hypothesize are due to the ability to increase capacity by growing larger birds in more modern houses.

Perhaps the most interesting category of potential heterogeneity in broiler and pork operations relevant to antibiotic use is the potential for heterogeneity in management variables and health and sanitation practices. There is growing evidence that the use of sub-therapeutic antibiotics might have the greatest marginal benefit for operations that are unsanitary or poorly-managed, i.e. that STA use is a substitute for other inputs to production, such as management effort or ability (Secchi and Babcock, 2002). Hayes et al. (1999, 2002) suggest that the costs of a ban will be greatest for producers that do not use all-in-all-out production, and for producers with larger, more modern facilities. Cromwell (2002) also notes that responses of antibiotics in swine operations are greater in dirty when compared to clean environments.

Hogberg et al. (2009) use production costs as a proxy for unobservable management styles and skill[19]. They use data from JBS United, a feed company, together with estimated production changes due to antibiotic use from Cromwell (2002) to do simple accounting simulations of production—and in turn, cost—changes. Dividing producers up into high, medium, and low cost groups, they find that higher cost and lower profit (i.e. smaller) producers are most likely to become unprofitable in the event of a complete ban on AGPs *if prices do not adjust*, though the economy of scale effect is less marked for breed-to-wean producers. Furthermore, despite the fact that smaller/higher-cost producers are more likely to go out of business in the event of a ban, the authors find that overall economies of scale are reduced by the removal of AGPs. Because they are unable to truly tease out the effects of management, their results read more like a discussion of how AGPs affect economies of scale than how AGP use and profits are related to good vs. poor management. The most suggestive evidence to date that sub-therapeutic antibiotics are a substitute for management or other factors is a subtle result from McBride et al. (2009) in their estimation of total factor productivity in pork operations from the 2004 ARMS survey:

> *"…the operations that fed STA to nursery pigs were otherwise, on average, less productive than other operations due to unmeasured factors. Therefore, feeding STA to nursery pigs may be compensating for differences in management, the quality of production inputs, or other unobserved aspects of the hog operation"* (McBride et al., 2009; pp. 285)

MacDonald and Wang's study using the 2006 ARMS data for broiler operations (MacDonald and Wang, 2011) is also suggestive that STAs are a substitute for other elements of management or sanitation practices:

[19] There are potential problems with this approach, including that some costlier practices, such as prevention programs that improve animal heath could be thought of as high-cost, but "good" management. The authors note that high-cost producers tend to be smaller, and low-cost producers tend to be larger (which mostly seems to capture economies of scale in swine production) but still decide to use low-cost as a proxy for high management capacity.

> *"Seventy-five percent of STA nonusers also use an HACCP plan; those farms are considerably more likely than other groups to test flocks and feed for pathogens, to fully clean out their houses after each flock, to feed exclusively from vegetable sources, to use all-in-all-out production, and to follow specified animal welfare guidelines. STA non-users who do not also have an HACCP program are more likely to test for avian influenza, clean their houses out, and feed from vegetable sources than STA users."* (MacDonald and Wang, 2011; pp. 86-87) [20]

They also find that operations that do not use STAs are more modern in general, and are more likely to have newer houses and use tunnel ventilation/evaporative cooling, and find that the variables mentioned above (testing for avian influenza, animal welfare practices, cleaning houses after each flock, all-vegetable feed) are strongly associated with not using STAs when the authors estimate the determinants of using or not using STAs with a regression model. Perhaps due to the fact that these decisions are made at the level of the integrator (rather than at the farm level), operator and housing characteristics have little estimated impact on STA use.

Discussion and Conclusions

Current and historical production practices vary widely with respect to the use of sub-therapeutic antibiotics in U.S. pork and poultry operations. While sub-therapeutic antibiotics are one way to control sub-clinical infection and improve feed efficiency in confined production facilities, modern producers have a suite of management tools available, some of which will likely substitute for STA use (see, e.g., Wierup, 2000). In poultry operations, nearly half of producers report that their integrator requires no sub-therapeutic antibiotic use, and early studies of U.S data suggest that producers that compensate by implementing improved sanitation practices and modernizing their facilities see little drop in productivity or increase in mortality, though it's possible that their costs of production increase and are compensated by increased grower fees (see MacDonald and Wang, 2011). Data from U.S. producers in the past decade also suggest that there is little economic or productive advantage to using STAs in hog finishing operations, but STA use appears critical to raising and weaning piglets in confinement nurseries using current technology. This supports reports of challenges during the first few years in Europe after STA bans were implemented.

The subject of this essay has not been to comment on whether regulation or policy intervention is warranted in the case of antibiotic use in animal operations, though most economists agree that antibiotics are overused in both human and animal populations, and some type of policy intervention is both justified and necessary to reduce the externality of resistance (Laxminarayan and Brown, 2001; McNamara and Miller, 2002; Anomaly, 2009). Instead, I hope to call attention

[20] HACCP plan stands for a Hazard Analysis and Critical Control Point plan, and means that the producer has used hazard analysis to identify, evaluate, and control food safety hazards via monitoring and corrective actions.

to several points. Firstly, sub-therapeutic antibiotics are still widely used in U.S. pork and poultry operations, but many producers are producing without them, or reducing their use. This could be, in part, due to price premiums for higher-quality products and increasing consumer demand for such products (see Kohler et al., 2008), or the perceived threat of regulation. It follows that, if restrictions on STA use were to be implemented, producers will be differentially impacted. Productivity and use of technologies that substitute for STA use vary amongst producers, and likely by region and farm size. Thus, the marginal abatement costs of reducing STA use vary across producers, production systems, and regions. They also vary by industry; the pork industry would be more severely impacted than the poultry industry by potential regulation, and producers who produce in farrow-to-finish, farrow-to-wean, or farrow-to-feeder pig operations (i.e. any operation that has stages other than finishing) will likely be more adversely impacted than feeder-to-finish operations.

Although we urgently need future research designed to better understand heterogeneity in marginal abatement costs or the heterogeneous impacts of regulation or policy on pork and poultry producers, there are many studies that have attempted to quantify the (average) welfare effects of a ban on STAs by looking at how a ban would increase producer costs, and in turn, retail prices. Beyond only limited treatment of heterogeneity, the existing research also does not estimate the marginal external cost of antibiotic use in animal operations, the elasticity of antibiotic use in agriculture with respect to changes in the price of antibiotics, or the potential external costs of *eliminating* antibiotic use in animal operations[21]. Without data on how the production of the externality (resistance) relates to antibiotic use in animal operations (on which there is also no data), generating a reasonable estimate of the marginal social benefit of reducing or banning STA use is also close to impossible.

[21]Potential external costs of limiting antibiotic use in animal operations could include (among other things): increased incidence of foodborne illness (though the opposite may also happen, and the European experience suggests that this may not be an issue), or increased need for animal feed due to decreased feed conversion efficiency and associated impacts on land-use change and carbon emissions.

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