Valuing the Absence of Feral Swine for US Corn, Soybean, Wheat, Rice, and Peanut Producers and Consumers. A Partial Equilibrium Approach

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1 Introduction

Conflicts between humans and wildlife are manifestations of inevitable divergences between human interests and wildlife presence and survival. Those conflicts can range from property damage to threatening and predatory behavior (U.S. Department of Agriculture APHIS 2015). In the United States, considerable financial resources are dedicated to managing human-wildlife conflicts. In 2014, the USDA allocated $106 million to the Wildlife Services division of the Animal and Plant Health Inspection Service for a portion of the federally funded human-wildlife conflict mitigation efforts (U.S. Department of Agriculture 2015). Among policy makers and researchers interested in human-wildlife conflicts, one species of particular recent interest is feral swine. The USDA has dedicated $20 million to support the ambitious goals to "eliminate feral swine from two States [sic] every three to five years and stabilize feral swine damage within 10 [sic] years" (Bannerman and Cole 2014).

Feral swine were introduced by Spanish Conquistadors to the southeastern United States and California in the sixteenth century and by Polynesians to Hawaii in the fourth or fifth century (Bevins et al. 2014; Kirch 1982; Mann 2006; Mayer and Brisbin 2008). By 1982, feral swine were present in 699 counties in nineteen states, primarily in the southeastern United States (Mayer and Brisbin 2008). Over the next thirty years, feral swine spread at an accelerated rate across the United States affecting 1,323 counties in 39 states (Bevins et al. 2014; Lutman 2013). The 624 counties feral swine moved into between 1982 and 2012 comprised a land area of approximately 1.9 million square kilometers, which is more than the combined land area of Texas, California, Montana, and New Mexico.

Feral swine are regarded as native wildlife in areas where they have been present for decades and control efforts by non-locals are met with resistance (Warner and Kinslow 2013; Weeks and Packard 2009). The opposite reaction holds in states where feral swine have come to reside over the past few decades, residents and policy makers in these states have regarded the introduction as a problem that needs to be addressed (Lawrence 2013; Michigan DNR 2016; Myers 2015; Wisconsin DNR 2014). One reason for the negative reception in these states is the property damage they inflict.

Feral swine are known to cause damage to crops among other types of property damage. Pimentel, Zuniga, and Morrison (2005) provide the only published research with a nationwide estimate of feral swine damage in the United States, estimating $800 million in crop and environmental damages per year. This estimate was an important step forward in discussing feral swine damages in monetary terms. More recent estimates have suggested that this $800 million figure may be understated. For example, Mengak (2012) found that 9.7 million acres in Georgia suffered $57 million in crop destruction in 2011. According to U.S. Department of Agriculture NASS (2014), this region in Georgia is responsible for approximately one-percent of total US crop sales. It seems plausible that by incorporating other types of property damage, the damage figure reported by Mengak (2012) would be much higher. By extending this analysis across 39 states with an estimated land area of more than 800 million acres, actual destruction losses would be substantially more than the figure reported by Pimentel, Zuniga, and Morrison (2005).

Damage estimates provided by Mengak (2012) and Pimentel, Zuniga, and Morrison (2005) are part of the foundation of knowledge required to arrive at an economic value of removal. However, they do not reflect a more complex reality. When crops are damaged the quantity brought to market decreases. Markets adjust to the lower quantities with higher prices. Farms suffering damage have less to sell at the higher market prices and farms that do not suffer damage have the same quantity at higher market prices. Changes in producer and consumer welfare describe if individuals are better or worse off from a given policy action or market change. To date, there are no studies that assess the welfare implications of feral swine crop damage. To address this need in the literature, we ask the following questions: *what are the welfare effects to US crop producers and consumers from an immediate removal of feral swine in nine southeastern US states? What would be the distribution of those effects?*

After reviewing the literature in the next section, a partial equilibrium model is presented based on historical US production data from USDA NASS, feral swine presence data from USDA APHIS, and feral swine damage estimates a recent USDA survey reported by Shwiff et al. (Forthcoming). The result of this model is a counterfactual to the current reality of feral swine damage to value the absence of feral swine. Results indicate that the magnitude and distribution of effects is sensitive to elasticities chosen. A simulation was undertaken to estimate the probability of welfare outcomes and there is a high probability for positive outcomes for all parties.

2 Literature Review

Feral swine have been present for centuries in some states, and in the last 30 years they have expanded their range dramatically. With this range expansion has come a realization that feral swine can be both a problem and an opportunity. This section details the literature's previous efforts of quantifying the costs and benefits of feral swine and then will explore the literature related to a promising technique previously unused in wildlife cost-benefit analysis.

Feral swine damage crops and property (Adams et al. 2005; Higginbotham et al. 2008; Mayer and Johns 2011; Mengak 2012); prey on native species (Engeman et al. 2003; Seward et al. 2004), livestock (Barrett and Birmingham 1994; Beck 1999; Seward et al. 2004), and humans (Love 2013; Mayer 2013); and act as a vector for foreign animal diseases (FAD) and other pathogens (Hall et al. 2008; Kreith 2007; Miller, Farnsworth, and Malmberg 2013; Pineda–Krch et al. 2010; Ward, Laffan, and Highfield 2007, 2009). Crop damage is a visible effect of feral swine presence. Consequently, policymakers and researchers have been addressing the topic of feral swine damage to crops as a first step the debate surrounding feral swine management.

There is room for improvement in the determination of crop damages from feral swine. A measure of loss in terms of yield or acres can be used to determine monetary outcomes for producers and to evaluate possible policy responses. Dollar denominated measures of utility and the gain to producers from engaging in production are known as welfare measures. Welfare measures can be used in describing how policies can change outcomes for individuals and society.

Methods used in previous damage estimates vary widely as do their validity. As the first nationwide estimate of feral swine damage, Pimentel, Zuniga, and Morrison (2005) used a simple method relying on an expert opinion that an individual feral swine caused approximately \$200/hog in property damage. Assuming there are 4 million feral swine in the United States, the average damage estimate is over \$800 million of crop, environmental, and property damage in 2005. Higginbotham et al. (2008) elicited producer responses during a workshop series where agricultural producers reported destruction to crops and property as a dollar estimate based on their opinion. Mengak (2012) implemented a producer level mail survey and obtained producer defined estimates of crop and property destruction in monetary terms. Producers were not asked to justify their estimate of damage by reporting the prices and change in yield used to calculate the estimate of damage in either Higginbotham et al. (2008) or Mengak (2012). By not eliciting the factors producers were using to arrive at their damage estimate these surveys are not generalizable across time or space.

To be able to generalize across time and space, a rate of damage controlling for contributing and mitigating factors must be estimated. Producers need to be asked questions that will lead to an understanding of how much would be grown in the absence of feral swine. An improvement in the method of eliciting damage can be found in Ober, Edmondson, and Giuliano (2011). Ober, Edmondson, and Giuliano (2011) surveyed producers in northeastern Florida regarding yield changes and destroyed acres attributed to feral swine. Damage estimates derived by Ober, Edmondson, and Giuliano (2011) were based on an extrapolation of survey responses to determine destroyed acres and then valued at the current market price in 2009. As a rate of damage, it can be extrapolated similar places and times to make an estimate of feral swine damage over a larger area.

A damage estimate in the form of a rate of damage must be found and applied to an analysis of social welfare to determine what the costs of feral swine are to society to improve upon the literature at this point. Recently, the USDA surveyed producers in Alabama, Arkansas, California, Florida, Georgia, Louisiana, Mississippi, Missouri, North Carolina, South Carolina, and Texas (Shwiff et al., Forthcoming). Questions were asked such that a damage can be stated in such a way as to describe the amount of increased production that would result from an absence of feral swine. A selection of results from this study have been presented in table 1. Shwiff et al. (Forthcoming) details how these percentage loss figures measure the increase in what would exist in the absence of feral swine.

It is still not clear based on these damage estimates how much worse off farmers or consumers are due to feral swine or how much they would be willing to pay to avoid suffering damages. An objective metric is needed to consider costs and benefits of a policy at a societal level. One such metric is the concept of social welfare. Welfare measures are extensively used to determine the effects of agricultural policy actions. Two commonly used measures are producer and consumer surplus. Some examples include the use of used producer and consumer surplus to study the distributional effects of Roundup Ready soybean seed (Qaim and Traxler 2005), effects of climate change on US agriculture (Antle and Capalbo 2010), the social value of transaction cost mitigating technology (Aker and Mbiti 2010; Jensen 2007), as well as the effects of crop damage (Anderson, Kirkpatrick, and Shwiff 2012; Elser 2013).

Producer surplus is a measure of the benefits of participating in market transactions to the sellers (Nicholson and Snyder 2011). Profit would be a possible measure of producer well-being, one with relatively high costs of acquisition to the researcher (Just, Hueth, and Schmitz 2004). Producer surplus is used as an approximation for returns in excess of variable costs, so they should be very similar measures.

Consumer surplus is a measure of the benefit consumers gain above what is paid to purchase a good (Nicholson and Snyder 2011). Equivalent variation or compensating variation would be superior measures because they account for substitution between goods due to price changes (Just, Hueth, and Schmitz 1982). However, the unobserved nature of compensated demand curves makes empirical use of these measures difficult leading to use of the observable Marshallian demand curves and consumer surplus measures (Just, Hueth, and Schmitz 1982; Just, Hueth, and Schmitz 2004).

One framework for measuring the effects of feral swine crop damage is an equilibrium displacement model (EDM). The EDM is a linear abstraction of supply and demand functions that describe the transition from one equilibrium to another without defining an exact functional form (Wohlgenant 1993; Wohlgenant 2011). The versatility of the EDM has allowed them to be used in multiple settings from examining export demand effects on grain, feed products, and livestock using genetically modified organisms (Preckel, Harrington, and Dubman 2002), returns to public research (Alston, Norton, and Pardey 1995), welfare effects of the Washington State University wheat breeding program (Nogueira et al. 2015), country of origin labeling (Brester, Marsh, and Atwood 2004), animal disease outbreaks (Pendell et al. 2007), to distributional impacts of crop insurance subsidies (Lusk 2016), among other uses. These varied applications are made possible by the flexibility inherent to the EDM.

The simplest EDM describes the change in the equilibrium of a single good in a single market. Relative change in supply and demand is used to motivate movement from one equilibrium to a new one while considering relative own price demand elasticity and own price supply elasticity (Wohlgenant 2011). Parallel shifts of linear functions can be interpreted geometrically (Wohlgenant 2011). James and Alston (2002) state that the elasticities used in an EDM can be acquired from three sources, the literature,“guestimated,” and estimation. Slightly more complex representations use constant elasticity functions that will calculate exact equilibrium changes rather than the approximations of the linear representation.

The accuracy of the EDM approach depends on the degree of nonlinearity of the true supply and demand functions and the magnitude of the changes being modeled (Pendell et al. 2010, 2007). Total surplus measured from linear approximations will likely include error, but changes in surplus should be relatively close to true values, provided that changes are small (Pendell et al. 2010, 2007). For the case of feral swine, it is likely that changes will be quite small relative to the quantities of commodities clearing the market, allowing the linear approximation to be appropriate.

The EDM has sufficient flexibility to cover larger problems than a single market. Wohlgenant (2011) shows the framework can be expanded beyond a single market. Perrin and Scobie (1981) use an EDM with both multiple markets and price wedges to study the options for increasing nutrient consumption among Colombia's poor. Nogueira et al. (2015) created a model that had both multiple products and multiple markets. Lusk (2016) presented a complex model that simulated the links from farmer to end user to show the distributional effects of crop insurance subsidies. Each of these models took a slightly different approach to measure welfare changes. Our model closely follows the lead of Nogueira et al. (2015) in covering more than one product in more than one location.

3 Methods

Building on the previous feral swine damage literature, a simulated exogenous shock of removing feral swine, thus eliminating feral swine crop damage, to affect market linkages has been constructed. The previous section conceptually introduced methods and models that are used in this study. In this section, those described tools will be derived for use in this application. The EDM is derived from a series of simple statements. At the farm gate, the end use of the crop is indistinguishable and damage from feral swine is primarily incurred at the farm level thus all markets are at the farm gate. First, supply and demand functions will be derived for the EDM. Second, the equations for measuring producer and consumer surplus will be derived.

The EDM is a flexible model that estimates relative changes in prices and quantities due to an exogenous shock. For this analysis, the exogenous shock is the immediate removal of feral swine from a targeted area. For illustration purposes, we will assume the market discussed herein is for farm gate commodity k. The commodities denoted by k are *corn, soybeans, wheat, rice,* and *peanuts*. At the core of this relationship is the idea that there is a market where conditions of perfect competition for both buyers and sellers holds. All modeled markets are farm level. A single national market demands each crop k. Derived demand for product k is defined as:

$$Q_k^d = D_k(P_{corn}, P_{soy}, P_{wheat}, P_{rice}, P_{peanuts}, C_k) \tag{1}$$

where Q^d is the quantity demanded of product k and is a function of a vector of all included prices, $\mathbf{P^d}$, and an exogenous demand shock, C_k. Supply is defined for product k in two regions (ω): states where feral swine removal occurs (FS) and all other states (AOS).

$$Q^s_{k,FS} = S_{k,FS}(P_{corn}, P_{soy}, P_{wheat}, P_{rice}, P_{peanuts}, B_{k,FS}) \tag{2}$$

Similarly, supply in all other states is a function of the same prices and an exogenous shock in that region.

$$Q^s_{k,AOS} = S_{k,AOS}(P_{corn}, P_{soy}, P_{wheat}, P_{rice}, P_{peanuts}, B_{k,AOS}) \tag{3}$$

where $\mathbf{P^s_\omega}$ is a vector of prices for each commodity in location ω and $B_{k,\omega}$ is the exogenous shock to supply. Market clearing conditions are found as:

$$Q^d_k = Q^s_{k,FS} + Q^s_{k,AOS}. \tag{4}$$

and

$$P^s_{k,\omega} = P^d_k = P_k \ \forall \ k \ and \ \omega. \tag{5}$$

At this point, given only two regions encompassing the entire United States adding basis for transportation would be no more accurate than not including it. The demand equation is logged.

$$\ln Q^d_k = \ln D_k(P_{corn}, P_{soy}, P_{wheat}, P_{rice}, P_{peanuts}, C_k) \tag{6}$$

Equation 2 is then logged.

$$\ln Q^s_{k,FS} = \ln S_{k,FS}(P_{corn}, P_{soy}, P_{wheat}, P_{rice}, P_{peanuts}, B_{k,FS}) \tag{7}$$

Equation 3 is logged.

$$\ln Q^s_{k,AOS} = \ln S_{k,AOS}(P_{corn}, P_{soy}, P_{wheat}, P_{rice}, P_{peanuts}, B_{k,AOS}) \tag{8}$$

Equations 6 through 8 are then totally differentiated.

$$d\ln Q^s_{k,FS} = \frac{\partial Q^s_{k,FS}}{\partial P_{corn}} d\ln P_{corn} + \cdots + \frac{\partial Q^s_{k,FS}}{\partial P_{Peanuts}} d\ln P_{Peanuts} + \frac{\partial Q^s_{k,FS}}{\partial B_k} d\ln B_k \tag{9}$$

$$d\ln Q^s_{k,AOS} = \frac{\partial Q^s_{k,AOS}}{\partial P_{corn}} d\ln P_{corn} + \cdots + \frac{\partial Q^s_{k,AOS}}{\partial P_{Peanuts}} d\ln P_{Peanuts} + \frac{\partial Q^s_{k,AOS}}{\partial B_k} d\ln B_k \tag{10}$$

$$d\ln Q^d_k = \frac{\partial Q^d_k}{\partial P_{corn}} d\ln P_{corn} + \cdots + \frac{\partial Q^d_k}{\partial P_{Peanuts}} d\ln P_{Peanuts} + \frac{\partial Q^s_k}{\partial C_k} d\ln C_k \tag{11}$$

We then replace $d\ln x$ with the relative change operator, Ex, $\frac{\partial Y^s}{\partial X}$ with price elasticities of supply ($\epsilon_{Y,X}$), and $\frac{\partial Y^d}{\partial X}$ with price elasticities of demand ($\eta_{Y,X}$)

and supply in equations 9 through 11. The result is the following set of supply and demand equations. First in a condensed form: $\frac{\partial Q_k^d}{\partial D_k} = 1$,

$$EQ_k^d \ = \eta_{k,k} * EP_k^d + \sum_k \eta_{k,j} * EP_k^d + EC_k \tag{12}$$

$$EQ_{k,\omega}^s = \varepsilon_{k,k,\omega} EP_{k,\omega}^s + \sum_k \varepsilon_{k,j,\omega} EP_{k,\omega}^s + EB_{k,\omega}. \tag{13}$$

Written individually:

$$EQ_{corn}^d = EP_c * \eta_{cc} + EP_p * \eta_{cp} + EP_r * \eta_{cr} + EP_s * \eta_{cs} + EP_w * \eta_{cw} + EC_c \tag{14}$$

$$EQ_{soy}^d = EP_c * \eta_{sc} + EP_p * \eta_{sp} + EP_r * \eta_{sr} + EP_s * \eta_{ss} + EP_w * \eta_{sw} + EC_s \tag{15}$$

$$EQ_{wheat}^d = EP_c * \eta_{wc} + EP_p * \eta_{wp} + EP_r * \eta_{wr} + EP_s * \eta_{ws} + EP_w * \eta_{ww} + EC_w \tag{16}$$

$$EQ_{rice}^d = EP_c * \eta_{rc} + EP_p * \eta_{rp} + EP_r * \eta_{rr} + EP_s * \eta_{rs} + EP_w * \eta_{rw} + EC_r \tag{17}$$

$$EQ_{peanut}^d = EP_c * \eta_{pc} + EP_p * \eta_{pp} + EP_r * \eta_{pr} + EP_s * \eta_{ps} + EP_w * \eta_{pw} + EC_p \tag{18}$$

$$\begin{aligned} EQ_{corn-AOS-s} = {} & EP_c * \epsilon_{AOS-cc} + EP_p * \epsilon_{AOS-cp} + \\ & EP_r * \epsilon_{AOS-cr} + EP_s * \epsilon_{AOS-cs} + EP_w * \epsilon_{AOS-cw} + B_{AOS-c} \end{aligned} \tag{19}$$

$$\begin{aligned} EQ_{corn-FS-s} = {} & EP_c * \epsilon_{FS-cc} + EP_p * \epsilon_{FS-cp} + \\ & EP_r * \epsilon_{FS-cr} + EP_s * \epsilon_{FS-cs} + EP_w * \epsilon_{FS-cw} + B_{FS-c} \end{aligned} \tag{20}$$

$$\begin{aligned} EQ_{soy-AOS-s} = {} & EP_c * \epsilon_{AOS-sc} + EP_p * \epsilon_{AOS-sp} + \\ & EP_r * \epsilon_{AOS-sr} + EP_s * \epsilon_{AOS-ss} + EP_w * \epsilon_{AOS-sw} + B_{AOS-s} \end{aligned} \tag{21}$$

$$\begin{aligned} EQ_{soy-FS-s} = {} & EP_c * \epsilon_{FS-sc} + EP_p * \epsilon_{FS-sp} + \\ & EP_r * \epsilon_{FS-sr} + EP_s * \epsilon_{FS-ss} - EP_w * \epsilon_{FS-sw} + B_{FS-s} \end{aligned} \tag{22}$$

$$\begin{aligned} EQ_{wheat-AOS-s} = {} & EP_c * epsilon - AOS - wc + EP_p * \epsilon_{AOS_wp} + \\ & EP_r * \epsilon_{AOS_wr} + EP_s * \epsilon_{AOS_ws} + EP_w * \epsilon_{AOS_ww} + B_{AOS_w} \end{aligned} \tag{23}$$

$$EQ_{wheat-FS-s} = EP_c * \epsilon_{FS-wc} + EP_p * \epsilon_{FS-wp} + \\ EP_r * \epsilon_{FS-wr} + EP_s * \epsilon_{FS-ws} + EP_w * \epsilon_{FS-ww} + B_{FS-w} \quad (24)$$

$$EQ_{rice-AOS-s} = EP_c * \epsilon_{AOS-rc} + EP_p * \epsilon_{AOS-rp} + \\ EP_r * \epsilon_{AOS-rr} + EP_s * \epsilon_{AOS-rs} + EP_w * \epsilon_{AOS-rw} + B_{AOS-r} \quad (25)$$

$$EQ_{rice-FS-s} = EP_c * \epsilon_{FS-rc} + EP_p * \epsilon_{FS-rp} + \\ EP_r * \epsilon_{FS-rr} + EP_s * \epsilon_{FS-rs} + EP_w * \epsilon_{FS-rw} + B_{FS-r} \quad (26)$$

$$EQ_{peanut-AOS-s} = EP_c * \epsilon_{AOS-pc} + EP_p * \epsilon_{AOS-pp} + \\ EP_r * \epsilon_{AOS-pr} + EP_s * \epsilon_{AOS-ps} + EP_w * \epsilon_{AOS-pw} + B_{AOS-p} \quad (27)$$

$$EQ_{peanut-FS-s} = EP_c * \epsilon_{FS-pc} + EP_p * \epsilon_{FS-pp} + \\ EP_r * \epsilon_{FS-pr} + EP_s * \epsilon_{FS-ps} + EP_w * \epsilon_{FS-pw} + B_{FS-p} \quad (28)$$

Market clearing conditions are not quite as straight forward to derive. Again, market clearing conditions are:

$$Q^d_k = Q^s_{k,FS} + Q^s_{k,AOS}. \quad (29)$$

Due to the addition in the right hand side the desired effect of logging the equation will not work. So we begin by totally differentiating:

$$dQ^d_k = \frac{\partial Q^d_k}{\partial Q^s_{k,FS}} dQ^s_{k,FS} + \frac{\partial Q^d_k}{\partial Q^s_{k,AOS}} dQ^s_{k,AOS}. \quad (30)$$

Instead of logging to get the effect of a relative change operator we multiply each term by one where, $1 = x/x$.

$$(\frac{Q^d_k}{Q^d_k}) * dQ^d_k = (\frac{Q^s_{k,FS}}{Q^s_{k,FS}}) * \frac{\partial Q^d_k}{\partial Q^s_{k,FS}} dQ^s_{k,FS} + (\frac{Q^s_{k,AOS}}{Q^s_{k,AOS}}) * \frac{\partial Q^d_k}{\partial Q^s_{k,AOS}} dQ^s_{k,AOS} \quad (31)$$

By substitution, $\frac{\partial Q^d_k}{\partial Q^s_{k,FS}} = \varepsilon_{k,FS}$ and $\frac{\partial Q^d_k}{\partial Q^s_{k,AOS}} = \varepsilon_{k,AOS}$. Effectively these are elasticities of transmission describing the impact of production in each region on national production. We also substitute: E for $\frac{dQ^d_k}{Q^d_k}$ as the relative change operator for each term. These substitutions leave:

$$(Q^d_k) * EQ^d_k = (Q^s_{k,FS}) * \varepsilon_{k,FS} EQ^s_{k,FS} + (Q^s_{k,AOS}) * \varepsilon_{k,AOS} EQ^s_{k,AOS}. \quad (32)$$

We can then divide each side by Q^d_k leaving:

$$EQ^d_k = \frac{Q^s_{k,FS}}{Q^d_k} * \varepsilon_{k,FS} * EQ^s_{k,FS} + \frac{Q^s_{k,AOS}}{Q^d_k} * \varepsilon_{k,AOS} * EQ^s_{k,AOS}. \quad (33)$$

Further simplifying, replace $\frac{Q^s_{k,FS}}{Q^d_k}$ with $s_{FS,k}$ and $\frac{Q^s_{k,AOS}}{Q^d_k}$ with $s_{AOS,k}$:

$$EQ^d_k = s_{FS,k} * \varepsilon_{k,FS} * EQ^s_{k,FS} + s_{AOS,k} * \varepsilon_{k,AOS} * EQ^s_{k,AOS}. \tag{34}$$

We then set the changes in price equal to maintain the single price assumption stated in equation 5.

$$EP^s_{k,\omega} = EP^d_k = EP_k \;\forall\;\; k. \tag{35}$$

This system of equations can be rewritten in a 20x20 matrix for solving where **M** is a matrix of elasticities and parameters associated with the exogenous variables, **Y** is a vector of changes in the endogenous price and quantity variables, **X** is a vector of percentage changes in exogenous shift variables.

$$\mathbf{Y} = \mathbf{M^{-1}} * \mathbf{X}. \tag{36}$$

Since all of the quantities are defined by prices, elasticities, and shocks it seems reasonable to substitute until a 5x5 matrix to solve for prices is achieved. First the quantity equations are substituted into the equilibrium condition described in 34 resulting in the following five equations. First corn demand is equal to the sum of production in the two regions and this is a function of prices, elasticities, weights and shocks.

$$\begin{aligned}&\eta_{cc} * EP_c + \eta_{cs} * EP_s + \eta_{cw} * EP_w + \eta_{cr} * EP_r + \eta_{cp} * EP_p + C_c = \\ &s_{AOS,corn}*\varepsilon_{corn,AOS}*(\epsilon_{AOS,cc}*EP_c+\epsilon_{AOS,cs}*EP_s+\epsilon_{AOS,cw}*EP_w+\epsilon_{AOS,cw}*EP_r+\epsilon_{AOS,cp}*EP_p+B_{AOS,c}) \\ &+s_{FS,corn}*\varepsilon_{corn,FS}*(\epsilon_{FS,cc}*EP_c+\epsilon_{FS,cs}*EP_s+\epsilon_{FS,cw}*EP_w+\epsilon_{FS,cr}*EP_r+\epsilon_{FS,cp}*EP_p+B_{FS,c}).\end{aligned} \tag{37}$$

The same for soybeans:

$$\begin{aligned}&\eta_{sc} * EP_c + \eta_{ss} * EP_s + \eta_{sw} * EP_w + \eta_{sr} * EP_r + \eta_{sp} * EP_p + C_s = \\ &s_{AOS,soy}*\varepsilon_{soybeans,AOS}*(\epsilon_{AOS,sc}*EP_c+\epsilon_{AOS,ss}*EP_s+\epsilon_{AOS,sw}*EP_w+\epsilon_{AOS,sr}*EP_r+\epsilon_{AOS,sp}*EP_p+B_{AOS,s}) \\ &+s_{FS,soy}*\varepsilon_{soybeans,FS}*(\epsilon_{FS,sc}*EP_c+\epsilon_{FS,ss}*EP_s+\epsilon_{FS,sw}*EP_w+\epsilon_{FS,sr}*EP_r+\epsilon_{FS,sp}*EP_p+B_{FS,s}),\end{aligned} \tag{38}$$

Wheat:

$$\begin{aligned}&\eta_{wc} * EP_c + \eta_{ws} * EP_s + \eta_{ww} * EP_w + \eta_{wr} * EP_r + \eta_{wp} * EP_p + C_w = \\ &s_{AOS,wheat}*\varepsilon_{wheat,AOS}*(\epsilon_{AOS,wc}*EP_c+\epsilon_{AOS,ws}*EP_s+\epsilon_{AOS,ww}*EP_w+\epsilon_{AOS,wr}*EP_r+\epsilon_{AOS,wp}*EP_p+B_{AOS,w}) \\ &+s_{FS,wheat}*\varepsilon_{wheat,FS}*(\epsilon_{FS,wc}*EP_c+\epsilon_{FS,ws}*EP_s+\epsilon_{FS,ww}*EP_w+\epsilon_{FS,wr}*EP_r+\epsilon_{FS,wp}*EP_p+B_{FS,w}),\end{aligned} \tag{39}$$

Rice:

$$\begin{aligned}&\eta_{rc} * EP_c + \eta_{rs} * EP_s + \eta_{rw} * EP_w + \eta_{rr} * EP_r + \eta_{rp} * EP_p + C_r == \\ &s_{AOS,rice}*\varepsilon_{rice,AOS}*(\epsilon_{AOS,rc}*EP_c+\epsilon_{AOS,rs}*EP_s+\epsilon_{AOS,rw}*EP_w+\epsilon_{AOS,rr}*EP_r+\epsilon_{AOS,rp}*EP_p+B_{AOS,r}) \\ &+s_{FS,rice}*\varepsilon_{rice,FS}*(\epsilon_{FS,rc}*EP_c+\epsilon_{FS,rs}*EP_s+\epsilon_{FS,rw}*EP_w+\epsilon_{FS,rr}*EP_r+\epsilon_{FS,rp}*EP_p+B_{FS,r}),\end{aligned} \tag{40}$$

and Peanuts

$$\eta_{pc} * EP_c + \eta_{ps} * EP_s + \eta_{pw} * EP_w + \eta_{pr} * EP_r + \eta_{pp} * EP_p + C_p ==$$
$$s_{AOS,peanuts} * \varepsilon_{rice,AOS} * (\epsilon_{AOS,pc} * EP_c + \epsilon_{AOS,ps} * EP_s + \epsilon_{AOS,pw} * EP_w + \epsilon_{AOS,pr} * EP_r + \epsilon_{AOS,pp} * EP_p + B_{AOS,p})$$
$$+ s_{FS,peanuts} * \varepsilon_{peanuts,FS} * (\epsilon_{FS,pc} * EP_c + \epsilon_{FS,ps} * EP_s + \epsilon_{FS,pw} * EP_w + \epsilon_{FS,pr} * EP_r + \epsilon_{FS,pp} * EP_p + B_{FS,p}). \tag{41}$$

By reducing to five equations we have reduced dimensionality and increased our ability to trace the impacts of a single parameter on the system as a whole. The resulting matrices are:

$$Y_{5x1} = \begin{bmatrix} EP_c \\ EP_s \\ EP_w \\ EP_r \\ EP_p \end{bmatrix}$$

$$X_{5x1} = \begin{bmatrix} B_{AOS,c} * \varepsilon_{AOS,corn} * s_{AOS,corn} - C_c + B_{FS,c} * \varepsilon_{FS,corn} * s_{FS,corn} \\ B_{AOS,s} * \varepsilon_{AOS,soybeans} * s_{AOS,soy} - C_s + B_{FS,s} * \varepsilon_{FS,soybeans} * s_{FS,soy} \\ B_{AOS,w} * \varepsilon_{AOS,wheat} * s_{AOS,wheat} - C_w + B_{FS,w} * \varepsilon_{FS,wheat} * s_{FS,wheat} \\ B_{AOS,r} * \varepsilon_{AOS,rice} * s_{AOS,rice} - C_r + B_{FS,r} * \varepsilon_{FS,rice} * s_{FS,rice} \\ B_{AOS,p} * \varepsilon_{AOS,rice} * s_{AOS,peanuts} - C_p + B_{FS,p} * \varepsilon_{FS,peanuts} * s_{FS,peanuts} \end{bmatrix}$$

$M_{5x5} =$

$$\begin{vmatrix}
\eta_{cc} - \epsilon_{AOS,cc} * \varepsilon_{AOS,corn} * s_{AOS,corn} - \epsilon_{FS,cc} * \varepsilon_{FS,corn} * s_{FS,corn} & \eta_{cs} - \epsilon_{AOS,cs} * \varepsilon_{AOS,corn} * s_{AOS,corn} - \epsilon_{FS,cs} * \varepsilon_{FS,corn} * s_{FS,corn} & \eta_{cw} - \epsilon_{AOS,cw} * \varepsilon_{AOS,corn} * s_{AOS,corn} - \epsilon_{FS,cw} * \varepsilon_{FS,corn} * s_{FS,corn} & \eta_{cr} - \epsilon_{AOS,cr} * \varepsilon_{AOS,corn} * s_{AOS,corn} - \epsilon_{FS,cr} * \varepsilon_{FS,corn} * s_{FS,corn} & \eta_{cp} - \epsilon_{AOS,cp} * \varepsilon_{AOS,corn} * s_{AOS,corn} - \epsilon_{FS,cp} * \varepsilon_{FS,corn} * s_{FS,corn} \\
\eta_{sc} - \epsilon_{AOS,sc} * \varepsilon_{AOS,soybeans} * s_{AOS,soy} - \epsilon_{FS,sc} * \varepsilon_{FS,soybeans} * s_{FS,soy} & \eta_{ss} - \epsilon_{AOS,ss} * \varepsilon_{AOS,soybeans} * s_{AOS,soy} - \epsilon_{FS,ss} * \varepsilon_{FS,soybeans} * s_{FS,soy} & \eta_{sw} - \epsilon_{AOS,sw} * \varepsilon_{AOS,soybeans} * s_{AOS,soy} - \epsilon_{FS,sw} * \varepsilon_{FS,soybeans} * s_{FS,soy} & \eta_{sr} - \epsilon_{AOS,sr} * \varepsilon_{AOS,soybeans} * s_{AOS,soy} - \epsilon_{FS,sr} * \varepsilon_{FS,soybeans} * s_{FS,soy} & \eta_{sp} - \epsilon_{AOS,sp} * \varepsilon_{AOS,soybeans} * s_{AOS,soy} - \epsilon_{FS,sp} * \varepsilon_{FS,soybeans} * s_{FS,soy} \\
\eta_{wc} - \epsilon_{AOS,wc} * \varepsilon_{AOS,wheat} * s_{AOS,wheat} - \epsilon_{FS,wc} * \varepsilon_{FS,wheat} * s_{FS,wheat} & \eta_{ws} - \epsilon_{AOS,ws} * \varepsilon_{AOS,wheat} * s_{AOS,wheat} - \epsilon_{FS,ws} * \varepsilon_{FS,wheat} * s_{FS,wheat} & \eta_{ww} - \epsilon_{AOS,ww} * \varepsilon_{AOS,wheat} * s_{AOS,wheat} - \epsilon_{FS,ww} * \varepsilon_{FS,wheat} * s_{FS,wheat} & \eta_{wr} - \epsilon_{AOS,wr} * \varepsilon_{AOS,wheat} * s_{AOS,wheat} - \epsilon_{FS,wr} * \varepsilon_{FS,wheat} * s_{FS,wheat} & \eta_{wp} - \epsilon_{AOS,wp} * \varepsilon_{AOS,wheat} * s_{AOS,wheat} - \epsilon_{FS,wp} * \varepsilon_{FS,wheat} * s_{FS,wheat} \\
\eta_{rc} - \epsilon_{AOS,rc} * \varepsilon_{AOS,rice} * s_{AOS,rice} - \epsilon_{FS,rc} * \varepsilon_{FS,rice} * s_{FS,rice} & \eta_{rs} - \epsilon_{AOS,rs} * \varepsilon_{AOS,rice} * s_{AOS,rice} - \epsilon_{FS,rs} * \varepsilon_{FS,rice} * s_{FS,rice} & \eta_{rw} - \epsilon_{AOS,rw} * \varepsilon_{AOS,rice} * s_{AOS,rice} - \epsilon_{FS,rw} * \varepsilon_{FS,rice} * s_{FS,rice} & \eta_{rr} - \epsilon_{AOS,rr} * \varepsilon_{AOS,rice} * s_{AOS,rice} - \epsilon_{FS,rr} * \varepsilon_{FS,rice} * s_{FS,rice} & \eta_{rp} - \epsilon_{AOS,rp} * \varepsilon_{AOS,rice} * s_{AOS,rice} - \epsilon_{FS,rp} * \varepsilon_{FS,rice} * s_{FS,rice} \\
\eta_{pc} - \epsilon_{AOS,pc} * \varepsilon_{AOS,rice} * s_{AOS,peanuts} - \epsilon_{FS,pc} * \varepsilon_{FS,peanuts} * s_{FS,peanuts} & \eta_{ps} - \epsilon_{AOS,ps} * \varepsilon_{AOS,rice} * s_{AOS,peanuts} - \epsilon_{FS,ps} * \varepsilon_{FS,peanuts} * s_{FS,peanuts} & \eta_{pw} - \epsilon_{AOS,pw} * \varepsilon_{AOS,rice} * s_{AOS,peanuts} - \epsilon_{FS,pw} * \varepsilon_{FS,peanuts} * s_{FS,peanuts} & \eta_{pr} - \epsilon_{AOS,pr} * \varepsilon_{AOS,rice} * s_{AOS,peanuts} - \epsilon_{FS,pr} * \varepsilon_{FS,peanuts} * s_{FS,peanuts} & \eta_{pp} - \epsilon_{AOS,pp} * \varepsilon_{AOS,rice} * s_{AOS,peanuts} - \epsilon_{FS,pp} * \varepsilon_{FS,peanuts} * s_{FS,peanuts}
\end{vmatrix}$$

As you can see, the M matrix is very complex. When inverted it becomes unmanageable for human eyes in this symbolic form. Each cell in the resulting **Y** is over 25,000 characters. Simplifying to try to find something manageable all of the *a priori* parameter values of zero are substituted into the system. This substitution simplifies equations 37 through 41 to the following five (much shorter) equations.

$$EP_c*\eta_{cc}+EP_s*\eta_{cs} = \varepsilon_{FS,corn}*s_{FS,corn}*(B_{FS,c}+EP_c*\epsilon_{FS,cc}+EP_r*\epsilon_{FS,cr}+EP_s*\epsilon_{FS,cs}+EP_w*\epsilon_{FS,cw}) + \varepsilon_{AOS,corn} * s_{AOS,corn} * (EP_c * \epsilon_{AOS_cc} + EP_s * \epsilon_{AOS_cs} + EP_w * \epsilon_{AOS_cw}) \tag{42}$$

$$EP_c{*}\eta_{sc}{+}EP_s{*}\eta_{ss} = \varepsilon_{FS,soybeans}{*}s_{FS,soy}{*}(B_{FS,s}{+}EP_c{*}\epsilon_{FS,sc}{+}EP_r{*}\epsilon_{FS,sr}{+}EP_s{*}\epsilon_{FS,ss}{+}EP_w{*}\epsilon_{FS_sw})$$
$$+\varepsilon_{AOS,soybeans}{*}s_{AOS,soy}{*}(EP_c{*}\epsilon_{AOS,sc}{+}EP_r{*}\epsilon_{AOS,sr}{+}EP_s{*}\epsilon_{AOS,ss}{+}EP_w{*}\epsilon_{AOS_sw}) \tag{43}$$

$$EP_w{*}\eta_{ww} = \varepsilon_{FS,wheat}{*}s_{FS,wheat}{*}(B_{FS,w}{+}EP_c{*}\epsilon_{FS,wc}{+}EP_r{*}\epsilon_{FS,wr}{+}EP_s{*}\epsilon_{FS,ws}{+}EP_w{*}\epsilon_{FS,ww})$$
$$+\varepsilon_{AOS,wheat}{*}s_{AOS,wheat}{*}(EP_c{*}\epsilon_{AOS,wc}{+}EP_r{*}\epsilon_{AOS,wr}{+}EP_s{*}\epsilon_{AOS,ws}{+}EP_w{*}\epsilon_{AOS,ww}) \tag{44}$$

$$EP_r{*}\eta_{rr} = \varepsilon_{FS,rice}{*}s_{FS,rice}{*}(B_{FS,r}{+}EP_c{*}\epsilon_{FS,rc}{+}EP_r{*}\epsilon_{FS,rr}{+}EP_s{*}\epsilon_{FS,rs}{+}EP_w{*}\epsilon_{FS,rw})$$
$$+\varepsilon_{AOS,rice}{*}s_{AOS,rice}{*}(EP_c{*}\epsilon_{AOS,rc}{+}EP_r{*}\epsilon_{AOS,rr}{+}EP_s{*}\epsilon_{AOS,rs}{+}EP_w{*}\epsilon_{AOS,rw}) \tag{45}$$

$$\begin{aligned} EP_p * \eta_{pp} = \varepsilon_{FS,peanuts} * s_{FS,peanuts} * (B_{FS,p} + EP_p * \epsilon_{FS,pp}) \\ + EP_p * \epsilon_{AOS,pp} * \varepsilon_{AOS,rice} * s_{AOS,peanuts} \end{aligned} \tag{46}$$

This simplified system in matrix form M =

$M_{5x5} =$

$$\begin{vmatrix}
\eta_{cc} - \epsilon_{AOS,cc} * \varepsilon_{AOS,corn} * s_{AOS,corn} - \epsilon_{FS,cc} * \varepsilon_{FS,corn} * s_{FS,corn} & \eta_{cs} - \epsilon_{AOS,cs} * \varepsilon_{AOS,corn} * s_{AOS,corn} - \epsilon_{FS,cs} * \varepsilon_{FS,corn} * s_{FS,corn} & -\epsilon_{AOS,cw} * \varepsilon_{AOS,corn} * s_{AOS,corn} - \epsilon_{FS,cw} * \varepsilon_{FS,corn} * s_{FS,corn} & -\epsilon_{FS,cr} * \varepsilon_{FS,corn} * s_{FS,corn} & 0 \\
\eta_{sc} - \epsilon_{AOS,sc} * \varepsilon_{AOS,soybeans} * s_{AOS,soy} - \epsilon_{FS,sc} * \varepsilon_{FS,soybeans} * s_{FS,soy} & \eta_{ss} - \epsilon_{AOS,ss} * \varepsilon_{AOS,soybeans} * s_{AOS,soy} - \epsilon_{FS,ss} * \varepsilon_{FS,soybeans} * s_{FS,soy} & -\epsilon_{AOS,sw} * \varepsilon_{AOS,soybeans} * s_{AOS,soy} - \epsilon_{FS,sw} * \varepsilon_{FS,soybeans} * s_{FS,soy} & -\epsilon_{AOS,sr} * \varepsilon_{AOS,soybeans} * s_{AOS,soy} - \epsilon_{FS,sr} * \varepsilon_{FS,soybeans} * s_{FS,soy} & 0 \\
-\epsilon_{AOS,wc} * \varepsilon_{AOS,wheat} * s_{AOS,wheat} - \epsilon_{FS,wc} * \varepsilon_{FS,wheat} * s_{FS,wheat} & -\epsilon_{AOS,ws} * \varepsilon_{AOS,wheat} * s_{AOS,wheat} - \epsilon_{FS,ws} * \varepsilon_{FS,wheat} * s_{FS,wheat} & \eta_{ww} - \epsilon_{AOS,ww} * \varepsilon_{AOS,wheat} * s_{AOS,wheat} - \epsilon_{FS,ww} * \varepsilon_{FS,wheat} * s_{FS,wheat} & -\epsilon_{AOS,wr} * \varepsilon_{AOS,wheat} * s_{AOS,wheat} - \epsilon_{FS,wr} * \varepsilon_{FS,wheat} * s_{FS,wheat} & 0 \\
-\epsilon_{AOS,rc} * \varepsilon_{AOS,rice} * s_{AOS,rice} - \epsilon_{FS,rc} * \varepsilon_{FS,rice} * s_{FS,rice} & -\epsilon_{AOS,rs} * \varepsilon_{AOS,rice} * s_{AOS,rice} - \epsilon_{FS,rs} * \varepsilon_{FS,rice} * s_{FS,rice} & -\epsilon_{AOS,rw} * \varepsilon_{AOS,rice} * s_{AOS,rice} - \epsilon_{FS,rw} * \varepsilon_{FS,rice} * s_{FS,rice} & \eta_{rr} - \epsilon_{AOS,rr} * \varepsilon_{AOS,rice} * s_{AOS,rice} - \epsilon_{FS,rr} * \varepsilon_{FS,rice} * s_{FS,rice} & 0 \\
0 & 0 & 0 & 0 & \eta_{pp} - \epsilon_{AOS,pp} * \varepsilon_{AOS,rice} * s_{AOS,peanuts} - \epsilon_{FS,pp} * \varepsilon_{FS,peanuts} * s_{FS,peanuts}
\end{vmatrix}$$

$$\text{X} = \begin{bmatrix} B_{FS,c} * \varepsilon_{FS,corn} * s_{FS,corn} \\ B_{FS,s} * \varepsilon_{FS,soybeans} * s_{FS,soy} \\ B_{FS,w} * \varepsilon_{FS,wheat} * s_{FS,wheat} \\ B_{FS,r} * \varepsilon_{FS,rice} * s_{FS,rice} \\ B_{FS,p} * \varepsilon_{FS,peanuts} * s_{FS,peanuts} \end{bmatrix}$$

Unfortunately the symbolic solution is still very large, with each element $> 25,000$ characters. Partial derivatives of analytical solutions would have been informative if they could have been simple enough to be understood. Analyzing the effect of each parameter on the variables of interest will have to be conducted numerically.

Elasticities, shocks, and weights are established for substitution. When possible, elasticities from published work are used. When a demand price elasticity is not found one was estimated, and the estimation methods are detailed in Appendix ??. Corn and Soybean own- and cross-price elasticities of demand were estimated using data from FAPRI–MU (2015). Wheat, rice, and peanut own price elasticities were gathered from the literature. Several elasticities were assumed to be zero because they are not necessarily substitutes. These elasticities are assumed to be zero. Table 2 shows the demand elasticities in use for the initial application of the model.

FAPRI–MU (2004) details the model used by the University of Missouri's Food and Agricultural Policy Research Institute (FAPRI–MU) to write the FAPRI briefing book presented to the US Congress each year. Own- and cross-price elasticities of production with respect to acreage were used for corn, soybeans, wheat, and rice. FAPRI–MU (2004) does not publish any supply elasticities for peanuts, however Beghin and Matthey (2003) does include an estimate for price elasticity of supply. Elasticities for the corn belt are used for AOS and Delta states for the FS region. Elasticities from FAPRI–MU (2004) are appropriate in the short run. In the short run, no technology changes are expected making a percent change in land analogous to a percent change in quantity produced. The elasticities used are presented in table 3.

In equation 34 equilibrium conditions were stated that included a term referred to as a quantity transmission elasticity ($\varepsilon_{k,AOS}$). Generally, for each commodity a linear regression model was estimated:

$$log(Q_{k,TOTAL}) = \alpha + \varepsilon_{AOS,k} * log(Q_{k,AOS}) + \varepsilon_{FS,k} log(Q_{k,FS}). \tag{47}$$

These transmission elasticities can be interpreted as describing the impact on national production from a change in production in one of the two regions for each crop. For example, a one percent change in corn production in All Other States leads to a 0.938% change in national production. This is very similar to the production shares presented in table 4. However, each has its own interpretation and its own heritage in derivation of the EDM.

Feral swine removal states are Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, and Texas. Damage values were obtained from state-level estimates from a survey reported by Shwiff et al. (Forthcoming). Shwiff et al. (Forthcoming) collaborated with USDA-NASS to distribute a farm level survey targeting corn, soybeans, wheat, rice, and peanuts producers in Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, and Texas. The applicable results to this study are summarized in table 1 Damage estimates from these reports are used to determine the exogenous supply shock associated with the instantaneous removal of feral swine. The calculated quantity and relative changes implied by Shwiff et al. (Forthcoming) are presented in table 5.

Substituting all elasticities, shocks, and weights into the system of five equations yields the following five.

$$0.11{*}EP_s{-}0.056{*}EP_c = 0.18{*}EP_c{-}1.1e{-}4{*}EP_r{-}0.096{*}EP_s{-}3.6e{-}3{*}EP_w{+}4.7e{-}5 \tag{48}$$

$$0.39{*}EP_c{-}0.11{*}EP_s = 0.12{*}EP_s{-}1.9e{-}3{*}EP_r{-}0.13{*}EP_c{-}4.1e{-}3{*}EP_w{+}5.9e{-}5 \tag{49}$$

$$-0.026{*}EP_w = 0.17{*}EP_w{-}1.2e{-}3{*}EP_r{-}0.09{*}EP_s{-}0.13{*}EP_c{+}1.4e{-}4 \tag{50}$$

$$-0.083*EP_r = 0.28*EP_r - 0.019*EP_c - 0.035*EP_s - 2.6e-3*EP_w + 2.6e-3 \tag{51}$$

$$-0.2 * EP_p = 0.33 * EP_p + 0.017 \tag{52}$$

The solution for this system of equations is presented in table 6.

In algebraic form the substitution of price changes into the quantity equations, equations 14 through 28, (after removing terms for which the elasticity is zero) is presented:

$$EQ^d_{corn} = 0.000489 * \eta_{cc} + 0.000787 * \eta_{cs} \tag{53}$$

$$EQ^d_{soy} = 0.000489 * \eta_{sc} + 0.000787 * \eta_{ss} \tag{54}$$

$$EQ^d_{wheat} = -0.000088 * \eta_{ww} \tag{55}$$

$$EQ^d_{rice} = -0.006981 * \eta_{rr} \tag{56}$$

$$EQ^d_{peanut} = -0.031747 * \eta_{pp} \tag{57}$$

$$EQ^s_{corn,AOS} = 0.000489 * \epsilon_{AOS,cc} + 0.000787 * \epsilon_{AOS,cs} - 0.000088 * \epsilon_{AOS,cw} \tag{58}$$

$$EQ^s_{corn,FS} = B_{FS,c}{+}0.000489{*}\epsilon_{FS,cc}{-}0.006981{*}\epsilon_{FS,cr}{+}0.000787{*}\epsilon_{FS,cs}{-}0.000088{*}\epsilon_{FS,cw} \tag{59}$$

$$EQ^s_{soy,AOS} = 0.000489{*}\epsilon_{AOS,sc}{-}0.006981{*}\epsilon_{AOS,sr}{+}0.000787{*}\epsilon_{AOS,ss}{-}0.000088{*}\epsilon_{AOS,sw} \tag{60}$$

$$EQ^s_{soy,FS} = B_{FS,s}{+}0.000489{*}\epsilon_{FS,sc}{-}0.006981{*}\epsilon_{FS,sr}{+}0.000787{*}\epsilon_{FS,ss}{-}0.000088{*}\epsilon_{FS,sw} \tag{61}$$

$$E^s_{wheat,AOS} = 0.000489 {*} \epsilon_{AOS,wc} - 0.006981 {*} \epsilon_{AOS,wr} + 0.000787 {*} \epsilon_{AOS,ws} - 0.000088 {*} \epsilon_{AOS,ww} \tag{62}$$

$$EQ^s_{wheat,FS} = B_{FS,w} + 0.000489 {*} \epsilon_{FS,wc} - 0.006981 {*} \epsilon_{FS,wr} + 0.000787 {*} \epsilon_{FS,ws} - 0.000088 {*} \epsilon_{FS,ww} \tag{63}$$

$$EQ^s_{rice,AOS} = 0.000489 {*} \epsilon_{AOS,rc} - 0.006981 {*} \epsilon_{AOS,rr} + 0.000787 {*} \epsilon_{AOS,rs} - 0.000088 {*} \epsilon_{AOS,rw} \tag{64}$$

$$EQ^s_{rice_FS} = B_{FS,r} + 0.000489 {*} \epsilon_{FS,rc} - 0.006981 {*} \epsilon_{FS,rr} + 0.000787 {*} \epsilon_{FS,rs} - 0.000088 {*} \epsilon_{FS,rw} \tag{65}$$

$$EQ^s_{peanut,AOS} = -0.031747 * \epsilon_{AOS,pp} \tag{66}$$

$$EQ^s_{peanut,FS} = B_{FS,p} - 0.031747 * \epsilon_{FS,pp} \tag{67}$$

Finally, substituting prices, elasticities, and all other parameters to solve for quantity changes and solving for solutions the results using baseline values are presented in table 7. The results for wheat, rice, and peanuts seem plausible. Corn and soybeans do not seem to be behaving properly. Suppose corn was distributed differently. The transmission elasticity certainly depends on the relative weights, but the relationship is not completely clear since the elasticity does not always sum to one. We can change run the model with different weights. Varying the weights of corn, soybeans, wheat, and rice across a uniform distribution between 0 and 1 in increments of 0.1 results in substantial variation in the effects of the baseline shocks. The prices of corn, soybeans, and wheat appears to be very sensitive to changing these parameters.

There are clear effect on price and quantity changes inflicted by supply shares, including the possibility of some counter-intuitive changes. The interpretation of these results are that a one unit change (a percent as defined) in production share of corn in removal states leads to a -0.004 unit (a percent as defined) change in the relative change in corn price. More interesting is the effect of share on quantity produced in each region. A one unit increase in feral swine region share leads to a decrease of 0.001 units in change in quantity produced. The intuition is that as the region's share of production increases the impact of a shock decreases. The opposite effect is noted in all other states, as one should expect, as share increases in removal states it must decrease in all other states.

We see that supply share has a clear impact on all of our variables of interest. However, the supply shares are known. We should look at elasticities. We know a good deal about elasticities, but the precise values are unknown.

This section will discuss the process used to simulate the effect of a range of elasticities.

We know that own price elasticities of demand are negative and for products such as this analysis is covering, the absolute value is less than one ($-1 < \eta_{xx} < 0$). This implies that higher prices of a good will lead to decreased demand of that product. Cross price elasticities of demand for substitutes should be positive and once again for these crops we would expect the absolute value to be less than one ($0 < \eta_{xy} < 1$). This implies that higher prices of a good will lead to higher demand of its substitute.

We also know that own price elasticities of supply are positive and that for these goods will be less than one ($0 < \epsilon_{xy} < 1$). Production will respond to higher prices with higher production levels. Cross price elasticities of supply are negative and their absolute value is less than one. When producers substitute production from one good to another the production of the original good necessarily decreases.

The initial results of this model were so counter-intuitive because we expected movements as just described. However, in this model with several prices and elasticities the producer is choosing what crop to grow based on four (peanuts excluded) relative price changes based on their relative elasticities. For this reason, I have simulated unknown elasticities to give a range of outcomes.

In a similar application to Falck-Zepeda, Traxler, and Nelson (2000), elasticities were simulated using a triangle distribution. A triangle distribution is often used when information about a distribution is limited. Generating the distribution requires only knowing the minimum, most likely, and maximum values. In this application the minimum was either -1 or 0 depending on the elasticity and the maximum was either 0 or 1. The most likely value used was the elasticity used in earlier calculations. If the elasticity was assumed to be equal to zero in the earlier calculation of the model this assumption was maintained. The model was then ran 10,000 times. Table 8 describes the distributions used to simulate the elasticities of the model.

The variables compared for this portion of the analysis are producer and consumer surplus. Welfare analysis following the implementation of the EDM requires initial price and quantity data. The 2014 quantities and prices were collected from U.S. Department of Agriculture NASS (2016). Welfare calculations follow Nogueira et al. (2015). Change in producer surplus is equal to

$$\Delta PS_{k,\omega} = P_k^0 * Q_{k,\omega}^0 * (EP_k + \psi) * (1 + 0.5 * EQ_{k,\omega}^s) \tag{68}$$

where $\psi = B_{\omega,r}/\epsilon_{\omega,kk}$. Change in consumer surplus was calculated:

$$\Delta CS_k = P_k^0 * Q_k^{d0} * (EP_k) * (1 + 0.5 * EQ_k^d). \tag{69}$$

Total change in producer surplus for each region is calculated:

$$\Delta PS_\omega = \sum_k \Delta PS_{k,\omega}. \tag{70}$$

Total producer surplus is calculated:

$$\Delta PS = \sum_{\omega} \Delta PS_{\omega}. \tag{71}$$

Total consumer surplus is calculated:

$$\Delta CS = \sum_{k} \Delta CS_{k}. \tag{72}$$

Finally, total change in surplus was calculated:

$$\Delta S = \Delta CS + \Delta PS. \tag{73}$$

The following section will discuss the results of this simulation.

4 Results

Simulation allows us to examine the welfare effects of this removal given uncertainty about elasticities. We vary the elasticities initially included in the model around a triangular distribution in an attempt to learn the most likely outcome and the limits of outcomes in terms of producer and consumer surplus. The exogenous shock simulated was the removal of damage described by Shwiff et al. (Forthcoming).

Table 9 describes the minimum, maximum, mean, and median values for each change in surplus. It is certainly possible to have extreme values in both positive and negative directions. We see from table 10 that with ninety percent or more probability producers and consumers both gain from the removal of feral swine. In fact there is a ninety percent probability that the total welfare gain will exceed \$3.8 billion. We see in figure 1 that with a probability of just under six percent the change in total surplus will be greater than or equal to zero. The distinct kink to the right of crossing zero is interesting and a cause has not been found. With 10,000 iterations I expected smoother functions.

Looking into the components of total surplus, we begin with consumer surplus. We see in the probability plot in figure 2 that most of this distribution is very close to zero. With ninety percent probability, consumers gain \$1.7 billion or more. Rice and peanut consumer surplus change stayed very close to zero, however they are much smaller markets than the other commodities presented in that chart.

Looking at producer surplus we see that the story is more complicated for producers. Corn producers (figure 3a) are better off with a probability of about 90 percent. This story holds for soybean and wheat producers as well illustrated in figure 3.

Rice and peanuts are grown primarily in the removal region. We also know that there is limited substitutability for producers into rice in the all other states region. Peanuts had no substitutability for either the producer or consumer. Rice suffered little damage and peanuts suffered high amounts of damage. As such, it is not surprising that rice behaved much like the other crops. Peanut producers, almost exclusively, are better off.

5 Conclusions

Feral swine inflict destruction in terms of damage, predatory behavior, and disease transmission. For this paper, we are particularly concerned about the destruction feral swine cause to crops. Simply valuing the crops that are destroyed is an inadequate measure of impact. To truly measure the impact we need to consider that the market for crops has adjusted for the absence of those products–we would expect prices to decrease slightly from the removal of feral swine damage.

To estimate the value of the absence of feral swine with respect to crop damage, estimates of the missing crops from Shwiff et al. (Forthcoming) were replaced in the market as an exogenous shock. This exogenous shock was used in an EDM to calculate the changes in price and quantity that would result from a removal of feral swine in nine southeastern US states.

Initial results seemed counter-intuitive with distribution of the effects nearly in the opposite direction as expected, *a priori*. Realizing that this counter-intuitive result may be the result of weights or elasticities used in the model, the model was solved again for a variety of weights and elasticities. Through this process we see that weights could play a role, however we are relatively certain of where crops are grown in the United States. The precise value of elasticities is something that is unknown. Furthermore, this model assumes market clearing, implicitly assuming that crops are not stored before being marketed such that they are not marketed in the year in which they are produced. This assumption could complicate the use of elasticities from the literature in this analysis.

Simulating the range of elasticities from a distribution around literature estimates allows us to examine the probability of different outcomes. A triangle distribution was chosen due to a lack information on the distribution of elasticities aside from their limits and means. The result of this simulation was a distribution of outcomes and the probability that they will occur.

The results showed that there is at least a ninety percent probability that consumers and both groups of producers are better off with removal. They also showed that there is at least a one percent probability of all parties except the producers in feral swine removal states being worse off.

The results also demonstrate the importance of sensitivity analysis on elasticities. The initial results were extremely counter-intuitive due to the baseline elasticities chosen being an unlikely combination resulting in consumers being worse off as producers in other states being better off. Using a simulation for analysis of the uncertain elasticities adds the benefit of not only knowing bounds (for which a uniform distribution would work adequately) but also for knowing the probability of a given outcome.

In this analysis, the removal of feral swine from these nine states would results in a net welfare gain of at least \$3.8 billion at least ninety percent of the time. The cost of eradication in those nine states could exceed this welfare gain. A common figure of \$57/head removed through multiple methods (Bodenchuk 2014) would cost \$114 million in Texas alone (assuming 2 million head). This does not account for the increased cost of removal as populations decrease. However, there is certainly a lot of room between $114 million and $3.8 billion for expansion of costs and there would be additional benefits than a lack of crop damage. However, the lost opportunity for recreation, permit revenue, and commercial hunting will also increase the cost of removal. There is still much uncertainty surrounding the impact of feral swine on US agriculture, however this indicates that they do inflict substantial crop damage.

6 Figures and Tables

Table 1: Percent of Crop Lost to Feral Swine (%) .

State	Corn	Soybeans	Wheat	Rice	Peanuts
Alabama	0.93	1.38	0.62%	NA	**6.17%**
Arkansas	1.09%	0.27%	0.75%	0.27%	NA
Florida	**4.41%**	**3.43%**	NA	NA	1.84%
Georgia	**4.73%**	1.07%	**4.39%**	NA	NA
Louisiana	0.83%	0.74%	0.94%	1.26%	NA
Mississippi	1.34%	0.4%	0.7%	0.12%	NA
North Carolina	0.38%	0.09%	0.15%	NA	0.49%
South Carolina	1.59%	1.52%	1.71%	NA	NA
Texas	1.65%	1.1%	**3.05%**	2.46%	**9.28%**

Source: Shwiff et al. (Forthcoming)

Table 2: Farm Level Price Elasticities of Demand by Commodity.

	Price Crops				
Quantity Crop	Corn	Soybeans	Wheat	Rice	Peanuts
Corn	-0.056 [1]	0.111 [1]			
Soybeans	0.391 [1]	-0.109 [1]			
Wheat			-0.026 [2]		
Rice				-0.083 [3]	
Peanuts					-0.2[4]

Sources [1] See Appendix for details. Estimated using data from FAPRI–MU (2015), [2] Bergtold, Akobundu, and Peterson (2004), [3] Barnes and Shields (1998), Hansen and Brooks (2012),[4] Beghin and Matthey (2003)

Table 3: Farm Level Price Elasticities of Supply by Crop and Region.

	Region	Corn	Soybeans	Wheat	Rice	Peanuts
Corn	All other states	0.201	-0.108	-0.004	0	0
	Removal states	0.326	-0.036	-0.003	-0.034	0
Soybeans	All other states	-0.167	0.153	-0.005	-0.001	0
	Removal states	-0.031	0.191	-0.008	-0.095	0
Wheat	All other states	-0.155	-0.11	0.28081	-0.001	0
	Removal states	-0.016	-0.047	0.331	-0.045	0
Rice	All other states	-0.016	-0.047	0.331	-0.045	0
	Removal states	-0.164	-0.117	-0.006	0.238	0
Peanuts	All other states	0	0	0	0	0.35 [1]
	Removal states	0	0	0	0	0.35 [1]

Sources: FAPRI–MU (2004), [1] Beghin and Matthey (2003)

Table 4: Percent of National Production By Region.

	Corn	Peanuts	Rice	Soybeans	Wheat
FS	5.58%	97.22%	76.39%	12.04%	9.74%
AOS	94.42%	2.78%	23.61%	87.96%	90.26%

Table 5: Calculated Production Shock.

	Corn (bu.)	Soybeans (bu.)	Wheat (bu.)	Rice (cwt.)	Peanuts (lb.)
Alabama	421,430	259,440	96,255	-	33,623,415
Arkansas	1,080,299	427,680	186,638	302,284	-
Florida	238,140	54,571	-	-	12,291,200
Georgia	2,492,710	124,120	494,753	-	-
Louisiana	744,718	842,712	117,218	177,610	-
Mississippi	956,358	315,272	65,100	39,533	-
North Carolina	391,248	62,280	66,990	-	1,968,624
South Carolina	520,884	234,080	195,624	-	-
Texas	4,859,580	57,178	2,058,750	264,253	42,663,872
Total Shock (Quantity)	11,705,366	2,377,333	3,281,328	783,680	90,547,111
Total Original FS Prod	793,860,000	472,887,000	197,440,000	169,739,000	5,044,365,000
Relative Shock	0.0147	0.0050	0.0166	0.0046	0.0180

Table 6: Relative Price Changes.

$EP_c =$	0.000489
$EP_s =$	0.000787
$EP_w =$	-0.000088
$EP_r =$	-0.00698
$EP_p =$	-0.0317

Table 7: Baseline Results.

	Relative Price Change	Relative Quantity Demanded Change	Relative Quantity Supplied Change (AOS)	Relative Quantity Supplied Change (FS)
Corn	0.000489	6.0008e-05	1.3621e-05	0.0151
Soybeans	0.000787	1.0540e-04	4.6213e-05	0.0058
Wheat	- 0.000088	2.2962e-06	-1.7318e-04	0.0168
Rice	-0.006981	5.7943e-04	-0.0018	0.0013
Peanuts	-0.031747	0.0063	-0.0111	0.0069

Table 8: **Triangular Distribution Parameters.**

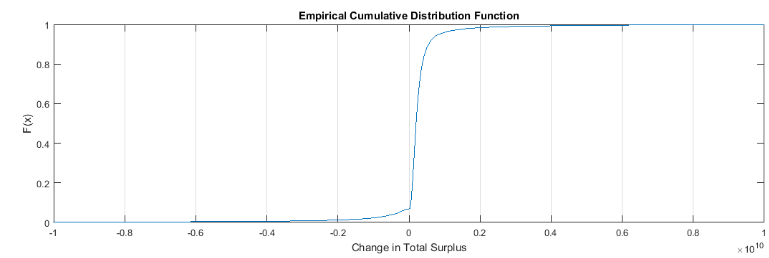
Parameter (Triangular)	Min Value	Most Likely Value	Maximum Value
η_{cc}	-1	-0.056	0
η_{sc}	0	0.391	1
η_{ss}	-1	-0.109	0
η_{cs}	0	0.111	1
η_{ww}	-1	-0.026	0
η_{rr}	-1	-0.083	0
η_{pp}	-1	-0.2	0
ϵ_{AOS-cc}	0	0.201	1
ϵ_{AOS-cs}	-1	-0.108	0
ϵ_{AOS-cw}	-1	-0.004	0
ϵ_{FRS-cc}	0	0.326	1
ϵ_{FRS-cs}	-1	-0.036	0
ϵ_{FRS-cw}	-1	-0.003	0
ϵ_{FRS-cr}	-1	-0.034	0
ϵ_{AOS-sc}	-1	-0.167	0
ϵ_{AOS-ss}	0	0.153	1
ϵ_{AOS-sw}	-1	-0.005	0
ϵ_{AOS-sr}	-1	-0.001	0
ϵ_{FRS-sc}	-1	-0.031	0
ϵ_{FRS-ss}	0	0.191	1
ϵ_{FRS-sw}	-1	-0.008	0
ϵ_{FRS-sr}	-1	-0.095	0
ϵ_{AOS-wc}	-1	-0.155	0
ϵ_{AOS-ws}	-1	-0.11	0
ϵ_{AOS-ww}	0	0.201	1
ϵ_{AOS-wr}	-1	-0.001	0
ϵ_{FRS-wc}	-1	-0.016	0
ϵ_{FRS-ws}	-1	-0.047	0
ϵ_{FRS-ww}	0	0.331	1
ϵ_{FRS-wr}	-1	-0.045	0
ϵ_{AOS-rc}	-1	-0.164	0
ϵ_{AOS-rs}	-1	-0.117	0
ϵ_{AOS-rw}	-1	-0.006	0
ϵ_{AOS-rr}	0	0.238	1
ϵ_{FRS-rc}	-1	-0.015	0
ϵ_{FRS-rs}	-1	-0.05	0
ϵ_{FRS-rw}	-1	-0.004	0
ϵ_{FRS-rr}	0	0.473	1
ϵ_{AOS-pp}	0	0.35	1
ϵ_{FRS-pp}	0	0.35	1

Table 9: Descriptive Statistics for Surplus Changes.

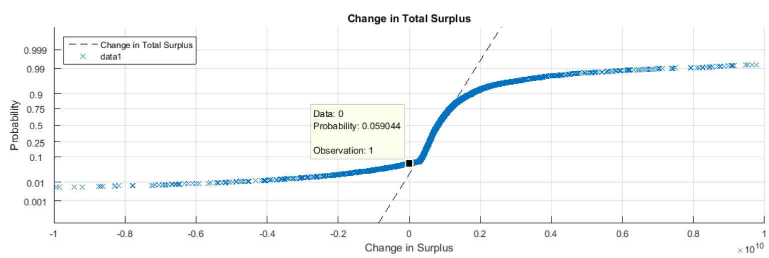
Variable	Min Value	Mean	Median	Maximum Value
Change in Consumer Welfare	-2.0221e+11	281,980,000	183,610,000	2.7229e+11
Change in Producer Welfare (AOS)	-1.7740e+11	273,460,000	199,590,000	2.3121e+11
Change in Producer Welfare (FS)	-2.9249e+11	408,230,000	373,280,000	1.3482e+10
Total Change in Producer Welfare	-2.1356e+11	681,687,000	605,685,000	2.4294e+11
Total Change in Welfare	-4.1577e+11	963,572,000	804,367,000	4.9817e+11

Table 10: Extreme Values of Surplus Changes.

	Percentile					
Variable (all in 1.0e+11x USD)	0.1	1	10	90	99	99.9
Change in Consumer Welfare	-3.2778	-0.2790	0.0017	0.0582	0.3396	5.7036
Change in Producer Welfare (AOS)	-2.9482	-0.2477	0.0051	0.0557	0.3004	5.0546
Change in Producer Welfare (FS)	-0.3582	0.0027	0.0240	0.0687	0.1692	0.7107
Total Change in Producer Welfare	-3.6066	-0.2416	0.0334	0.1182	0.4135	5.4828
Total Change in Welfare	-0.6535	-0.0515	0.0038	0.0175	0.0742	1.0950



(a) Empirical Cumulative Density Function for the Change in Total Welfare.



(b) Probability Plot for Change in Total Welfare.

Figure 1: Change in Total Surplus.

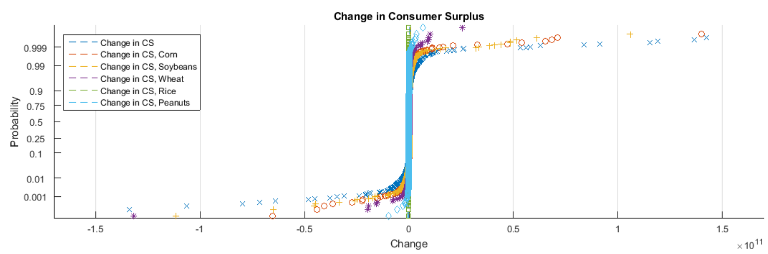
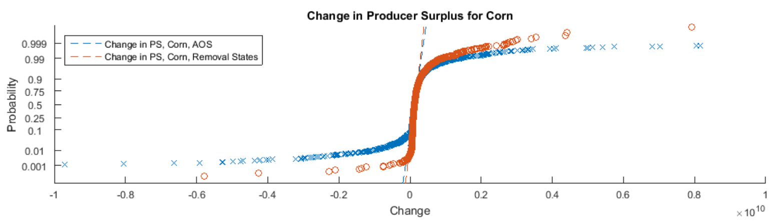
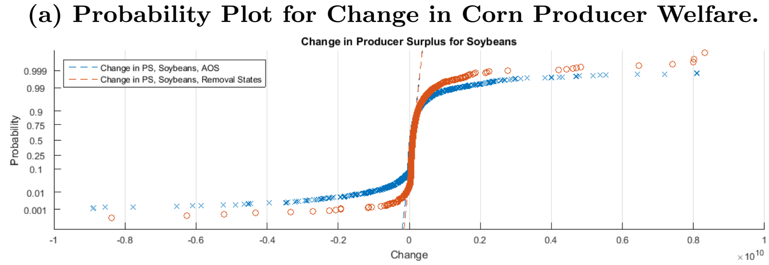


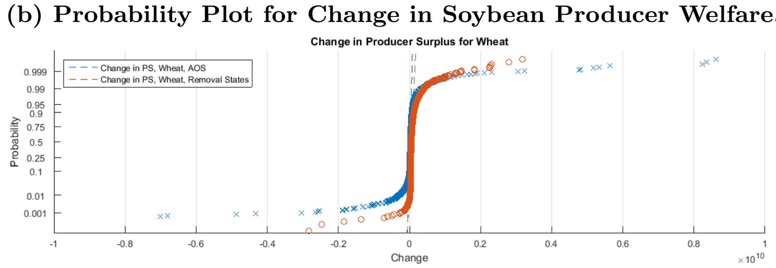
Figure 2: Change in Consumer Welfare.



(a) **Probability Plot for Change in Corn Producer Welfare.**

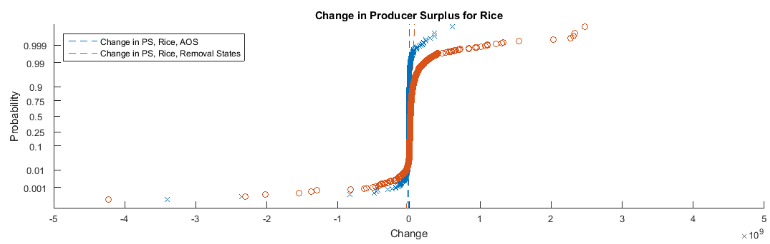


(b) **Probability Plot for Change in Soybean Producer Welfare.**

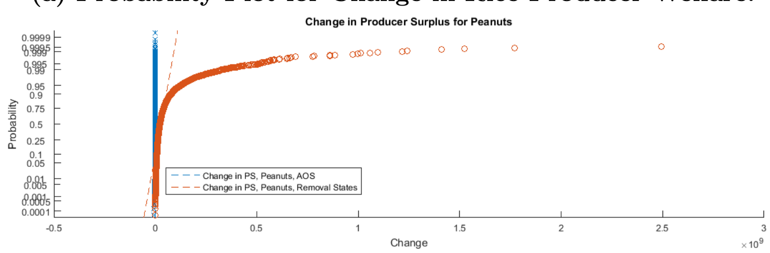


(c) **Probability Plot for Change in Wheat Producer Welfare.**

Figure 3: Change in Producer Welfare For Corn, Soybeans, and Wheat.



(a) **Probability Plot for Change in Rice Producer Welfare.**



(b) **Probability Plot for Change in Peanut Producer Welfare.**

Figure 4: Change in Producer Welfare For Rice and Peanuts.

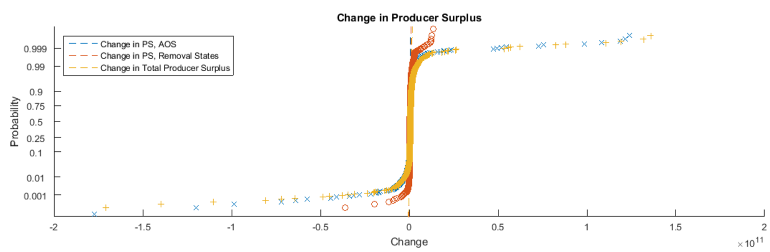


Figure 5: Probability Plot for Change in Producer Welfare, By Region and in Total.

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