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INTERNATIONAL PORK TRADE AND FOOT-AND-MOUTH DISEASE

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ABSTRACT

International pork trade has been affected by two conflicting effects in recent years: lower trade barriers because of free trade agreements and trade disruptions caused by disease outbreaks. This study investigates how global pork trade is affected by foot-and-mouth disease among major exporting/importing countries. The 41 countries included in this analysis account for 99% of world pork exports and 92% of world pork imports. A Pseudo Poisson Maximum Likelihood (PPML) estimator with a series of controlled fixed effects in the gravity equation was utilized. Results were statistically confirmed that pork exports fall when an exporting country reports foot-and-mouth disease. Exporters with a vaccination policy suffer larger negative impacts than those with a slaughter policy. Pork importers that report FMD and institute a slaughter policy will import more pork, but importers with a vaccination policy will import less pork.

Keywords: foot-and-mouth disease, gravity model, pork exports, regional trade agreement, zero-valued trade

JEL Classifications: C52, Q17, Q18

INTRODUCTION

Foot-and-mouth disease (FMD) is a highly contagious viral-type disease which infects cloven-hoofed ruminant animals, such as cattle and pigs. The disease has had very destructive impacts on animal herds throughout the world. FMD symptoms include fever, erosions, and blister-like lesions on the hooves, lips, mouth, teats, and tongue (APHIS, 2007). FMD outbreaks can also affect consumption behavior because the disease can influence consumer perceptions about food health and safety. Food safety and animal life issues are increasingly

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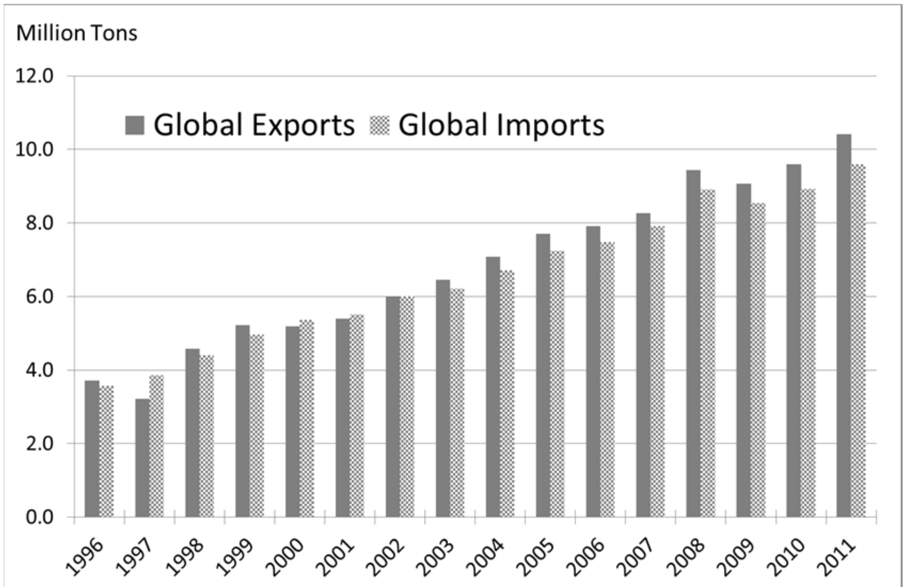
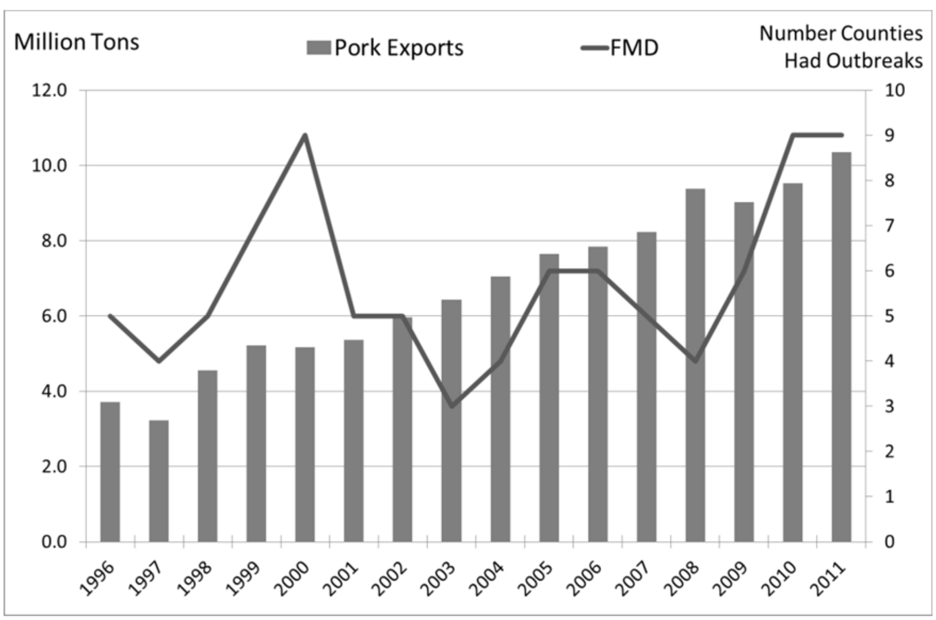
impacting international agricultural trade. Member countries of the World Trade Organization (WTO) can apply measures of the Sanitary and Phytosanitary (SPS) Agreement to prevent the spread of pests or disease among animals and plants, and ensure safe food for consumers. Thus, it is common to have livestock and meat exports from a country banned because of FMD. Such a ban can have devastating impacts on a country's livestock industry.



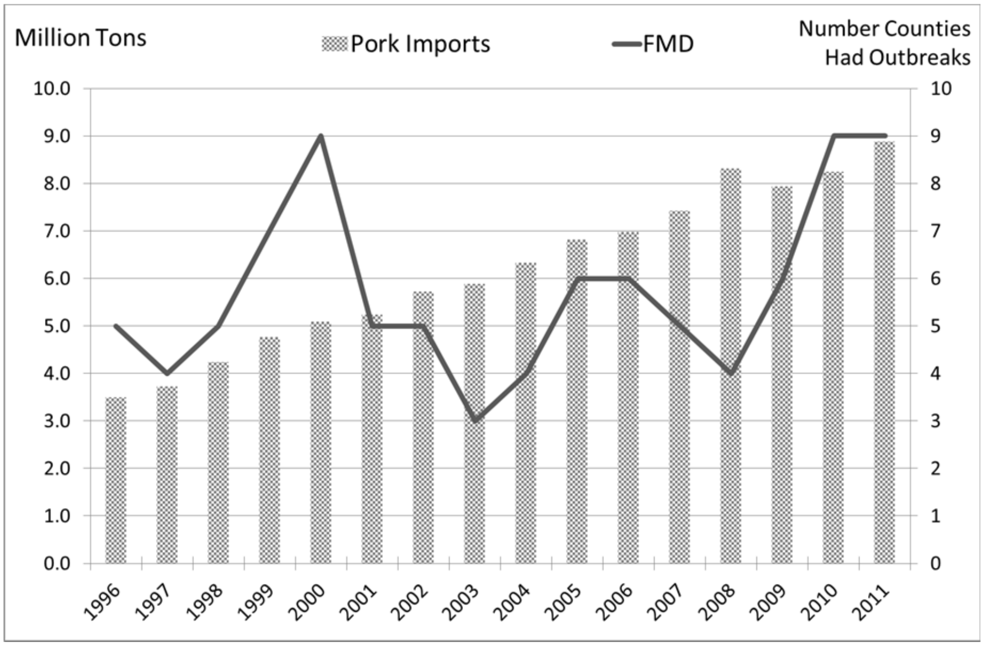
Source: UN Commodity Trade Database.

Figure 1. World Pork Exports and Imports.



Source: UN Commodity Trade Database and Office of International Epizootics.

Figure 2. Pork Exports and FMD Outbreaks of the Forty-one Countries.



Source: UN Commodity Trade Database and Office of International Epizootics.

Figure 3. Pork Imports and FMD Outbreaks for the Forty-one Countries.

This study investigates the effects of FMD outbreaks on bilateral pork trade. The proposition is that these FMD outbreaks have had a tremendous impact on bilateral pork flows. The first objective of this study is to investigate how an FMD outbreak in a pork exporting country impacts pork trade patterns for exporting and importing countries. The second objective is to find out how the trade flows of FMD-infected importers are influenced by the outbreak. A third objective stems from the use of a gravity model for a commodity, rather than total trade or total agricultural trade; especially concerning the treatment of zero trade observations. This study investigates the effects of including zero trade observations in the trade analysis for a disaggregated commodity, pork.

In swine species, 59 countries were infected by FMD during 1996 to 2011, but the volume of the global pork exports still grew from 3.7 to 10.4 million tons (figure 1). Global pork imports also grew from 1996 to 2011 (although it did show a drop during 2009 and 2010). In order to understand the relationship between global pork trade and FMD outbreaks, 41 countries that account for the vast majority of global pork trade (99% of exports and 92% of imports during the observation period) are included in this analysis to explain the potential shock from the incident of FMD outbreaks (see Appendix I for the country list).

Figures 2 and 3 show pork exports and imports, respectively, related to FMD outbreaks. Although it is difficult to see the effects of FMD outbreaks from these graphs, there is some unsteadiness in pork export growth (Figure 2) that seems correlated with FMD outbreaks. It is important to investigate which pork exporters reported FMD and investigate the effects on pork trade, especially when one highly suspects that it will have impacts and yet it is not easily discerned from the data. There is no question that the pork market and its supporting industries in importing and exporting countries are influenced by FMD and the associated policies to address it. Information on the exact effects will not only be helpful to the pork industry but also to policy-makers.

These 41 FMD-infected countries reported a total of 92 FMD outbreaks in swine species to the Office International des Epizooties (OIE) during 1996 to 2011. Many of these FMD-infected countries were eventually able to regain an FMD-free position, yet others are still suffering from it. FMD outbreaks impact supply and demand (Yeboah and Maynard, 2004; Paarlberg, et al., 2008) -- an FMD outbreak diminishes livestock production in all stages (due to slaughtering the disease-infected herds or lower herd health) and reduces consumption for meat products in the short-run (Perry and Grace, 2009).

International pork trade can be hindered or stimulated by FMD outbreaks. As an FMD-free exporter, pork exports can obviously be stimulated when other major pork exporters experience an FMD event. Yet exports by those countries affected by the outbreak are reduced from the disease because of import bans by disease-free countries. Pork imports can be hindered during an FMD outbreak because of food safety concerns and reductions in consumption. The net effects on importers are unknown so the overall effects on FMD-free exporters are also unclear.

An FMD-infected country can apply either a slaughter or vaccination policy to protect domestic animals (Pendell et al., 2007). The central goal of a slaughter policy is to strengthen the efficacy in controlling FMD outbreaks, so all disease-infected animals are slaughtered to prevent additional outbreaks. The central goal of a vaccination policy is to protect healthy animals from infection. Since a vaccinated animal cannot be distinguished from an infected animal (Mackay, et al., 1998), countries with a vaccination policy usually face the FMD stigma for a longer period. With a slaughter policy pork exports can still be hindered from one to two years. A pork importer that adopts a slaughter policy might import more pork, while an importer with a vaccination policy might not change its import quantities.

Regional trade agreements (RTAs) have been discussed and investigated a great deal in the literature and have been found to be important factors that have influenced agricultural trade in the last three decades (Baier and Bergstrand, 2007; Grant and Lambert, 2008; Lambert and McKoy, 2009; Sun and Reed, 2010; Cipollina and Salvatici, 2011). Previous studies have investigated the effects of RTAs on total agricultural trade, but not a particular sector, so this study's focus on pork trade will enhance our understanding of RTAs. The RTA variable in this study covers: Free Trade Agreements (FTAs), Preferential Trade Agreements (PTAs), and Customs Union (CU). In total, these agreements consist of eight different trading groups (including the ASEAN Free Trade Area, Andean Community of Nations, Asia-Pacific Trade Agreement, Central European Free Trade Agreement, Common Economic Zone, European Free Trade Association, EU27, and North American Free Trade Agreement). An RTA will likely stimulate international pork trade and must be included in the model.

Several other factors that have been widely used in the literature may also affect pork exports, such as distance between trading partners, contiguity, and past colonial connections. Proximity among countries is an obvious stimulus to trade. Countries with past colonial connections are more likely to trade with each other due to similar culture. This study contributes to basic understanding of the impacts of FMD outbreaks in international pork trade, while analyzing their different influences on FMD-infected and FMD-free countries.

The pork trade data employ the Harmonized System (HS) coding 0203, i.e., meat of swine, fresh, chilled, and frozen. The dataset consists of many zero trade flows (over 63% of the observations are zeroes). Zero trade flows have been discussed and examined in the gravity model literature because of the potential biased estimation and missing information (Santos-Silva and Tenreyro, 2006; Baylis, et al., 2010; Cipollina and Salvatici, 2011). Large numbers of zero observations raise an important question on whether they should be included in the analysis.

This study employs a gravity model with estimation procedures that have performed well when large numbers of zeroes are included. Hence, this study reports a number of empirical analyses: some that include zero trade flows and others that exclude zero trade flows to see the empirical differences between including and excluding zero trade flows. A two-step Heckman procedure is also followed to investigate potential selection bias in the treatment of zero trade flows.

LITERATURE REVIEW

Numerous studies have found that FMD outbreaks can dramatically influence consumption behavior, market prices, production in all stages, and meat product trade. Some of the studies focus on the effects on livestock supply contemporaneously and over time. Roh, et al. (2006) estimated the negative effects of FMD outbreaks on cattle, beef, hog, and pork prices in Korea during 2000 and 2002. They showed that after the first FMD outbreak in 2000, beef and pork prices fell 15-20% before the Korean government intervened to stabilize prices. The second FMD outbreak in 2002 led to many more animal deaths than the first outbreak, but the impact on prices was smaller. Costa et al. (2011) investigated the effects of FMD outbreaks on the Brazilian meat market. They found that beef, pork, and chicken export prices declined after the FMD outbreak. They argued that price decreases, though, were partially due to the imposition of an import ban by Russia because of the FMD outbreak.

Paarlberg, et al., (2008) integrated an epidemiological model into an economic model to estimate the impacts of potential FMD outbreaks, tracking the results over 16 quarters. They found large trade-related losses for beef, beef cattle, hogs, and pork, causing all of their prices to decline in the short-run. Pork and hog prices recovered after three to five quarters even under their high-outbreak scenario. So the effects were severe, but short-lived.

Some studies have focused on the effects of FMD on meat demand. Yeboah and Maynard (2004) investigated Japanese consumer response to the discovery of BSE and discussed consumers' understanding of the difference between the health risks associated with BSE and FMD. Their study showed that consumers reacted negatively against all the meat products that could be carriers of FMD. Piggott and Marsh (2004) confirmed that major food scares in meat (including FMD) caused extensive negative demand responses, but these responses were small economically and they dissipated rapidly. They found no evidence of a cumulative effect. They did find some instances of highly skewed negative information concerning food safety scares that resulted in larger effects, but still only in the short-run. They contrasted these effects from information on health issues and meat consumption, which have a more long-lasting effect on demand. Saghaian et al. (2007) studied the impact of E. Coli 0157:H7, FMD, and BSE on Japanese retail beef prices and confirmed that food safety and animal health concerns had negative impacts on retail beef prices in the Japanese retail market. Consumers considered animal health issues as a negative quality attribute.

Paarlberg et al. (2003) focused on the welfare changes among consumers and producers in the United States from an FMD outbreak. They distinguish between producers who have animals quarantined or slaughtered from producers who only are affected by price changes. Consumers who have health concerns from an FMD outbreak are differentiated from those who have no such fears (since there is no evidence that an FMD outbreak affects human health). These distinctions among classes of individuals were important for understanding the full impacts of FMD.

Thompson et al. (2002) measured economic costs to agriculture and tourism from the FMD outbreak in the United Kingdom (UK) in 2001. They concluded that the agricultural losses were £3.1 billion while the loss in tourism was between £2.7 and £3.2 billion. Because some of the losses were compensated by gains in other parts of the economy (particularly tourists moving to other UK locations), the total loss in UK was less than 0.2% of gross domestic product.

Previous studies that have estimated economic impacts of FMD have focused on specific domestic markets; the analysis of FMD outbreaks on global trade in pork products or the aggregate world trade is less discussed. In order to enhance the implication of global trade, this study attempts to investigate the effects of FMD on pork trade among numerous countries.

The Gravity Model

The gravity model is widely used to examine bilateral trade flows (Anderson, 2008). Numerous studies reveal how to measure the impacts of regulations, policies, and standards on food trade using this model (Swann, et al., 1996; van Beers and van den Bergh, 1997; Peridy, et al., 2000; Wilson and Otsuki, 2004; Anderson and van Wincoop, 2004; and Anders and Caswell, 2009). Recent research has overcome two challenges identified by the literature: first, possible endogeneity problems, and second, the presence of heteroskedasticity.

The possible endogeneity problem involves the idea that RTAs could be endogenous in gravity models (Grant and Lambert, 2008; Sun and Reed, 2010). Anderson and van Wincoop (2003) and Feenstra (2004) suggest using country-specific fixed effects in specifying multilateral price terms to overcome this problem. Baldwin and Taglioni (2006) argue that multilateral resistant terms can be fully controlled by using importer-time and exporter-time fixed effects. However, using importer-time or exporter-time fixed effects eliminates some important FMD-related variables in this study, so this procedure is not used. Grant and Lambert (2008) suggest using the gravity model with a series of fixed effects, i.e., time fixed effects, time plus country-specific, and time plus bilateral country pair fixed effects. Hence, the endogeneity problems due to omitted variables can be controlled.

The second challenge, the presence of heteroskedasticity, involves zero-valued trade and the log-linearized gravity equation. Santos-Silva and Tenreyro (2006) point out that heteroskedasticity can be quantitatively important in a gravity equation because Jensen's inequality, i.e., $E(\ln y) \neq \ln E(y)$, is neglected. The problem is especially important using disaggregated trade data which often contain a number of zero trade observations. When observations of the dependent variable include zeroes, heteroskedasticity can lead to biased estimation, even if the gravity equation is controlled by fixed effects. Hurd (1979) argues the problem of heteroskedasticity can be exacerbated if zeroes are excluded. Santos-Silva and Tenreyro (2006) propose an augmented gravity equation in levels using a Pseudo-Maximum-Likelihood (PML) estimator, which can handle zero-valued trade, so the problem of heteroskedasticity can be avoided. Santos-Silva and Tenreyro (2006) use Monte Carlo simulation to show that the Poisson PML (PPML) estimator is relatively robust and adequately behaved among different estimators including ordinary least square (OLS), Tobit, and non-linear least square (NLS). The PPML estimator is often used for count data but Santos-Silva and Tenreyro, 2006, show that if the conditional variance is proportional to the conditional mean, the estimator based on the Poisson likelihood function will be consistent. Furthermore the estimator gives the same weight to all observations (unlike OLS and NLS). Their simulations show that the PPML estimator is still well behaved among different estimators when the dependent variable is non-negative (Santos-Silva and Tenreyro, 2006; 2009). Westerlund and Wilhelmsson (2009) also examine the effects of zero trade with the gravity model using a Monte Carlo simulation under a panel data structure. They had up to 83% of the values equaling zero for the dependent variable in their simulations. They also suggest using the Poisson fixed effects estimator.

Sun and Reed (2010) were the first to use the PPML estimator with fixed effects in the gravity model to deal with FTA variables on agricultural trade. The potential endogeneity problems with the FTA variable involve reverse causality between higher trade volumes and trade agreements (Sun and Reed, 2010). Their application of fixed effects shows that the endogeneity problem from omitted variables can be controlled.

EMPIRICAL MODELS AND DATA

Empirical Framework

This study employs a gravity equation in levels and applies the PPML estimator with a series of fixed effects, i.e., time, time plus country-specific, and time plus bilateral country pair fixed effects, for more robust results. The time fixed effects control for time-specific shocks in pork trade; the country specific fixed effects capture unobserved country-specific shocks/impacts; the bilateral country pair fixed effects capture the effects of omitted variables. The specification is similar to those empirical models referenced earlier (Sun and Reed, 2010).

We specify our first empirical models without the variable *RTA* as:

(A) Time fixed effects without RTA variable:

$$X_{ijt} = \exp\{\alpha_0 + \alpha_t^{\theta} + \alpha_1 \ln(RGDP_{it}) + \alpha_2 \ln(RGDP_{jt}) + \alpha_3 \ln(Distance_{ij}) + \alpha_4 (Contiguity_{ij}) + \alpha_5 (Colony_{ij}) + \alpha_6 (EXP\_Vac_{it}) + \alpha_7 (EXP\_Sla_{it}) + \alpha_8 (IMP\_Vac_{jt}) + \alpha_9 (IMP\_Sla_{jt}) + \varepsilon_{ijt}\} \quad (1)$$

(B) Time plus country-specific fixed effects without RTA variable:

$$X_{ijt} = \exp\{\alpha_0 + \alpha_t^{\theta} + \alpha_i^{\theta} + \alpha_j^{\theta} + \alpha_1 \ln(RGDP_{it}) + \alpha_2 \ln(RGDP_{jt}) +$$

$$\alpha_3 \ln(Distance_{ij}) + \alpha_4(Contiguity_{ij}) + \alpha_5(Colony_{ij}) + \alpha_6(EXP\_Vac_{it}) + \alpha_7(EXP\_Sla_{it}) + \alpha_8(IMP\_Vac_{jt}) + \alpha_9(IMP\_Sla_{jt}) + \varepsilon_{ijt}\} \quad (2)$$

(C) Time plus bilateral country pair fixed effects without RTA variable:

$$X_{ijt} = \exp\{\alpha_0 + \alpha_t^\theta + \alpha_{ij}^\theta + \alpha_1 \ln(RGDP_{it}) + \alpha_2 \ln(RGDP_{jt}) + \alpha_6(EXP\_Vac_{it}) + \alpha_7(EXP\_Sla_{it}) + \alpha_8(IMP\_Vac_{jt}) + \alpha_9(IMP\_Sla_{jt}) + \varepsilon_{ijt}\} \quad (3)$$

In equations (1) to (3), t denotes time, i denotes exporting country and j denotes importing country; X_{ijt} is the pork export value in levels from exporting country i to importing country j in time t; α_t^θ are time fixed effects; α_i^θ and α_j^θ are country-specific fixed effects; α_{ij}^θ denote bilateral country pair fixed effects. Both $RGDP_{it}$ and $RGDP_{jt}$ are real gross domestic product of the exporting and importing countries, respectively, as a proxy for economic size. $Distance_{ij}$ is the distance between exporting country i and importing country j which is used as a proxy for transportation costs. Other geographic and preference similarities, such as two countries that are contiguous ($Contiguity_{ij}$) and past colonial connections since 1945 ($Colony_{ij}$), are commonly used in gravity equations. The variables $EXP\_Vac_{it}(IMP\_Vac_{jt})$ denote an interaction dummy variable indicating when the exporting country i (importing country j) with FMD adopts a vaccination policy; the variables $EXP\_Sla_{it}(IMP\_Sla_{jt})$ denote an interaction dummy variable indicating when the exporting country i (importing country j) with FMD adopts a slaughter policy. The ε_{ijt} is assumed to be a log-normally distributed error term.

The next approach is to add an RTA variable to equations (1) to (3). The models with time plus country-specific, and time plus bilateral country pair fixed effects should control for any endogeneity from including an RTA variable:

(D) Time fixed effects including an RTA variable:

$$X_{ijt} = \exp\{\alpha_0 + \alpha_t^\theta + \alpha_1 \ln(RGDP_{it}) + \alpha_2 \ln(RGDP_{jt}) + \alpha_3 \ln(Distance_{ij}) + \alpha_4(Contiguity_{ij}) + \alpha_5(Colony_{ij}) + \alpha_6(EXP\_Vac_{it}) + \alpha_7(EXP\_Sla_{it}) + \alpha_8(IMP\_Vac_{jt}) + \alpha_9(IMP\_Sla_{jt}) + \alpha_{10}(RTA_{ijt}) + \varepsilon_{ijt}\} \quad (4)$$

(E) Time plus country-specific fixed effects including an RTA variable:

$$X_{ijt} = \exp\{\alpha_0 + \alpha_t^\theta + \alpha_i^\theta + \alpha_j^\theta + \alpha_1 \ln(RGDP_{it}) + \alpha_2 \ln(RGDP_{jt}) +$$

$$\alpha_3 \ln(Distance_{ij}) + \alpha_4 (Contiguity_{ij}) + \alpha_5 (Colony_{ij}) + \alpha_6 (EXP\_Vac_{it}) +$$
$$\alpha_7 (EXP\_Sla_{it}) + \alpha_8 (IMP\_Vac_{jt}) + \alpha_9 (IMP\_Sla_{jt}) + \alpha_{10} (RTA_{ijt}) + \varepsilon_{ijt}\} \quad (5)$$

(F) Time plus bilateral country pair fixed effects including an RTA variable:

$$X_{ijt} = \exp\{\alpha_0 + \alpha_t^{\theta} + \alpha_{ij}^{\theta} + \alpha_1 \ln(RGDP_{it}) + \alpha_2 \ln(RGDP_{jt}) + \alpha_6 (EXP\_Vac_{it}) +$$
$$\alpha_7 (EXP\_Sla_{it}) + \alpha_8 (IMP\_Vac_{jt}) + \alpha_9 (IMP\_Sla_{jt}) + \alpha_{10} (RTA_{ijt}) + \varepsilon_{ijt}\} \quad (6)$$

RTA_{ijt} is a dummy variable (which is time variant for all country pairs) indicating the existence of a regional trade agreement between the exporting country *i* and importing country *j* in time *t*.

In order to understand whether inclusion of zero trade flows leads to biased and inconsistent results, this study provides results from the full sample and the sample with positive trade outcomes for each empirical model: without the RTA variable and including the RTA variable. Further, to avoid omitted variable bias, this study adopts a Heckman selection model to determine whether the zero trade flows should be included (Baylis, et al., 2010; Cipollina and Salvatici, 2011).

Data

The study period is from 1996 to 2011; accurate FMD data before 1996 are not consistently available. Bilateral pork trade data (X_{ijt}) in U.S. dollars from 1996 to 2011 are derived from the United Nations Commodity Trade Statistics Database. There are 26,240 observations (41 x 40 x 16) on the forty one countries, including 16,640 zeroes (over 63% of the sample). The records of FMD outbreaks and control policies come from the Office of International Epizootics. Real gross domestic product (RGDP) in U.S. dollars is obtained from the Foreign Agricultural Service (USDA). Distance, contiguity, and colonial relations are collected from the Centre d'Etudes Prospectives et d'Informations Internationales. The RTA variable is collected from the WTO website. The definition and statistical summary of variables are shown in Table 1.

EMPIRICAL RESULTS

The empirical results are presented in two different tables in order to reveal issues with endogeneity. Table 2 presents results without an RTA variable while Table 3 includes an RTA variable. Each table includes results of the Heckman selection model and results when only positive trade flows are included. Table 3 is considered the main specification. Both models adopt the same fixed effect schemes, i.e., time, time plus country-specific, and time plus bilateral country pair fixed effects. Each model distinguishes FMD impacts on exporters versus importers that vary between slaughter and vaccination policies for FMD outbreaks. For each estimated equation a robustness test is performed to check for any potential heteroskedasticity and the robust standard errors are reported.

Table 1. Descriptive Statistics of Variables (N = 26,240)

Variables	Description of variable	Mean	Std. Dev.	Min.	Max.
Exports (X_{ijt})	Continuous variable; annual total value of countries' pork exports (U.S. $ in thousands)	9,404	58,100	0	1,880,000
$RGDP_{it}$	Continuous variable; annual real GDP for exporting countries (2005 U.S. $ in billions)	949	1,959	7.357	13,299
$RGDP_{jt}$	Continuous variable; annual real GDP for importing countries (2005 U.S. $ in billions)	949	1,959	7.357	13,299
Distance ($Distance_{ij}$)	Continuous variable; the shortest distance between the largest population regions for each country (kilometers)	6,396	4,568	141	18,868
Contiguity ($Contiguity_{ij}$)	Binary variable=1 if exporting countries are adjacent with importing countries	0.048	0.215	0	1
Colony_1945 ($Colony_{ij}$)	Binary variable=1 if importing countries had colonial relations with exporting countries since 1945	0.013	0.115	0	1
*Exporter*Vaccination* (EXP_Vac_{it})	Binary variable=1 if exporting countries had FMD outbreaks and applied a vaccination policy	0.094	0.292	0	1
*Exporter*Slaughter* (EXP_Sla_{it})	Binary variable=1 if exporting countries had FMD outbreaks and applied a slaughter policy	0.038	0.191	0	1
*Importer*Vaccination* (IMP_Vac_{jt})	Binary variable=1 if importing countries had FMD outbreaks and applied a vaccination policy	0.094	0.292	0	1
*Importer*Slaughter* (IMP_Sla_{jt})	Binary variable=1 if importing countries had FMD outbreaks and applied a slaughter policy	0.038	0.191	0	1
RTA (RTA_{ijt})	Binary variable=1 if importing countries have RTA relations with exporting countries	0.284	0.451	0	1

Table 2. The Outcomes of the Gravity PPML Estimator –RTA Not Included

	Full Sample			*Positive Trade*	*Heckman Model*
	α_t^θ	$\alpha_t^\theta, \alpha_i^\theta, \alpha_j^\theta$	$\alpha_t^\theta, \alpha_{ij}^\theta$	$\alpha_t^\theta, \alpha_{ij}^\theta$	$\alpha_t^\theta, \alpha_{ij}^\theta$
$RGDP_{it}$	0.574***	0.179	–0.667	–0.399	–0.006
	(0.029)	(0.497)	(0.715)	(0.645)	(0.640)
$RGDP_{jt}$	0.742***	3.298***	3.473***	3.221***	3.663***
	(0.022)	(0.338)	(0.502)	(0.441)	(0.406)
$Distance_{ij}$	–0.686***	–1.455***	.	.	.
	(0.036)	(0.053)			
$Contiguity_{ij}$	0.769***	0.609***	.	.	.
	(0.077)	(0.083)			
$Colony_{ij}$	–0.285	1.359***	.	.	.
	(0.513)	(0.432)			
EXP_Vac_{it}	–1.666***	–0.896 **	–0.847***	–1.172 **	–1.410 **
	(0.265)	(0.414)	(0.314)	(0.596)	(0.578)
EXP_Sla_{it}	–0.837 **	–0.034	0.020	0.339	–0.535 *
	(0.402)	(0.514)	(0.314)	(0.262)	(0.314)
IMP_Vac_{jt}	–0.700***	–0.040	–0.045	–0.044	–0.423***
	(0.201)	(0.175)	(0.059)	(0.058)	(0.097)
IMP_Sla_{jt}	0.786***	–0.017	–0.016	–0.033	.
	(0.206)	(0.141)	(0.071)	(0.076)	
Intercept	13.005***	4.985			
	(0.419)	(4.048)			
Mills ratio					2.815***
					(0.648)
Observations	26,240	26,240	26,240	9,600	9,600
Wald $I?^2$	4423	23,318	604	584	573
Log Pseudo-likelihood	–3.8e+11	–1.1e+11	–3.4e+10	–2.7e+10	–2.7e+10
Pseudo R^2	0.485	0.838			

Note: *10% significance, ** 5% significance, and *** 1% significance.

Parentheses represent robust standard error.

The coefficients of time, time plus country-specific, and time plus bilateral country pair fixed effects are omitted for brevity.

Table 3. The Outcomes of the Gravity PPML Estimator – RTA Included

	Full Sample			*Positive Trade*	*Heckman Model*
	α_t^θ	$\alpha_t^\theta, \alpha_i^\theta, \alpha_j^\theta$	$\alpha_t^\theta, \alpha_{ij}^\theta$	$\alpha_t^\theta, \alpha_{ij}^\theta$	$\alpha_t^\theta, \alpha_{ij}^\theta$
$RGDP_{it}$	0.569***	–0.049	–0.552	–0.278	0.333
	(0.029)	(0.524)	(0.714)	(0.640)	(0.601)
$RGDP_{jt}$	0.739***	2.837***	3.100***	2.900***	3.288***
	(0.022)	(0.328)	(0.473)	(0.412)	(0.424)
$Distance_{ij}$	–0.613***	–1.081***	.	.	.
	(0.034)	(0.062)			
$Contiguity_{ij}$	0.774***	0.757***	.	.	.
	(0.076)	(0.084)			
$Colony_{ij}$	–0.136	1.313***	.	.	.
	(0.516)	(0.391)			
EXP_Vac_{it}	–1.647***	–0.895**	–0.841***	–1.172 *	–1.448***
	(0.266)	(0.420)	(0.317)	(0.604)	(0.562)
EXP_Sla_{it}	–0.802 **	–0.047	–0.010	0.324	–0.646 *
	(0.403)	(0.510)	(0.304)	(0.260)	(0.383)
IMP_Vac_{jt}	–0.665***	–0.018	–0.030	–0.030	–0.386***
	(0.204)	(0.166)	(0.057)	(0.057)	(0.142)
IMP_Sla_{jt}	0.817***	0.015	0.007	–0.016	.
	(0.208)	(0.135)	(0.069)	(0.075)	
RTA_{ijt}	0.240***	1.372***	0.901***	0.759***	2.039***
	(0.072)	(0.126)	(0.180)	(0.175)	(0.474)
Intercept	12.377***	6.018			
	(0.379)	(4.048)			
Mills ratio					2.750***
					(0.959)
Observations	26,240	26,240	26,240	9,600	9,600
Wald $I?^2$	4,457	24,362	680	659	798
Log Pseudo-likelihood	–3.7e+11	–1.1e+11	–3.3e+10	–2.7e+10	–2.6e+10
Pseudo R^2	0.486	0.846			

Note: *10% significance, ** 5% significance, and *** 1% significance. Parentheses represent robust standard error.
The coefficients of time, time plus country-specific, and time plus bilateral country pair fixed effects are omitted for brevity.

We are most interested in the FMD policy results, but briefly discuss results for the typical gravity variables. The income coefficients for $RGDP_i$ and $RGDP_j$, the real gross domestic product of the exporting and importing countries, have the expected sign but are more than two standard deviations away from unity when fixed effects are controlled (Tables 2 and 3). This is inconsistent with the theoretical gravity model in Anderson and van Wincoop (2003) but it is not unusual with gravity models. When the other two fixed effect schemes are employed (and in the Heckman model and the model with only positive trade flows) the GDP for the exporting country is not significantly different from zero (and negative). The GDP of the importing country has a coefficient around three for these models. One can conclude that importing country GDP has a significant positive impact on imports but that exporting country GDP may not.

The coefficients for *Distance* and *Contiguity* have the expected signs and are significant at the 1% level in the first two specifications (of course they drop out of the time and bilateral fixed effects model). The larger distance between countries means higher transportation costs, so the negative sign is expected. Among international pork traders, if countries are adjacent, then there is more pork trade between them. The coefficients for Colony_1945 are not significant in Tables 2 and 3 when time fixed effects are controlled, but the colony relationships do reveal an expected sign and are significant at the 1% level when time plus country-specific fixed effects are used. This suggests that pork trade could be stimulated by a colonial relationship.

The coefficients for RTA (Table 3) have the expected sign and are significantly different from zero at the 1% level for all fixed effects. The magnitudes are different among the specifications, but this is to be expected because the RTA dummy variable is correlated with country fixed effects and bilateral country fixed effects. Separating out the effects of the RTA in these later specifications would be impossible, though. The results clearly reveal that countries with RTAs are more likely to trade pork with each other.

Effects of FMD Policies

Using the Full Sample

The coefficients for *EXP_Vac*, *EXP_Sla*, *IMP_Vac*, and *IMP_Sla* are consistent no matter whether the variable *RTA* is included or not when time fixed effects are applied. Note that the coefficients for *EXP_Vac* are about two times larger than the coefficients for *EXP_Sla* with time fixed effects (in Tables 2 and 3). This implies that exporters with a vaccination policy would experience larger FMD impacts on pork trade than those with a slaughter policy. With other fixed effects, i.e., time plus country-specific and time plus bilateral country pair, the coefficient for *EXP_Vac* is the only one significantly different from zero among FMD-related variables. The more complex fixed effects schemes might be picking up the negative effects of a slaughter policy for exporters. Nonetheless it is clear that exporters with FMD outbreaks are more likely to have negative impacts on their exports if they adopt a vaccination policy.

The estimated parameters for *IMP_Vac* and *IMP_Sla* are significantly different from zero when time fixed effects are used, and are opposite in sign, indicating that importers with FMD outbreaks would have different impacts depending on which treatment policy is adopted. Tables 2 and 3 (when the time fixed effects are used) reveal that importers with a vaccination policy import less pork, while importers with a slaughter policy import more pork. These findings are consistent with a reduction in pork demand when FMD occurs and a reduction in pork supply through a slaughter policy. The importing country must increase pork imports if it slaughters hogs because of the outbreak, but a vaccination policy seems to allow the importer sufficient production to meet lower consumption requirements. These results for importers, though, are not robust with respect to the other specifications.

When time plus country-specific fixed effects or time plus bilateral country pair fixed effects are included, these variables are not significantly different from zero. As with the effects of a slaughter policy on exporters with FMD, either these impacts are picked up in the country fixed effects or the bilateral country fixed effects, or these policies have no impact on imports. Although the coefficients of *IMP_Vac* and *IMP_Sla* with country-specific fixed effects or bilateral country pair fixed effects are not significantly different from zero, the signs for the coefficients are the same as those from when only time fixed effects are controlled and the RTA variable is included.

Table 4 presents the elasticities for the FMD policy variables under various specifications. The magnitudes are between 0.03 and 0.16 in absolute value, so FMD can have a large impact on a country, but the magnitudes are not huge. The model with time fixed effects only estimates that an FMD outbreak in an exporter would reduce exports by 15% if the country vaccinated and 3% if they slaughtered animals instead. An importer that suffered an outbreak would reduce imports by 6% if they vaccinated but increase imports by 3% if they slaughtered animals. The elasticities that are not significantly different in the various specifications are near zero in magnitude also.

Table 4. The Elasticity of Pork Trade with Respect to FMD Variables

		Full Sample			*Positive Trade*	*Heckman Model*
		α_t^θ	$\alpha_t^\theta, \alpha_i^\theta, \alpha_j^\theta$	$\alpha_t^\theta, \alpha_{ij}^\theta$	$\alpha_t^\theta, \alpha_{ij}^\theta$	$\alpha_t^\theta, \alpha_{ij}^\theta$
RTA Excluded	EXP_Vac_{it}	–0.156***	–0.084**	–0.079***	–0.110 *	–0.132***
	EXP_Sla_{it}	–0.031**	–0.001	–0.0008	0.012	–0.020*
	IMP_Vac_{jt}	–0.065***	–0.003	–0.004	–0.004	–0.039***
	IMP_Sla_{jt}	0.029***	0.0006	0.0006	–0.001	.
RTA Included	EXP_Vac_{it}	–0.154***	–0.084**	–0.079***	–0.110 *	–0.136***
	EXP_Sla_{it}	–0.030**	–0.001	–0.0004	0.012	–0.024*
	IMP_Vac_{jt}	–0.062***	–0.001	–0.002	–0.002	–0.036***
	IMP_Sla_{jt}	0.031***	0.0006	0.0003	–0.0006	.
	RTA_{ijt}	0.068***	0.389***	0.255***	0.215***	0.579***

Note: The elasticity is calculated with the sample mean.

Positive Trade Flows and the Heckman Model

The question concerning whether zero trade observations should be included in the estimation hinges on whether there is selection bias when only positive trade flows are included. There is also a potential estimation issue of heteroskedasticity too. It is important to examine and identify whether zero trade flows generate any noise during the estimation. Two approaches are adopted in this study: 1) examining the results using only positive trade flows and 2) performing a sample selection framework (Heckman model) for zero trade flows. In order to examine these two approaches, this study adopted the empirical specification with time plus bilateral country pair fixed effects for better control of unobserved impacts.

The empirical results in Tables 2 and 3 when only positive trade flows are included are very close to the full sample outcomes when the time plus bilateral country pair fixed effects are controlled, although the signs of a few coefficients (that are not significantly different from zero) changed in Table 3. The elasticities between the full sample and positive trade model in Table 4 are quite close to each other.

A sample selection framework is further provided to identify whether zero trade flows should be included in the analysis. A two-step procedure suggested by Disdier and Marette (2010) is used. The variable *IMP_Sla* was chosen to provide the identifying restriction in the second stage (Puhani, 2000). That variable was the only one not significantly different from zero in the first stage. The coefficients for the Mills ratio in Tables 2 and 3 are positive and significantly different from zero; confirming that there is sample selection bias from deleting zero observations. The variables *EXP_Sla, EXP_Vac* and *IMP_Vac* are significant at the 10% level or better and negative in Tables 2 and 3, indicating that an FMD outbreak will reduce exports under both policies and reduce imports under a vaccination policy. Note that the signs for all three of these coefficients are the same as when only time fixed effects are controlled; and the values of these coefficients are close to each other as well. Although we don't see major differences between positive trade and full sample outcomes, the Heckman model results provide proof that zero trade observations should be used in the data set.

CONCLUSION

This study's empirical results show that international pork trade can be hindered or stimulated by FMD outbreaks. An FMD outbreak in a pork exporting country will reduce its exports. Yet this study indicates that a slaughter policy by an exporter will generate less trade disruption than a vaccination policy. Exporters with a vaccination policy experience larger negative impacts than exporters with a slaughter policy. The slaughter policy rids the country of the FMD problem more quickly and has a smaller impact on exports. However it is not possible for all countries to adopt an effective slaughter policy that will rid the country of FMD. Furthermore, the level of their exports versus the size of their domestic market, and the export destinations for its pork (FMD endemic versus FMD-free countries) will be a concern in choosing between a vaccination and slaughter policy. Each country's situation is different with regard to the structure of pork production, the importance of the pork processing sector in the economy, and the infrastructure that can be used to combat the disease. These issues are important in the decisions about combating the disease, but beyond the scope of this study.

FMD-infected importers may not increase their pork imports, depending on which policy importers adopt. When time-related unobserved impacts were controlled, pork importers with a slaughter policy tend to increase pork imports. This relates to the shortage of domestic supply from controlling FMD outbreaks by destroying pigs. On the other hand, importing countries with a vaccination policy do significantly decrease pork imports when time-related unobserved impacts are controlled. In this case any shortage in domestic supply under a vaccination policy is more than offset by a reduction in domestic pork demand.

The concerns of endogeneity and heteroskedasticity have often been raised with gravity models. This study has followed previous research by using a PPML estimator with fixed effects to properly handle these two concerns. The issue of zero trade flows was also examined by contrasting the estimation with positive trade observations with the full sample, and examining the Heckman sample selection framework to identify whether sample selection bias exists. The strategy of contrasting positive trade outcomes with the full sample outcomes does not find important differences in the results, but the Heckman sample selection model suggests that excluding zero trade flows could bias the estimation results.

Appendix I – The List of Exporters and Importers

	Country List	Country Code
26 Developed Countries	Australia	AUS
	Austria	AUT
	Belgium	BEL
	Canada	CAN
	Chile	CHL
	Cyprus	CYP
	Czech Republic	CZE
	Denmark	DNK
	Estonia	EST
	Finland	FIN
	France	FRA
	Germany	DEU
	Greece	GRC
	Hungary	HUN
	Ireland	IRL
	Italy	ITA
	Japan	JPN
	South Korea	KOR
	Lithuania	LTU
	Netherlands	NLD
	Norway	NOR
	Portugal	PRT
	Spain	ESP
	Sweden	SWE
	United Kingdom	GBR
	United States	USA
15 Developing Countries	Brazil	BRA
	Bulgaria	BGR
	China	CHN
	Hong Kong	HKG
	India	IND
	Malaysia	MYS
	Mexico	MEX
	Poland	POL
	Romania	ROM
	Russian Federation	RUS
	South Africa	ZAF
	Taiwan	TWN
	Thailand	THA
	Ukraine	UKR
	Viet Nam	NNM

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WATER IN THE INTERNATIONAL ECONOMY

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ABSTRACT

Approximately 75% of all water used by humans goes towards food production, much of which is traded internationally. This study presents a model of international agricultural trade that incorporates new data on water use by crop and country. The main innovation is the linking of a gravity-based trade model back to distributions of water use by country. In one application of the model, changes to irrigation water availability, by country, are traced through to changes in production and trade. Trade is shown to help countries deal with a shock that is too big for one country to handle by itself in isolation. In a second application of the model, trade liberalization in agricultural products is examined for how it would affect production patterns and water usage at the global level. While trade liberalization is unlikely to 'water saving,' it improves economic welfare among the 23 countries of the sample.

Keywords: agriculture, environment, hydrology, irrigation, trade liberalization, water

JEL classifications: F14, F18, Q15, Q25

1. INTRODUCTION

There is a growing literature that places water issues in an explicitly international context. Much attention has been devoted to the virtual water concept described in Allan (1998), which posits that water-scarce countries can make up for their deficit by importing products that require a lot of water in their production. One strand of the resulting literature has focused on the pure economics of virtual water trade, specifically whether it is a legitimate concept and how it relates to the comparative advantage concept of economics (Merrett, 2003; Wichelns, 2004; Ansink, 2010; Reimer, 2012, 2014). Another strand has focused on the measurement of existing virtual water trade flows around the world (de Fraiture et al., 2004; Yang et al. 2006; Chapagain, Hoekstra, and Savenjie, 2006; Varma and de Fraiture, 2009).

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Many of these studies focus on agriculture since this sector places the heaviest burden on national water supplies in most countries.

A corollary debate is whether renewable freshwater availability is a good predictor of trade patterns, with moderately positive evidence provided by Yang et al. (2003) and Novo et al., (2009), and negative results found in studies such as Kumar and Singh (2005) and Ramirez-Vallejo and Rogers (2004). Trade barriers in agriculture, such as tariffs, tariff-rate quotas, and technical barriers to trade, can be so high as to obscure any role for water availability as a predictor of trade patterns.

Since water is not always a large out-of-pocket expense, its relationship to international trade is sometimes overlooked. Rainwater is by far the most important type of freshwater resource for crop agriculture, yet irrigation also plays a role in most countries. Water for agriculture is often subsidized, and private irrigation costs typically fail to internalize resource depletion costs or environmental externalities (Tsur and Dinar, 1997; Rossi, Schmitz, and Schmitz, 2005).

The current study complements the above literature by taking a somewhat different perspective on the issue of water in the international economy. A model of international trade in water-intensive products is developed which links agricultural output back to average water requirements. Once this model is parameterized through a mix of econometrics and calibration, it is used to illustrate how changes in water availability, such as the water applied through irrigation, can potentially impact trade patterns and volumes. The objective is to quantitatively illustrate how international trade in water-intensive products can serve as a mechanism for adaptation to changes in freshwater availability, whether this arises from future policy change or from natural variability.

A second objective is to show how changes in the economic environment potentially affect the use of water in different countries of the world. In contrast to the earlier objective, in this case the effect of international trade policy is traced back to patterns of water use, production, and trade. Trade liberalization could potentially lead to production occurring in areas where less water is typically used, i.e., be ‘water saving.’ The opposite could happen as well; it is an empirical question.

The model used in this study is similar the one presented in Reimer and Li (2010), which itself draws from Eaton and Kortum (2002). In contrast to these studies, the model is developed to focus on the role of water as an input for agricultural production. The focus on crop agriculture is due to the heavy burden this sector places on national water supplies.

The data source that makes the approach possible concerns estimates of the embedded water of crop production by Mekonnen and Hoekstra (2011). These are sometimes referred to as a product’s ‘water footprint.’ The water footprint is a measure of the amount of water volume evapotranspirated (consumed) in the entire process of producing a given amount of crop. This is the sum of evaporation, and plant transpiration of water, from land to the atmosphere.

Taking the inverse of the water footprint for an individual product provides a measure of the output per unit of water that is used. This value is influenced by – but does not have a perfect correspondence with – regional water abundance, technology, input availability, and management skill. Even if a country’s farmers use best practices and have optimal amounts of water, soil, seed, and fertilizer, they may appear to be ‘inefficient’ in using water if much is lost naturally through evapotranspiration. This can happen more in windy, warm, and dry weather, for instance, and less in calm, cool, and humid weather. A farmer may be using optimal techniques yet still using relatively large amounts of water to produce a given type of crop, depending on the nature of the local climate.

This study does not evaluate whether countries are efficient users of water, whether they are abundant or scarce in water, and whether relatively water-abundant countries specialize in relatively water-intensive crops, for example. A distinction is made, however, with respect to a country's reliance on rainfall as opposed to irrigation. In particular, 'green' water, which refers to soil water originating from rain, is distinguished from 'blue' water, which is surface water or groundwater evaporated as a result of production of a crop (Chapagain, Hoekstra, and Savenjie, 2006; Mekonnen and Hoekstra, 2011). These measures of water use vary greatly by crop and country. Within the trade model, this measure of water usage will be characterized as having a distribution.

In addition to information on blue and green water use, the basic data for the model concern bilateral trade and production by country. Parameters not specified by a gravity equation are calibrated to produce a benchmark equilibrium. Once parameterized, the model can be used to generate a counterfactual that consists of new values of endogenous variables arising from changes in the exogenous variables.

As such, the approach is similar to that of a computable general equilibrium (CGE) model, which is typically used as a sort of computational laboratory. For example, Randhir and Hertel (2000) and Liu et al. (2013) have used this approach in relatively comprehensive, economywide examinations of climate issues in the international economy. The latter study finds that regions under water stress will someday have to cut back on food production and turn into net food importers.

In contrast to a CGE model, the approach of this study is relatively stylized; it is partial equilibrium and does not attempt to provide an exhaustive accounting of input use in the economy, or trace the circular flow of income in the economy. In addition, the characterization of bilateral trade is not Armington (1969), but based on a gravity equation derived from the underlying trade model.

In this study, two counterfactuals are set up to demonstrate two general types of problems that arise with respect to trade in water-intensive commodities. The first counterfactual illustrates how international trade can be used to adapt to changes to water availability by country. Following a shock, countries reallocate production around the world according to the cost of production, bilateral trade costs, and parameters concerning water. This counterfactual sheds light on many of the adjustments that might be seen when there is a natural resource shock too big for one country to handle by itself in isolation.

A strength of the approach at hand lies in showing how shocks within a country are transmitted imperfectly around the world, due to the many trade barriers in existence. The characterization of bilateral trade in this study is flexible enough so that a new trade flow may be created between two locations that never previously traded. Meanwhile, the model can also predict that existing trade flows between other locations may shut down. This flexibility is not always found in alternative models of trade, and is described in more detail below.

The second counterfactual considered examines how trade liberalization may affect water use requirements, production patterns, and trade patterns at the global level. The idea is that when barriers to trade are lowered, crop production will shift to places where less water is needed to produce the same amount of output.

To preview the finding in this regard, under trade liberalization there is a small tendency for production to move to locations with lower production costs, but where water use for agriculture is already relatively high. Thus trade liberalization does not appear to be 'water saving' at the global level. It would, however, improve economic efficiency among the 23 countries of the sample.

2. Model Overview

To understand how water affects and is affected by trade in water-intensive final products, a suitable model of bilateral trade is required that can handle large shocks. Existing quantitative trade models have not always performed well. An example can be found in the models that were used to predict the impacts of the North American Free Trade Agreement (NAFTA).

A retrospective evaluation of these models by Kehoe (2003) shows that most tended to greatly underpredict the amount of U.S.-Mexican trade that resulted from NAFTA. Many of these models adopted the so-called taste-for-variety approach on the consumer side to account for large trade flows of slightly differentiated products.

The problem with this approach is that trade increases occur only in sectors for which there already is significant trade, that is, changes are at the intensive margin (Kehoe, 2003). By contrast, under NAFTA large increases in trade took place in product categories with little or no previous trade, that is, at the extensive margin. Models based on Armington's (1969) national product differentiation have the same limitation owing to similarities in approach.

Given the large, uncertain changes to water availability that could occur under climate change, along with future policy shocks possibly larger than NAFTA, accounting for the extensive margin would seem important. This study's adaptation of Eaton and Kortum (2010) allows for this key feature. As shocks to the international baseline equilibrium occur, a new trade flow may be created between two locations that never previously traded. On the other hand, some existing trade flows may shut down altogether. In this way the big changes that may occur under future climate change, or trade policy change, can be captured.

In one sense, the approach is related to spatial equilibrium models (e.g., Takayama and Judge, 1971; Mittal and Reimer, 2008). As in those models, a country imports from those countries that can supply it most cheaply, according to factors such as transportation costs and border policies. Furthermore, a given product is homogeneous across countries, and production is constant returns to scale. Traditional spatial equilibrium models, however, are too simple to replicate and predict trade flows well; they often make predictions that are too extreme.

In this study's approach, by contrast, bilateral trade relations are given by a gravity equation that allows for a rich set of determinants of trade. Since the gravity equation is econometrically estimated, it arguably provides a better characterization of actual trade constraints.

This study's approach differs from existing gravity models in at least two ways. First, the gravity model is embedded within a broader economic structure that includes inputs and outputs, with productivity of water use given by a distribution. Second, instead of just looking at trade volumes between different countries, predictions are also made about how much each country sources from itself.

3. Model Details

There is a continuum of commodities, discrete number of countries, and one internationally immobile input (water). The productivity with which water is used to produce crops is determined by a draw from a probability distribution, with each country having some chance of producing at a lower cost than any other country. Bilateral trade costs give rise to the possibility that a country produces goods for which it is otherwise not the lowest cost producer. This probabilistic representation of productivity fits well with crop production, the output of which is inherently random, even when controlling for the amount of water that is available.

There are *N* countries indexed alternatively by *i* and *n*. When a country exports it is denoted by *i*; when it imports it is denoted by *n*. The amount of output *j* derived per unit of water evapotranspiration in country *i* is random and denoted $Z_i\left(j\right)$. Total production costs are w_i, and cover all expenses associated with crop production, including water, fertilizer, capital, labor, and land. Only water is modeled explicitly, which is viewed as something for which substitution is very limited.

In a competitive market the price that *n* pays for crop *j* from country *i* is $P_{ni}(j)$ given by:

$$P_{ni}(j) = \frac{d_{ni} w_i}{Z_i(j)}, \tag{1}$$

where $d_{ni} \geq 1$ is the trade cost from *i* to *n*, including tariff and non-tariff policy barriers to trade. Trade costs are iceberg in nature, implying that delivery of one unit to country *n* requires d_{ni} units produced in *i*. Zero costs of bilateral trade imply that $d_{ni} = 1$. Large trade costs imply that d_{ni} is large and positive.

Country *n* buys crop *j* from the cheapest of *N* potential suppliers (due to international trade costs, this supplier need not have the world's lowest production cost). The price paid is random due to the underlying randomness in output. In effect, country *n* chooses the minimum from a sequence of random prices:

$$P_n(j) = \min\left\{P_{n1}(j), P_{n2}(j),\ \ldots\ , P_{nN}(j)\right\}. \tag{2}$$

This type of probability can be characterized by the Fréchet extreme value distribution (Eaton and Kortum, 2002). In terms of Z_i, which is the fundamental source of the randomness in the model, the Fréchet cumulative distribution function is stated:

$$\Pr\left[Z_i \leq z\right] = \exp\left(-T_i z^{-\theta}\right), \tag{3}$$

where $T_i > 0$ and $\theta > 1$ are parameters. Equation (3) signifies that a commodity's productivity of water usage in different countries is distributed multivariate extreme value.

The location of the distribution is shifted by T_i, with higher values of T_i being associated with higher levels of output for a given level of water use. As such, T_i affects absolute productivity and can be thought of as one driver of a country's absolute advantage in international markets. Parameter θ governs the breadth of the distribution, with lower values of θ implying a greater range of output per level of water use. A lower value of θ means there are greater differences in the relative productivities of water usage across crops when comparing across countries. This is the one part of the model that allows for comparative advantage in international markets. Relative productivity differences and hence comparative advantage become stronger as θ falls (Eaton and Kortum, 2002).

The probability that country *i* supplies country *n* at the lowest price is:

$$\Pr\left[P_{ni}(j) \leq \min\left\{P_{ns}(j);\ s \neq i\right\}\right] = \frac{T_i(w_i d_{ni})^{-\theta}}{\sum_{i=1}^{N} T_i(w_i d_{ni})^{-\theta}}. \tag{4}$$

Equation (4) can further be related to the share of *n*'s spending on crops from *i*. Let X_{ni} be *n*'s spending on crops from country *i*, with *i*=*n* when a country buys from home. Summing over all sources of supply gives: $\sum_{i=1}^{N}\left(X_{ni}/X_n\right)=1$. The share of *n*'s spending on crops from *i* is equal to (4), which implies that:

$$\frac{X_{ni}}{X_n} = \frac{T_i(w_i d_{ni})^{-\theta}}{\sum_{i=1}^{N} T_i(w_i d_{ni})^{-\theta}}. \tag{5}$$

Equation (5) shows that the pattern of goods trade is determined by production cost (w_i), water use productivity (T_i), bilateral trade costs (d_{ni}), and relative differences in productivity across countries (θ). The price index for crops bought by country *n* can be derived using the moment generating function for the extreme value distribution to get:

$$P_n = \left[\Gamma\left(\tfrac{\theta+1-\sigma}{\theta}\right)\right]^{1/1-\sigma} \left[\sum_{i=1}^{N} T_i(w_i d_{ni})^{-\theta}\right]^{-1/\theta}, \tag{6}$$

where Γ is the Gamma function used to express certain types of definite integrals (all derivations available upon request). Price index P_n relates the overall prices paid in country *n* back to water use productivity, water costs, and trade costs.

Trade shares can also be linked to data on prices by first dividing (5) by the analogous expression for the share that country *i* sources from home (X_{ii} / X_i), and then substituting in (6):

$$\frac{X_{ni}/X_n}{X_{ii}/X_i} = \left(\frac{P_i d_{ni}}{P_n}\right)^{-\theta} . \tag{7}$$

The amount of water evapotranspirated in the course of producing crops is denoted L_i. The input market clearing condition with one internationally immobile input is such that production cost (w_i) and the total amount of water evapotranspirated (L_i) equals the sum of country *i*'s worldwide sales to all destinations *n*: $w_i L_i = \sum_{n=1}^{N} X_{ni}$. This expression also gives a measure of total production of crops for source *i*. There is also a second non-crop agricultural sector that uses water, denoted Y_i^O . It is a numéraire good and remains fixed in all counterfactual simulations. Overall crops spending in country *n* is given by $X_n = \alpha(w_n L_n + Y_n^O)$, where α is crops' fixed share of total spending. Using this and (5), the input market clearing condition can be shown to be:

$$w_i L_i = \sum_{n=1}^{N} \left(\frac{T_i (w_i d_{ni})^{-\theta}}{\sum_{i=1}^{N} T_i (w_i d_{ni})^{-\theta}} \left[\alpha (w_n L_n + Y_n^O) \right] \right). \tag{8}$$

Equations (5), (6), and (8) comprise a two sector model of the agricultural sector, with all detail and focus on the crops sector. They are solved simultaneously for endogenous trade shares, crop prices, and input prices.

4. Estimation of Parameters

The model described above is developed for a continuum of goods, with countries specializing in a section of this continuum. With this approach, it makes the most sense to work with an aggregate of goods. Working with an aggregate – crops in this case – also means that it is easier to observe bilateral trade between virtually all of the diverse range of countries that are examined. The aggregate that is studied includes all grains (e.g., wheat, rice, and corn) and all oilseeds (e.g., soybeans). These crops are either highly substitutable in the global market for calories, important substitutes in production, or both. Data on bilateral crop purchases for 23 countries are from the United Nations' Comtrade data, compiled within the Global Trade Analysis Project (GTAP) 6 data (Dimaranan and McDougall, 2007). The 23 countries were chosen primarily because they all have good quality data on the required water input for a number of crops, and vary greatly in terms of development and geography. Note that newer GTAP data are now available, but 2001 coincides with key data for the analysis, in particular, Mekonnen and Hoekstra's (2011) innovative data concerning the amount of crop that is derived with a given quantity of water. These data correspond to a 1996-2005 average.

The amount of crop output derived per unit of water evapotranspirated differs greatly among crops. This variability is presented in Table 1 for the 23 countries and six major crops of the sample. The values concern the average number of grams of harvested crop that is produced with one cubic meter of water, by country. It is derived by taking the inverse of Mekonnen and Hoekstra's (2011) estimates of crops' water footprint, which is essentially a measure of evapotranspiration. The country that derives the highest amount of wheat per meter cubed of water evapotranspirated is France, at 171.7 grams. The country that derives the lowest amount of wheat per meter cubed of water evapotranspirated is Ethiopia, at 23.7 grams. In the case of rice, the highest output for a given amount of water is in Japan, with 133.9 grams for a cubic meter of water. The lowest amount of rice per cubic meter of water evaporated is in South Africa, at 23.4 grams.

In examining this link between output and water use, the underlying reasons for differences are necessarily left unexamined within this study. They could come from differences in the availability and quality of other inputs (fertilizer, seeds, land, capital, labor), or climatic conditions. On this last point, recall that evapotranspiration can be quite different for reasons of solar radiation, temperature, wind, and humidity.

The coefficient of variation with respect to the number of grams of output per cubic meter of water gives an indication of the variability across crops, by country. The median coefficient of variation based on the six crops in Table 1 is calculated to be 43. Australia has a coefficient of variation of only 16, and therefore is most consistent in the level of water usage, by crop. Peru has the most variability, with a coefficient of variation of 78. It has relatively low water needs with respect to rice, but relatively high water needs for all other crops.

Table 2 reports the entire 23×23 matrix of bilateral trade flows, in 2001 million dollars. These data are fully reconciled across each exporter *i* and importer *n*. Among the 23 countries, imports from the other 22 countries as a share of total imports are 76% on average. This implies that the sample covers much of the world's trade in these products. Average spending on domestic crops as a share of total spending on crops exceeds 88%, indicative of so-called home bias in consumption.

With these data the d_{ni} parameters can be estimated, the process of which is reported in Reimer and Li (2010) and also in the appendix of this study. To do this, start with trade equation (5) and normalize (X_{ni} / X_n) by the home sales of a buyer (X_{nn} / X_n) to get:

$$\frac{X_{ni}}{X_{nn}} = \frac{T_i (w_i d_{ni})^{-\theta}}{T_n w_n^{-\theta}} = \frac{T_i}{T_n}\left(\frac{w_i}{w_n}\right)^{-\theta} d_{ni}^{-\theta}. \tag{9}$$

Taking the log one can get:

$$\ln\left(\frac{X_{ni}}{X_{nn}}\right) = \ln\frac{T_i}{T_n} - \theta \ln\frac{w_i}{w_n} - \theta \ln d_{ni}. \tag{10}$$

This expression can be estimated more easily if the definition is made: $S_i \equiv \ln T_i - \theta \ln w_i$, where S_i can be thought of as a measure of *i*'s competitiveness, that is, as output per unit of water evapotranspirated, adjusted for costs. S_i can be substituted into (10) to get:

$$\ln\left(\frac{X_{ni}}{X_{nn}}\right) = -\theta \ln d_{ni} + S_i - S_n \,. \qquad (11)$$

In estimating (11) the S_i are captured by way of dummies. Since the d_{ni} cannot be observed, they are estimated this using variables typically employed in gravity equations. Distance is accounted for using six dummy variables, d_k (k = 1,…,6), which represent different intervals of Great Circle distance between capitals: d_1 represents a distance of 375 miles or less, d_2 represents a distance of 375 to 750 miles, and so on. Also included is whether two countries share a border (b), share membership in a trade agreement (e_h), and have a common language (l). Finally, an overall destination effect (m_n) is included that proxies for openness to imports, i.e., trade costs that are more likely to be controllable. Substituting these in for $\ln d_{ni}$ in (11) gives:

$$\ln\left(\frac{X_{ni}}{X_{nn}}\right) = S_i - S_n - \theta m_n - \theta d_k - \theta b - \theta l - \theta e_h + \theta \xi_{ni} \,. \qquad (12)$$

To avoid the dummy variable trap the following are imposed: $\sum S_i = 0$, $\sum m_n = 0$, and no overall intercept.

Details on the estimation of equation (12) are provided in Reimer and Li (2010), and also included in the appendix to this study. Key results are summarized here. Negative coefficients are found for the distance dummies, which suggests that freight costs, and possibly other aspects of transport costs, are an important impediment to trade in crop markets. Positive coefficients on border, language, NAFTA, and EU imply that these factors reduce trade costs, which is as expected. In looking at the country-specific effects, the countries most open to imports are the U.S. and France, with $-\theta m_n$ estimates of 5.875 and 3.228, respectively. The countries least open to imports are Zimbabwe and Bulgaria, with estimates of -4.294 and -4.046, respectively. The lower-left portion of the appendix table reports the estimates of S_i. The U.S. is the most competitive country (5.425), followed by Argentina, another important exporter (3.927). Peru and Zimbabwe are the least competitive, at -3.216 and -3.063, respectively. Estimation of the remaining parameters is as follows. To estimate θ the relationship between trade shares, prices, and θ that was derived in equation (7) is exploited. The logarithm of both sides of (7) is taken, and then θ is estimated as in a conventional regression equation. Eaton and Kortum (2002) recommend calculating the logarithm of the right-hand side as:

$$\ln\left(\frac{p_i d_{ni}}{p_n}\right) = \max 2\left\{\ln p_n(j) - \ln p_i(j)\right\} - \frac{\sum_{j=1}^{J}\left\{\ln p_n(j) - \ln p_i(j)\right\}}{J} \,. \qquad (13)$$

The left-hand side of the logged version of (7), which is the dependent variable of the regression, is constructed using data on bilateral crop purchases. Equation (13), which is the right-hand side variable of the regression, is constructed using data collected by the Food and Agricultural Organization on producer prices in U.S. dollars per ton. The least squares estimate of θ is 4.96, with standard error 1.37.

The parameter T_i is taken to be the average number of kilograms of grain per meter cubed of water evapotranspirated. This is from Mekonnen and Hoekstra (2011) for the period 1996-2005 and is for six water-intensive crops: wheat, rice, maize, soybeans, barley, and oats, all of which are produced by the 23 countries. Table 1 reports $\hat{T}_i$ along with the standard deviation. The Mekonnen and Hoekstra (2011) data have the key benefit of distinguishing between green water, which is soil water originating from rain, and blue water, which is surface water and/or groundwater evaporated as a result of the production of the product. This information is also reported in Table 1.

Production cost (w_i) can be imputed using the expression $S_i \equiv \ln T_i - \theta \ln w_i$ that was introduced above. Rearranging one can get $\hat{w}_i = \exp\left([\ln \hat{T}_i - \hat{S}_i]/\hat{\theta}\right)$, using the estimates of T_i, S_i, and θ to calculate this. L_i is found by rearranging the expression for total domestic product to be: $\hat{L}_i = \left(\sum_{n=1}^{N} X_{ni}\right) \Big/ \hat{w}_i$. Estimates of w_i are reported in Table 1, and estimates of L_i are reported in Table 3.

The final parameter to estimate is α. This is first calculated for individual countries, then a unified α is found by taking a weighted average. The estimate is $\hat{\alpha} = 0.21$, with standard deviation 0.05.

Once the model is parameterized, two counterfactual simulations are carried out. These are evaluated according to criteria such as a country's change in production, crop prices, exports, imports, and welfare.

5. COUNTERFACTUAL 1: A SHOCK TO IRRIGATION

The first counterfactual traces the link from water use back to trade patterns and volumes. Climate change will affect the earth's hydrologic cycle in a variety of important ways, and therefore its water resources (Bates et al., 2008). While changes in water availability are difficult to predict (including the quantity, variability, timing, form, and intensity of precipitation), there is particular reason to worry about the availability of irrigation water. For example, incomplete property rights concerning groundwater supplies are pervasive, encouraging over-exploitation of groundwater by irrigators who draw from common aquifers. Another common irrigation source is surface water derived from snow- and ice-melt, but snowpack and glaciers in many mountain regions are likely to be smaller in the future (Barnett, Adam, and Lettenmaier, 2005). Finally, even without the above supply issues, irrigation can be difficult to manage for long term sustainability, due to rising levels of soil salinity, especially in arid regions.

Table 1. Output per unit of water

	Grams of crop per cubic meter water, 1996-2005 avg.								
Country	Wheat	Rice	Maize	Soybeans	Barley	Oats	Green water proportion	Estimate of T_i (std. dev.)*	Estimate of w_i *
Argentina	56.1	64.4	94.4	47.6	68.7	40.2	0.918	0.062 (0.019)	0.259
Australia	49.6	71.3	70.1	52.8	61.0	51.2	0.771	0.059 (0.010)	0.392
Brazil	50.2	43.5	61.7	45.8	53.4	30.2	0.972	0.047 (0.011)	0.282
Bulgaria	68.0	73.3	95.7	20.4	128.6	75.5	0.907	0.077 (0.036)	0.762
China	77.7	125.8	115.6	35.7	171.3	138.9	0.848	0.111 (0.048)	0.387
Ethiopia	23.7	34.1	23.6	21.0	20.4	18.2	0.846	0.023 (0.006)	0.391
France	171.7	77.0	193.0	51.4	186.6	125.9	0.818	0.134 (0.060)	0.453
Greece	66.0	118.9	180.2	76.5	95.3	78.8	0.774	0.103 (0.042)	1.071
Hungary	106.6	63.1	157.5	52.4	168.9	122.8	0.916	0.112 (0.048)	0.878
Italy	83.1	97.7	194.1	77.9	138.9	86.4	0.863	0.113 (0.045)	0.838
Japan	92.4	133.9	64.8	33.8	202.6	120.5	0.957	0.108 (0.059)	0.996
Mexico	112.2	63.0	52.3	28.0	52.6	37.1	0.664	0.058 (0.030)	0.609
Morocco	33.3	63.7	14.9	57.8	27.1	12.3	0.685	0.035 (0.022)	0.580
Peru	28.6	109.8	65.7	28.5	21.6	19.4	0.819	0.046 (0.036)	1.026
Romania	58.4	56.9	96.8	37.9	129.4	82.2	0.870	0.077 (0.033)	0.782
Russia	42.9	39.8	62.8	25.0	44.3	37.2	0.815	0.042 (0.012)	0.527
South Africa	78.8	23.4	59.0	35.4	69.5	26.4	0.695	0.049 (0.023)	0.495
Spain	69.4	64.6	133.2	30.2	92.0	38.8	0.547	0.071 (0.038)	0.754

Table 1. (Continued)

	Grams of crop per cubic meter water, 1996-2005 avg.								
Country	Wheat	Rice	Maize	Soybeans	Barley	Oats	Green water proportion	Estimate of T_i (std. dev.)*	Estimate of w_i *
Turkey	45.4	84.2	117.2	101.7	68.9	54.8	0.810	0.079 (0.028)	0.596
Ukraine	57.3	69.4	87.1	34.4	70.3	60.3	0.888	0.063 (0.018)	0.517
United States	51.0	78.8	170.7	60.5	87.2	52.4	0.770	0.083 (0.045)	0.203
Uruguay	52.8	73.0	70.9	32.1	54.4	29.0	0.916	0.052 (0.019)	0.812
Zimbabwe	84.7	25.4	23.4	39.7	152.5	101.3	0.600	0.071 (0.051)	1.088

Note: Values are derived from estimates presented in Mekonnen and Hoekstra (2011). * Calibrated within this study.

Table 2. Base levels of trade, 2001 million U.S. dollars

		Source country *i*											
		Argentina	Australia	Brazil	Bulgaria	China	Ethiopia	France	Greece	Hungary	Italy	Japan	Mexico
Destination country *n*	Argentina	3,860.1	0.1	8.9	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
	Australia	31.6	2,374.1	8.5	0.2	0.8	2.1	0.4	0.0	0.2	0.0	0.2	0.1
	Brazil	201.0	0.3	6,769.3	0.1	0.2	0.8	0.2	0.0	0.1	0.0	0.0	0.1
	Bulgaria	0.4	0.0	0.1	5,259.0	0.0	0.2	0.1	0.0	0.2	0.0	0.0	0.0
	China	661.7	22.8	177.9	6.8	62,299.4	58.3	11.9	0.2	5.2	1.2	194.9	3.1
	Ethiopia	24.2	0.6	6.5	1.4	0.6	6,951.2	0.4	0.1	1.1	0.3	0.1	0.1
	France	264.6	6.8	95.8	51.0	6.7	23.3	3,988.7	7.3	38.8	173.9	1.0	1.6
	Greece	34.9	0.9	12.6	44.2	0.9	17.8	48.3	712.4	16.5	15.8	0.2	0.2
	Hungary	0.9	0.0	0.2	0.5	0.0	0.4	0.3	0.0	457.5	0.1	0.0	0.0
	Italy	127.0	3.3	46.0	78.8	3.2	64.8	822.5	11.3	59.9	4,762.8	0.5	0.6
	Japan	49.2	1.7	13.2	0.5	23.2	3.2	0.7	0.0	0.4	0.1	12,021.2	0.2
	Mexico	61.7	0.4	6.2	0.1	0.3	1.1	0.3	0.0	0.1	0.0	0.1	4,592.6
	Morocco	12.2	0.2	3.3	0.5	0.2	0.8	3.1	0.0	0.4	0.3	0.0	0.1
	Peru	184.9	0.2	27.2	0.1	0.2	0.6	0.1	0.0	0.1	0.0	0.0	0.9
	Romania	0.5	0.0	0.1	0.6	0.0	0.2	0.2	0.0	0.3	0.1	0.0	0.0
	Russia	6.2	0.2	1.7	1.2	0.2	0.5	0.6	0.0	1.3	0.2	0.0	0.0
	S. Africa	52.6	2.7	14.1	0.4	0.7	3.4	0.7	0.0	0.3	0.1	0.1	0.2

Table 2. (Continued)

	Argentina	Australia	Brazil	Bulgaria	China	Ethiopia	France	Greece	Hungary	Italy	Japan	Mexico
Spain	271.0	2.6	36.8	28.6	2.6	9.0	658.8	2.8	14.9	14.3	0.4	1.7
Turkey	127.7	3.3	34.4	79.2	3.2	65.1	13.3	2.8	18.7	4.4	0.6	0.6
Ukraine	2.4	0.1	0.6	1.5	0.1	1.2	0.8	0.1	1.6	0.1	0.0	0.0
USA	200.9	10.2	54.0	1.5	2.8	9.8	2.7	0.1	1.2	0.3	0.5	34.5
Uruguay	118.6	0.0	2.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Zimbabwe	3.6	0.2	1.0	0.0	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0

		Morocco	Peru	Romania	Russia	S. Africa	Spain	Turkey	Ukraine	USA	Uruguay	Zimbab.
Destination country n	Argentina	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	5.8	0.4	0.0
	Australia	0.4	0.0	0.4	0.4	0.6	0.1	0.1	0.9	179.8	0.0	0.0
	Brazil	0.2	0.0	0.1	0.2	0.1	0.0	0.0	0.4	35.4	0.2	0.0
	Bulgaria	0.0	0.0	0.8	0.1	0.0	0.0	0.1	1.0	1.2	0.0	0.0
	China	7.8	0.1	10.1	15.9	4.4	2.1	2.0	26.1	1,414.3	0.7	0.0
	Ethiopia	0.4	0.0	2.1	0.4	0.2	0.1	0.4	5.5	51.8	0.0	0.0
	France	78.7	0.0	75.7	25.2	2.4	307.1	4.6	196.4	761.2	0.3	0.0

	Morocco	Peru	Romania	Russia	S. Africa	Spain	Turkey	Ukraine	USA	Uruguay	Zimbab.
Greece	3.2	0.0	32.1	10.8	0.3	8.7	13.0	83.3	100.4	0.0	0.0
Hungary	0.1	0.0	1.1	0.4	0.0	0.1	0.0	2.8	2.4	0.0	0.0
Italy	37.7	0.0	116.8	39.3	1.1	31.5	7.2	94.2	365.3	0.1	0.0
Japan	0.6	0.0	0.7	0.8	0.3	0.1	0.1	1.9	105.1	0.1	0.0
Mexico	0.3	0.0	0.2	0.2	0.1	0.1	0.0	0.5	1,835.8	0.1	0.0
Morocco	1,677.9	0.0	0.8	0.9	0.1	1.8	0.2	2.1	26.0	0.0	0.0
Peru	0.1	1,198.0	0.1	0.1	0.1	0.1	0.0	0.3	25.6	0.2	0.0
Romania	0.0	0.0	1,497.4	0.2	0.0	0.0	0.1	2.3	1.4	0.0	0.0
Russia	0.6	0.0	2.6	4,584.7	0.0	0.1	0.4	57.5	17.9	0.0	0.0
S. Africa	0.6	0.0	0.6	0.5	1,361.4	0.1	0.1	1.5	222.6	0.1	0.3
Spain	97.2	0.0	9.0	9.7	0.9	2,291.5	1.8	23.3	292.6	0.3	0.0
Turkey	11.7	0.0	117.5	39.5	1.1	2.4	3,497.3	94.8	367.4	0.1	0.0
Ukraine	0.2	0.0	3.1	6.4	0.0	0.0	0.1	25,107.2	6.9	0.0	0.0
USA	2.4	0.0	2.3	2.5	2.7	0.5	0.5	5.9	25,542.1	0.2	0.0
Uruguay	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	557.9	0.0
Zimbabwe	0.0	0.0	0.0	0.0	1.7	0.0	0.0	0.1	15.0	0.0	378.6

Table 3. Counterfactual 1: All irrigation water is taken away

Source country i	L_i calibrated value	L_i new value	Production $w_i L_i = \sum_n X_{ni}$ % change	Crop price P_n % change	Production cost w_i % change	Crop exports $\sum_{n,i \neq n} X_{ni}$ % change	Crop imports $\sum_{i,i \neq n} X_{ni}$ % change
Argentina	29,941	27,486	8.0	17.6	13.5	16.2	12.8
Australia	5,577	4,300	-1.9	27.0	20.7	-18.8	11.0
Brazil	28,244	27,453	7.3	10.6	8.0	63.0	-28.7
Bulgaria	9,463	8,583	2.9	13.5	10.3	42.3	-21.5
China	118,124	100,169	0.4	18.5	14.0	-7.5	-7.4
Ethiopia	24,180	20,456	0.6	19.0	14.5	10.0	-8.9
France	9,467	7,744	0.6	22.8	17.5	3.7	1.6
Greece	602	466	-5.4	20.9	17.1	-0.3	7.0
Hungary	925	847	7.3	17.1	13.1	21.5	-3.8
Italy	5,532	4,774	3.2	20.1	14.8	14.9	-4.9
Japan	16,730	16,011	2.4	7.1	5.4	66.8	-46.1
Mexico	7,560	5,020	-10.9	31.6	26.3	-27.9	20.0
Morocco	4,183	2,865	-7.5	34.5	26.5	-33.2	60.5
Peru	1,004	822	-1.9	19.3	15.1	16.0	7.6
Romania	3,455	3,006	3.1	18.5	14.1	12.1	4.8
Russia	10,028	8,173	-0.7	21.7	16.7	-2.2	24.0
South Africa	2,502	1,739	-8.2	30.3	24.6	-21.7	27.9
Spain	3,625	1,983	-25.9	29.2	28.0	-39.0	26.8

Source country i	L_i calibrated value	L_i new value	Production $w_i L_i = \sum_n X_{ni}$ % change	Crop price P_n % change	Production cost w_i % change	Crop exports $\sum_{n,i \neq n} X_{ni}$ % change	Crop imports $\sum_{i,i \neq n} X_{ni}$ % change
Turkey	4,674	3,786	-1.6	21.2	16.5	-0.4	4.4
Ukraine	59,824	53,123	1.2	14.0	10.7	39.1	-25.0
United States	163,935	126,230	-2.3	26.7	20.4	-7.2	42.7
Uruguay	695	636	3.9	14.1	10.2	38.4	-13.1
Zimbabwe	254	152	-10.2	47.1	37.4	-55.4	129.1

Table 4. Counterfactual 1: Percentage changes in bilateral trade

		Source country *i*											
		Argentina	Australia	Brazil	Bulgaria	China	Ethiopia	France	Greece	Hungary	Italy	Japan	Mexico
Destination country *n*	Argentina	2.8	-30.3	41.1	23.1	-0.3	-2.5	-17.3	-14.6	5.2	-5.1	65.0	-46.4
	Australia	45.3	-1.5	99.5	74.0	41.0	37.8	16.9	20.7	48.7	34.1	133.1	-24.3
	Brazil	-25.1	-49.2	2.8	-10.4	-27.4	-29.0	-39.8	-37.8	-23.4	-30.9	20.1	-61.0
	Bulgaria	-15.9	-43.0	15.5	0.7	-18.4	-20.2	-32.3	-30.2	-13.9	-22.4	35.0	-56.2
	China	3.5	-29.8	42.0	23.9	0.4	-1.9	-16.8	-14.1	5.9	-4.5	66.0	-46.1
	Ethiopia	5.8	-28.3	45.1	26.6	2.6	0.3	-15.0	-12.2	8.2	-2.4	69.6	-44.9
	France	23.5	-16.3	69.5	47.9	19.8	17.1	-0.7	2.6	26.4	14.0	98.2	-35.6
	Greece	13.7	-22.9	56.0	36.1	10.3	7.8	-8.6	-5.6	16.3	4.9	82.4	-40.8
	Hungary	-0.1	-32.3	37.1	19.6	-3.1	-5.3	-19.6	-17.0	2.3	-7.8	60.3	-47.9
	Italy	11.3	-24.5	52.8	33.2	8.0	5.5	-10.5	-7.6	13.9	2.7	78.6	-42.0
	Japan	-36.8	-57.2	-13.3	-24.4	-38.7	-40.1	-49.2	-47.6	-35.4	-41.7	1.3	-67.1
	Mexico	71.3	16.1	135.0	105.0	66.1	62.4	37.7	42.2	75.3	58.0	174.7	-10.7
	Morocco	90.4	29.1	161.3	127.9	84.7	80.5	53.1	58.1	94.8	75.6	205.4	-0.8
	Peru	6.9	-27.6	46.7	27.9	3.7	1.3	-14.1	-11.3	9.4	-1.4	71.4	-44.3
	Romania	4.5	-29.2	43.4	25.1	1.4	-0.9	-16.0	-13.3	6.9	-3.6	67.6	-45.5
	Russia	18.2	-19.9	62.2	41.5	14.7	12.1	-5.0	-1.9	21.0	9.0	89.6	-38.4
	S. Africa	63.5	10.8	124.4	95.7	58.6	55.0	31.5	35.7	67.3	50.8	162.3	-14.8

	Argentina	Australia	Brazil	Bulgaria	China	Ethiopia	France	Greece	Hungary	Italy	Japan	Mexico
Spain	52.7	3.5	109.6	82.8	48.1	44.8	22.8	26.8	56.3	40.9	145.0	-20.4
Turkey	15.5	-21.7	58.5	38.2	12.0	9.5	-7.1	-4.1	18.2	6.5	85.3	-39.8
Ukraine	-14.4	-42.0	17.5	2.5	-17.0	-18.8	-31.2	-28.9	-12.4	-21.0	37.3	-55.4
USA	43.7	-2.6	97.1	71.9	39.3	36.2	15.5	19.3	47.0	32.5	130.4	-25.1
Uruguay	-13.4	-41.3	18.9	3.7	-16.0	-17.9	-30.3	-28.1	-11.3	-20.1	39.0	-54.8
Zimbabwe	195.9	100.6	306.1	254.1	187.0	180.5	137.9	145.6	202.8	173.0	374.6	54.2

		Morocco	Peru	Romania	Russia	S. Africa	Spain	Turkey	Ukraine	USA	Uruguay	Zimbab.
Destination country *n*	Argentina	-48.0	-5.7	-0.8	-13.6	-42.1	-48.8	-12.4	20.5	-29.3	23.1	-68.8
	Australia	-26.6	33.3	40.3	22.2	-18.2	-27.6	23.9	70.3	0.0	74.0	-55.9
	Brazil	-62.2	-31.3	-27.7	-37.1	-57.9	-62.7	-36.2	-12.3	-48.5	-10.3	-77.3
	Bulgaria	-57.5	-22.8	-18.8	-29.3	-52.7	-58.1	-28.3	-1.4	-42.1	0.8	-74.5
	China	-47.7	-5.0	-0.1	-13.0	-41.8	-48.4	-11.8	21.3	-28.8	23.9	-68.6
	Ethiopia	-46.6	-3.0	2.1	-11.1	-40.5	-47.3	-9.9	23.9	-27.3	26.6	-67.9
	France	-37.6	13.3	19.2	3.8	-30.5	-38.4	5.3	44.7	-15.0	47.9	-62.5
	Greece	-42.6	4.3	9.7	-4.4	-36.0	-43.4	-3.1	33.2	-21.8	36.1	-65.5
	Hungary	-49.5	-8.3	-3.6	-16.0	-43.8	-50.2	-14.8	17.1	-31.3	19.7	-69.7

Table 4. (Continued)

	Morocco	Peru	Romania	Russia	S. Africa	Spain	Turkey	Ukraine	USA	Uruguay	Zimbab.
Italy	-43.8	2.1	7.4	-6.4	-37.4	-44.5	-5.1	30.4	-23.4	33.3	-66.2
Japan	-68.1	-42.1	-39.1	-46.9	-64.5	-68.5	-46.2	-26.0	-56.6	-24.4	-80.8
Mexico	-13.5	57.1	65.3	44.0	-3.6	-14.7	46.0	100.7	17.8	105.1	-48.0
Morocco	-3.8	74.7	83.7	60.1	7.1	-5.1	62.3	123.1	31.0	128.0	-42.2
Peru	-46.0	-1.9	3.1	-10.2	-39.9	-46.7	-8.9	25.2	-26.5	28.0	-67.6
Romania	-47.2	-4.1	0.8	-12.2	-41.2	-47.9	-11.0	22.4	-28.1	25.1	-68.3
Russia	-40.3	8.4	14.1	-0.6	-33.5	-41.1	0.7	38.5	-18.7	41.6	-64.1
S. Africa	-17.4	50.0	57.8	37.4	-8.0	-18.5	39.3	91.6	12.5	95.8	-50.4
Spain	-22.8	40.1	47.4	28.4	-14.1	-23.9	30.1	78.9	5.1	82.9	-53.6
Turkey	-41.6	6.0	11.5	-2.9	-35.0	-42.5	-1.6	35.3	-20.6	38.3	-64.9
Ukraine	-56.8	-21.5	-17.4	-28.0	-51.8	-57.3	-27.1	0.3	-41.1	2.5	-74.0
USA	-27.4	31.8	38.6	20.8	-19.2	-28.4	22.4	68.3	-1.2	72.0	-56.4
Uruguay	-56.2	-20.5	-16.4	-27.2	-51.3	-56.8	-26.2	1.5	-40.4	3.8	-73.7
Zimbabwe	49.5	171.4	185.5	148.7	66.5	47.4	152.1	246.7	103.5	254.3	-10.2

Table 5. Counterfactual 2: Liberalized import policy

Source country i	$-\theta m_n$ original estimate	$-\theta m_n$ imposed value	Production $w_i L_i = \sum_n X_{ni}$ % change	Crop price P_n % change	Production cost w_i % change	Crop exports $\sum_{n,i\neq n} X_{ni}$ % change	Crop imports $\sum_{i,i\neq n} X_{ni}$ % change
Argentina	2.705	3.259	5.9	5.8	4.6	12.6	112.7
Australia	2.274	2.832	-1.7	-2.3	-1.2	68.4	31.2
Brazil	2.633	3.173	1.7	1.4	1.4	36.5	42.4
Bulgaria	-4.046	-3.505	1.3	1.3	1.0	19.9	66.7
China	1.732	2.251	-1.6	-1.8	-1.2	67.4	30.2
Ethiopia	1.873	2.406	0.7	0.5	0.5	32.0	48.9
France	3.228	3.765	-1.6	-4.7	-0.5	33.3	27.8
Greece	-0.986	-0.437	-5.8	-7.3	-4.2	71.3	11.5
Hungary	-1.179	-0.643	2.7	2.4	2.2	12.7	77.1
Italy	0.028	0.577	-5.2	-6.7	-3.7	72.7	18.6
Japan	-0.861	-0.344	0.1	0.0	0.1	51.7	45.2
Mexico	-0.704	-0.153	-4.4	-5.4	-3.2	136.7	11.4
Morocco	0.593	1.127	1.4	1.0	1.1	21.0	57.3
Peru	-3.554	-3.018	-3.0	-3.5	-2.3	72.3	11.8
Romania	-2.286	-1.746	2.8	2.8	2.2	12.4	83.4
Russia	-0.749	-0.219	0.0	-0.2	0.1	33.4	55.5
South Africa	1.698	2.227	-3.3	-4.1	-2.4	80.4	16.1
Spain	1.107	1.643	-3.5	-6.1	-2.1	58.7	19.0
Turkey	0.853	1.381	-4.4	-5.2	-3.3	60.0	14.2

Source country i	$-\theta m_n$ original estimate	$-\theta m_n$ imposed value	Production $w_i L_i = \sum_n X_{ni}$ % change	Crop price P_n % change	Production cost w_i % change	Crop exports $\sum_{n,i \neq n} X_{ni}$ % change	Crop imports $\sum_{i,i \neq n} X_{ni}$ % change
Ukraine	-2.522	-1.988	0.8	0.8	0.6	29.5	61.8
United States	5.875	6.426	3.3	3.1	2.6	18.0	76.0
Uruguay	-3.418	-2.864	-2.7	-3.2	-2.0	86.0	11.5
Zimbabwe	-4.294	-3.768	-2.2	-2.6	-1.7	61.0	29.5

For all of these reasons, counterfactual 1 considers a situation in which a country loses a fraction of its water availability (L_i) corresponding to the water that it uses as irrigation. In particular, all blue water (surface water and groundwater evaporated as a result of the production of the product) is taken away so that only green water (soil water originating from rain) is left. This counterfactual is a purely hypothetical situation not intended to be any sort of forecast. Yet it allows us to see what role international trade can play as there are changes in the amount of water that is currently evapotranspirated. It also has the benefit of making use of the new data of Mekonnen and Hoekstra (2011).

To mimic the taking away of irrigation water, a proportional shock to input quantity is made as shown in Table 3, based on the proportion of water that is green water. The 'L_i new value' column shows what amount of water is left once irrigation (blue) water is gone (this is the product of the calibrated L_i and the green water share). The country for whom this makes the smallest difference is Brazil, as 97.2% of total agricultural water is green water. The country for whom this makes the biggest difference is Spain, as only 54.7% of total agricultural water is green water (Table 1).

With these new values of L_i in place, the model is solved for new values of the endogenous variables in the GAUSS programming language, following the approach of Eaton and Kortum (2002). Changes in production, output price, w_i, exports, and imports are reported in Table 3. As water becomes scarcer, crop output price and production costs of using water rise in all countries. The smallest rises are in Japan (7.1% and 5.4%, respectively) and the largest rises are in Zimbabwe (47.1% and 37.4%, respectively).

While all prices rise, price response varies by country due to the impediments to trade that are characterized in the gravity equation. Transmission of the shock within each country reverberates around the world imperfectly.

Changes in production, exports, and imports are mixed in sign. Production falls off greatly in countries that suffer a dramatic decline in irrigation water. For example, Spain has a 25.9% drop in crops output. The amount of Spanish exports fall by 39%, and imports rise by 26.8%. Yet despite the drop in water availability, production does not contract in all countries. In 12 of 23 countries, production actually increases despite the decline in resources. Recall that output is related back to costs as $w_i L_i = \sum_n X_{ni}$. While L_i always falls in this counterfactual, w_i always rises, in some cases relatively more than L_i has fallen. Rising w_i implies higher investments are being made in crop production (including substitution among factors that are not explicitly modeled here). Two countries for which this happens are Argentina and Brazil, for which production rises by 8% and 7.3%, respectively. Demand for their production rises sharply as a result of their relatively low dependence on irrigation, on their general competitiveness, and the relatively higher need elsewhere. This puts greater pressure on their water resources, and raises the value of their production.

Another interesting aspect is how countries use their relations with one another to alleviate the effects of a shock to water availability. Table 4 reports the entire 23×23 matrix of trade flow changes. For example, Australia and the United States, which both derive 77% of crop water from green sources, have falls in production of 1.9% and 2.3%, respectively. Their shortfall is met by Brazil, for example, which increases exports to Australia and the

United States by 99.5% and 97.1%, respectively. Meanwhile, Australia and the United States reduce their exports to countries that are undergoing a relatively small contraction in water availability. For example, their exports to Japan (which derives 96% of crop water from green sources) fall by 57.2% and 56.6%, respectively, meaning they are less than half of what they were previously. Some countries have even larger drops in their exports to Japan, such as Mexico and Morocco; they lose more than two-thirds of their exports to Japan.

A lot is being held constant during this simulation, which is hypothetical in any case, so these estimates are not forecasts or predictions. The point is that the results in Table 3 are the result of a vast array of adjustments that countries make among themselves to reach a new equilibrium. Even though trade barriers are high, the composition of trade is sensitive to irrigation water availability, especially in those countries where it plays a large role in agriculture. More importantly, this change is tempered by high levels of trade barriers in many cases.

6. COUNTERFACTUAL 2: HOW TRADE LIBERALIZATION AFFECTS DEMAND FOR WATER

The impacts of trade liberalization on water use is now considered. In one sense this is the opposite question asked in counterfactual 1: If a policy shock to final product trade occurs, how does this filter back into production patterns and water usage by country? With constant returns to scale and a single (composite) input, this might seem to be a simple, straightforward issue, as the input-output coefficient is fixed. However, the framework is flexible enough to ensure that this is an empirical issue; the estimated gravity equation shows that transmission of effects is highly variable. The most technically efficient or water-abundant countries may be geographically distant, isolated by restrictive border policies, or influenced by a number of other factors.

Tariffs, tariff-rate quotas, and technical barriers to trade are pervasive and high in the crop agriculture sector. For this reason, a form of trade liberalization is considered in which countries liberalize their import policies. Recall that estimates of the associated parameters, $-\theta m_n$, have been made with a standard error. The approach taken here is to assume that this standard error can be used to provide an upper bound on how open a country could be. This is presented in Table 5. The original $-\theta m_n$ econometric estimate is in the left column, while the new imposed value is in the second column. For example, the original estimate for Argentina is 2.705. The associated standard error is 0.554, and the new value in the counterfactual is 3.259. It is now less costly to ship to Argentina than before, by about six percentage points. The associated change for other countries is very similar; the cost of shipping to a given country falls in each case by about six percentage points relative to the baseline.

There are many other ways that a liberalization could be represented, of course, but one advantage of this approach is that it makes systematic use of the estimated measure of uncertainty that surrounds the parameter estimates.

Note that the parameter change only concerns each country's openness to imports. However, this has a beneficial effect on each country's ability to export as well. Since other countries loosen their import restrictions, it becomes easier to export to them.

Results are reported in Table 5. Approximately half the countries experience a rise in production as they expand to meet increased foreign demand. The absolute change in production is by far the highest in the United States, followed by Argentina. The largest percentage increases are for Argentina, the United States, Hungary, and Romania (5.9%, 3.3%, 2.8%, and 2.7%, respectively). Rising foreign demand for their product raises their domestic prices by 5.8%, 3.1%, 2.4%, and 2.7%, respectively. These rises occur in part due to high competitiveness (S_i) relative to other countries, along with favorable production costs and geographical position relative to key importers.

Roughly half of the countries experience a decline in production, and associated decline in prices due to the availability of comparatively cheap imports from abroad. The largest percentage production declines are in Greece, Italy, Mexico, and Turkey (5.8%, -5.2%, -4.4%, and -4.4%, respectively). While their domestic crops sector shrinks somewhat, their consumers benefit from lower average crop prices (-7.3%, -6.7, -5.4%, and -5.2%, respectively). These and a number of other countries with similar outcomes had relatively high initial protection and less competitiveness. When they no longer protect their farmers as intensively, their production declines as a result, with imports reducing the average crop price at home.

Intermixed with these results is the fact that every country exports more than before, and imports more than before (two rightmost columns of Table 5). It might be surprising that even countries which experience a fall in production can export more than before. This is very different from counterfactual 1, where a reduction in production generally coincided with a reduction in exports. The difference is that in counterfactual 2 access to foreign markets is improved since all other countries have liberalized their import policy. For this reason all countries export more than before, even if their overall production falls.

The percentage value of world trade is 24% higher than in the baseline, after the six percentage point relaxation of import barriers takes place. Under liberalization, the average share of consumption that is sourced domestically (reliance on home production X_{nn}) falls from 88% in the baseline to 85% in the new situation. As such, a benefit of trade liberalization is that a country's consumption profile no longer has to look so similar to its production profile.

Even as overall exports are up for each country, there are some trade flows that are shut down entirely. Greece initially imported $16.5 and $15.8 million from Hungary and Italy, respectively (Table 2), but this declines 99.9% and 99.7% after liberalization. The United States, among others, picks up the slack, increasing its exports to Greece by 976%. The competitiveness of the United States in water-intensive products easily overcomes geographical distance once trade policy barriers are lowered.

The issue of whether trade liberalization might play a role in 'conserving' water among the sample countries can also be considered. It is mostly found that trade liberalization is unlikely to lead to water saving. This result is displayed in Figure 1. It shows how the percentage change in production following trade liberalization compares to amounts of water evapotranspirated, given by the natural log of L_i. There is clearly a positive relationship; the correlation is 0.39. Correlations between absolute changes in production, and negative water usage, are also positively correlated.

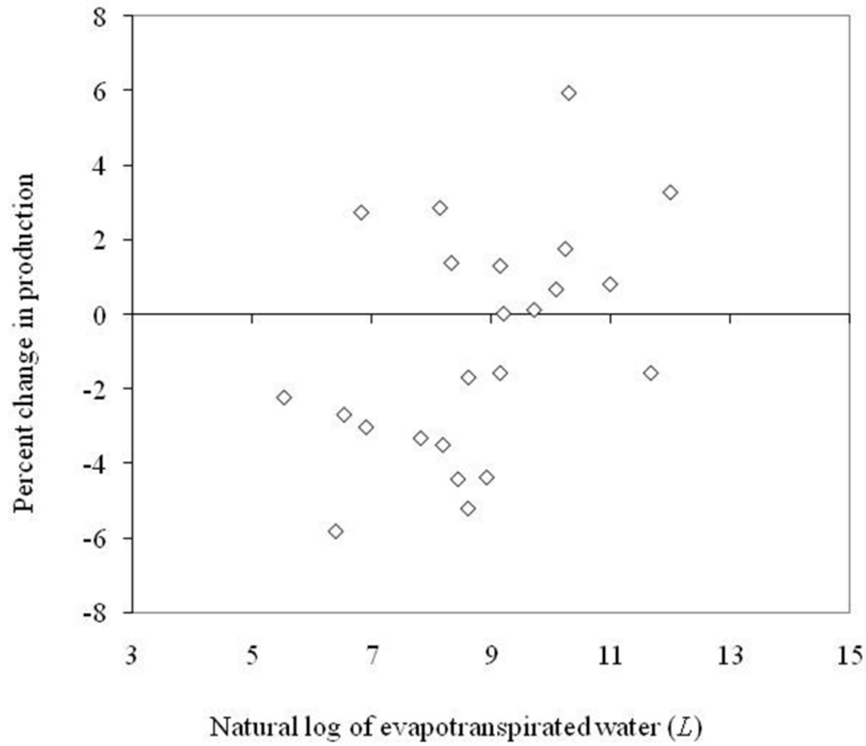

Figure 1. Scatter plot of production change under import liberalization.

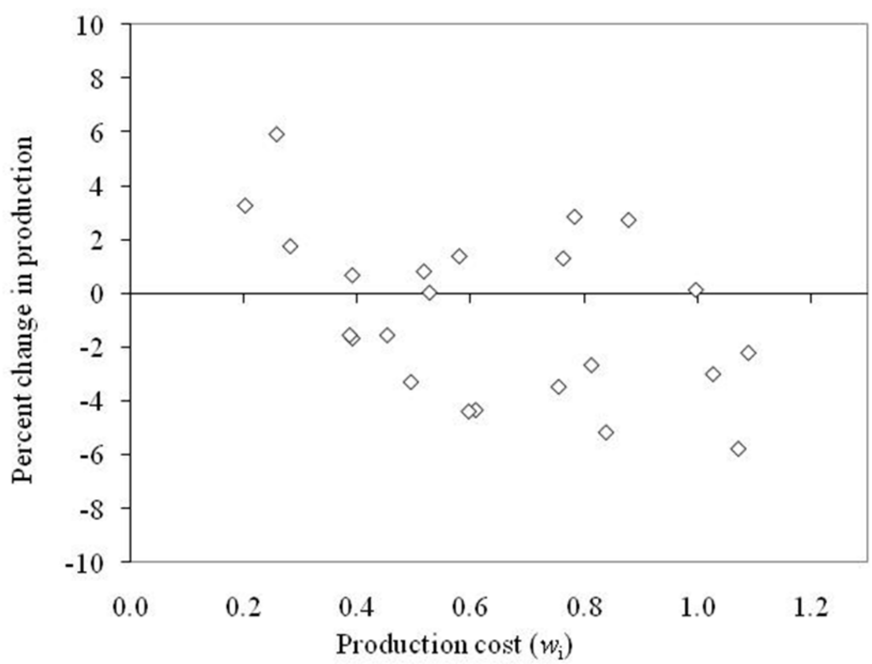

Figure 2. Scatter plot of production change under import liberalization.

Another useful relationship to consider is the percentage change in production against production cost (w_i). This relationship is plotted in Figure 2, and is generally negative. The correlation is -0.53, suggesting that under a liberalized import policy, production shifts to regions where the overall cost of production is cheaper, all else the same. The correlation is not (and cannot) be perfectly negative due to remaining bilateral trade costs, such as freight costs and numerous other policy distortions that has not been considered within counterfactual 2.

Taken together, these results suggest that there could be a tendency for production to relocate in regions where there are lower production costs, and where water is already more readily available for agriculture. This is by no means a foregone conclusion of the model. All of these countries have reasonably active agricultural sectors. Because water is generally not an important balance sheet expense in many countries (at least compared to land, seed, machinery, fuel, and fertilizer costs), it is not necessarily an important determinant of trade for many commodities. Nonetheless, the results suggest that water could emerge as a stronger determinant of trade once import restrictions are reduced, as considered in counterfactual 2.

A measure of the welfare change under trade liberalization can be made by comparing the real domestic product of the sector under the baseline (Y_n / P_n^{α}) to the real domestic product under the counterfactual shock. There is a positive improvement in this measure for each country, although small; it never exceeds one percent and is not reported here. The net change to welfare tends to be small because of the offsetting effect of domestic product (Y_n) versus domestic price (P_n). For example, some countries have rising exports and expanding domestic product (which increases welfare), but rising prices faced by domestic consumers (which decreases welfare). Other countries have falling exports and shrinking domestic product (which decreases welfare), offset by rising imports and lower prices for consumers (which increases welfare). While one can debate the merits of this particular measure of welfare, the point is that trade liberalization appears likely to bring welfare gains for countries of the sample. This is perhaps a positive note to keep in mind given that trade liberalization is unlikely to prove to be water saving.

7. Summary and Conclusion

In this paper a model is developed to study the link between freshwater usage in crop agriculture and international trade. The model makes use of innovative new data concerning the water use requirements of crops around the world, in conjunction with a detailed characterization of the constraints and incentives for international trade in crop agriculture.

Bilateral trade predictions are based on an estimated gravity equation set within a broader homogeneous-products spatial equilibrium model, with productivity given as a distribution. The approach allows for two countries which initially trade very little or nothing to start trading a great deal more following a shock to the system. Meanwhile, countries which trade substantially in the baseline can end up trading very little or nothing with each other. These types of dramatic effects are believed to be important for characterizing the role of water in the international economy, and may be less likely to occur with alternative, differentiated-product models of trade.

Once the model is parameterized, two applications are developed. In the first application (counterfactual 1) there is a negative shock to irrigation water availability by country. This causes a rise in production costs, and also in consumer prices, in each of the countries. One point to emphasize is that the effects are not as strong as they could be, since international trade serves as a vehicle to dissipate the shock. In this sense, increased trade is a potential means for adaptation to future climate change.

The effects of the shocks to irrigation water availability, nonetheless, are still large in many cases. Price changes by country are highly uneven given the unique circumstances faced by each, including the nature and extent of a country's potential vulnerability. Some countries, such as Argentina, Brazil, and Hungary, rely little on irrigation and are incentivized to expand crops production, raising their level of exports to the rest of the world, while decreasing their level of imports. Demand for their production rises sharply as a result of their competitiveness and the relatively higher need elsewhere. This puts greater pressure on their water resources, and raises the value of their production. Other countries, such as Spain and Mexico, experience a marked contraction in production, and cut exports significantly while increasing their level of imports.

The second application (counterfactual 2) shows how policy changes that affect trade in agricultural products influence water usage around the world. Model parameters that represent policy barriers to imports are simulated to be relaxed by six percentage points on average. Under this shock, approximately half the countries experience a rise in production as they expand to meet increased foreign demand, while the other half experience a decline in production, and associated decline in prices due to the availability of comparatively cheap imports from abroad.

This trade liberalization scenario shows that there tends to be a migration of crop production towards countries which already have higher rates of water use, and lower production costs. This suggests that agricultural trade liberalization is not necessarily going to be 'water saving' at the global level. Trade liberalization is nonetheless shown to improve economic welfare, as measured by the real domestic product of the crops sector.

It seems fair to say that the connection between international trade and water will become increasingly visible, and the subject of increased scrutiny, as climate change and economic development put greater pressure on the water resources of many countries. Further work in this area would fruitfully consider a more detailed characterization of the production process, including explicit treatment of more inputs, than has been done here. Spatial disaggregation, such as by agro-ecological zone, would also add more realism to the analysis, as would consideration of water policy instruments. These refinements are necessarily saved for future work. The study at hand can be viewed as an exploratory analysis that highlights a number of interesting relationships between water and the international economy, along with some of the challenges that economists will face in modeling these relationships.

APPENDIX. ESTIMATION OF GRAVITY EQUATION

Our estimation of equation (12) is based on Reimer and Li (2010). The error term of equation (12) is $\xi_{ni} = \xi_{ni}^2 + \xi_{ni}^1$. ξ_{ni}^2 affects two-way international trade and has variance σ_2^2, with $\xi_{ni}^2 = \xi_{in}^2$. ξ_{ni}^1 affects one-way international trade and has variance σ_1^2. Under this error structure, diagonal elements of the variance-covariance matrix are $E(\xi_{ni}\xi_{ni}) = \sigma_1^2 + \sigma_2^2$ while certain off-diagonal elements are $E(\xi_{ni}\xi_{in}) = \sigma_2^2$. This allows for reciprocity in geographic barriers; i.e., for the possibility that the disturbance concerning shipments from *n* to *i* is positively correlated to the disturbance concerning shipments from *i* to *n*.

We use generalized least squares and have 506 observations. We find that the fit is good, as the adjusted R^2 is 0.70, and most of the coefficients are statistically non-zero at the 1% level. The following table reports the coefficients, with standard errors presented next to the coefficients.

APPENDIX. ESTIMATION OF GRAVITY EQUATION

Description		Estimate	S. error		Estimate	S. error
Dist [0,375]	$-\theta d_1$	-5.522	0.892			
Dist [375,750]	$-\theta d_2$	-5.860	0.721			
Dist [750,1500]	$-\theta d_3$	-7.028	0.689			
Dist [1500,3000]	$-\theta d_4$	-8.205	0.674			
Dist [3000,6000]	$-\theta d_5$	-9.961	0.631			
Dist [6000,max]	$-\theta d_6$	-10.258	0.630			
Border	$-\theta b$	0.375	0.426			
Language	$-\theta l$	0.980	0.354			
NAFTA	$-\theta e_1$	1.482	1.356			
EU	$-\theta e_2$	1.412	0.593			
Mercosur	$-\theta e_3$	-0.811	0.891			
Argentina	S_1	3.927	0.367	$-\theta m_1$	2.705	0.554
Australia	S_2	1.824	0.368	$-\theta m_2$	2.274	0.558
Brazil	S_3	3.226	0.361	$-\theta m_3$	2.633	0.540
Bulgaria	S_4	-1.220	0.362	$-\theta m_4$	-4.046	0.541
China	S_5	2.507	0.354	$-\theta m_5$	1.732	0.518
Ethiopia	S_6	0.900	0.359	$-\theta m_6$	1.873	0.533
France	S_7	1.920	0.361	$-\theta m_7$	3.228	0.538
Greece	S_8	-2.615	0.365	$-\theta m_8$	-0.986	0.549
Hungary	S_9	-1.543	0.360	$-\theta m_9$	-1.179	0.536
Italy	S_{10}	-1.304	0.365	$-\theta m_{10}$	0.028	0.549
Japan	S_{11}	-2.205	0.353	$-\theta m_{11}$	-0.861	0.517

Description		Estimate	S. error		Estimate	S. error
Mexico	S_{12}	-0.393	0.366	$-\theta m_{12}$	-0.704	0.551
Morocco	S_{13}	-0.653	0.359	$-\theta m_{13}$	0.593	0.534
Peru	S_{14}	-3.216	0.360	$-\theta m_{14}$	-3.554	0.536
Romania	S_{15}	-1.348	0.361	$-\theta m_{15}$	-2.286	0.540
Russia	S_{16}	0.002	0.357	$-\theta m_{16}$	-0.749	0.530
South Africa	S_{17}	0.470	0.358	$-\theta m_{17}$	1.698	0.529
Spain	S_{18}	-1.243	0.360	$-\theta m_{18}$	1.107	0.536
Turkey	S_{19}	0.021	0.357	$-\theta m_{19}$	0.853	0.529
Ukraine	S_{20}	0.506	0.358	$-\theta m_{20}$	-2.522	0.534
United States	S_{21}	5.425	0.366	$-\theta m_{21}$	5.875	0.551
Uruguay	S_{22}	-1.924	0.367	$-\theta m_{22}$	-3.418	0.554
Zimbabwe	S_{23}	-3.063	0.356	$-\theta m_{23}$	-4.294	0.526

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HAS FOOD AID TARGETING WORKED IN ETHIOPIA? A REVIEW OF THE EMPIRICAL EVIDENCE

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ABSTRACT

While Ethiopia has received vast amounts of food aid in recent decades, many analysts still question the effectiveness of international food transfers in addressing food insecurity in this developing nation. This paper provides a critical survey of the recent literature on food aid targeting programs and summarizes the available empirical evidence on the impacts of food aid on the most vulnerable groups (especially children, elderly, pregnant women, nursing mothers). The main conclusion is that self-targeting of food aid through food-for-work programs has been limited as an effective means of distributing food aid to the most food insecure households in Ethiopia.

Keywords: food aid, targeting, nutrition, food-for-work, production, Ethiopia

JEL: F35, O19, Q17, Q18

1. INTRODUCTION

Recently there has been an increased emphasis on questions about the effectiveness of food aid as a useful resource for economic development and alleviating under-nutrition in low-income countries (Admassie and Abebaw, 2014; Lentz et al., 2013; Margolies and Hoddinott, 2012; Awokuse, 2011; Little, 2008). Specifically, more empirical investigations are focusing on whether food aid is adequately targeted at the most food-deficit and vulnerable demographic groups (Kuhlgatz, Abdulai, Barrett, 2010; Caeyer and Dercon, 2012). This new emphasis on food aid targeting effectiveness has been motivated, in part, by the shift in the food aid landscape from development to relief and the decline in food aid resources as major donors have cut back on food donations. After accounting for population growth in most recipient countries, shipments of food aid has significantly fallen in the past three decades and there has been notable year-to-year fluctuations in food aid donations as a

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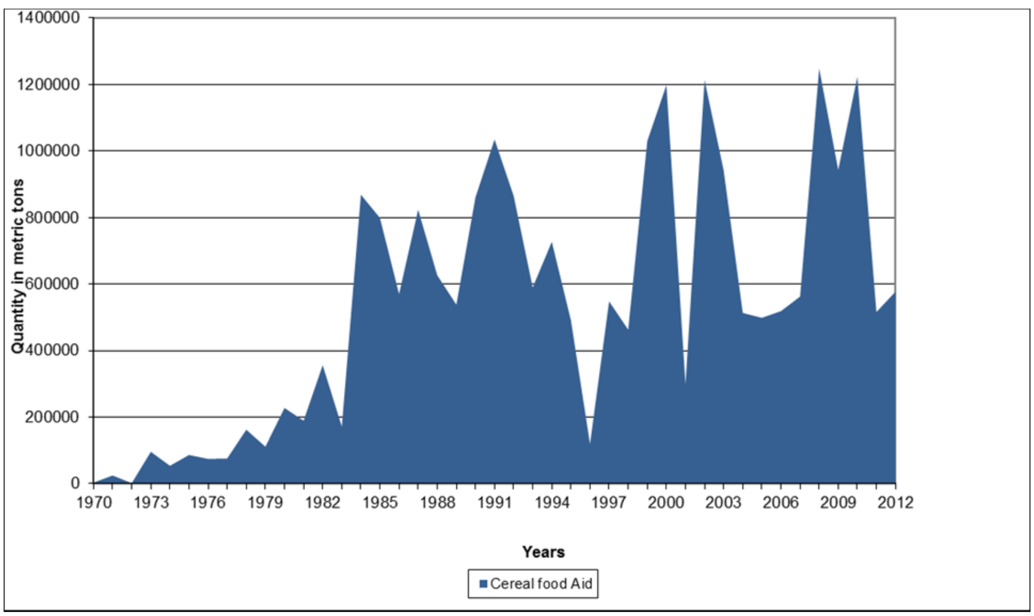
result of changes in agricultural production policies in major donor countries (e.g., US, EU and Canada). In a recent study, Lentz and Barrett (2008) explored several food aid policy regimes and sought to determine which regime produces the greatest positive welfare effect on recipients. They concluded that improved targeting is the most important factor in determining food aid effectiveness.

Given its status as the second largest global recipients of food aid, Ethiopia has been at the center of recent debates on food aid policy (Little, 2013; Abebaw, Fentie, and Kassa, 2010). While Ethiopia has been the recipient of vast amounts of food aid in recent decades, many analysts still question whether the international food transfer to this nation has been effective in significantly reducing the level poverty and malnutrition. For instance, Ethiopia received about 14.8 million metric ton of cereal food aid from 1983 to 2003. On average, food aid imports represent approximately 10 percent of total domestic cereal production. The volume of food aid shipment tends to rise with the extent of emergencies in the country. As shown in Figure 1, the flow of food aid into Ethiopia (1970-2010) fluctuated significantly and the peak points reflect the response of the international community to various food crises in the country. During the past decades, there were five major droughts in Ethiopia (1984-85, 1990-92, 1999-00, 2002-03, and 2009-2011). The national famine of 1984-85 captured international attention because of its severity and the huge toll on human lives (del Ninno et al, 2005). Ethiopia's food insecurity problems and hence the reliance on international food aid donations can be attributed to its fragile agricultural economy and a growing poor population.



Source: FAOSTAT.

Figure 1. Food and aid flows into Ethiopia, 1970-2012.

Despite the relatively high volume of food aid received by Ethiopia in recent decades, the prevalence of poverty and increasing vulnerability to food insecurity, especially among women and children, is disheartening. According to del Ninno et al (2005, p. 63), "While 41 percent of the rural population was food poor in 1999/2000, six million people are at risk of starvation every year in the drought prone areas in Tigray." This underscores the fact that food aid is a marginal resource and can only partially alleviate food insecurity problems in low-income countries. Although some empirical evidence have shown that food aid could have a positive impact in reducing malnutrition and household food insecurity, others suggest that food aid has been ineffective in assisting individuals and households to successfully overcome chronic poverty (Dercon and Krishnan, 2003; Quisumbing, 2003; Yamano et al., 2005; Kuhlgatz and Abdulai, 2012). Nevertheless, in addition to more comprehensive macroeconomic policies to promote national economic growth, food aid could fill the gap as a short-term safety net (Broussard, 2012). In this respect, more could be done to ensure that more food is available and that the current food donations are reaching the intended beneficiaries. Many recent empirical analyses have focused on this issue in the context of Ethiopia.

This paper provides a critical review of the growing literature on the effectiveness of food aid targeting programs. An earlier examination of the impact of food aid targeting methods in Ethiopia was a review article by Sharp (1997). Nevertheless, Sharp's survey of the literature was primarily qualitative and did not emphasize empirical studies. Since Sharp's work, subsequent studies have empirically examined the effectiveness of food aid targeting issues in the Ethiopian context. However, no recent studies exist that review and synthesize the growing empirical literature on food aid targeting. Thus, this paper complements Sharp's (1997) qualitative review of the food aid targeting literature by providing an up-to-date survey of more recent studies (primarily empirical analyses) of food aid targeting in Ethiopia. The main conclusion is that self-targeting of food aid through FFW programs has been limited as an effective means of addressing food insecurity in Ethiopia. Significant cases of targeting errors still persist in the distribution of food aid.. To a limited extent, some improvements in the design and variety of the FFW projects could increase the level of participation of women who are able to work.

The remainder of the paper is organized as follows. Section 2 provides a general overview of food aid targeting methods and practical issues of relevance to policymakers, practitioners and researchers. Then, sections 3 and 4 provide a critical survey of FFW programs and summarize the findings from recent empirical analyses of self-targeting through FFW schemes in Ethiopia. The paper concludes with a discussion of some practical policy recommendations for improving food aid targeting.

2. Overview of Targeting Methods and Issues

Jaspars and Young (1995) define food aid targeting as "restricting the coverage of an intervention to those who are perceived to be most at risk in order to maximize the benefit of the intervention whilst minimizing the cost." This definition of targeting emphasizes the question: who should receive food aid? A more comprehensive definition of food aid targeting is given by Barrett and Maxwell (2005) who define targeting as "the practice of ensuring that those (countries, regions, households, individuals) that require food actually receive it, and that those who do not require it do not get it (whether instead or in addition to the intended beneficiaries)." The latter definition more explicitly accounts for the possibility of targeting errors. Food aid targeting methods can be broadly divided into four types: and self-targeting, administrative targeting, indicator-based targeting, and community-based targeting. These four alternative targeting methods are usually not applied individually, but rather combinations of several targeting methods are commonly adopted in practice (Barrett and Maxwell, 2005).

Relative to other forms of food aid targeting*, self-targeting methods* are increasing in popularity because analysts and practitioners are seeing more evidence of its effectiveness. In practice, self-targeting requires that the transfer program be available to anyone who may be interested in participating. However, the programs are usually designed such that it attracts the targeted groups (the poor and food insecure) while the non-targeted groups (non-poor and food secure) have significantly low incentive and no reason to justify participating in the program. The self-targeting methods inherently restrict the number of beneficiaries by imposing a transaction or opportunity cost (e.g., forgone income, labor time) on beneficiaries or by offering benefits with lower quality which may not be as desirable to the non-poor who may then self-select out of the program (Alderman, 1987; Barrett, 2002). Most self-targeting-based programs have at least one or more of the following characteristics: (i) transaction costs of waiting or queuing to receive program benefits, (ii) social costs from negative stigma of participation, (iii) subsidization of low quality food items, (iv) and public works programs with high opportunity cost of time to the non-poor potential participants (Coady, et al., 2004; Barrett and Maxwell, 2005). By far, the two most common forms of self-targeting involve subsidies on inferior goods and food-for-work (FFW) programs.

Some self-targeting programs exploit the diversity in consumer preferences by targeting and subsidizing a good that is attractive to one group but not to others. Usually, basic foodstuff of relatively lower quality (perceived prestige by consumers) and nutritionally equivalent to more prestigious foodstuff (e.g., sorghum versus corn; yellow versus white corn) are chosen for subsidization. For a foodstuff that has a negative income elasticity of demand (i.e., quantity demanded decreases as income rises), subsidizing such food items should have higher nutritional impact on the poor. Because such goods ("inferior goods") are hard to find, it usually suffices to subsidize normal goods that are perceived to be relatively inferior. Although there is insufficient evidence that food subsidies result in significantly higher nutritional status, some empirical evidence suggest that food subsidies have a positive impact on the nutritional status of children in low-income countries (Pinstrup-Andersen, 1988). The effectiveness of food subsidization programs in addressing food insecurity would be limited if the poor do not normally consume the chosen foodstuff or if there is significant leakages to the non-poor households. Past analyses showed that food secure households and regions are as likely to receive food aid as food insecure groups (Kumar and Alderman, 1988; Webb and Reardon, 1992).

Self-targeting programs via FFW are attractive because they promote the creation of employment and the provision of permanent physical outputs that could contribute to a region's overall development (e.g., infrastructure building projects). The compensation to participants of FFW schemes are usually in-kind and the wages are set to be relatively lower than the prevailing market wage rate for unskilled labor in order to discourage participation by non-poor individuals who can earn higher alternative wages elsewhere. The success of FFW schemes hinges on the project design and implementation. Projects must be carefully designed to ensure that there is local demand for the projects output and that the cost of participation does not outweigh the expected benefits (Hoddinott, 2001). Furthermore, since public works programs could potentially have disincentive effects on the local labor market, the wage rate needs to be set appropriately. If wages are set too high, the non-poor may self-select to participate and crowd out the poor (Barrett, 2002; Ravallion et al., 1993; von Braun, 1995).

FFW programs are designed to accomplish the multiple objectives of facilitating economic development (job creation via public infrastructure construction), combating food insecurity (food aid distribution), and natural resource conservation (Clay, 1986; Ravallion, 1991; Devereux, 1999; Gebremedhin and Swinton, 2001). Some FFW projects focus on providing short-term relief to the participant workers. This type of projects could be classified as “safety-net” or “relief” projects that could be expected to only soften the impact of short-term economic shocks and prevent them from becoming permanent. In contrast, most FFW projects emphasize long-term development and have the primary objective of assets creation. Examples of asset-creating development-based projects include productivity-enhancing projects (e.g., irrigation, drainage, land reclamation, reforestation and soil conservation, etc.) and socio-economic infrastructure development projects (e.g., construction of roads, bridges, schools, clinics, community buildings, domestic water supply, etc.).

In an ideal situation, FFW programs could address both short-term (safety-net) and long-term (development) objectives through the provision of publicly funded projects that could potentially generate employment and income. A well-documented case of successful self-targeting of food aid through public works programs is the Employment Guarantee Scheme (EGS) in Maharashtra, India (*Herring* and Edwards, 1983; Ravallion et al., 1993; Dev, 1995; Barrett and Maxwell, 2005). However, it is very challenging to simultaneously accomplish both development and safety-net goals through FFW projects. Clay (1986, p. 1248) notes that “projects which are simultaneously highly successful in terms of employment and income generation, and have positive distributional benefits from asset creation in the long run, are few in number."

Administrative targeting involves the selection of the appropriate beneficiaries of food aid by donor or local government officials through the evaluation of potential recipients’ applications documenting low-income status and food security needs. A commonly used form of administrative targeting is means testing and its variants (e.g., proxy means testing). Means testing require that program managers evaluate the eligibility of potential beneficiaries by comparing their personal information and household economic resources (e.g., assets, income, gender, age, etc.) to a predetermined threshold or cut-off. A notable challenge to the application of means testing (especially in low-income nations) is its requirement of costly administrative capacity. Another limitation of this targeting approach is that it requires the documentation and verification of economic transactions and other information provided by the potential participants (Barrett, 2002; Coady, et al., 2004). This approach is more appropriate in the administration of food assistance programs in developed countries where administrative capacity is high and declared assets and income information by the targeted sub-population is more easily verifiable.

The application of means testing poses a larger problem in developing countries where the administrative capacity is much lower and many of the potential program participants are part of the informal sector where verification of personal economic information is more difficult. Barrett (2002, p. 2162) notes that “means testing based on income is relatively uncommon in low-income countries because it demands considerable administrative capacity in order to measure accurately assets and incomes and counteract the potential for fraud and abuse, although means testing based on land ownership may be feasible where land holdings are closely correlated with income and readily observable.” The use of income-based criteria, as in means testing, primarily captures overall household level food security needs. It does not always reflect the intra-household distribution of food insecurity. Food aid program transfers via heads of households where eligibility is based on means testing, could not be assumed to benefit all the individuals in the household (Haddad and Kanbur, 1990). There is a need for individual level indicators to complement the household level indicators. For reasons discussed above, means testing is not commonly used in the allocation of food aid in developing countries.

In contrast to administrative targeting, *indicator-based targeting* emphasises non-income demographic characteristics and it involves the use of identifiable attributes (e.g., age, gender, nutritional status, geographic region, etc.) in the determination of food security needs and eligibility for food aid. Indicator-based targeting is an alternative to administrative and means testing which may be very costly and not always accurate (Hoddinott, 2001). This targeting approach is particularly useful in poor developing countries where data on income are not readily available (Besley and Kanbur, 1993; Houssou and Zeller, 2011). The chosen non-income based criteria used as indicators are usually highly correlated with income-based measures of food security (Barrett, 2002). Administrative and indicator targeting are closely related and are often combined. Household level targeting via means testing could be used in initially identifying food insecure households. Then, individual level indicators could be used next to determine which members of the household need food transfer the most. For example, age could be used as an indicator to help identify food insecure children who could be enrolled in supplementary feeding programs. Demographic indicators are particularly useful in targeting transfers to the most vulnerable groups (i.e., infants, preschool children, pregnant women, and nursing mothers) where the nutritional effects of food assistance are highest. Demographic indicator targeting has been shown to be effective in addressing food insecurity in both the US and developing nations (Barrett, 2002).

The *community-based targeting* approach allows for community members and leaders to have considerable input in the determination of which individuals or households should be beneficiaries of transfer programs. Relative to administrative targeting, the selection criteria used in community-based targeting tend to be more subjective. In practice, local leaders led by an individual or group of community members deliberates and decides which individuals and households are eligible to receive program assistance. For example, local school officials may determine which school-age children should participate in a school-related feeding program while a group of village elders may determine households who should receive food assistance after a regional drought (Coady, et al., 2004).

The three commonly cited advantages of community targeting are: better and more up-to-date information, better enforcement, and positive spillovers (Conning and Kevane, 2002). Relative to the outside program managers' and analysts' use of means testing targeting and often dated proxy means indicators for assets and levels of needs, the local community members could obtain better information (and at lower cost) on local household characteristics and food security status (Cremer et al., 1996). The use of more accurate information on potential participants' food security status helps to reduce the size of potential targeting errors. Furthermore, the local community leaders could potentially use their social capital and clout to discourage corruption. Also, several analysts have provided accounts of how the success of community-based targeting has had positive spillover effects by increasing local social capital in the form of private safety nets and local public goods projects (Fox, 1996; Conning and Kevane, 2002).

Although a few studies found some evidence that community-based targeting could make a positive contribution to food aid project performance, this form of targeting is not universally optimal and it has several limitations (Skoufias et al., 2001; Conning and Kevane, 2002). First, the role of the local elites could have a negative impact as they may be self-seeking in their activities and thereby contribute to leakages in transfers to the food insecure. Also, this targeting approach tends to perpetuate local power structures that are prone to problems of local-level corruption and costly rent seeking. The local leaders are not always motivated by the goal of maximizing community level welfare. Rather, many community leaders are more motivated by self-interest and the desire to direct resources to their own families and social network of friends (Conning and Kevane, 2002; Coady, et al., 2004). Second, this targeting method may further reinforce the social exclusion of certain sub-groups in the community (e.g., ethnic minorities, disabled people, etc.). The benefits of community based targeting are best achieved when targeted communities are well defined and when resources to be allocated are relatively scarce (Gilligan and Hoddinott, 2004). Barrett and Maxwell (2005, p. 145) notes that community-based targeting is particularly prone to reinforcing pre-existing social problems "in communities where there exists significant cleavages (e.g., along religious, ethnic, or caste lines), or in which there live a significant number of immigrants not yet assimilated into the community, or whose leadership is corrupt or venal."

How to accurately determine the individuals or groups who are most at risk of malnutrition is a major challenge to effective food aid targeting. Although most people would agree that the "most at risk" should be the primary beneficiaries of the bulk of food aid allocations, the dynamics and logistics of food aid distributions is much more complex. In practice, food aid allocation decisions in food-deficit low-income countries involve both the domestic governmental agencies and donor operational agencies. While local governmental agencies are directly involved in food aid allocations (e.g. the DPPC in Ethiopia), donor operational agencies (e.g., WFP, local NGOs, etc.) conduct the majority of the direct distribution of food aid. However, in the case of government-led food assistance programs, domestic politics tends to have a negative impact in the selection of beneficiaries. For political reasons, domestic recipient governments sometimes find it difficult to adequately target food aid to the neediest people (Caeyer and Dercon, 2012). They often include non-poor beneficiaries to avert making "political enemies" by the exclusion of some constituents that may not qualify under the stringent criteria of need. There are several well-documented cases where food aid distributions (or refusal) has been driven by political motives during periods of internal regional wars and conflicts in Ethiopia and other parts of Africa (de Waal, 1997; von Braun et al., 1999). Poorly targeted food aid is often spread too thin so that the impact is significantly diluted.

For effective targeting, the goal is to minimize leakage and the incidence of both inclusion and exclusion errors. In the distribution of food aid to the needy, it is often the case that some members of the target group may be unintentionally excluded (exclusion error) while some individuals or households outside of the target group may inadvertently receive food aid (inclusion error). The third possibility is that of leakage when parts of the allocated food aid fail to reach the intended beneficiaries in the cases of corrupt diversion of aid for market sales or losses during food storage and other forms of mismanagement. High incidences of these types of errors are symptomatic of ineffective targeting. The impact of food aid would be diluted as targeting errors increase. Although there is no standard way to assess targeting performance or effectiveness, a common approach is the comparison of under-coverage and leakage rates (Coady, et al., 2004). While the level of under-coverage is measured as the proportion of food insecure (poor) households not included in the food aid program (error of exclusion), leakage is measured as the proportion of food secure (non-poor) households who are allowed to participate in the program (error of inclusion).

It is not realistic to expect zero inclusion and/or exclusion errors in food aid targeting. Barrett and Maxwell (2005) identified several reasons for the pervasiveness of food aid targeting errors. Reasons for targeting errors includes: (i) imperfect and high cost of information about recipients' needs; (ii) multiple allocation criteria beyond need; (iii) use of imperfect proxies and indicators of food insecurity; (iv) donor-orientation driven food aid allocations that are sometimes at odds with recipients' needs. There is a trade-off between the two types of errors as the increase in inclusion error implies a reduction in exclusion error (and vice versa). Since targeting errors are inevitable, the decision to target should not be a forgone conclusion. The policymakers have to first address the following questions: Are potential gains from targeting (e.g., efficient allocation of scarce resources, maximizing benefits to the poor) outweighed by the potential costs (e.g., administrative costs, participants' private opportunity costs, socio-political costs, etc.)? How should targeting be conducted? Which targeting methods are most appropriate?

The best strategy is to carefully plan and implement food aid donations and distributions so that both inclusion and exclusion errors are minimized. Furthermore, policymakers and program managers must ensure that the levels of targeting errors are justified by observed improvements in targeting. Subsequent sections focus on the case of Ethiopia and examine the impact of food aid targeting via FFW on the vulnerable groups.

3. Food Aid and Food-For-Work (FFW) Programs in Ethiopia

Food aid in Ethiopia can be classified into two categories: free distribution (primarily for emergency food aid needs) and FFW (involves use of local labor for development projects in exchange for food). The Ethiopian government food aid policy mandates that all citizens who are physically able must participate in FFW projects in exchange for food aid while free food aid is only available to the elderly and those individuals who lack the physical ability to work (Clay et al., 1999). The stated official policy and goal of the Ethiopian government is to devote about 80 percent of available food aid to FFW programs while the remaining 20 percent is freely distributed (FDRE, 1996; Barrett and Clay, 2003). Since a notable proportion of the food insecure individuals in Ethiopia are labor-poor, the government's goal of 80-20 distributions between FFW and free food aid distribution may be overly ambitious and unrealistic as it may impose hardship on vulnerable groups (e.g., the elderly, children, pregnant women and nursing mothers).

Currently, food aid distribution via FFW is the largest form of targeting in rural Ethiopia. In addition to the larger effort of non-governmental operational agencies (local and international), the Ethiopian government also plays a vital role in food distribution efforts. The national agency responsible for managing food aid allocations is the Disaster Prevention and Preparedness Commission (DPPC) which was initially formed as a response to the 1974-75 famine in the northern regions of Wollo and Tigray (Jayne et al., 2001). The disaster prevention mandate of the DPPC is addressed through the administration of free food distribution and FFW programs via the establishment of Employment Generation Schemes (EGS). The FFW program serves as the largest government-run mechanism for promoting national food security and reducing Ethiopia's vulnerability to various economic shocks. Thus, a poorly designed and mismanaged FFW program would have far-reaching negative repercussions for the food security of millions of Ethiopians. In collaboration with several international development partners, the Ethiopian government began the Productive Safety Net Programme (PSNP) in 2005. The PSNP addressed food insecurity issues in Ethiopia by focusing on providing food for about 5 million chronic food insecure people in the country. Several research teams conducted a comprehensive assessment of the PSNP in 2006 and made key recommendations about the best strategies to pursue for the second phase of the program (for more details, see Devereux et al 2006; Sharp et al 2006; Slater et al 2006).

Food aid allocation involves a dynamic interaction between government officials at various levels (national, regions, and districts). The assessment of food needs at the household level is performed by local administrators at the level of the *weredas* (districts or any of the 450 local administrative units in rural Ethiopia) and communicated to the DPPC via the regional administrators. The process involves two stages. At the first stage, the federal officials at the DPPC determine the quantity of food aid to be allocated to each *wereda* (after consultation with regional and local officials). In the second stage, *wereda* authorities distribute food allocations, from the federal level, to local peasant associations or committees who in turn distribute the food to the final beneficiaries (Jayne et al., 2001).

FFW programs in Ethiopia are very extensive in scope and various projects are distributed across diverse regions of the country. Table 1 provide an overview of some of the major FFW programs in Ethiopia. By far the largest of these public works projects is the Project 2448 that is under the auspices of the UN World Food Program (WFP). For over two decades, the FFW programs supported by the WFP have funded various development projects such as the rehabilitation of forest, grazing, and agricultural lands. Many local workers in food deficit regions of Ethiopia (e.g., Tigray, Oramya, and Amhara) have participated in these public works projects in exchange for food. Nevertheless, there have been regional differences in targeting effectiveness. While food aid targeting in Tigray and Oromiya have successfully encouraged FFW participation by poor households and screened out ineligible households, there was no significant link between FFW participation and household income status in the Amhara and Southern regions (Jayne et al., 2001).

Although very limited in scope, cash-for-work (CFW) and cash-for-food (CFF) programs were also supported by the Ethiopian government in collaboration with various donor agencies and non-governmental organizations (NGOs) during the 1984-85 famine and afterwards. Instead of payment with food, CFW programs compensate participants via the more traditional medium of money in exchange for labor services rendered in completing various projects (e.g., road construction). Under the CFF program, cash was provided to farmers to use in purchasing local grains instead of imported grain (Humphrey, 1999).

Food aid distribution in Ethiopia has not been problem-free. There have been documented incidences of both targeting errors of inclusion and exclusion (Sharp, 1997; Clay et al., 1999). Instead of allocating food aid to the most food insecure and vulnerable households, the administrators sometimes use food aid as political tool for garnering support from food secure members of the electorate. There were also cases of "over-targeting" of women and old people for food aid even though there are relatively more food insecure individuals and households excluded from food aid appropriations.

Table 1. Food-For-Work (FFW) and Cash-For-Work (CFW) Projects in Ethiopia

Project & Location	Duration	Agencies	Description of Works
Project 2448 (Multiple sites)	1980-	WFP and MoA	Rehab of forest, grazing & agricultural lands
Cash for Food (Gonder & Shoa)	1984-1990	UNICEF/RCC	Water wells/ponds, vegetable gardening
Damot Weyda FFW	1985-	Concern	Relief FFW
Peasant Agr. Development Program (Shoa)	1989	EC and MoA	Soil conservation & forestry
ESBN Pilot Projects (Addis Ababa)	1991-	WFP/Concern	Slum upgrading, health & socio-economic development
Wobera, East Haraghe	1992-	WFP/MoA/Oxfam UK	Rehab of agricultural lands/rural infrastructure
Merti-Jeju,Arsi	1992-1994	WFP/MoA	Road construction
Kilte Awlaelo, Tigray	1993-	WFP/GTZ	Construction (roads, dams, terraces)
Employment Generation Scheme	1993-	TGE	Various activities
Tekle Haimanot, FFW (Addis Ababa)	1992-	WFP/SIDA&IHAUDP	Integrated Urban Development Project
Koisha CFW (North Omo),	1992-	SOS Sahel	Local road construction
Microproject Program FFW (Tigray)	1995-2005	REST/31 donors	501 micro-dams
Hintalo-Wajirat, FFW (Tigray)		ERCS/SEART	Dams building
Somali region RAIN	2009-2011	MC/SCUK	Protect and build assets, distaste assistance
Amhara, Dire Dawa, Oromiya, SNNP, Somali, Tigray regions MERET	1994-2002	Ethiopian government & WFP	Asset creation and rehabilitation
Damot Woide, #2394-11	2011-2012	WRC/WKHC	Agricultural activities
Afar, Amhara, Dire Dawa, Harare, Oromiya, Somali and Tigray, PSNP	2005-	Ethiopian government & WFP	Resilient livelihood and develop community level infrastructure

Furthermore, instead of income status and food need being the primary criteria, the frequency of historical receipt of food aid is a stronger indicator of future food aid allocations (Clay et al., 1999). The "sunk cost" of investments in food aid delivery infrastructure by government agencies and NGOs created an incentive for returning to the same geographical area even when there are newer communities with equal or greater need for food transfer. For example, due to historical precedence and the existence of prior investment in food aid distribution capacity and infrastructure, the Tigray region tends to receive more food aid than other comparable food deficit regions. After accounting for all other relevant factors, the likelihood of a *wereda* receiving food aid rises by 50 percent if the *wereda* is in Tigray (Jayne et al., 2001). In general, regional differential effects in targeting effectiveness could be attributed to the following factors: regional variation in rent-seeking behaviour; the misuse of historical data on past food aid allocations; and the "gravitational pull" of more food aid allocation to areas with prior development of food aid distribution infrastructure.

4. Impact of Food-for-Work Programs in Ethiopia

Although each of the four categories of targeting methods have been used in the allocation of food aid in Ethiopia, scant empirical literature exists that comprehensively examined each form of targeting in the case of Ethiopia. For example, due to its ad hoc nature and variations in criteria across communities, there is little documentation or empirical evidence available on community-based targeting in Ethiopia, as well as in most developing countries. The exception is a recent study by Gilligan and Hoddinott (2004) who examined the effectiveness of community-based targeting of drought relief in nine Ethiopian villages. They concluded that the criteria set by the communities for access to transfer programs was not always based on poverty status and that even when poverty related criteria was used, it did not have a significant impact. Given the recent popularity of self-targeting programs such as FFW schemes and its application in the majority of food aid allocations in Ethiopia, it is not surprising that the majority of the available empirical studies and evidence on Ethiopia focused on FFW programs. Thus, the remaining sections of this paper focuses on providing a critical review of the recent empirical evidence on FFW schemes in Ethiopia.

4.1. Determinants of FFW Participation

The selection criteria of participants in Ethiopia's FFW programs vary across projects and agencies and ranges from objective measures (e.g., income status, physical ability to work) to more subjective measures. The primary eligibility criteria for FFW participation are wealth and income per capita status that could be established through economic well-being indicator variables such as livestock ownership, off-farm income, and remittances received (Teklu and Asefa, 1999; Gebremedhin and Swinton, 2001; Fanta and Upadhyay, 2009). Ideally, only the most food insecure and most vulnerable recipients should receive food aid. However, this is impractical and is seldom the case in practice. Also, not all eligible individuals participate in FFW programs. Available empirical evidence suggests that the best indicator of FFW participation in Ethiopia is whether male and female members of the household have extra labor to spare for non-farm work activities. In contrast, participation in public works projects by the elderly and people who have a secondary school or higher education diplomas is low because they have alternative off-farm employment opportunities (Gebremedhin and Swinton, 2001; Holden et al., 2006). Other factors affecting participation in FFW projects are gender, household size, and households that leased out land. Larger household size and the leasing of land tend to indicate greater need.

4.2. Targeting the Poor in Rural Agricultural Communities

Ethiopia is essentially an agricultural economy and the vast majority of the poor in need of food aid are farming households whose livelihood depends on the outputs from the agricultural sector. These households need food aid as they face recurring food insecurity due to regular periods of droughts and other economic shocks to agricultural production and incomes. Since food aid is a scarce resource, targeting plays a critical role in ensuring its effectiveness. FFW programs are designed to attract only low-income and food insecure individuals who typically have low opportunity cost of time. Public works programs through employment creation and the accompanying food wages tend to increase the labor income of poor households and thus alleviate food insecurity (von Braun et al., 1991). FFW projects (e.g. local road construction) could have a positive effect on the agricultural community by providing better access to input and product markets and services. Since many of the participants in Ethiopian FFW programs only work a few months during the agricultural off-season, a positive labor incentive could be created when projects provide seasonal employment for farmers who would have been idle otherwise. Thus, the labor supply for FFW projects may fluctuate over the course of the agricultural planting and harvesting cycle. Also, more farm households could be expected to participate in FFW programs especially during years of drought.

Despite its positive features and potential benefits, the effectiveness of FFW programs as a means of providing food aid to the neediest in Ethiopia is still a subject of debate. Given the large scope and size of FFW operations in Ethiopia and the potential for targeting errors, FFW programs could create disincentives to agricultural labor and production. The empirical evidence on the effect of FFW programs in alleviating poverty among Ethiopian farm households has been mixed. Several recent analyses of Ethiopia's FFW programs have found that food aid targeting has a high level of errors and has not been effective in providing food aid to the neediest people (Clay et al., 1999; Jayne et al., 2002; Barrett and Clay, 2003).

In general, previous empirical studies found a low correlation between household food needs and food aid receipts from the Ethiopian FFW programs. It is common to observe cases where the poor who should receive food aid did not (exclusion error) while unintended beneficiaries (non-poor) have received food aid (inclusion error) through the FFW programs. Specifically, results from a northern Ethiopian household survey in 1998 suggest that when food wages are set too high, the additional labor demand generated by FFW projects could have a crowding-out effect on farm labor and production through the loss of farm labor. Except for the few cases when people are compensated for working on their own farms (see Holden et al., 2006), participation in FFW projects tends to create disincentives for participants to work on their private farms. This agricultural labor substitution effect of FFW schemes could have unintended negative implications for domestic agricultural production and long-term food security.

Given the scope of the economic development needs in most low-income economies, food aid alone is inadequate in addressing the problem of world hunger and under-nutrition. A significant and sustained level of economic growth is a necessary condition for ensuring a basic level of economic development. As a marginal resource, food aid can only be expected to make a limited contribution to alleviating poverty problem in developing countries. Nevertheless, FFW schemes do have positive economic features. Some analysts argue that FFW schemes in Ethiopia could do better in its contribution to poverty reduction. There are a few reasons for the low impact of Ethiopia's FFW programs on poverty reduction. Several of the problems stem from the fact that FFW projects design contains some features that inherently distort incentives for participation by potential beneficiaries. Targeting errors have occurred because the FFW wages in several regions have been significantly higher than the prevailing local market wages (Webb et al., 1992; Sharp, 1997; Jayne et al., 2001).

Hence, FFW labor demands competed with the labor demand in the private sector. Because FFW wages were set too high there was an added incentive for non-poor individuals to participate in public works program thus crowding out the poor who were the intended beneficiaries of food aid (Maxwell et al., 1994; von Braun, 1995; Barrett and Clay, 2003). Even when FFW wage is at the optimal level, the prevalence of factor market failures in low-income agrarian communities could also be a significant source of targeting errors where the relatively economically well-off individuals may participate in FFW schemes at the expense of the poor and food insecure (Barrett and Clay, 2003). In agricultural communities, FFW projects with flexible design to accommodate the seasonal availability of farm labor would be particularly effective in providing additional off-farm income and assist in reducing the high level of poverty among farming households.

4.3. Targeting Vulnerable Groups (Elderly, Women and Children)

A large proportion of the food insecure is elderly who are usually labor-poor and may not be able to participate in various FFW schemes, especially those that require strenuous physical activities. Children, pregnant and nursing women are also constrained by various factors and are not able to participate in the labor force. Thus, low participation in FFW schemes could be expected from this sub-group due to their inability to satisfy the physical work requirement of such food aid programs. The food insecurity of children is closely linked with that of their mothers. If women (especially pregnant or nursing mothers) are not adequately targeted, then it could be implied that children at risk of undernourishment are also under-targeted. Jayne et al (2002, p. 265) found that “separately from income, the proportion of children with severe stunting and wasting have independent impacts on the receipt of free distribution, but not on food-for-work.” This empirical finding underscores the implications of the low participation of women in FFW programs on the food insecurity of vulnerable children. Given that the majority of food aid allocation in Ethiopia is devoted to the FFW programs, the empirical evidence suggests that at risk children are not adequately targeted.

Quisumbing and Yohannes (2005) contend that women are under-targeted by FFW programs and that they should be especially targeted for higher participation since they are more vulnerable to income and other shocks and they lack adequate access to various insurance mechanisms to mitigate unanticipated economic problems. The level of female participation in FFW programs in Ethiopia is of particular interest because women play a central role in most households. They serve in multiple roles as household food managers, as mothers providing food to children (the most vulnerable demographic group), and as head of households with high economic vulnerability (Haddad et al., 1997; Barrett et al., 2004; Quisumbing, 2004). Furthermore, female-headed households with no adult male in the family have been identified as one of the main indicators of chronic poverty and food insecurity in Ethiopia (Jayne et al., 2001).

There are few quantitative studies focusing on the level of women’s participation in FFW projects and the ease of access to food aid. Although there are some cases where female-headed households received more food aid than male-headed households (Clay et al., 1999; Jayne et al., 2002), various survey data have shown that female-headed households in Ethiopia are under-targeted and have relatively low participation rates in FFW projects. For example, empirical evidence from recent analysis of the Ethiopian Rural Household Survey show that female participation, compared to men’s, in FFW programs is relatively low and the effect of program characteristics on participation in FFW varies across gender (Quisumbing and Yohannes, 2005).

The determinants of female participation in FFW projects include: level of schooling, type of project, days worked, wages, availability of childcare, and distance from home. The number of years of schooling is positively correlated with FFW participation. The type of project matters, as females are less likely to participate in infrastructure projects that involve more physically strenuous tasks. In contrast, women are more likely to participate in less physically strenuous FFW activities such soil conservation and forestry projects. These types of projects may also be more conducive to women's participation because they provide longer duration of employment and allow for more flexible scheduling for women with competing farm and childcare responsibilities (Coady, et al., 2004; Quisumbing and Yohannes, 2005).

Since the majority of food aid resources in Ethiopia are devoted to FFW programs, there is a need to re-evaluate the effectiveness of this self-targeting approach in the context of its effects on women and children. FFW programs have to be more gender-sensitive in terms of its project design and implementation in order to ensure greater female participation. In addition, higher proportion of food aid resources needs to be allocated to non-FFW (e.g., free distribution). The official policy and goal of 80 percent of food aid resources devoted to FFW schemes may be too high and unrealistic in meeting the food security needs of the most vulnerable groups. By design, the work requirement component of FFW schemes would always favor able-bodied laborers that are predominantly young and middle-aged men. This implies that children, pregnant women, nursing mothers, and the elderly would be left with a much smaller proportion of the food aid resources.

CONCLUSION

In the past three decades foreign food aid donations have played an important role in Ethiopia's national food security policy. Although Ethiopia remains a leading recipient of food aid, the overall volume of global food aid flow has been declining since the beginning of the 1990s. The fall in food aid availability is driven by recent decrease in agricultural surpluses of major donors. The decline in food aid supply is one of the factors that underlie the need for more effective targeting. In the context of Ethiopia, the FFW program is the largest government food policy tool in feeding the hungry. The Ethiopian government's stated goal is to devote 80 percent of all food aid to FFW programs (FDRE, 1996; Barrett and Clay, 2003). Thus, it is important to examine how effective FFW has been in ensuring the participation of the most vulnerable food-deficit groups. Self-targeting of food aid through FFW programs has been proven to be an effective means of transferring food to the neediest people in South Asia and to a limited extent in Ethiopia (Dev, 1995; Ahmed et al., 1995; Barrett and Maxwell, 2005). However, cases of significant targeting errors still persist.

The most obvious area for improvement for the FFW program in Ethiopia is in addressing the problem of low participation of women of female-headed households. Most of the types of projects supported by FFW are gender-biased in favor of able-bodied men and inherently exclude women. A review of many FFW projects in Ethiopia reveals that the tasks generally require the ability to lift heavy loads and engage in other physically strenuous activities because most projects emphasize local infrastructure development (e.g., construction of roads, bridges, schools, clinics, community buildings, domestic water supply, etc.). Thus, FFW programs in Ethiopia have low participation from female-headed households (especially pregnant women or nursing mothers). Low participation in FFW programs for women usually imply less access to food aid for them and other members of their households (particularly food-deficit infants and children). This is a significant error of exclusion (of women and children) that needs to be addressed.

To a limited extent, some improvements in the design and variety of the FFW schemes could increase the level of participation of women who are able to work. Each food-deficit Ethiopian *wereda* should have FFW projects corresponding to the demographic distribution and characteristics of the potential beneficiaries. For example, a predominance of construction-based FFW projects in a *wereda* with majority women and children would be gender-biased and would most likely have low participation by pregnant or lactating women. Rather, projects involving less physically strenuous tasks should be funded. These types of projects would include natural resource conservation public works such as reforestation, soil conservation, vegetable gardening, etc. More FFW projects should be established in more geographically dispersed and accessible locations so that more needy households could participate.

Self-targeting of food aid through FFW programs is a valuable tool for reaching the food insecure. But FFW programs need to be re-evaluated and re-designed to further reduce the prevalence of targeting errors. Particularly, the national government of Ethiopia needs to revise its 80-20 rule and allocate more food aid resources to non-FFW schemes that would further benefit the labor-poor who could not participate in FFW programs. Furthermore, donor agencies and NGO involved in distributing food aid should continue to develop more gender-sensitive projects so that a significant portion of the public works projects are conducive to higher likelihood of participation by women. In conclusion, more empirical studies of food aid targeting effectiveness are needed both at the macro and micro level. This would ensure that better information is available to policymakers in evaluating the impact and effectiveness of current food aid policies.

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COST-BENEFIT ANALYSIS OF FARMER TRAINING SCHOOLS: THE CASE OF GHANAIAN COCOA

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ABSTRACT

Using primary data collected in summer 2011 from the 2010-2011 growing season and a baseline model from Mahrizal et al. (2013), the goal of this study was to estimate the NPV of CLP training over a 50-year period—two cocoa production cycles. Using multiple regression analysis to determine the effect of CLP on yield and thus NPV, it was estimated that cocoa yield rose 75.25% per hectare after completing all CLP training. This resulted in an annual NPV gain of $401.00 per hectare or a 90% increase in annual NPV compared to the baseline model. When extrapolated over 50 years to account for human capital development, training is associated with a $20,050 per hectare total increase in NPV. With a total training cost of $252, the BCR of the CLP was 79.56:1 meaning for every $1 invested in the program, farmers' income increased by $79.56 per hectare, a considerable increase by most standards.

Keywords: Cost-Benefit Analysis, Farmer Training Schools, Ghanaian Cocoa, NPV

JEL: O32, O55, Q01

1. INTRODUCTION

While billions of dollars flow into low-income countries each year to help alleviate poverty, assessing the effectiveness of these dollars is a challenging task. Because of poor infrastructure and communication networks, as well as a lack of transparency in the sources of information, collecting and evaluating data to measure the impact of development projects in low-income countries is difficult. Meanwhile the global economic recession coupled with budget cuts across high-income countries have resulted in fewer unrestricted funding sources

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for large-scale development projects (CGIAR, 2012). Donors to poverty alleviation projects are increasingly asking for higher resolution impact and evaluation data for their projects. Thus, to adequately measure the impacts of a poverty alleviation project, monitoring and evaluation teams must be inherently results-oriented with the data to support claims (UNDP, 2009).

The literature is rich in studies that measure the benefits of rural development programs. However, many of these studies lack a temporal dimension because they measure costs and benefits for only capital investments and for only a "average" year, while not accounting for skill enhancement dividends paid over a longer horizon. Farmer training programs typically result in human capital acquisition. The benefits can persist long after the training program has officially ended.

As a result, farmers develop skill sets that can extend well past the single year (or few years) of the training program. By accounting only for net producer benefits during the life of the development program, the cost-benefit analyses (CBA) may not truly capture the full net benefits of a given program. Therefore, a more comprehensive approach of cost-benefit analysis must be utilized when evaluating projects that invest in human capital. Such analyses should give future donors a more complete portrait of potential investment returns. With that in mind, this study undertakes a cost-benefit analysis (CBA) of a 2009-2014 Bill and Melinda Gates/World Cocoa Foundation (WCF) training program for Ghanaian cocoa producers. The goal of the training program is to teach cocoa producers in five West African countries agricultural practices such as proper pruning, drying techniques, and harvesting methods to improve their agricultural production and thus their livelihoods. To more comprehensively measure the costs and benefits of such a program, the economic returns should be calculated over an extended horizon, rather than simply accruing the five-year benefits that correspond with the life of the program itself. Net present value (NPV) is a standard measure of intertemporal net benefits resulting from an investment. By calculating the NPV change over an extended horizon due to the human capital obtained, the net benefits of the grant and training program(s) can be more accurately measured. This type of intertemporal accounting of net benefits estimates the full return to grant programs more precisely and comprehensively.

In Ghana, where approximately 52% of the population lives on USD $2 a day or less, 27% live on $1.25 or less per day, and 19% of rural households produce cocoa, measuring the full impact of agricultural development programs can generate information needed to more efficiently invest scarce resources (World Bank, 2013; Breisinger et al., 2008). With the introduction of structural adjustment programs (SAPs) in the 1980s, there was an overall decline in agricultural research, farm extension, and rural banking services that play an integral role in tree crop production enterprises like cocoa in Ghana. To fill this void for cocoa, in 2009 WCF undertook the Cocoa Livelihoods Program (CLP) in conjunction with the Bill and Melinda Gates Foundation and sixteen member companies involved in the chocolate, cocoa, and coffee industries.

The goal of CLP is to increase cocoa production and thereby strengthen the economies of cocoa-growing communities. CLP operates production and management training and credit programs to help accomplish its goals. To estimate the benefits of this program, this study uses primary data collected from the 2010-2011 growing season in Ghana to estimate the impact that the training program has had on producer output and thus returns. The primary data allowed a comparison between yields and costs for farmers who attended the farmer training and for those who did not. From this comparison, the study implements an NPV model using the 25-year parabola shaped lifecycle yield curve (average productive life) of a cocoa tree in Ghana based on research conducted by the International Institute of Tropical Agriculture (IITA) and Mahrizal et al. (2013). The NPV model estimates the value of CLP training over two production cycles, or a 50-year period, assuming that one hectare is planted after a producer completes CLP training. The hypothesis of the study is that CLP farmers will experience an increase in livelihood quality due to increased cocoa yields associated with farmer training.

2. Literature Review

2.1 Poverty in Ghana

Real Ghanaian gross domestic product (GDP) has increased 4% annually since 1986, helping real per real capita income grow by over 30% for the period 1986 to 2004 (Brooks et al., 2007). Between 2007 and 2011, annual GDP growth rate was 8.3% (World Bank, 2013). In 2011, the country's per capita income reached $1,410 and it attained lower middle-income status according to World Bank classifications. However, this increase could be deceiving given the recent discovery of oil and high gold prices, which can lead to unevenly distributed growth and development (World Bank, 2013).

In Ghana, food poverty (the estimated food expenditure per person per year needed to meet minimum nutritional requirements hence "extreme poverty") as well as overall poverty (measured at an income of $1.25 per day) has consistently fallen since 1991 (Breisinger et al., 2008; Ghana Statistical Service, 2000; National Development Planning Commission, 2012). Ironically, farm households experienced a higher incidence of food poverty ranging from 52% to 45% between 1991 and 1998, respectively. In the past thirty years, the percentage of the poor that produce food crops has increased while the share attributed to export crop producers has decreased (National Development Planning Commission, 2012). Thus, in Ghana like many low-income countries those who are the poorest and the most food insecure are smallholder agricultural producers.

In Ghana, 60.1% of cocoa farmers were below the poverty line in 1991. By 2007, that figure had dropped to 23.9% (Coulombe and Wodon, 2007). Economic growth has also positively affected poor cocoa farmers more than the poor in other sectors of the economy (Breisinger et al., 2008). Much of this can be attributed to improved cocoa varieties. However, these hybrids may cause greater soil damage than conventional varieties if used without fertilizers, thus necessitating the need for production skill development and credit access. In recent years, poverty has actually increased for the more arid, northern regions of Ghana less involved in cocoa production, largely due to a decrease in agricultural and non-farm income (Brooks et al., 2007). Many cocoa-growing regions have poverty rates below the national average (Breisinger et al., 2008). Nevertheless, Afari-Sefa et al. (2010) estimates that the average annual per capita income among cocoa-producing households is $153.30, indicating there is still ample room for income enhancement.

2.2. Impact of Structural Adjustment Programs on Cocoa

In the early 1980s, the World Bank and International Monetary Fund began instituting structural adjustment programs (SAPs) that led to a reduction of government initiatives to "open up economic activities to the free play of market forces," which led to a decline in agricultural research, farm extension, and rural banking that play an integral role in tree crop production enterprises like cocoa (Nyemeck et al., 2007; Wilcox and Abbot, 2006). This decline in public funding was coupled with a decline in official development assistance, decreasing by almost half between 1980 and 2005 when adjusted for inflation and resulting in fewer funds to implement agricultural development projects in West Africa and across the globe (Cabral, 2007).

Before the SAPs, many West African cocoa producers received free or subsidized fungicides, herbicides, fertilizers, and technical training, which in their absence have led to declining yields and increasing income volatility for cocoa producers, particularly for the rural poor who live on marginalized land susceptible to weather and yield variability (Nyemeck et al., 2007). This can lead to lower output, sale of productive assets, reduced consumption, and/or reduced investments in education if problems persist (Hill and Torero, 2009). Current agricultural loans to Ghanaian cocoa farmers come in the form of input packages, primarily through farmer associations or non-governmental organizations (NGOs). A larger banking (lending) system that provides credited inputs to more producers has the potential to both: 1) ease the capital constraints currently imposed on farmers by smoothing seasonal cash flow deficits that are currently solved by discretionary use of limited resources by households, and 2) improve the ability of cocoa producers to obtain and utilize agricultural inputs (Nyemeck et al., 2007).

2.3. Cocoa Production in Ghana

Agriculture represented 32.3% of Ghanaian GDP in 2010, the second highest export behind gold (World Bank, 2012; Mhango, 2010). In 2005, cocoa production was 18.9% of agricultural GDP and 7.3% of overall Ghanaian GDP (Breisinger et al., 2008). By 2015, cocoa is projected to account for 16.5% of agricultural GDP and 6.5% of overall GDP (Breisinger et al., 2008). During the 2010 growing season, Cameroon, Côte d'Ivoire, Ghana, and Nigeria together accounted for 71.4% of world cocoa production (WCF, 2012). Ghana alone represented 20.5% of global cocoa production in 2010 and was (and remains) the second largest exporter behind Cote d'Ivoire (WCF, 2012). Yet, it should be noted that the number of beans harvested per hectare in Ghana is "among the lowest in the world" (Caria et al., 2009).

The Ghana Cocoa Board (COCOBOD) is the sole exporter of Ghanaian cocoa, guaranteeing farmers a minimum price at 70% of the net free on board (FOB) price (Kolavilli et al., 2012). In the 1998 growing season, the actual Ghanaian farm gate price as a percent of increased to nearly 80% (Kolavalli and Vigneri, 2011). For the 2012 growing season, farmers received 76.04% of the FOB price (Government of Ghana, 2012). Still, net FOB prices in Ghana are lower than its more liberalized neighbors Côte d'Ivoire, Togo, Nigeria, and Cameroon (Mohammed et al., 2012; Kolavalli and Vigneri, 2011). Ghanaian cocoa production is partially liberalized, allowing private licensed buying companies (LBCs) to buy, sell, and transport cocoa. However, COCOBOD sets a minimum price and is currently the only exporter. COCOBOD's primary LBC competitors are Kuapa Kokoo, Olam, Armajaro, and Global Haulage (Kolavalli and Vigneri, 2011). LBCs are allowed to export, though none have reached the minimum quantity of beans to be eligible to export (Kolavalli and Vigneri, 2011). Given COCOBOD's predetermined minimum pricing system, the LBCs' sole option for competing with each other on price is through price bonuses for higher quality cocoa (often tied to a certification program). They can also differentiate themselves through gifts such as exercise books, cakes of soap, salt, subsidized inputs, or credit programs largely implemented through farmer-based organizations (FBOs) like Cocoa Abrabopa (Laven, 2007; Caria et al., 2009; Kolavalli and Vigneri, 2011). Cocoa Abrabopa is a not-for-profit partner of the Dutch/Ghanaian agricultural company Wienco and provides credit for farmers to buy Wienco agricultural inputs before the season begins. LBCs rarely pay above the minimum COCOBOD price due to the cost associated with doing so (Seini, 2002; Kolavalli et al., 2012).

2.4. The World Cocoa Foundation and the Cocoa Livelihoods Program

The World Cocoa Foundation is a Washington, D.C.-based NGO with programs in Central and Latin America, Southeast Asia, and West Africa. The Foundation promotes sustainable cocoa production, both economically and environmentally, while improving the livelihoods of cocoa growers and cocoa-growing communities. The Cocoa Livelihoods Program (CLP) is supported by $17 million from sixteen member companies (The Hershey Company, Mars Inc., Mondelez International, Cargill, Archer Daniels Midland, Barry Callebaut, Olam, Starbucks, Armajaro, Ecom, Transmar, Noble Cocoa) involved in the chocolate, cocoa, and coffee industries. Additionally, it has received financial support of $23 million from the Bill and Melinda Gates Foundation, as well as technical support from the German government's Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), TechnoServe, ACDI-VOCA (ASI), Canada-based NGO Société de Coopération pour le Développement International (SOCODEVI), U.S.-based NGO TechnoServe, Ghana's COCOBOD, ANDADER, ONC (Cameroon), ADP, Nigeria, and the governments of Ghana, Cameroon, Nigeria, and Côte d'Ivoire.

In Ghana, CLP operates three cocoa farming training programs and one credit operation. The cocoa training programs relate to three areas (in this order): production management, business management, and input management. The credit operation provides input loans via TechnoServe. The three training programs are respectively labeled farmer field school (FFS), farmer business school (FBS) and input promoter (IP). When the funding expires in January 2014, CLP will have granted credit access to 6,000 farmers to and trained 44,200 Ghanaian cocoa farmers between 2009 and 2013. The CLP operates in four countries. The number of farmers trained per country is proportional to the share of cocoa production within the five West African countries and multiplied by the 200,000 total farmers trained in West Africa. Farmers wishing to participate in CLP are asked to form groups of 15-30 individuals. Further selection criteria are: age not greater than 60 years old, farms at least 2.5 acres planted with hybrid cocoa with a maximum age of ten years, and access to at least one hectare of land to establish a new cocoa farm planted with hybrid cocoa.

COCOBOD teaches the FFS. The immediate impact of FFS should be improved agronomic production skills to better manage the agronomic health of cocoa trees through fertilizer use and prevention of disease and pests. Specifically, farmer field schools provide training in safety practices, fermentation methods, replanting, farming techniques, estimating farm size, pruning, and managing persistent pests like mealy bugs and aphids. FFS also educates farmers on broader social goals such as HIV awareness and children's education. FFS in Ghana is not a traditional FFS. The curriculum is customized based on preliminary questions to ascertain specific farmer deficiencies.

The second phase of CLP is the FBS taught by GIZ. FBS gives farmers the financial tools to balance a budget, work within FBOs, and act as a farmer entrepreneur. The program is primarily concerned with shifting farmer perceptions from farming as a lifestyle to farming as a business. The curriculum accomplishes this by reviewing the farming measurements (hectare, kilometer, kilogram, liters), observing caloric values to ensure families receive the required nutrition, stressing the importance of a balanced budget, practicing balancing a budget, and demonstrating the benefits of crop diversification. The course also evaluates financial services, methods to increase cocoa quality, FBO membership, and the advantages of replanting cocoa. The central message of FBS is that farming is an entrepreneurial activity.

The Ghanaian COCOBOD teaches the final phase of CLP: input promoter. The course involves using inputs and, upon graduation, farmers are able to receive input loan packages via TechnoServe at a 10% down payment, underwritten by Micro-Finance Institute Opportunity International Savings and Loan. The curriculum specifically assesses ways in which the farmer can expand production through the use of inputs, such as chemical fertilizer, fungicides, and insecticides. Safety precautions when spraying and mixing chemicals are also included in the program. By the final phase of CLP, farmers should know proper crop management techniques, how to budget and coordinate financial resources, and finally how to safely use chemical inputs.

2.5. Previous Cost-Benefit Analyses in Development Programs

Several past cost-benefit analyses of tropical agriculture are used for comparisons with the results of this study. Wienco's FBO Cocoa Abrabopa in conjunction with the Center for the Study of African Economies (CSAE) conducted a study in 2007 to assess the impact of Cocoa Abrabopa's field representative training and farmer loan program in Ghana (Caria et al., 2009). The program differs from CLP in that farmers are not trained. Instead, Cocoa Abrabopa representatives are trained in production practices like FFS and then go into the field to advise the 11,000 member-farmers. These representatives do not directly sell inputs to farmers, but do provide group-based input loans. Cocoa Abrabopa also gathered information from non-participating farmers to directly compare participating farmers to non-participating farmers. There were 239 farmers in the sample. The methods used to collect the data are not clear. The notable results of the study were a recognizable 40% average increase in yield for the 2007/2008 growing season and an economic return of over 250% (benefit cost ratio (BCR) of 2.5) after accounting for the cost of the input loan excluding operational costs of program (Caria et al., 2009). The study found increased labor use was not substantial enough to alter the cost-benefit ratio. More importantly, the study found incorrect use of fertilizer and other inputs was still a common problem, signifying that credit accessibility is only part of the solution, while training on proper input usage can be as pivotal as the availability of inputs themselves. Afari-Sefa et al. (2010) conducted another CBA for cocoa production, estimating the costs, benefits, and NPV of Rainforest Alliance-certified cocoa production in Ghana. Certification requires farmers to adopt medium shade density (70 trees per hectare with a minimum of 12 compatible indigenous species) to "increase biodiversity and other environmental services" (Afari-Sefa et al., 2010, 5). The other major burden of certification is purchasing protective equipment for pesticide mixing and application. The core benefit was the 144 Ghana cedi (GH₵) per ton price premium for certified cocoa, a value assumed by Afari-Sefa et al. The NPV of certification calculated over 15 years for high input, medium shade Amazon-certified cocoa was positive for an 85% FOB price share with a 1.075 BCR and again positive for a hypothetical 25% training yield increase with a 1.087 BCR (Afari-Sefa et al., 2010). These estimates included a training yield gain and accounted for human development capital that remained unaddressed in prior studies. The study notes its limitations in not incorporating all certification costs and not accounting for future price or cost volatility.

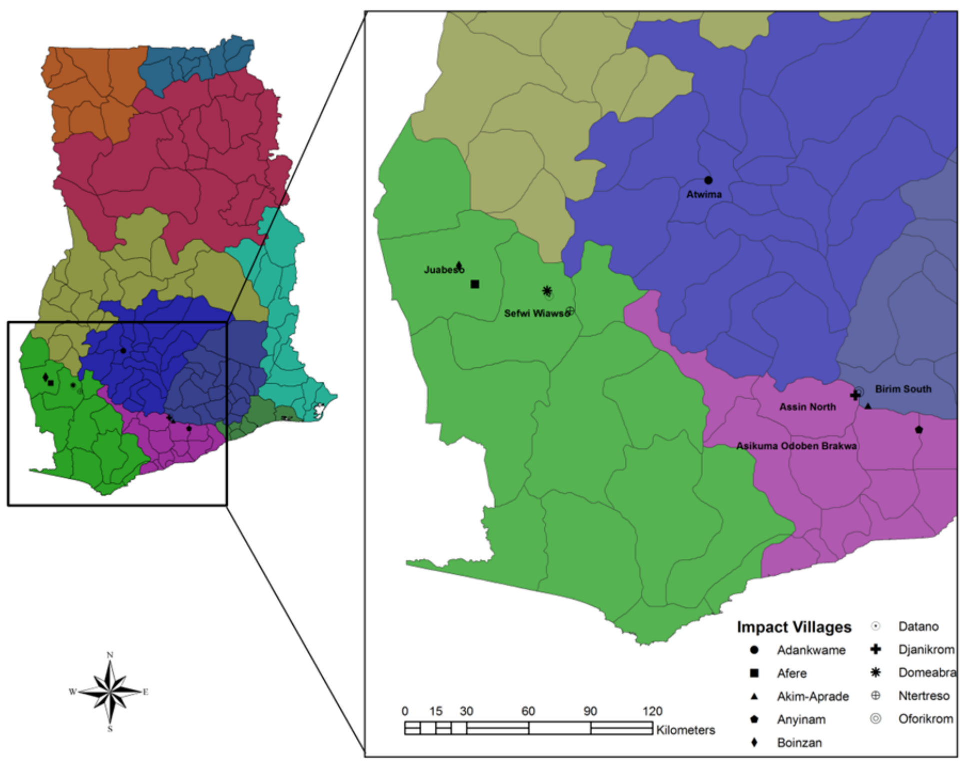
Another cost-benefit analysis, Alam et al. (2009) examined a participatory agroforestry program in Bangladesh, intended to combat unregulated, unsustainable deforestation. The study observed financial viability, environmental sustainability, and management issues of a forestry program created to manage farmers' needs within forest ecosystems. Farmers were allotted one hectare per participating farmer. Costs were calculated for land preparation, maintenance, pesticides, fertilizer, seeds, and labor. Benefits included income attained from pineapple, zinger, and mustard production, among others. The study found a BCR of 4.12 and an NPV of $17,710 over a 10-year rotation. Alam et al. (2009) illustrated the financial viability of sustainable agroforestry programs.

Mahrizal et al. (2013) utilized cocoa production data collected by STCP and IITA to estimate an optimal replacement rate (ORR) and initial replacement year (IRY) to maximize a 50-year NPV for a hectare of cocoa production in Ghana by employing a phased replanting approach. The authors found that the annual ORR is 5% to 7% across the three different production systems studied: Low Input, Landrace Cocoa (LILC), High Input, No Shade Amazon Cocoa (HINSC), and High Input, Medium Shade Cocoa (HIMSC). They also estimated that the optimal IRY ranges from year five to year nine as a function of cocoa prices, fertilizer prices, labor prices, and percentage yield loss due to disease outbreaks. From the ORR and IRY values, the authors estimated economic gains that exceed currently practiced replacement approaches by 5.57% to 14.67% across production systems with reduced annual income volatility. They concluded their method could be used to increase cocoa yields and stabilize income over time, thus facilitating substantial quality of life improvements for many subsistence cocoa farmers in Ghana and around the world.

3. Methodology

3.1. Data

A survey was conducted in ten WCF CLP communities during July 2011 in the cocoa growing regions of Ghana (Figure 1) which were selected using cluster sampling of three production regions[1]. All CLP communities were grouped according to training received (FFS, FFS/FBS, or FFS/FBS/Input) and selections for the survey were randomly made within the respective groups. Once the ten communities were chosen, purposive sampling was employed to select both male and female cocoa producers.[2] The targeted and attained sample size was 183 farmers (126 men and 57 women). The sample size was calculated to have approximately 18 farmers from each of the ten communities. The sampling frame was obtained from Fortson et al. (2011), a study conducted by Mathematica Policy Research Inc. during the 2009/2010 cocoa growing season on behalf of WCF to measure yields of farmers "most likely to benefit from the program" (Fortson et al., 2011). Thus, the sample identified by Mathematica should be representative of cocoa producers in Ghana who are likely to participate in the training program. It should be noted that each community had received some form of CLP training by the time this survey was implemented. Of the 549 training units (one farmer graduating from any one of the three programs) experienced by the 183 farmers in our survey, 256 (46.6%) of these training units occurred after the 2010-2011 harvest. Because the yields from this group's farmers were not affected by the training at the point of data collection in July 2011, they are the controls for measuring the impact of the training programs.



Map Source: ArcGIS (2013).

Figure 1. Location of Cocoa Livelihood Program (CLP) Villages used in the Study.

[1] The 10 villages (district in parentheses) were: Adankwame (Atwima Nwabiagya), Afere (Juaboso), Datano (Juaboso), Bonzain (Juaboso), Ntertreso (Sefwi Wiawso), Domeabra (Sefwi Wiawso), Akim-Aprade (Birim South), Oforikrom (Birim South), Anyinam-Kotoku (Birim South), and Djanikrom (Birim South).

[2] Women were intentionally overrepresented in the sample to provide reporting data to donor agencies on female farmers' practices and yields.

The CLP survey was implemented to collect qualitative and quantitative information about the producers and their production behavior. Data collected included: 1) name, 2) gender, 3) district, 4) village, 5) total area planted in hectares, 6) FBO membership, 7) total farm yield (measured in 64kg bags), 8) WCF training received including the year, 9) source of planting material for their farm both pre- and post-training, and 10) implementation of different farm management practices. Farm size was based on farmer estimations because many farms were non-contiguous and GPS mapping was not common. Since FFS incorporates a module on the proper measurement of farm size, producer-reported farm size should be a relatively accurate approximation. For observations where multiple family members co-managed a farm, only one manager was interviewed. For farms with both a farm manager and a farm owner in which only one received training, the two were interviewed together. If language barriers existed between farmers and interviewers, a translator was utilized. The questionnaire was administered with the assistance of local technical partners under supervision of the WCF Monitor and Evaluation team.

3.2. Methods and Data

To estimate the yield enhancement attributable to the various levels of CLP farmer training, a semi-log linear regression model is specified and estimated by ordinary least squares. The dependent variable is yield measured in kilograms of cocoa beans per hectare. The independent variables are FFS training, FBS training, input promoter (IP) training, gender, farm size, FBO membership, fertilizer use, fungicide use, insecticide use, herbicide use, improved cocoa varieties, seed source, and location.

The model can be written as:

$$\log Y_i = \alpha + \beta_1 FFS_i + \beta_2 FBS_i + \beta_3 IP_i + \beta_4 Gender_i + \beta_5 FarmSize_i + \beta_6 FBO_i + \beta_7 Fert_i + \beta_8 Fung_i + \beta_9 Insect_i + \beta_{10} Herb_i + \beta_{11} ImprVar_i + \boldsymbol{\varphi}_1 SeedSource_i + \boldsymbol{\varphi}_2 Location_i + e_i \quad (1)$$

The dependent variable Y_i represents yield of dried cocoa beans for individual farm i in kilograms per hectare. A natural log transformation is used because a semi-log regression model calculates the percentage yield increase associated with training (rather than in kilograms per hectare), resulting in a more accurate estimate for the NPV model. *FFS*, *FBS*, and *IP* are binary variables taking on a value of one if the i^{th} participant had completed the CLP farmer field school (FFS), farmer business school (FBS) and input promoter (IP), respectively. The control producer group consists of those farmers who had no CLP training. *Gender* is a binary variable taking on the value of one if the i^{th} participant is male. *FarmSize* is the natural log of participant *i*'s cocoa farm size in hectares. *Fert*, *Fung*, *Insect*, *Herb*, *ImprVar*, and *FBO* are binary variables taking on the value of one if the i^{th} participant used inorganic fertilizer, fungicide, insecticide, herbicide, improved cocoa varieties, or was a member of an FBO, respectively.[3] The coefficient vector φ_1 contains coefficients for the

[3] Ideally, the amounts of fertilizer, fungicide, herbicide, pesticide, and insecticide would have been collected. However, given the non-contiguous nature of most producers' farms, the two growing seasons for cocoa, and that fertilizer may not be applied every year, these more ideal measurements were not obtained.

origin of seed stock binary variables (own farm and friend's farm, with government certified seed acting as the reference origin) and φ_2 contains coefficient binary variables indicating the location of the farm (the districts Atwima Nwabiagya, Juaboso, and Sefwi Wiawso, with Birim South acting as the reference district). Because of the cross sectional nature of the sample, the standard errors of the estimated coefficients are heteroscedasticity consistent standard errors as given in White (1980). As a result, the ratio of the estimated coefficients to their estimated standard errors is distributed asymptotically as standard normal under the null hypothesis.

3.3. Net Present Value

Given the estimated yield increases from the various CLP training programs from equation (1), a net present value (NPV) of total benefits can be calculated using the methods implemented in Mahrizal et al. (2013). Like Mahrizal et al. (2013), this study solves for the optimal IRY and ORR. Given this solution, the net future value (NFV) in each year is computed as a function of returns, the replacement rate, year of replacement, and inflation rate. Then, the NPV is computed as the sum of the annual discounted NFV in each year. This study considers the importance of both the inflation rate (often high in low-income countries), because it increases the nominal price level over time and strongly affects the future value of money, and the importance of the discount rate, because it determines the present value of net returns from future periods.

A baseline NPV was computed using the results of the Mahrizal et al. (2013) study that used the same production data set as this study. A two-dimensional matrix is constructed in Excel with varying annual replacement rates along the columns and an initial replacement year (IRY) along the rows. Each element in this matrix is the NPV for a given replacement rate and the associated initial replacement year. The optimal replacement rate (ORR) ranges from 4% to 10% and the IRY ranges from year 5 to year 20.[4] The combination of the percentage replacement rate and IRY which gives the highest NPV is the optimal solution.[5]

From the optimal ORR and IRY that maximizes NPV solved for in the Mahrizal et al. (2013) study, a baseline scenario can be computed to estimate the NPV for participants who are maximizing NPV without the benefit of CLP training. A baseline was established using ORR and IRY to highlight the maximum potential profit that could be achieved for producers given current production practices without CLP training. Given the biological life cycle of a cocoa tree which has a production peak with a decreasing yield over time, an alternative baseline, not addressed in this study, would be to simply not replace trees, letting the entire orchard reach zero yield, and subsequently replacing all of the trees at once. Following Mahrizal et al. (2013) who concluded that cocoa yield decreases at an increasing rate over time, it is clear that some form of replacement is needed to both stabilize and optimize cocoa producers' annual returns over time. Thus, the baseline is established using ORR and IRY

[4] "Replacing cocoa trees by less than 4% or over 10% indicates that the complete replacement of an entire farm for one production cycle would take 33.3 to 100 years or 9 years or less, respectively. Setting the IRY at less than 5 years of age or over 20 years of age is not necessary since the cocoa trees bear fruit starting at age three and decreasing yields begin after year 20" (Mahrizal et al., 2013, 17).

[5] "For all scenarios solved, all optimal solutions were in the interior of the matrix, i.e., no corner solutions. This justifies having 4% ≤ ORR ≤ 10% and 5 ≤ IRY ≤ 20 in the search procedure for the ORR and optimal IRY" (Mahrizal et al., 2013, 17).

implying that producers are acting in a profit-maximizing manner before the CLP training is implemented.

It is assumed that the yield benefits estimated in Equation 1 as attributable to the various training programs (*FBS, FFS, and Input Promoter*) could be a constant percentage gain associated with each level of training, above those cocoa producers who did not participate in the various CLP trainings (baseline scenario) over the life of the cocoa tree.[6]

The calculations for net future value, and net present value were made as follows.

Net Future Value (NFV) is equal to:

$$NFV_t = Yld_t(1+X\%) * P_t(1+r)^t - C_t(1+r)^t \tag{2}$$

where: NFV_t = Net future value in period t.

Yld_t = Yield (kg/ha) of cocoa in period t for a given hectare, and depends upon the age distribution of trees on that hectare.

(1+X%) yield increase with various CLP training. X=0 represents the baseline yield.

$P_t * (1 + r)^t$ = Cocoa price in period t compounded by inflation rate r.

$C_t * (1 + r)^t$ = Cost of cocoa production in period t compounded by inflation rate r.

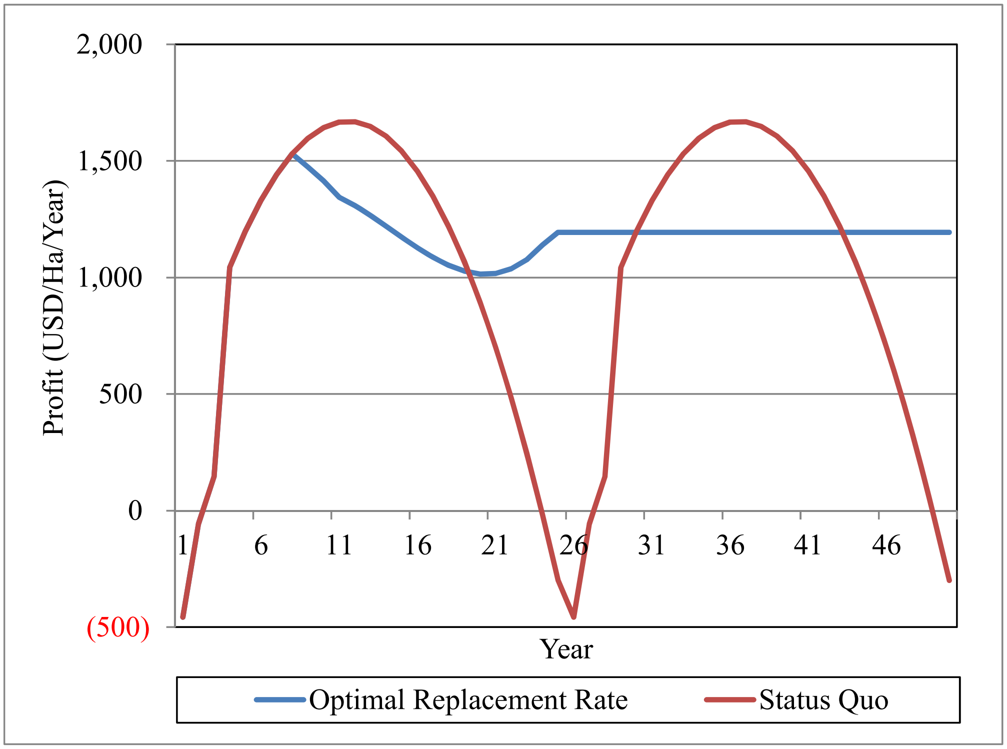
The NPV for a hectare is computed as:

$$NPV = \sum_{t=1}^{T} NFV_t \frac{1}{(1+r_d)^t} \tag{3}$$

where r_d is the discount rate and t runs from year 1 to year 50, or two cocoa production cycles if the farm manager did not do phased replacement but simply grew trees, clear cut at age 25 and then repeated another twenty-five year cycle.

Several reasons provide justification for use of a 50 year horizon of a NPV model in estimating the benefits of the studied training program. As part of the CLP program, cocoa producers are taught the value of replacing trees instead of letting their yields decline to zero. Because cocoa trees can yield fruit for up to 50 years but peak at a much earlier age, culling and replanting are considered necessary to maintain maximum orchard profitability over time. However, most impoverished cocoa producers find it difficult to forgo immediate income to enhance long run revenue potential. Thus, by using a model which extends 50 years (which is typically the full cycle of two cocoa trees at 25 years a piece) the model shows the effects that CLP can have on human capital knowledge of replacement rates and the potential to provide low-income cocoa producers a higher and less volatile income stream. The importance of this is illustrated on Figure 2 which shows that by allowing the model to extend well past 25 years the benefits of the CLP training program in regards to revenue smoothing and eliminating negative profits through replacement training are fully captured.

[6] The constant gain would increase yields at each stage of growth by that percent. That is, at a 10% yield increase level, 100 kg/ha at year 10 would increase to 110 kg/ha while 200 kg/ha at year 20 would increase to 220 kg/ha.



Status Quo denotes common practice in Ghana where producers simply let yields diminish to zero and then replant the entire orchard. Optimal replacement rate (ORR) denotes the optimal year and percentage of trees to be replaced to maximize NPV. Source: Mahrizal et. al (2013).

Figure 2. Yearly Profit Per Hectare from Cocoa Production in Ghana Under Medium Shade High Input Production Practices Under Phased Replacement and Status Quo Production.

The annual average return is calculated by dividing the NPV by 50, giving the annual average present value of profit per hectare per year. The model assumes no salvage value for cocoa trees consistent with Ward and Faris (1968) and Tisdell and De Silva (2008). A baseline NPV (no CLP training implying X=0) is estimated using a cost, yield, and input price structure as derived from Gockowski et al. (2009) and the optimal ORR and IRY calculated by Mahrizal et al. (2013) of 6% and year 9, respectively.[7]

The baseline production practice chosen for the study was classified as Low Input Landrace Cocoa (LILC) production system described in Mahrizal et al., (2013). The system uses unimproved, local landrace cocoa varieties with pesticides and fungicides over the life cycle, but no inorganic fertilizer. Costs and returns are estimated for 1 hectare of unimproved cocoa planted at 3 x 3 m spacing (1,100 plants per hectare). No nursery costs are incurred as the farm is directly seeded with unimproved LILC cocoa varieties. Typical of most Ghanaian

[7] The importance of the 50 year time horizon is more thoroughly explained in Mahrizal et al. (2013). One might assume that extending the study horizon would inflate the BCR. This would be the case if benefits were linear. Once the tree rotation hits a steady-state, the length of the horizon is largely immaterial. As can be seen in Fig. 2, the orchard is at a constant ORR at about year 24. What our analysis shows is how the profitability changes from this state without CLP to a higher rate of return with CLP. The 50 year horizon gets the model to the steady-state and also shows the benefits of eliminating the negative profits in years 26-29.

farmers, it is assumed that there is no use of agrochemicals other than those provided by the Government of Ghana's mass spraying program, which is subsidized by COCOBOD. The amount of pesticides and fungicides used on average for LILC is 0.11 liters of Confidor per year and 31.68 sachets (50 grams) of Ridomil per year, respectively provided by the government. Prices for these inputs were obtained from Afrari-Sefa et al. (2010). The study also assumes that shade levels for LILC system are 70 shade trees per hectare. The LILC production system is chosen as the baseline because it is popular with impoverished producers who cannot obtain financing for inputs, the very target of the CLP program. Thus, the baseline scenario portrays those producers who implement LILC cocoa production using the optimal ORR and IRY to maximize NPV, but who have had no CLP training. Once a producer has finished input training (*IP*), it is assumed that they would have access to inorganic fertilizer and fungicide, thus production costs would need to increase as well. To account for this, all producers who have input training (*IP*) have associated higher costs of production. Cost estimates for High Input Medium Shade Cocoa (HIMSC) were obtained from Afari-Sefa et al. (2010). The only difference between the cost estimates of LILC and HIMSC is the use of inorganic fertlizer, fungicde, and herbicide. From these new cost estimates, a more accurate profit can be estimated because the large theoretical yield increases associated with *IP* should be associated with higher input costs.

Revenue was calculated by multiplying yield in kilograms per hectare for time period *t* by the price of cocoa in time period *t* in USD per kilogram. Given the COCOBOD marketing board pricing structure, Ghanaian farmers received 76.04% of the FOB price in 2012 so cocoa price was set at USD $2,513.72 per metric ton of beans or 76.04% of the ICCO price of USD $3,305.79 (2011 dollars) per metric ton of beans as observed on May 2, 2011. The COCOBOD retains a portion of the FOB price to reinvest in the cocoa economy in the forms of educational scholarships, input and supply subsidies, and research in an attempt to increase yields and decrease costs. Inflation was estimated at 10.26% based on the annual average inflation in December 2010 (Bank of Ghana, 2011a). The discount rate was 10.67% using Treasury bill rates for a six-month period (Bank of Ghana, 2011b).

3.4 .Benefit Cost Ratio

The difference between the baseline NPV (no training) and the CLP training program estimated NPV in Equation 3 would be the discounted benefits of the training program. Thus, the benefit-cost ratio (BCR) would be equivalent to:

$$BCR = \frac{B_X}{C_{0x}} \tag{4}$$

where B_x is the discounted benefits of the CLP training program minus the baseline NPV (no training) in USD per hectare and C_{0x} is the total cost of the training program per person assuming all costs of training are incurred at time 0. Training costs for the CLP program in Ghana were assumed to all occur in year one of the program. The World Cocoa Foundation estimated costs of the farmer field school (FFS) and farmer business school (FBS) to be USD $36 and USD $16, respectively, per participant (2010 dollars). WCF also stated that the input promoter training costs USD $200 (2010 dollars) per producer to implement. Therefore, the total cost of training one farmer is USD $252.

4. RESULTS

4.1. Regression

Table 1 presents a summary of average variable values by district. The average farm size was 3.2 hectares. Juaboso had the largest average farm size at 4.2 hectares, while Birim South had the smallest at 2.3 hectares. The average yield in kilograms per hectare was 562.6. Sefwi Wiawso had the largest yield with 854.9 kilograms per hectare. Atwima Nwabiagya had the smallest at 213.2 kilograms per hectare. Of the sample farmers, 68.9% were male, 76.5% completed FFS, 72.1% completed FBS, and 11.5% completed IP. The 11.5% that completed IP were concentrated in Juaboso and Sefwi Wiawso.

Table 2 presents the results of the regression. The R-squared is 0.36, which is reasonable for cross sectional data. Seven of the 16 variables (not counting the constant term) are statistically significant at the 10% level or better. Gender is statistically significant at the 5% level, demonstrating that being male was associated with a 33% increase in yield, all other variables held constant.[8] This may be correlated with the social status of males versus females in West African societies, particularly with banking access or land ownership, as well as the physical labor demands of cocoa farming. Farm size (measured in natural logs) with an estimated coefficient of -0.04 is significant at the 1% level, meaning that for every 1% increase in farm size, yield decreases by 0.04%. Considering a farmer's labor resources are typically finite, it would be expected that yield per hectare would decrease as hectares increase, since farmers have fewer resources to provide to each tree. Fertilizer and insecticide use are also statistically significant at the 5% and 10% levels with a 54% increase and 34% in yield, respectively. Yield would be expected to increase with use of these inputs, given that fertilizer improves soil quality and pests like mirids can cause a 30-40% yield loss.

The training coefficient estimates provide the most interesting feature of the regression. Attending FFS (farmer field school) is associated with a 77.2% increase in yield, but it is not statistically significant. FBS (farmer business school) had a positive coefficient (2.2% increase in yield with training); however, it is also not statistically significant. The only training that is statistically significant is *IP* (input promoter), which is significant at the 1% level and associated with a 75.24% increase in yield.

There are several reasons why FFS and FBS are not statistically significant. FFS is the introductory program to CLP and provides foundational production practices that may not be implemented without additional inputs and sound financial management.

[8] Baseline Labor is fixed at GH₵ 3.5 per day per laborer or USD $2.37 (2010 dollars) as estimated in Gockowski et al. (2009). Fertilizer, insecticide, and fungicide prices are respectively fixed at GH₵ 14.7 per 50kg or USD $9.98, GH₵ 16.8 per liter or USD $11.40, GH₵ 1.8 per sachet or USD $1.2 (all in 2010 dollars). By setting inflation at 10.26% per year, the prices of labor and inputs would rise at this rate. The baseline exchange rate is held constant at GH₵ 1.47 per USD, per the 2010 average (Mahrizal et al., 2013).

Table 1. Descriptive statistics for regression analysis

District	Atwima Nwabiagya	Juaboso	Sefwi Wiawso	Birim South	Overall
Total Participants (*n)*	16	59	32	76	183
Average Yield (kg/ha)	213.2	681.9	854.9	420.3	562.6
Farmer Field School Training *(FFS)* % (1=trained, 0=not trained)	50	93.2	68.8	72.4	76.5
Farmer Business School Training *(FBS)* % (1=trained, 0=not trained)	93.8	64.4	96.9	63.2	72.1
Input Promoter Training *(IP)* % (1=trained, 0=not trained)	0	32.2	6.3	0	11.5
Gender % (1=male, 0=female)	81.3	55.9	71.9	75	68.9
Average Farm Size (ha)	2.9	4.2	3.8	2.3	3.2
Farmer-Based Organization *(FBO)* Membership % (1=FBO membership, 0=no FBO membership)	50	59.3	28.1	32.9	42.1
Inorganic Chemical Fertilizer *(Fert)* % (1=used inorganic fertilizer, 0=did not)	12.5	84.7	62.5	48.7	59.6
Fungicide *(Fung)* % (1=used fungicide, 0=did not)	18.8	93.2	59.4	68.4	70.5
Herbicide *(Herb)* % (1=used herbicide, 0=did not)	6.3	22	25	44.7	30.6
Insecticide *(Insect)* % (1=used insecticide, 0=did not)	18.8	88.1	53.1	57.9	63.4
Using Improved Varieties *(ImprVar)* % (1=used improved varieties, 0=did not use)	18.8	66.1	46.9	55.3	54.1
Certified Seed Source %	18.8	30.5	12.5	36.8	29
Friend's Farm Seed Source %	68.8	40.7	37.5	23.7	35.5
Own Farm Seed Source %	12.5	27.1	50	34.2	32.8

*Due to missing observations, *n*=138 for the regression model estimates.

Table 2. Regression Results

Variable	Coefficient	Variable	Coefficient
Constant	4.92		0.29
	(7.16)***	Insect	(1.78)*
FFS	0.57	Herb	-0.20
	(0.86)		(-1.19)
FBS	0.022	ImprVar	0.13
	(0.14)		(1.00)
IP	0.56	FrieFarm	-0.19
	(3.38)***		(-1.53)
Gender	0.29	CertSeed	-0.26
	(2.31)**		(-1.62)
FarmSize	-0.037	Atwima	-0.63
	(-3.34)***		(-3.07)***
FBO	0.11	Juaboso	0.12
	(0.74)		(0.60)
Fert	0.43	Sefwi	0.45
	(2.36)**		(2.88)**
Fung	-0.094		
	(-0.53)		

Note: n=138 and R^2=0.36.
*** Denotes statistically significant at the 1% level.
** Denotes statistically significant at the 5% level.
* Denotes statistically significant at the 10% level.
Parentheses denote t-ratio.

Among other concepts, FFS covers safety practices, fermentation methods, and farm size estimation that could lead to a higher quality of life and a higher quality of cocoa bean, but may not necessarily increase yield per hectare.

Additionally, FBS stresses the importance of a balanced budget, demonstrates the benefits of crop diversification, analyzes the caloric intake of farm families, and reviews common farming measurements such as kilograms and hectares. A balanced budget and crop diversification will facilitate a healthier financial position, but like safety practices or fermentation methods with FFS, those practices may not manifest themselves in yield enhancements. It is assumed that ensuring families receive enough calories to subsist and have access to financial services would increase overall quality of life; however, this regression model does not seek to explain quality of life factors, so it is not surprising that FBS and FFS are not statistically significant.

Initially, it was expected that *IP* would be statistically significant, considering it is the capstone course of three training courses. It teaches farmers how to expand production through the use of chemical fertilizer, fungicides, and insecticides. Upon graduation farmers are able to access the human capital and knowledge base that they obtained from all three programs and, perhaps more importantly, they qualify for microcredit loans via TechnoServe (>95% of graduates take out loans). The financial skills they attain during FBS could be fully realized if they are able to access credit, and the use of inputs could fully utilize the production skills obtained in FFS. For this reason, the yield increase associated with IP is used with the NPV model to approximate the overall value of training in comparison to the baseline scenario.

4.2. Net Present Value

Table 3 presents the annual NPV estimates for the (1) baseline analysis from Mahrizal et al. (2013), (2) for the 75.24% yield increase associated with the statistically significant input promoter (*IP*) training course found on Table 2, and (3) a sensitivity analysis to provide reference and break-even points. Given that input promoter (*IP*) is the capstone training course, the percentage yield increase associated with its completion can be recognized as the total yield increase for completing the CLP farmer training program.

Table 3. Summary of net present value (NPV) and percentage change in NPV over two production cycles (50 years) for the LILC production system with estimated yield increases from the Cocoa Livelihoods Program (CLP) input training

Yield Increase	Net Present Value (NPV)*†	NPV Change ($ per Ha)	Percent Change from Baseline
Baseline**	$445.57	-	-
75.24%***	$846.57††	$401.00	90.00
50%	$652.89	$207.32	46.53
25%	$459.20	$13.63	3.06
23.25%	$445.57	$0.00	0

* Denotes net present value in 2010 USD per hectare per year.

† The discount rate is based on Ghanaian Treasury bill rates for a six month period in 2010, is 10.67%. (Bank of Ghana, 2011a).

** Equivalent to the Baseline Value in Mahrizal et al. (2013), which is a producer with no CLP training

*** Estimate obtained from Table 3.

††Includes the increased costs used on inputs assumed to be used after input training. Annual total cost increase from use of inputs is 54% or $163.73 per year.

The baseline NPV (Low Input Landrace Cocoa or LILC), as calculated from Mahrizal et al. (2013), was $445.57 per hectare per year for the 50 years of the two production cycles. The NPV associated with the completion of CLP training was estimated at $846.57 or a 90% increase from the baseline. This includes $163.73 per year in increased input costs, modeled after High Input Medium Shade Cocoa (HIMSC) in Afrari-Sefa et al. (2010). Initially, it would seem infeasible for yield to increase only 75% but the NPV to increase by 90%. Yield, however, is increasing at a greater rate than cost, 75% compared to 54%. Thus, as long as yield increases at a rate of greater than 54%, NPV gain can be larger than yield gain. This would seemingly indicate that CLP training is an effective way of increasing producer revenue even with the associated new input costs for fertilizer, fungicide, and herbicide. If all 44,200 Ghanaian CLP participants were to experience this gain ($401.00 per hectare), that would result in an annual total gain of $17,724,200 in Ghana alone. For the 52% of the Ghanaian population living on $2 or less a day ($730.00 annually), $401.00 equates to a 54.9% increase in income, a considerable jump by most standards. For the poorest of the poor, the 27% of the population living on $1.25 or less per day ($456.25 annually), $401.00 results in an 87.9% increase in income. Roughly 2% of the Ghanaian population are poor cocoa farmers, indicating that cocoa production could be a means to greatly reduce poverty. From the calculations in Table 3, it is clear that CLP training is helping to raise incomes for cocoa farmers, ideally leading to improved livelihoods and overall quality of life.

Given that output results could be inflated on an interview-based survey, a sensitivity analysis was also conducted to see how various levels of yield increases affected NPV and what the minimum level of yield increase was needed to at least break even and cover the costs of the increased inputs (Table 3). Instead of using the 75.24% yield increase as estimated from Table 2 for the completion of input promoter (*IP*) training, 50% and 25% yield increases were selected as reference points to calculate NPV percent gain from the baseline and to compare with the BCR associated with a 25% assumed training gain (1.087) as estimated in Afari-Sefa et al. (2010). NPV increased 46.53% and 3.06% for the 50% and 25% yield increases, respectively.

In these cases, costs increases (54%) were greater than yield increases and thus the NPV increase was smaller than the yield increases. Finally, the break-even yield, the yield at which additional revenue would equal the increased input cost producing a 0% change in NPV, was estimated at 23.25%. Given the large difference between the estimated 75.24% *IP* yield increase and the break-even yield increase of 23.25%, these results appear to be robust in terms of increased producer profitability (Table 4). These figures also suggest farmers would need to artificially inflate their yield by 324% (75.24/23.25) for the additional input costs to negate the NPV gains from farmer training.

Table 4. Sensitivity Analysis of the Benefit Cost Ratio for the Cocoa Livelihoods Program (CLP) Input Training Course in Ghana

Yield Increase	Net Present Value (NPV)* †	NPV Change From Baseline	Total Training Costs**	Benefit Cost Ratio
Baseline***	$22,279	-	-	-
75.24%****	$42,329††	$20,050	$252	79.56
50%	$32,645	$10,366	$252	41.13
25%	$22,960	$682	$252	2.70
23.89%	$22,531	$252	$252	1.00

* Denotes net present value in 2010 USD for one hectare over two cocoa production cycles (50 years).

† The discount rate is based on Ghanaian Treasury bill rates for a six month period, or 10.67% in 2010 (Bank of Ghana 2011a).

**Costs are not discounted because they are all incurred in year one of the program.

*** Equivalent to the Baseline Value in Mahrizal et al. (2013), which is a producer with no CLP training.

**** Estimate value obtained from Table 3.

†† Includes the increased costs used on inputs assumed to be used after input training. Annual total cost increase from use of inputs is 54% or $163.73 per year.

4.3 Benefit Cost Ratio

Table 4 presents the 50-year extrapolations (two cocoa production cycles) of the annual NPV calculations found on Table 3. As such, the table illustrates (1) the total NPV for the baseline scenario (LILC) from Mahrizal et al. (2013), (2) the total NPV for completing the training program (*IP*) utilizing the 75.24% yield increase associated with the statistically significant *IP* training course found on Table 2, and (3) a sensitivity analysis to provide reference points and the break-even point. By comparing the baseline scenario NPV and the training NPV, the NPV gain (benefit) associated with training can be approximated.

When extrapolated over 50 years, the LILC, baseline scenario (no CLP training) NPV was $22,279, whereas the 75.24% yield increase (from completing *IP*) NPV was $42,329, a difference of $20,050 (2010 dollars) per hectare. Therefore, the benefit associated with training represents $20,050 per hectare.

With a total training cost of $252 per farmer ($36 for FFS, $16 for FBS, and $200 for IP), BCR was calculated to be 79.56:1 (20,050/252).[1] That is, for every $1 invested into the CLP farmer training program, the return on investment (increased NPV per hectare for small scale cocoa producers) was roughly 80 dollars, which is a large return based on any measure, and particularly when compared to the 1.087 BCR from Afari-Sefa et al.,[2] (2010). The BCR ratio provides a clear illustration of the strength of human capital development in poverty alleviation, instilling knowledge in the farmers that can be used well past the year of training while increasing incomes by $79.56 per hectare for every $1 invested in initial training.

A sensitivity analysis was also conducted at the 50% and 25% yield increase levels to provide BCR reference points. Compared to the baseline, LILC model calculated from Mahrizal et al., (2013), the 50% and 25% levels respectively resulted in NPV gains of $10,366 and $682 per hectare over the 50-year period. With a total training cost of $252, the BCR was calculated to be 41.13:1 and 2.70:1. These returns are still well above the break-even ratio of 1.0 and are well below the yield increases reported by producers leading to the notion that these results are both robust and that investment in the CLP was worthwhile.

To further analyze the benefit cost ratio, a break-even yield increase was estimated that results in a BCR of 1:1. The break-even yield increase necessary for benefits to equal costs was estimated at 23.89%, which includes both the cost of training ($252) and costs of increased input use ($163.73 per year). Any training yield increase less than 23.89% per hectare results in a BCR less than one. The BCR could be greater than one with a lesser yield gain if they produced on more than one hectare. While most cocoa producers are small scale in Ghana, in this study producers typically produce more than one hectare.[3]

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[1] Note that the estimated coefficient of Gender is 0.29. Because the dependent variable (yield) is in natural logs, the coefficient of any given variable is the continuous change rate for a one-unit change in the associated independent variable for a dependent variable. But for a binary variable like Gender, the full impact of going from zero to one in a discrete jump requires exponentiating the coefficient, subtracting one, and multiplying this difference by 100 to get the full percentage change when a binary variable goes from zero to one.

[2] This assumes there are not multiple people farming the same hectare.

[3] Our analysis ignores market price effects. If all cocoa producers increase output then there are likely to be noticeable price declines. Gilbert and Varangis (2004) estimate the cocoa demand elasticity at 0.19 which indicates an inelastic demand. So the BCR would decrease as prices decreased.

CONCLUSION

In Ghana, where approximately 52% of the population lives on USD $2 a day or less, 27% live on $1.25 or less per day, and 19% of rural households produce cocoa, agricultural development in the cocoa sector has the potential to increase incomes for the poorest of the poor. While billions of dollars flow into low-income countries each year to alleviate poverty, assessing the full impact of these programs can be difficult. For studies that do measure the benefits of development programs, many lack a temporal dimension because they measure costs and benefits in a single, static year or do not account for the full benefit of human capital development. Farmer training programs can provide skill development that is utilized long after the training is complete. Given that the primary intent of the CLP is to increase cocoa yield and farmer quality of life through training in production practices, financial management, and input use, calculating the costs and benefits that extend beyond the five years of the program generates information to more efficiently invest scarce resources.

Using primary data collected in summer 2011 from the 2010-2011 growing season and a baseline model from Mahrizal et al. (2013), the goal of this study was to estimate the NPV of CLP training over a 50-year period—two cocoa production cycles. Using multiple regression analysis to determine the effect of CLP on yield and thus NPV, it was estimated that cocoa yield rose 75.25% per hectare after completing all CLP training. This resulted in an annual NPV gain of $401.00 per hectare or a 90% increase in annual NPV compared to the baseline model. When extrapolated over 50 years to account for human capital development, training is associated with a $20,050 per hectare total increase in NPV. With a total training cost of $252, the BCR of the CLP was 79.56:1 meaning for every $1 invested in the program, farmers' income increased by $79.56 per hectare, a considerable increase by most standards.

These results should be considered a conservative estimate given the fact that the costs are fixed at $252, but the benefits vary by farm size. That is, this study assumed that producers only produced one hectare of cocoa (when in actuality mean size is above 3). If they produced on more than one hectare, the costs remain fixed at $252 per person but the benefits increase, thus increasing the BCR. As noted previously, the average farm size was 3.2 hectares. WCF also estimates that training costs decrease over time as training networks are established. The higher costs of the trial programs allow for a more conservative NPV estimate for training. Furthermore, it was assumed farmers were already maximizing income stability through an optimal tree replacement rate and an optimal initial year of replacement. Farmers who were not optimizing replacement would have lower yield values than the baseline scenario, and thus receive a greater NPV gain after training if they adopted the optimal replacement scenario.

Nevertheless, there are some limitations to this study. Farmers were reported to either use specific inputs or not, but the input application rate was not known. A more accurate survey would include specific rates to better compare input use and yield. Collecting this data would likely result in a higher R-squared value in the regression model. Additionally, the age of the trees was not gathered because of farmers' inability to recall the ages and replacement rates of all of their plots. Future research should also incorporate a control group completely unaffiliated with the training program and that has received no prior training, even for training that could not have an effect on yield. This is significant for the self-selection issues that exist within communities that receive training and the ability for farmers to share CLP skills with other farmers in the community. Finally, the NPV and the model are based on one year's CLP data. Having multiple years with a measure of inter-annual yield variability would allow for a range of BCRs as well as estimates for best and worst case scenarios.

These four limitations exist largely from the financial infeasibility of conducting a study in West Africa with perfect information on agricultural practices, yield, and cost.

These results can be used by development NGOs to illustrate the potential of skill attainment in alleviating poverty, particularly when encouraging prospective donors, technical partners, or governments. Moreover, by measuring costs and benefits beyond the years of the program, this study provides an established standard in estimating the net present values of other development programs, ideally providing citizens of low-income countries more opportunities to lift themselves out of poverty and contribute to the global economy.

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A DYNAMIC QUARTERLY MODEL OF U.S. SOFT WHEAT DEMAND WITH A FUTURES MARKET LINKAGE

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ABSTRACT

This paper provides provides a cointegrated VAR model of the quarterly U.S. soft wheat market that endogenizes a price linkage to a soft wheat futures market. A long run Cobb-Douglas processor demand for U.S. soft wheat emerged as a cointegrating relation and rendered two important parameter estimates: an own-price elasticity (-0.82) that is in line with the literature's estimate range, and a first-time estimate of a cross price demand elasticity with respect to futures price (+0.41). The latter suggests that forwardly priced futures positions are treated as a close time-differentiated substitute for currently priced soft wheat. Strong statistical evidence suggests that U.S. processor demand for soft wheat is a function of both own-price and futures price that provides the first empirical indication of the importance of futures market events in soft wheat demand discovery. The paper discusses the important policy implications of the results.

Keywords: cointegration, cointegrated vector autoregression, U.S. soft wheat product & futures markets, Cobb-Douglas demand functions

JEL Codes: C32, G13, Q13, Q17

INTRODUCTION

As pointed out in prior work in this journal, wheat markets, particularly those in the United States and Canada, have long comprised a fertile, if not contentious, area of research and analysis in farm/trade policy formulation, trade disputes and investigations, trade remedy implementation, agribusiness, and commodity-related food cost issues (Babula, 2011; Babula, Rogowsky, and Romain 2006). Such is reflected by the following array of events, policies,

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investigations, and legislation that have collectively involved a number of U.S. agencies (particularly the U.S. International Trade Commission or USITC and the U.S. Departments of Commerce and Agriculture), Canadian ministries, and major private and state-owned grain trading enterprises:

- The high-profile 1994 U.S. Section-22 investigation, initiated by President Clinton and implemented by the USITC, of injury to the U.S. wheat farm support program from increasing imports (mostly Canadian-sourced) of wheat, wheat flour, and semolina (USITC 1994).
- A 1995 bi-national inquiry on U.S-Canadian trade in grains (primarily wheat) [see Canada-U.S. Joint Grains Commission 1995].
- U.S. imposition of two tariff rate quotas (TRQs) on imports of certain wheat for the year ending September 11, 1995 (Glickman and Kantor).
- A USITC (2001) Section-332 fact-finding investigation on Canadian wheat trading practices.
- An array of U.S. preliminary and final anti-dumping and countervailing duty (AD/CVD) orders placed on certain imports of Canadian wheat during 2002 – 2005 (USITC 2003).
- The U.S. farm bills of 1996, 2002, and 2008.

Study Goals and Previous Related Research

Therefore, estimating a quarterly econometric model of the U.S. soft wheat market and incorporating an endogenous linkage to the soft wheat futures market to illuminate how the soft wheat and futures markets inter-act to formulate demand, supply, and price would be research that, as seen below, not only extends existing published research, but would be of keen interest to researchers, farm/trade/financial policy makers, legislators, agribusiness agents, and agents interested in food cost and food inflation issues. This paper aims to extend two recent areas or tranches of econometric commodity market research in this journal, parts of which overlap:

- The first tranch has illuminated the policy-relevant workings of and inter-relationships among U.S. wheat product markets: the Babula, Rogowsky, and Romain (BRR 2006) study on U.S. all-wheat product markets aggregated across the five U.S. wheat classes and Babula's (2011) study on the U.S. soft wheat market (soft red Winter or SRW class).
- Given that past literature on U.S. commodity markets has placed little or no empirical focus on futures market influences on U.S. commodity-related demand, supply, and price discovery, a second group of articles has mitigated this analytical gap. These articles endogenized futures price linkages into econometric systems of U.S. commodity-based markets to capture real market impacts of futures prices and related events. This tranch also provided handles of policy analysis with which to empirically compare estimated market impacts of two sorts of policy/market events: those with a "commodity market focus" that work through commodity price versus

those with a "financial focus" that work through changes in futures price (hereafter, commodity-focused and financially-focused policies/events). This tranch includes Babula's study on soft wheat mentioned above, as well as Babula and Rothenberg's (2012) work on U.S. pork-based product markets and Babula, Zhang, and Rothenberg's (2013) study on the U.S. soft wood lumber market.

Articles on U.S. Wheat Product Markets

Babula, Rogowsky, and Romain (BRR 2006) commented that unlike well-researched wheat commodity markets, there is a dearth of empirical econometric research on value-added wheat product markets primarily because of a lack of critical data on distribution, costs, and inventories needed to build well-specified models. Such data on processed food product markets are often precluded from the public domain by agribusiness agents, who classify such data as business confidential information (CBI). BRR specified and estimated a cointgrated VAR model of the following six U.S. all-wheat product markets with quarterly 1985 – 2005 data: the farm market upstream, and the downstream processed wheat product markets for flour, mixes/doughs, bread, wheat-based breakfast cereals, and cookies/crackers. Three long-run cointegrating equilibrium relationships emerged: a U.S. wheat supply and two policy-relevant reduced form price transmission mechanisms. When interpreted and analyzed, BRR's relationships provided an array of estimates of market-driving elasticity and price transmission parameters, and of market impacts of specific events and policies. BRR did not include a futures market linkage to the modeled markets.

Babula (2011) extended the BRR study in a number of ways. First, he focused on the four monthly U.S. soft wheat product markets, an important all-wheat market subset, for which he specified and estimated a cointegrated VAR model with monthly 1993:01 – 2010:06 data: SRW market, flour, crackers and related products, and cake mixes. Second, his cointegrated VAR model included an endogenous soft wheat futures price that linked the four soft wheat product markets with events occurring in the futures market. In addition to an array of empirical estimates of price transmission parameters and market impacts of specific policies and market events, Babula provided empirical comparisons of the market impacts of policy alternatives with commodity and financial focus and demonstrated that policies working through futures price have statistically strong real market impacts through price and are important determinants in U.S. soft wheat price discovery. This work's primary limitation was an admitted sole reliance on price relationships given that the USDA does not publish monthly wheat supply and use data, and given the noted lack of CBI data on processed soft wheat product markets. So his monthly model was unable to illuminate how futures prices movements directly influence formulation of soft wheat quantities demanded.

Commodity-Focused Articles that Endogenize Linkages to Futures Markets

Babula and Rothenberg (2011) used monthly 1989:01 – 2011:12 data to estimate a cointgrated VAR model of the following six U.S. pork-related variables that cover a system of five U.S. pork-based food product markets: commercial pork slaughter, slaughter pork price, a relevant futures price, and the wholesale prices of processed pork, sausage, and ham.

In what appears to be the literature's first monthly cointegrated VAR model of U.S. pork-based product markets that includes an endogenous price linkage to a relevant futures market, three cointegrating equilibrium relationships emerged. One such relationship was a monthly U.S. processor demand for pork as a productive input. In addition to being, as expected, negatively related to own-slaughter price, this long run demand reflected the unique aspect of being positively and equally related to the forward price of its close substitute, lean pork futures positions priced an average of 70 days forward. The study also provided a test for hedging at the pork slaughter pricing point; a method of incorporating hedging's existence into the finally restricted model; an analysis of hedging's role in the workings of the modeled U.S. pork-related food product markets; and an array of empirical estimates of market and price transmission parameters and market impacts of a number of important policies and events.

With 1992 – 2012 data, Babula, Zhang, and Rothenberg (2013) estimated what appears to be the literature's first monthly cointegrated VAR model of the U.S. softwood lumber market that explicitly incorporates an endogenous price linkage to a relevant futures market. The cointegrated VAR model included U.S. production, own-price, futures price, and housing starts, and generated a single cointegrating relationship in the form of a Cobb-Douglas U.S. demand for softwood lumber. This Cobb-Douglas function posited U.S. softwood lumber demand as a negative function of own-price (as expected), and a positive function of housing starts, and perhaps most interestingly, as a positive function of futures price. This latter result suggests that softwood lumber futures positions forwardly priced at an average time-stamp of 45 days serves as a close time-differentiated substitute for the currently priced product. In fact, the Cobb-Douglas relationship suggests with notable statistical strength that U.S. softwood lumber demand is a function of the *relative* own-price/futures price ratio, rather than of own-price alone. The results suggest, for the first time in the literature, that futures price plays an equally important role as own-price in U.S. softwood lumber demand discovery. U.S. market agents clearly manage risk and hedge (and perhaps speculate), and optimize based on the relative costliness of softwood lumber priced currently versus lumber priced forwardly – a statistically strong indication of the importance that futures markets play in the U.S. real softwood commodity market.

My aim is to apply the cointegrated VAR model to a quarterly U.S. soft wheat market to extend both tranches of the above cited literature in several ways. First, I included a market-clearing quantity variable using the USDA's published quarterly supply and usage data – an option that, as explained, was not open to Babula (2011) in his monthly study of U.S. upstream and downstream soft wheat product markets. Second, I propose a model focused on the U.S. soft wheat market alone, rather than on value-added U.S. soft wheat product markets examined by Babula (2011). In so doing, my model extends the latter study's results by providing insights on the role of futures price in formation of demanded quantities directly that Babula (2011) was not able to fully accomplish in his monthly model without quantities. I follow Babula, Zhang, and Rothenberg's modeling strategy with softwood lumber and apply it to the U.S. soft wheat market. In so doing, I extend results of the second tranch of literature concerning the direct demand discovery role of futures prices to a third important U.S. commodity market.

The timeliness of this wheat-related and futures-focused research is enhanced by an ever-escalating debate chronicled by Auerlich et. al. (2009) over whether or not certain changes in or events relevant to commodity futures markets (including soft wheat) are detrimentally affecting the stability of U.S. commodity markets.

Such changes include, among others:

- Notable increases in futures trading pools to include substantial numbers of non-traditional, profit-seeking, and speculative traders who hold commodity futures positions as an asset class, to the distress of more traditional traders who have focused on price discovery and risk management.
- Dramatic increases in the levels of open interest in various U.S. commodity futures contracts. For example, Auerlich et al. (2009) noted that open interest in the Chicago Board of Trade's soft wheat contract rose 200% during 2004-2009.
- Issues of increased volatility in futures prices on contracts trading a wide array of commodities ranging from crude oil to soft wheat. Allegations from all corners (Congress, regulators, consumer groups, producer groups, Wall Street investment and banking groups, etc.) of impacts of rising futures price volatility have been seen repeatedly in the press during the last few years, particularly for energy products and also to a lesser but nonetheless notable extent on grains (soft wheat included).

One need only attend one of the many Commodity Futures Trading Commission's public hearings (still ongoing at this writing) where Commissioners vote on the implementation rules for the massive Dodd-Frank Financial Reform Act signed into law on July, 2010 to see the fervor with which agents on both sides of this debate argue their case. This paper's results show, along with findings of the noted two tranches of research, that such trends and developments certainly do influence real commodity markets and prices through futures price movements that directly influence U.S. commodity market demand, supply, and/or price.

A Dynamic Demand Model for the U.S. Soft Wheat Market

Hicksian commodity demand functions have been expressed as a Cobb-Douglas function (Uri and Boyd 1990; Babula, Zhang, and Rothenberg 2013):

$$Q = \mu P_0^{\alpha} P_s^{\omega}, \text{ or} \tag{1}$$
$$\ln Q = \ln\mu + \alpha \ln P_0 + \omega \ln P_s + \varepsilon \tag{2}$$

Q is the quantity demanded, P_0 is own-price; P_s is the price of a substitute good; α and ω are parameters to be estimated; ln is the natural logarithm operator; and ε is an error term. U.S. commodity users, say food processors that use soft wheat as a productive food product input, may consider price expectations expressed in futures prices as an indicator of demand in the near future. Consequently, one has:

$$Q = \mu P_0^{\alpha} P_f^{\omega}, \text{ or} \tag{3}$$
$$\ln Q = \ln\mu + \alpha \ln P_0 + \omega \ln P_f + \varepsilon \tag{4}$$

Here, P_0 and P_f are taken as the prices of closely substitutable soft wheat products: the currently valued own-price, P_0, having a negative exponent/coefficient ($\alpha < 0$) and its time-differentiated substitute delivered at a later date and priced at P_f, having a positive coefficient ($\omega>0$).

ESTIMATION METHODS AND DATA

The Cointegration Approach and Data

Granger and Newbold (1986, pp. 1-5) note that economic time series often fail to achieve conditions of weak stationarity (also known as stationarity and ergodicity) required of valid inference and in some cases unbiased estimates. Before Engle and Granger's (1987) work on cointegration, econometricians more frequently first-differenced non-stationary data that were integrated of order-one to achieve stationarity and to avoid compromised inference. However, such individually non-stationary series sometimes form stationary linear combinations whereby the group of series moves in a stationary manner through time. Such occurs when the individually non-stationary series are cointegrated and comprise an error-correcting system (Engle and Granger 1987; Johansen and Juselius 1990). Differencing such cointegrated series would achieve stationarity, but at the expense of encountering mis-specification bias of regression estimates from the omission of important long run components (namely the cointegrating relationships or stationary linear combinations critical to explaining the system's behavior) that such differencing jettisons. It is well known that the cointegrated VAR model permits the retention of levels-based information otherwise jettisoned by differencing, and in the reduced-rank or stationary form of an correction space described below. Hence, mis-specification is avoided.

Given the futures market focus of this study, monthly data would have been preferred. However, while monthly U.S. soft wheat and futures prices are available, monthly U.S. quantities (beginning stocks, production, and supply) are not published by the U.S. Department of Agriculture or USDA, but rather are available on a quarterly basis as the highest periodicity. So this study focused on a quarterly U.S. soft wheat model.

Based on the above considerations and on equations 3 and 4, the following quarterly data series were collected and organized in accordance with the USDA's June 1/May 31 wheat market year (denoted throughout by the parenthetical labels):

- The U.S. market-clearing quantity of soft wheat (Q_s): The sum of the beginning stocks, production, and imports published by the USDA's Economic Research Service (USDA, ERS 2013).
- U.S. wholesale price of soft red Winter wheat (P_s). This is the U.S. producer price index (PPI), soft red winter wheat, series no. WPU01210104 from the U.S. Department of Labor, Bureau of Labor Statistics (Labor, BLS, 2013).
- The June 1/May 31 market year quarterly averages of the settlement price of the Chicago Board of Trade's (CBOT's) soft wheat contract (P_f) downloaded from

Bloomberg.[1] Monthly average daily contract settlement prices were in turn averaged into market year quarters.[2] On average, it is estimated that P_f prices soft wheat futures positions at a time-point that is an average of 39 days forward from the current price, P_s.[3]

My goal is to discern the effects of futures market workings (particularly futures price movements) on U.S. soft wheat demand and price discovery. And as a consequence, the CBOT soft wheat contract was chosen because it is the most active and the most closely monitored soft wheat contract nationally as could be found.

All data are quarterly and were collected for the following quarterly market year sample period: 1993/94:01 – 2011/12:04, a sample with information extending through May 31, 2012. At this writing, the 2012/13:04 data were not yet published.[4] The data are seasonally un-adjusted, modeled in natural logarithms, and are shown below to be non-stationary [integrated of order-1 or I(1)]. Regression estimates and cointegrating parameter estimates are generated throughout by Q_s, P_s, and P_f variables that are modeled in natural logarithmic levels.

Following prior literature, I examined the three series in logged levels and differences to assess the series' non-stationarity properties, that in turn led to formulation of specification implications that utilized such information on the non-stationarity properties (see Juselius and Toro 2005; Juselius and Franchi 2007; and Juselius 2006, chs. 1-4). Inclusion of such specification implications in the estimated model can avoid compromised inference and biased estimates (Granger and Newbold, pp. 1-5). My inclusion of such implications, as shown below, resulted in a statistically sound underlying VAR model (and algebraically equivalent unrestricted vector error correction or VEC model) with cointegration properties that were in turn exploited (see Juselius 2006, chs. 1-6).

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[1] This CBOT contract is listed under the ticker symbol "W" symbol and has the following deliverables: No. 2 soft red Winter wheat, No. 2 hard red Winter wheat, No. 2 dark northern Spring wheat; No. 2 Dark Northern Spring wheat, and No. 2 northern Spring wheat at par. See www.bloomberg.com.

[2] For example, the 2010/2011 U.S wheat market year is defined by the following quarters: June, July, and August of 2010 as quarter-1; September, October, and November of 2010 as quarter-2; December, 2010, January, 2011, and February, 2011 as quarter-3; and March, April, and May of 2011 as quarter-4.

[3] The estimate that futures price, P_f, prices a product at a time-point that is an average 39 days forward from current price, P_s, was provided to the author by an economist at the Commodity Futures Trading Commission or CFTC. The calculations and estimate were based on a number of factors. The contract's five delivery months are March, May, July, September, and December, and are thereby spaced unevenly throughout the year. The underlying CBOT soft wheat contract has a delivery window of about half the month and the contract trades through most of it. However, he assumed that once a contract is in its deliverable window, it was essentially trading at spot, and led to his roll before the delivery month. The 39-day average estimate arose from taking the average number of days from the first delivery for each day in a given month and then averaging these monthly results over the entire series. A spreadsheet with data used to calculate these averages, the calculations of the averages, and selected charts that demonstrate the 39-day calculation were provided to the author by the CFTC economist in two private communications dated April 15 and August 1, 2013, and are not reported due to space considerations.

[4] While the USDA publishes all-wheat data in its monthly and quarterly outlook wheat publications, it publishes quarterly data on its five wheat classes only once a year.

The Underlying Statistically Model: A Levels VAR and Unrestricted VEC Equivalent[5]

A VAR model posits each endogenous variable as a function of k lags of itself and of each of the other modeled endogenous variables (Sims). After applying Tiao and Box's (1978) lag selection procedure to the logged levels data for Q_s, P_s, and P_f, a lag structure of order-1 was chosen, and the following 3-equation VAR model was formulated:

$$X(t) = a(c) + a(1)*Q_s(t-1) + a(2)*P_s(t-1) + a(3)*P_f(t-1) + a(T)*TREND + \gamma(t) \quad (5)$$

The $X(t) = Q_s(t)$, $P_s(t)$, and $P_f(t)$. The asterisk denotes the multiplication operator; t refers to the current time period; and $\gamma(t)$ is a vector of white noise residuals. The a-coefficients are ordinary least squares regression estimates, with the parenthetical digit denoting the endogenous variables as ordered above in equation 5. The a(c) is an intercept and a(T) is the coefficient generated by a time trend. Also included but not notationally depicted in equation 5 are a vector of quarterly centered seasonal variables and a number of important binary or dummy variables introduced below.

As demonstrated by Juselius (2006, pp. 59-63) and Johansen and Juselius (1990), equation 5 is more compactly re-written as an algebraically equivalent unrestricted VEC model:

$$\Delta x(t) = \Gamma(1)*\Delta x(t-1) + \ldots + \Gamma(k-1)*\Delta x(t-k+1) + \Pi*x(t-1) + \Phi D(t) + \varepsilon(t) \quad (6)$$

The number of endogenous variables is p = 3. The $\varepsilon(t)$ are white noise residuals and the deltas represent the difference operator. The x(t-1) is a p by 1 vector of endogenous lagged levels variables. The $\Gamma(1), \ldots, \Gamma(k-1)$ are p by p matrices of short run regression coefficients and π is a p by p long run error correction term that captures information in the endogenous levels data. The $\Phi D(t)$ is a set of deterministic variables, including selected binary variables introduced below to capture influences of stationarity properties of the three series, as well as influences of important policies and market events.

Patterson (2000, p. 600) noted that with a lag structure of k = 1, equation 6 simplifies to equation 7:

$$\Delta x(t) = \Pi*x(t-1) + \Phi D(t) + \varepsilon(t) \quad (7)$$

The error correction matrix decomposes as follows:

$$\Pi = \alpha*\beta' \quad (8)$$

The α is a p by r matrix of adjustment coefficients ("alphas") and β is a p by r vector of error correction coefficients or cointegrating parameters ("betas"), with r being the reduced rank of equation 8 as determined below. The error correction or EC term captures levels-based and other long run information: stationary linear combinations of the non-stationary

[5] This section heavily relies on Johansen and Juselius (1990) and Juselius (2006). As well, this section is organized similarly to specification enhancement effort descriptions in Babula, Zhang, and Rothenberg (2013) and Babula and Rothenberg (2012).

levels data (under cointegration); permanent shift binaries to capture long run or enduring effects of policies and/or market events; and a linear trend.

Having followed recent cointegrated VAR work on U.S. wheat product markets in this journal along with market knowledge and expertise, I initially restricted the following non-differenced permanent shift binary variables to the levels-based error-correction space to account for the long run effects of 7 important and potentially market-influencing policies:

- NAFTA: to capture the effects of the North America Free Trade Agreement's (NAFTA's) January, 1994 implementation.
- URUGUAY: to capture the effects of the Uruguay Round's (UR's) January, 1995 implementation.
- QUOTA: to capture the effects of the two temporary U.S. tariff rate quotas or TRQs placed on certain imports of Canadian durum and non-durum wheat for the year ending September 11, 1995.
- TITLE7: to account for the effects if the various U.S. implementation of preliminary and final antidumping and countervailing duties on certain imports of Canadian durum and/or hard red spring wheat during 2002-2005. These resulted in the U.S international Trade Commission or USITC investigation no. 701-TA-430A & 430B and 731-TA-1019A and 1019B (Final). See USITC (2003) and BRR (2006).
- FAIR96, FBILL02, and FBILL2008: to account for the effects the U.S. Farm Bills of 1996, 2002 sand 2008.

ESTIMATION RESULTS

I followed Juselius' (2006, ch. 6) method of identifying and including "outlier" binaries in order to capture impacts of extraordinarily influential quarter-specific events/influences. When a potentially includable outlier was identified with a large standardized residual, an appropriately specified variable was included in differenced form as part of equation 7's ΦD(t) term; equation 7 was re-estimated; and the binary variable was retained if a battery of diagnostics moved favorably to suggest enhanced specification. [6]

Table 1's battery of diagnostic test values for the levels VAR (and its algebraically equivalent unrestricted VEC) before and after specification enhancement efforts suggest clear benefits.

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[6] A quarter-specific event was taken as potentially "extraordinary" if its standardized residual exceeded 3.0 in absolute value. This rule was designed based on the effective sample size of 76 observations using the Bonferoni criterion: INVNORMAL$(1\text{-}1.025)^{T}$, where T = 76. INVNORMAL is a function for the normal distribution that returns the variable for the cumulative density function as a standard normal distribution (Estima, RATS version 8.02). The Bonferoni variable had an absolute value of 3.40. Having realized that there were some quarter-specific events with potentially extraordinary effects with absolute standardized residual values of about 3.0, I opted to follow recent research in this journal and chose a more conservative Bonferoni absolute value criterion of 3.0 rather than 3.4 (see Babula 2011; Babula and Rothenberg 2012). Observations with absolute standardized residuals of 3.0 or more were considered potential outliers and appropriately defined binary variables were specified for the relevant observation for the sequential estimation procedure. Two outlier binary binaries were included. Due to space limitations, I do not analyze these binaries as they are in the short run/deterministic part of the cointegrated VAR model that is not focused on in this paper's analysis of long run U.S. soft wheat market relationships.

Table 1. Mis-Specification Tests for the Unrestricted VEC Model Before & After Specification Enhancement Efforts

Test & equation	Null hypothesis &/ or test explanation	Prior specification efforts	After specification efforts
Trace correlation	Goodness of fit; large proportion desirable.	0.246	0.610
LM test, serial correlation, lag-1.	Ho: No serial correlation. Reject for p-values of 0.05 or less	22.68 (p = 0.007)	8.96 (p = 0.44)
ARCH test, lag-1.	Ho: No heteroscedasticity. Reject for p-values of 0.05 or less.	60.67 (p = 0.006)	31.91 (p = 0.66)
Doornik-Hansen test, system-wide	Ho: Modeled system's residuals behave normally. Reject for p values of 0.05 or less.	7.35 (p = 0.289)	8.98 (p = 0.17)
Univariate Doornik-Hansen tests.	Ho: An equation's residuals behave normally. Reject for H-D test values > 9.2.		
ΔQ_s		3.30	5.94
ΔP_s		5.05	7.35
ΔP_f		3.88	2.74
Skewness (kurtosis) values.	Skewness: ideal is 0; "small values accebable. Kurtosis: ideal = 3.0; acceptable range is 3.0-5.0.		
ΔQ_s		-0.34 (2.46)	-0.42 (4.1)
ΔP_s		0.015 (3.87)	0.17 (4.2)
ΔP_f		0.42 (3.7)	0.30 (3.5)

The trace correlation, a goodness of fit indicator, rose 135% to 0.61. And while serial correlation and heteroscedasticity were initially issues, the finally estimated model after specification enhancement efforts generated evidence that both conditions were ultimately mitigated. Doornik-Hansen tests failed to reject the null hypotheses of normally-behaving residuals for the entire system and for each of the three equations univariately. Finally, Table 1 suggests that the statistically adequate model generated skewness and kurtosis indicator values that fell within acceptable ranges.

COINTEGRATION: TEST FOR AND IMPOSITION OF AN APPROPRIATE REDUCED RANK

Juselius (2006, p. 8) notes that cointegrated variables are driven by common trends and stationary linear combinations called cointegrating vectors or CVs. The π-matrix (equation 8) is a p by p (here, 3 by 3) matrix equal to the product of two p by r matrices. The first is matrix β of error correction coefficient estimates that under cointegration combine into $r < p$ stationary CVs of the three individually non-stationary soft wheat market variables ("betas"). The second is matrix-α of adjustment speed coefficients ("alphas"). Under cointegration, the rank of β'*x(t) is reduced although the three series in x(t) are each I(1).

The literature has often established the EC space's reduced rank based on the widely-applied trace tests of Johansen and Juselius (1990). Subsequent related work by Juselius and Toro (2005), Juselius and Franchi (2007), and Juselius (2006, ch. 8) strongly recommend against a sole reliance on the trace test results in discerning π's reduced rank, and in turn, the number of cointegrating relationships that error-correct the system. And while this subsequent work suggests that trace test results are an important indicator of reduced rank, the work also suggests two additional complementary sources of rank-relevant evidence that ought to be consulted: Patterns of characteristic roots in relevant companion matrices and analysis of plotted cointegrating relationships for elements of disqualifying non-stationary behavior (Juselius 2006, ch. 6). I followed such recommendations and consulted all three sources of evidence.

Table 2 provides nested trace test results. Evidence at the five percent significance level was sufficient to reject the first two null hypotheses that $r \leq 0$ and that $r \leq 1$. Evidence at the 5% significance level was insufficient to reject the third null that $r \leq 2$. Given the nested nature of these trace tests, these results collectively suggest that r = 2.

The second source of rank-relevant evidence lies in the patterns of characteristic roots in the companion matrix under alternative restrictions that r = 1 and r = 2. If the chosen r is appropriate, then the companion matrix under r should generate (p-r) unit roots, and the next or "(p-r+1)st" root should be substantially below unity. Should the (p-r+1)st root be near-unity, then r likely should be reduced (Juselius 2006, ch. 8). The following summary results suggest, rather strongly, that appropriate reduced rank is more likely 1 rather than 2:

- Under r = 2, there was (p-r) = (3-2) = 1 unit root with the (p-r+1)st or second root being 0.85, a value that approaches unity, so as to suggest that r should be reduced to r = 1.
- Under r = 2, there were (p-r) = (3-1) = 2 unit roots with the third being 0.199, a value that is noticeably and decidedly sub-unity (and nowhere near the 0.85 value in the prior bullet's case).

Table 2. Nested Trace Test Statistics and Test Results

Null hypothesis	Trace value	95% Fractile	Test Result
Rank or $r \leq 0$	105.30	57.17	Reject the null that $r \leq 0$
Rank or $r \leq 1$	55.56	40.13	Reject the null that $r \leq 1$
Rank or $r \leq 2$	23.19	26.85	Fail to reject the null that $r \leq 2$

Notes. – As recommended by Juselius (2006, CATS2-generated fractiles are increased by 8*1.8 = 14.4 to account for the eight deterministic components restricted to be in the cointegration space. Also recommended by Juselius (2006, ch. 8) and programmed by Dennis (2006) while using RATS 8.02, trace values are corrected with Bartlett's small sample adjustment.

This evidence strongly suggests that the appropriate reduced rank of π is likely nearer to 1 than to 2.[7] The sizeable difference between the (p-r+1)st or second root of 0.85 under r = 2 and the (p-r+1)st or third root of 0.199 under r = 1 was deemed particularly compelling.

The plots of cointegrating relations 1 and 2, the third source of evidence, are provided in Figures 1 and 2, respectively. Two versions of each CV are presented: The BETA*x(t) plots are for the model with the short run effects and the BETA*R1(t) plots are for the model corrected for the short run, with the latter being favored as the most reliable.[8] Behavior of a

[7] Due to space considerations, full results of the companion matrices under r = 1 and r = 2 are not reported and are available from the author on request.

[8] The recommendation to focus on the plotted CV versions that are corrected for short run influences for being the more reliable has two sources. The first is Juselius (2006, ch. 8). The second was the following econometrics course where Dr. Juselius made these points to the author: "Econometric Methodology and Macroeconomic Applications," a Summer school course taught by Dr. Katarina Juselius, Dr. Soren Johansen, Dr. Anders

CV that should be included in the EC space exhibits stationary behavior. Figure 1 suggests that CV1 behaves, for the most part, in a stationary manner: The plot frequently and repeatedly reverts to the zero mean with fairly constant durations of variation and without prolonged episodes of cycling, aside from minor episodes during 1996-97 and 2001-2002. Figure 2 suggests that CV2's behavior is more non-stationary than CV1's behavior: While CV2 exhibits some mean-reverting behavior, variation levels are far more non-constant than with CV1's plot and there are prolonged sub-periods of non-stationary cycling, particularly during 1995-1999 and 2002-2007. CV2's plot indicates non-stationary behavior and suggests that CV2 should perhaps be excluded from the EC space. These two figures support the above analysis of the characteristic roots of companion matrices that the reduced rank of the EC space, r, is probably nearer to 1 than to 2.

And so on balance, the three sources of evidence suggest that r is more likely 1 than 2. A reduced rank of r = 1 was imposed on model's EC space, suggesting that there is one CV that error-corrects cointegrated system of the three U.S. soft wheat market variables.

HYPOTHESES TESTS ON THE COINEGRATING RELATIONSHIP

One begins with the unrestricted CV that emerged from imposing the reduced rank of r = 1 on the EC space (not reported due to space considerations). I conducted a sequence of hypothesis tests on the EC space; the statistically supported hypotheses were imposed; and the restriction-ridden model was re-estimated with Johansen and Juselius' (1990) reduced rank estimator to generate the finally restricted cointegrating relation that error-corrects the system and that is reported below. Hypothesis tests on the betas take the form:

$$\beta = H^*\varphi \qquad (9)$$

The β is a p1 by r vector of coefficients included in the EC space,[9] and H is a p1 by s design matrix, with s being the number of unrestricted or free beta coefficients. The φ is an s by r matrix of unrestricted beta coefficients. The hypothesis test value or statistic is:

$$2\ln(Q) = T^*\sum [(1-\lambda_i^*) / (1-\lambda_i)] \text{ for } i= 1\ (=r) \qquad (10)$$

Asterisked (non-asterisked) eigenvalues (λ_i , i = 1) are generated with (without) the tested restrictions imposed.

I first conducted system-based and rank-dependent stationarity tests on the three endogenous variables. Juselius (2006), Juselius and Toro (2005), and Juselius and Franchi (2007) recommend this approach over univariate unit root tests (e.g. Dickey-Fuller and Phillips-Perron tests) for a multi-variate cointegrated VAR system such as this paper's model.

The three unit root tests, and all subsequent tests, were programmed by Dennis (2006) and conducted with the CATS2 and RATS (Version 8.2) packages.

Rahbek, and Dr. Heino Bohn Nielsen, *inter alia,* during August 2-22, 2004 within the Institute of Economics at Copenhagen University, Copenhagen, Denmark.

[9] The p1 equals 11: it is the sum of p = 3 endogenous variables plus the eight previously discussed deterministic variables that were restricted to lie in the cointegration space.

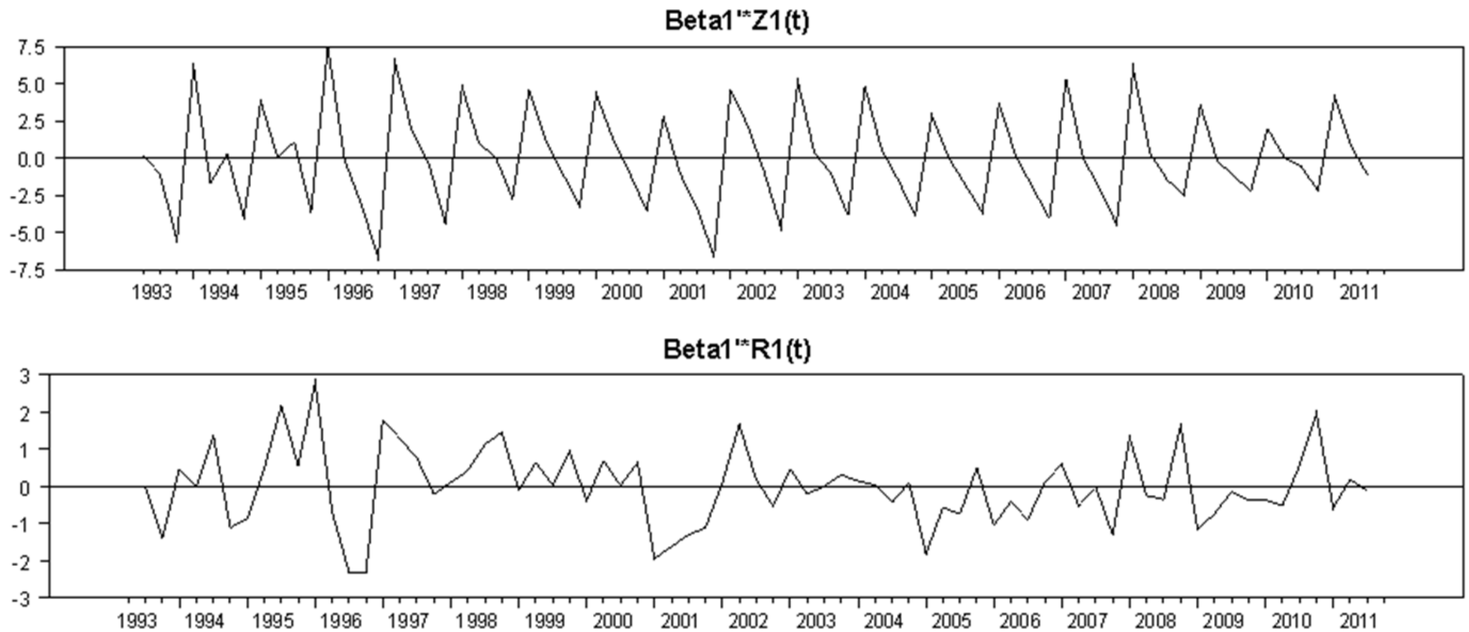

Figure 1. Plot of Cointegrating Relationship or CV No. 1.

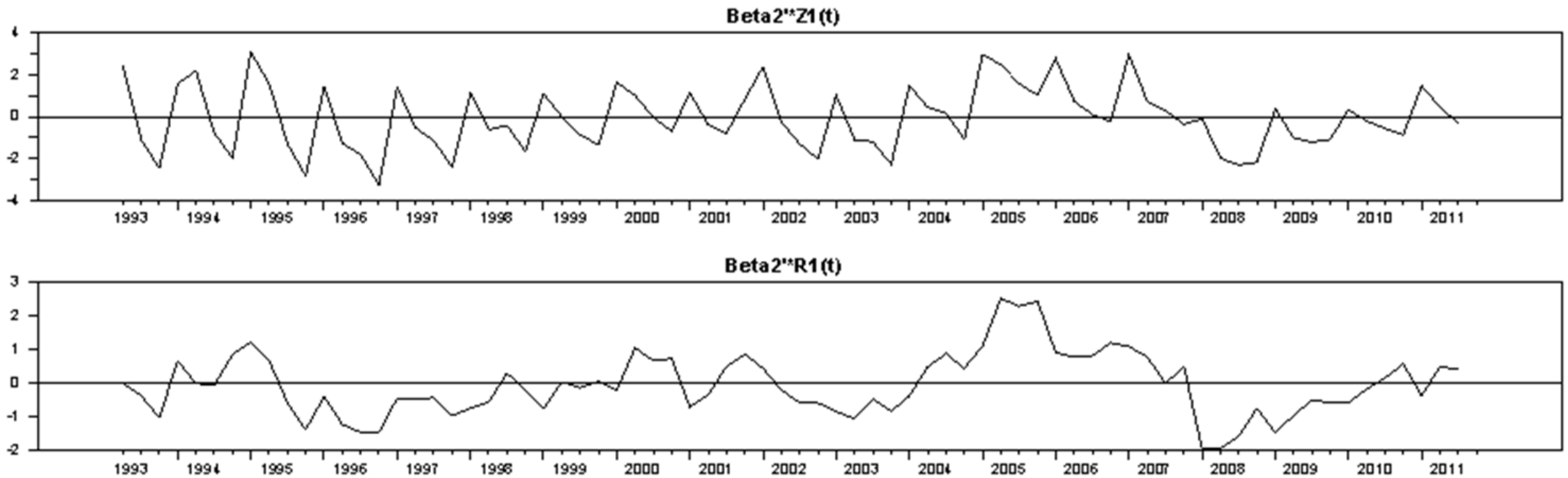

Figure 2. Plot of Cointegrating Relationship or CV No. 2.

Evidence suggested that all three endogenous variables are non-stationary in logged levels.[1].

The second group of tested hypotheses contains those that emerged and/or were suggested by

(a) values of the estimated CV's parameter estimates,
(b) market/industry knowledge and expertise, and
(c) economic and econometric theory.

It is well known from Sims (1980) that the levels VAR of equation 5 that underlies equation 6 is a reduced form one, where estimated relations often lack clear structural interpretation because they reflect a mix of demand-side and supply-side elements. So equation 5's reduced form regression coefficients encompass an intertwined mix of influences of long run and short run components.

The advantage of dichotomizing equation 5 into equation 6's long run EC space and a short run/deterministic component is to enable researchers to focus on the long run component's cointegrating relationships in equation 8 and to integrate economic/econometric theory and market knowledge into equation 8's estimation through imposition of statistically supported restrictions obtained from hypothesis tests. In so doing, long run theoretical relations may be (as in this paper) separated-out from short run influences, and then illuminated through a more rigorous economic and statistical analysis than had been possible with earlier reduced-form VAR models that lacked the benefit of such dichotomization.

The following five restrictions arose from (a) , (b) and (c) above, and were tested and strongly accepted by the data using equations 9 and 10:[2]

- $\beta(P_f) = -0.5*\beta(P_s)$: In the unrestricted (and unreported) CV that initially arose from reduced rank estimation after having imposed r = 1 on the cointegration space, P_s generated a coefficient of -0.775 and P_f generated a coefficient of +0.36. These relative magnitudes approximated and hence inspired this restriction as a testable hypothesis and is analyzed in detail below.
- Zero restriction on the β-estimates for FBILL02, FBILL08, TITLE7, and NAFTA.

After having imposed these five statistically supported restrictions and having re-estimated with Johansen and Juselius' (1990) reduced rank estimator, the finally restricted CV that emerged as equation 11 appears to be a U.S. processor demand for soft wheat as a productive input.

Equation 11 takes the Cobb-Douglas form of equations 3 and 4.

[1] More specifically, Equation 9 is re-written as $\beta^c = [b,\varphi]$. The β^c is a p1 by r or 11 by 1 matrix with one of the variable's levels restricted to a unit vector and b is a p1 by 1 or 11 by 1 vector with a unity value corresponding to the variable the stationarity of which is being tested. The φ is a p1 by (r-1) matrix that vanishes under r=1 since (r-1) is zero. Given the rank of 1, the test values and parenthetical p-values for the three stationarity tests are as follows with the null of stationarity rejected for p values below 0.05: 18.19 (p = 0.00011) for Q_s; 19.89 (p = 0.000048) for P_s; and 19.05 (p = 0.000073) for P_f.

[2] The Chi-square test value (5 degrees of freedom) was 1.46 with a p-value of 0.92. Evidence was clearly insufficient to reject the restrictions. So these five restrictions were strongly accepted statistically.

Discussion of the Long Run U.S. Demand for Soft Wheat as a Productive Input

$$Q_s = \underset{(-6.25)}{-0.82*P_s} \quad \underset{(+6.25)}{+\,0.41*P_f} \quad \underset{(-6.51)}{-0.80*URUGUAY}$$
$$\underset{(+5.70)}{+0.6*QUOTA} \quad \underset{(+7.71)}{+0.53*FAIR96} \quad \underset{(+13.13)}{+0.024*TREND} \qquad (11)$$

As expected, the U.S. quantity of soft wheat (Q_s) demanded by U.S. food processors is negatively related to its own price, P_s. The U.S. own-price elasticity of soft wheat demand [denoted ε(ss)] is estimated in equation 11 at -0.82. Since this elasticity emerges from the cointegrated VAR model's long run component, it is consequently a long run elasticity. And not surprisingly, this own-price elasticity estimate lies within the upper bound of the literature's estimate range that emerged either from studies that did not concentrate on the long run and/or from studies that employed models without the previously discussed benefit of the cointegrated VAR's dichotomization into long and short run components that facilitates illumination of the error correction space's long run relationships. Mankiw (2012, ch. 5) discusses the well-known property that longer run elasticities are generally more price-elastic than short run elasticities.

Perhaps more interestingly, equation 11 suggests, perhaps for the first time in the literature, that U.S. soft wheat demand is also positively related to the price of soft wheat futures that value product at an average forward time-stamp of 39 days. Given the statistical strength of P_f's coefficient and its positive sign, equation 11 suggests that U.S. demanding agents consider forwardly priced soft wheat futures positions as a close time-differentiated substitute in the demand for currently priced quantities. More specifically the β-estimate for P_f of +0.41 reflects the cross-price elasticity of U.S. soft wheat demand with respect to futures price [hereafter denoted ε(sf)], and this appears to be the literature's first such econometric estimate of this cross-price parameter.

This finding that currently priced soft wheat consignments and forwardly priced futures positions are treated as close time-differentiated substitutes closely resembles results found for U.S. softwood lumber by Babula, Zhang, and Rothenberg (2013) and for U.S. slaughter pork by Babula and Rothenberg (2012).

These own-price and cross-price elasticity estimates may suggest that U.S. soft wheat market agents exploit patterns of substitutability between soft wheat and soft wheat futures that in turn acts to cushion the severity of demand impacts from soft wheat price changes. But before exploring this point, I emphasize that P_f and P_s do not reflect, and are not intended to reflect, the price basis for the CBOT soft wheat contract that generates P_f. This is because this paper aims to capture the dynamic long run influences of futures prices on U.S. national soft wheat demand. And as such, the "national" soft wheat price was chosen as the noted U.S. PPI for soft wheat from Labor, BLS (2013), and it is well known that this PPI is a modified Laspeyres index of multiple soft wheat prices surveyed throughout the country. This national soft wheat price index was chosen along with a contract-specific futures price (P_f) that nonetheless reflects pricing of the most nationally monitored and widely traded soft wheat futures contract as could be located. And while the modeled soft wheat and soft wheat futures prices are expected to move somewhat in tandem, the two prices are not expected to, and indeed do not, precisely converge in the long run as would be expected of the contract's settlement and cash prices.

Equation 11's results may be interpreted to show how futures market events working through futures price can offset or cushion the price-induced effects on U.S. soft wheat demand. Given the close qualitative similarity of equation 11's results with those generated by prior work in this journal noted above, equation 11's interpretations are similar to those provided by Babula, Zhang, and Rothenberg (2013) for U.S. soft wood lumber and by Babula and Rothenberg (2012) for U.S. slaughter pork. As soft wheat price rises relative to futures price, U.S. food processors' demand for soft wheat priced at the current pricing point, P_s, becomes relatively more costly than at the futures pricing point, P_f, some 39 days forward. Some agents are likely to shift some of their now more expensive demand for currently priced soft wheat towards demand for forwardly priced wheat at the P_f pricing point by taking positions in the CBOT soft wheat contract. As a result, the full negative effect on demand from the P_s-increase as reflected by ε(ss) = -0.82 may be partly offset or cushioned by offsetting futures market position-taking to a degree reflected by ε(sf) = +0.41 as futures price rises from the shift towards the substitute.

Likewise, as equation 11's ε(ss) and ε(sf) terms suggest, as own price declines relative to futures price, demand for soft wheat at the current pricing point (P_s) becomes relatively cheaper than at P_f some 39 days ahead. As a result, there may be a P_s-induced increase in demand for currently priced product that may be partly offset or cushioned by a decline in the now relatively more expensive demand at the futures pricing point as P_f falls due to the shift from the substitute.[3]

DEMAND RESULTS' CONSISTENCY WITH PRIOR RESEARCH

Mohanty and Peterson (1999) note that U.S. wheat markets in general have been the focus of substantial research inquiry, particularly the all-wheat market and markets aggregated across multiple wheat classes. Far less research has focused on U.S. soft wheat markets. Nonetheless, this study's long run own-price elasticity of U.S. demand for soft wheat (SRW class) of -0.82 fits in towards the upper end of the literature's existing range of relevant estimates. Equation 11's estimated cross-price elasticity of U.S. soft wheat demand with respect to futures price of +0.41 appears to be the literature's first.

The following summarize the literature's estimates of own-price elasticities of U.S. demand for soft wheat; these estimates ranged from -0.24 of Barnes and Shields (1998) to -0.85 of Mohanty and Peterson.[4]

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[3] Due to space considerations, I only mention the important point that increases and decreases in futures price have similarly reasoned effects on soft wheat demand as just noted above for change in soft wheat price.

[4] Marsh (2005) published a study on U.S. domestic wheat demand for the five U.S classes of wheat. In order to quantify price responsiveness and economic substitutability across these classes, he conceptualized and econometrically estimated a U.S. flour production function that permitted him to include, as input prices, prices for the five U.S. wheat classes. And in turn, he obtained Hicksian input demand functions for each class of wheat using Shepherd's Lemma. Among other parameters, he estimated that the price-elasticity of demand for U.S. soft wheat ranged from about -0.03 to -0.04 – a range so far below the literature's range of estimates that I excluded Marsh's estimates from the main text. The only potential reason that I could discern for

- Barnes and Shields formulated a seemingly unrelated or SUR model of five Marshallian demands for U.S. wheat, one equation for each of the five U.S. wheat classes.[5] Each component Marshallian demand that comprised the 5-equation SUR system posited a wheat class' demand (domestic use) as a function of own-price, an income proxy, and of the prices of the remaining four wheat class classes. Barnes and Shields' own-price elasticity estimate for U.S. soft red wheat was -0.24.
- Mohanty and Peterson (1999) econometrically estimated a general dynamic almost-ideal demand system or AIDs model of a U.S. demand-system for non-durum wheat differentiated not only by origin, but by three end uses, all of which had some focus on soft wheat use. The model's imposed restrictions suggested a longer run set of parameter estimates. Their estimated U.S. own-price elasticities of demand dependent on end use ranged from -0.25 to -0.85.
- Mulik and Koo (2011) developed a quarterly Bayesian estimation model of seven U.S. wheat demands – for the five U.S. classes and for two Canadian classes – using a Metropolis-Hastings algorithm and the Markov Chain Monte Carlo Method. They estimated the own-price elasticity of SRW wheat demand at -0.35.

POLICY IMPLICATIONS OF THE RESULTS

A number of policy implications of equation 11's results emerge. First, futures price is a main determinant of U.S. soft wheat demand. Since this is, to my knowledge, the first econometric quarterly U.S. soft wheat demand study that incorporates a futures price linkage, then the result that futures prices importantly matter, and the degree to which they matter, in soft wheat demand and price discovery should be of keen interest to agents on both sides of the debate summarized by Auerlich et. al.: those who feel that changes in futures trading pools to include non-traditional speculative traders and increasing levels of futures price volatility have detrimental real market impacts (often traditional traders who focus on price formation and risk management) vs. those who feel that they do not (speculative traders from hedge funds and other financial firms, agents from futures exchanges, banking groups, etc.). Equation 11 suggests that for U.S. soft wheat, movements in futures prices, as well as in own price, are crucial to demand formation for soft wheat, such that changes highlighted by the noted debate likely matter.

Hence, equation 11 seems to refocus the debate noted by Auerlich et. al., at least for markets related to U.S. soft wheat, from the question of "if" increased non-traditional trading, higher levels of futures price volatility (among other trends and events) and other noted financially-focused policies/events are affecting real commodity markets to the

Marsh's low estimates of the soft wheat demand elasticities may be a relatively minor role that soft wheat (the classes of soft red Winter or SRW and soft white Winter) may play in a profit function for the entire U.S. flour industry. As noted by Barnes and Shields (1998), the role of hard red Winter (HRW) and hard red Spring (HRS) not only dominate U.S. domestic wheat supply, but are crucial in production of flour for breads, bread flour, and all-purpose flour. Soft wheat, however is relegated to low-protein flours that are relevant to making cookies, cakes, and other bakery products. Such a peripheral soft wheat role in a general "U.S. flour industry profit function" may have resulted in soft wheat coefficients having captured low or muted levels of price responsiveness relative to responsiveness levels captured for other classes (HRS, HRW, e.g.) so as to have rendered very low elasticitity estimates for the soft wheat classes.

[5] The five U.S. wheat classes are hard red Winter (HRW), hard red Spring (HRS), soft red Winter (SRW), white wheat, and durum.

question of "how much" real market effect they are having. This re-focus of the debate for U.S. soft wheat markets is similar to the re-focus justified by the results of Babula, Zhang, and Rothenberg (2013) for the U.S. softwood lumber market and of Babula and Rothenberg (2012) for U.S. pork product markets (especially at the pork slaughter pricing point).

The second major policy implication also serves as a recommendation for future research. Financially-focused policies/market events that are associated with changes in futures price appear to indeed have real soft wheat market effects along with commodity-focused policies/events working through soft wheat price. Such financially-focused policies/events may include accelerated trading by speculative traders (mentioned above); actions (or inaction) by futures exchanges; and new regulatory legislation such as the Dodd-Frank financial reform, among others. Implications of the results here for U.S. soft wheat should inspire similar research on other markets -- whether markets are for grains/oilseeds, crude oil, or energy products.

A notable result emerged from the binary variable coefficients. The statistically significant coefficient on QUOTA, designed to capture impacts of the two U.S. temporary TRQs placed on certain imports of Canadian durum and non-durum wheat during the year ending September 11, 1995 (see Glickman and Kantor) was positive, such that U.S. processor demand was higher than without the TRQs. At first glance, this result appears counter-intuitive, insofar as the TRQs were designed to restrict imports of certain Canadian wheat and to shore-up domestic U.S. farm wheat prices in the wake of the high-profile U.S./Canada wheat dispute following the 1994/95 implementations of NAFTA and the Uruguay Round, and would conceivably have led to less domestic demand from the higher priced soft wheat. However, the efficacy of these TRQs has long been debated, insofar as some allege that President Clinton had set the in-quota amounts at levels high enough so as to likely not have been very restrictive (see USITC 1994; Glickman and Kantor). Equation 11's positive and significant coefficient on QUOTA suggests that the two temporary TRQs may not have been effective.

SUMMARY AND CONCLUSION

For perhaps the first time, a cointegrated VAR model is estimated for the quarterly U.S. soft wheat market that includes an endogenous price linkage to the soft wheat futures market. This model yielded an equilibrium cointegrating relationship supported by notably strong statistical evidence in the form of a long run Cobb-Douglas U.S. processor demand for soft wheat as a productive input. This demand function suggests that U.S. processor demand for soft wheat is not only a function of own-price (as expected), but also a positive function of the forward price of soft wheat futures positions. These findings suggest that soft wheat futures positions are considered a close time-differentiated substitute with currently priced product. Hence U.S. soft wheat demand discovery hinges not only on own-price, but on futures prices, and in turn on futures market events, policies, and market changes that influence futures price. The emergent demand's cointegrating parameters are interpreted as long run elasticities and they suggest that for long run U.S. soft wheat demand, the own-price elasticity is -0.82 and falls within the upper bound of the literature's range of relevant estimates. Equation 11's cross-price elasticity with respect to futures price of +0.41 may be the literature's first estimate.

Insofar as statistical evidence strongly suggested that the cross price elasticity was half the absolute magnitude of the own-price elasticity, then U.S. processor agents appear to allocate total demand among currently and forwardly priced soft wheat quantities depending on relative own-price/futures price ratio over an average 39-day time horizon. In so doing, hedging, other risk management activity, and perhaps speculative trading may serve as an offsetting cushion on demand impacts from large changes in soft wheat price and vice-versa.

Policy implications are clear. Financially-focused policies and market events that work through futures price clearly impact the real soft wheat market through processor soft wheat demand. For the U.S. soft wheat market, no longer should the debate summarized by Auerlich et. al. of whether rising levels of futures price volatility, changing trader pool compositions to include non-traditional speculator-traders, or noted other policies/events working through futures price focus on "if" such things matter in the real market, but rather should focus on "how much" they matter. Additionally, this study also provided some corroborating evidence that supports Babula's (2011) prior findings that the temporary U.S. TRQs placed on certain imports for the year ending September 11, 1995 may not have been effective.

With this study, this journal's research findings that futures market events and prices are critical in U.S. commodity demand and price formation and in turn have real commodity market impacts have been extended to a third important U.S. commodity areas, soft wheat.

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INCORPORATING CLIMATIC VARIABILITY IN A PARTIAL EQUILIBRIUM MODEL OF ETHANOL TRADE: THE CASE OF U.S. AND BRAZIL

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ABSTRACT

This study analyzes the impact of climatic variability on ethanol trade between Brazil and the U.S, over a study period of 30 years, from 1980-2009. An econometric model was set up to estimate a net export supply function for Brazil, and a net import demand function for the U.S, as impacted by market and climatic variables. The climatic variables for the model were derived from prior literature, linking them to the yields of corn and sugarcane, which are feedstock for ethanol production in the U.S and Brazil respectively. The results suggest that climatic factors play an important role in the feedstock production for ethanol in these two countries, thereby influencing the direction of exports and imports. In South East Brazil, both low temperature and increased precipitation during winter show a positive relation with the net export supply. With regard to the net import demand in the U.S, it shows a negative relation with both increased summer precipitation and higher summer temperatures, while the relation with the average annual minimum temperature is positive. The outcome of this study provides an initial framework for conducting international trade policy studies for bio-fuels like ethanol, by incorporating climate change variables.

Keywords: Brazil, climatic variability, ethanol trade, market variables, U.S

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1. INTRODUCTION

Witnessing an increase in the global population levels, several countries have recognized the intensifying demand for food and energy, and have emphasized the development of renewable energy technologies in the past few decades. The importance of reducing dependence on nonrenewable sources of energy by switching to alternative sources like bio-fuels was specifically highlighted in the early 1970s (Martinez-Gonzalez, Sheldon and Thompson, 2007), with the imposition of an initial oil embargo by the OAPEC (Organization of Arab Petroleum Exporting Countries), and further with the dramatic increase in world oil prices after the lifting of the embargo. Consequently, the energy policies of several industrialized countries have been modified to promote bio-fuel production, specifically ethanol and bio-diesel, which are one of the most sought after sources of renewable energy. In the last three decades, Brazil has emerged as a pioneer in ethanol production, followed by the U.S, and both countries have expanded their ethanol industries to meet current demands and strengthen their capacities for future requirements.

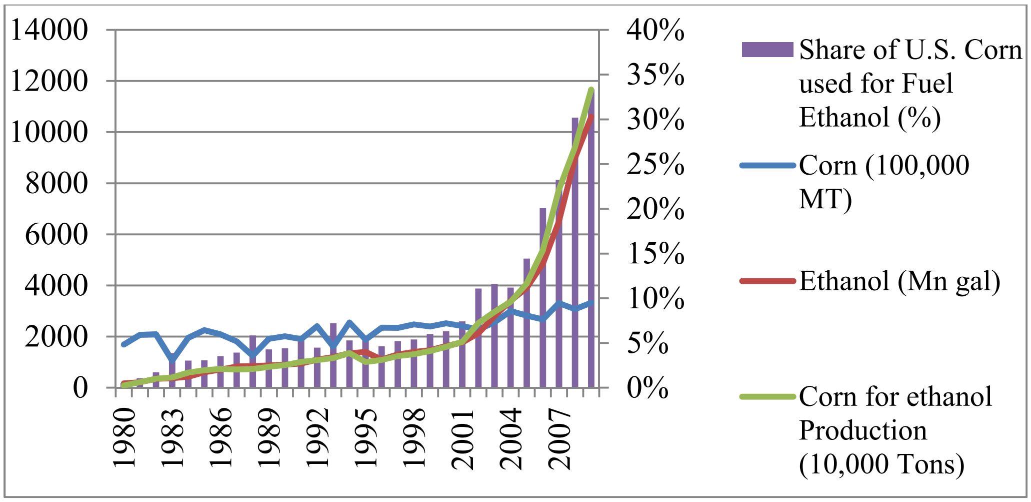
As mentioned above, among the ethanol producing countries in the world, U.S and Brazil have been the leading producers for past thirty years, and the statistics regarding world ethanol production for the years 2007- 2009, further elaborate on the importance of these giant players in the world ethanol market. According to the Renewable Fuels Association (2012), U.S and Brazil, have led the global ethanol production significantly in the years 2007-2009, and together accounted for more than 85% of the world ethanol production in these years. The data reported in Table 1 show that the U.S dominated the market in all the three years, with Brazil following up next. From 2007-2009, U.S held an increasing share of the global ethanol production and accounted for 53.1% of the total world production in 2009, which is a 4.4 % increase from 2007. On the other hand, Brazil's share declined from 2007 to 2009, although it still is the second largest ethanol producer in the world following the U.S.

Table 1. Global ethanol production and leading countries in the world (2007-2009)

Ethanol Production (Million gallons)						
Country	2007	%	2008	%	2009	%
USA	6,499	49.5%	9,000	51.9%	10,600	53.1%
Brazil	5,019	38.2%	6,472	37.3%	6,578	32.9%
European Union	570	4.3%	734	4.2%	1,040	5.2%
China	486	3.7%	502	2.9%	542	2.7%
Thailand	79	0.6%	90	0.5%	435	2.2%
Canada	211	1.6%	238	1.4%	291	1.5%
Colombia	75	0.6%	79	0.5%	83	0.4%
India	53	0.4%	66	0.4%	92	0.5%
Australia	26	0.2%	26	0.2%	57	0.3%
Other	104	0.8%	128	0.7%	247	1.2%
Total	13,123	100.0%	17,335	100.0%	19,964	100.0%

Source: Renewable Fuels Association (2012).

The inevitable link between agriculture and production of bio-fuels like ethanol in both Brazil and the U.S. highlights the fact that any impacts on agricultural production of raw materials will directly affect the total ethanol production in these two countries. Given that ethanol production in the U.S and Brazil comes from corn and sugarcane respectively, it is imperative to understand the vulnerability of the ethanol industry to changes in agricultural production of these two commodities, which is highly impacted by climate. Figure 1 provides a comparison of annual corn production with the annual ethanol production and quantity of corn used for ethanol production in the United States from 1980-2009. It is observed that although there has been a rise in both corn and ethanol production in the last three decades, the increase in ethanol production has been more or less exponential in the 2000s.



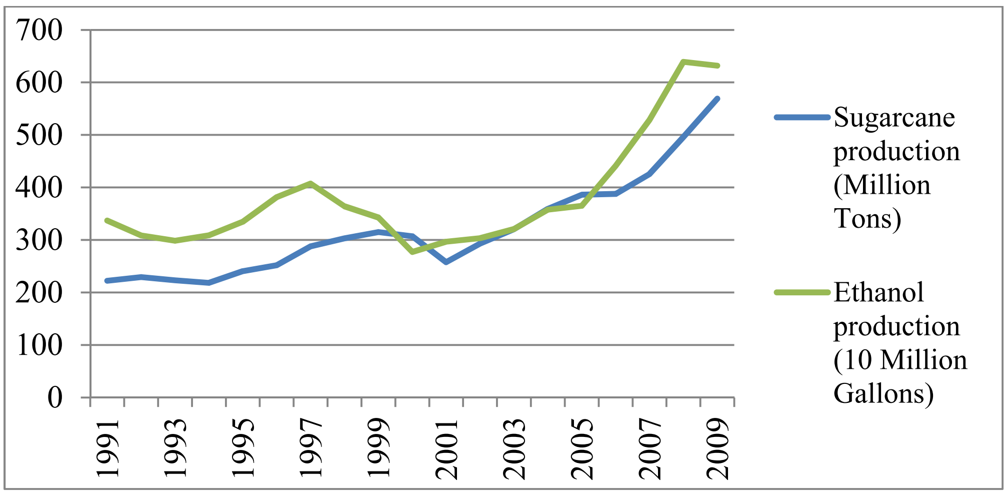
Source: Data compiled from EIA Annual Energy Review (2011), and Renewable Fuels Association (2012).

Figure 1. Corn and ethanol production in the U.S (1980-2009).

Figure 2 provides a comparison of the sugarcane production and ethanol production for Brazil from 1990-2009, which is the most readily available data in this regard. This represents a similar trend to that in the U.S, with a distinct rise in the production of both sugarcane and ethanol, in the early 2000s, when car producers in Brazil increasingly started manufacturing flex-fuel cars that could run on both ethanol and petrol. Prior to the time period depicted in Figure 2 below, some important developments occurred in the Brazilian ethanol policy, and had significant implications which are discussed here.

The history of using ethanol as fuel for cars in Brazil dates back to the introduction of the Proálcool program in 1975, and the introduction of the first pure-ethanol-fueled cars in 1979 (Valdes, 2011). This program intended to provided support to ethanol producers in a time of rising oil prices and a crisis in the international sugar market (Valdes, 2011), and continued to do so for more than 15 years until it was eliminated in the late 1980s. Soon after, the sugarcane and hydrated ethanol markets were fully liberalized in 1999 (Miranda, Swinbank, and Yano, 2011).

In 2003, the introduction of flex-fuel cars revived hydrous ethanol consumption in Brazil which saw a 27 percent annual increase from 2003-09, while during the same period am annual decrease of 2 percent was observed for anhydrous ethanol consumption. The reason for the latter was that, the decline in gasoline demand was not sufficiently offset by increases in the blending rate of ethanol in gasoline (Valdes, 2011). Government policies have played an important role in increasing the demand for hydrous ethanol and for increasing Brazil's flex-fuel vehicle fleet. For example, automobile manufacturers have been given tax breaks to produce cars that run on hydrous ethanol, and the blending of anhydrous ethanol with gasoline, has been made mandatory. Another important measure is that ethanol is exempt from the levy charged on fuel, which has been varied to protect the domestic market from the shocks of international oil price variability (Miranda, Swinbank, and Yano, 2011).



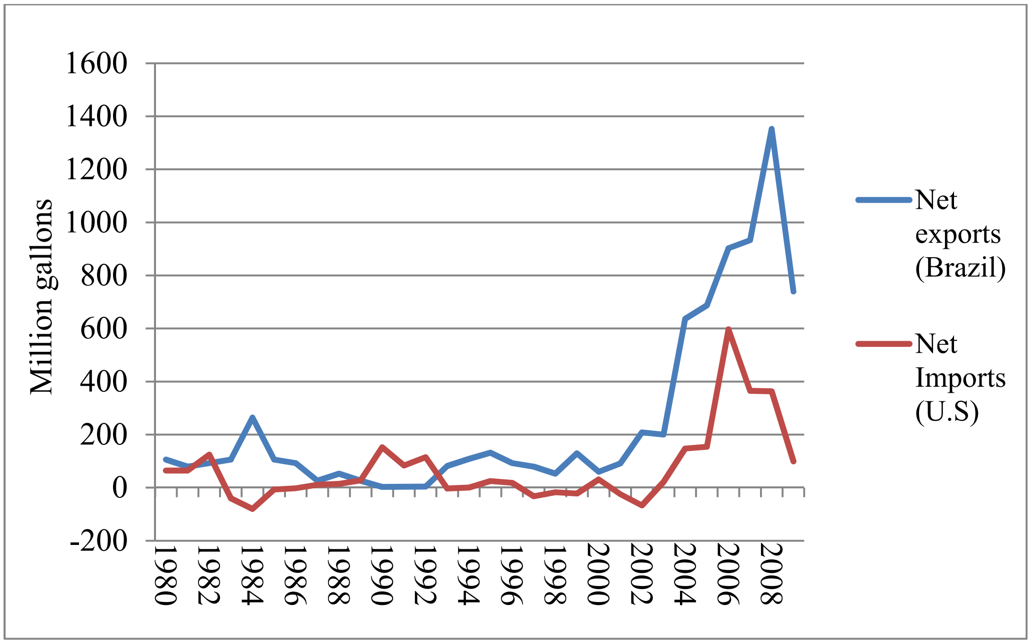
Source: Data compiled from Uniao da Industria de Cana de Açúcar (ÚNICA), 2012.

Figure 2. Sugarcane and ethanol production in Brazil (1990-2009).

From the historical depiction of ethanol production for U.S and Brazil as shown above in figures 1 and 2 respectively, it can be suggested that ethanol production has been on the rise in both countries in the past decades, and may continue to increase in future. As recently as until 2007, Brazil has been supplying about 50 percent of global ethanol exports in the world at lower prices, because of the higher sugar content in sugarcane when compared to corn. It has also been observed that the prices of U.S. and Brazilian ethanol have shown significant rise and fall with oil prices, and also the relative cost of ethanol in the US and Brazil is highly sensitive to the prevailing exchange rate and prices of their respective feedstock (Crago, 2010).

Most recently in the year 2010, the U.S generated a trade surplus of $556 million, and became a net exporter of ethanol for the first time in recent history (USDA, 2011). The 2011 U.S annual ethanol exports surpassed the 2010 numbers, and the total exports reached 1.19 billion gallons, with Brazil being the leading importer for 33% of total shipment (RFA, 2012). Figure 3 provides a depiction of the trend in net ethanol imports and exports for the U.S and Brazil respectively, over the study period of 1980-2008. This further supports the fact that both net exports from Brazil and net imports by U.S followed a similar trend until the late

90s, and witnessed an increasing growth pattern in the early 2000s, the reasons for which have been discussed above.

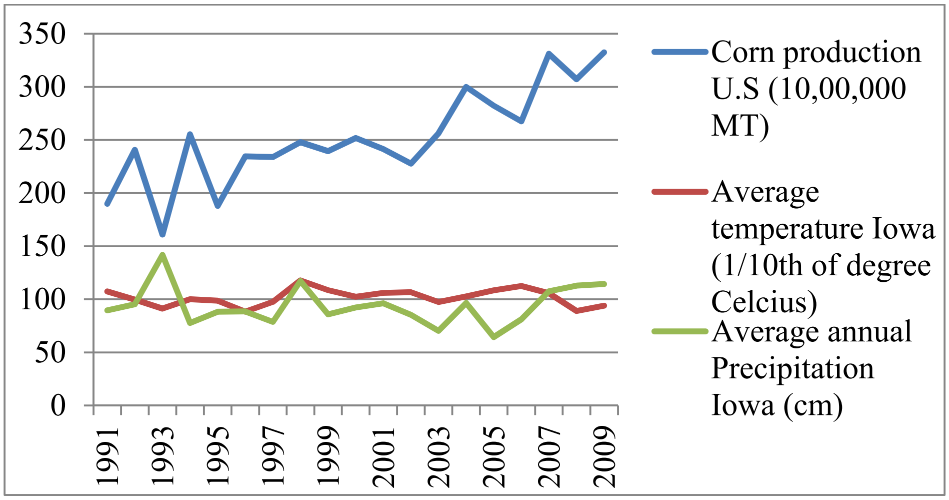


Source: Data compiled from EIA Annual Energy Review (2011), Renewable Fuels Association (2012), and Uniao da Industria de Cana de Açúcar (ÚNICA), 2012.

Figure 3. Net Brazilian Exports and Net U.S Imports (1980-2009).

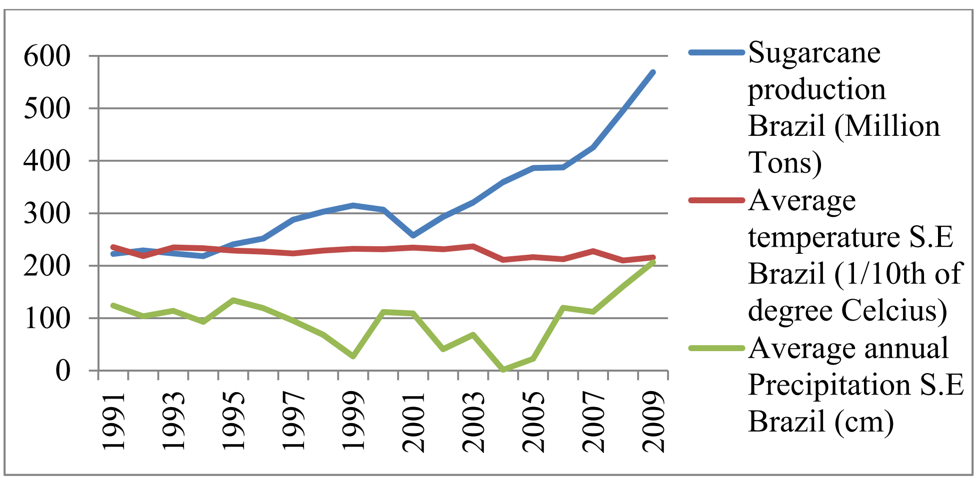
Prior studies regarding ethanol trade have incorporated market variables which impact the supply and demand of ethanol in the two countries of study. However, the annual yield of both corn and sugarcane which are raw materials to the ethanol industry is directly impacted by climatic indicators like temperature and precipitation. Figures 4 and 5 describe the movement in corn and sugarcane production in Iowa and South East Brazil respectively, with regard to average annual temperature and precipitation in the corresponding areas, over the period of 1990- 2009. As is evident from these visual illustrations, both corn and sugarcane production show a higher degree of similarity in the trend movements with average annual precipitation when compared to average annual temperature. This observation gives rise to the need for specific seasonal indicators to be developed for the study specifically with regard to temperature and precipitation in the critical stages of production which impact the yield of feedstock for ethanol production.

The above discussion clearly indicates the importance of climatic variables in the production of feedstock for a tradable bio fuel commodity like ethanol. Also, with climatic changes and frequent weather abnormalities like drought being witnessed in the last few years, it becomes all the more imperative that trade studies consider the impact of climate. The incorporation of these indicators while developing the ethanol trade models could be a useful tool to better predict the unexplained variability in ethanol trade between different countries. This study intends to set the stage for the same, and could be considered as an exploratory study with regard to the inclusion of climatic variability in predicting the trade of bio fuels. Further, the adjournment of the thirty year old U.S tax subsidies to the ethanol industry, as well as the import tariff on Brazilian ethanol in December 2011 further ensures that the ethanol trade between the U.S and Brazil will witness significant impacts, especially in the event of a changing climate.



Source: Data compiled from EIA Annual Energy Review (2011), Renewable Fuels Association (2012), and NOAA (2012).

Figure 4. Total corn production in U.S and average annual precipitation and temperature in Iowa (1990-2009).



Source: Data compiled from Uniao da Industria de Cana de Açúcar (ÚNICA), 2012, and NOAA (2012).

Figure 5. Total sugarcane production in Brazil and average annual precipitation and temperature in South East Brazil (1990-2009).

In light of the above, it will be of interest to understand the trade patterns of ethanol between Brazil and the United States in a free market, impacted by both market variables as well as climatic factors influencing ethanol production in the international ethanol market dominated by the above two countries.

2. LITERATURE REVIEW

This section explores prior work done on ethanol trade, and provides a background to develop the framework for this study. Past studies have developed partial equilibrium trade models, and analyzed several factors that impact ethanol trade in the world. In a study by Koizumi (2003) the impact of Brazil's ethanol production on the world ethanol, and sugar markets, was studied. This study developed a dynamic partial equilibrium model to analyze policies regarding ethanol production and trade, as well as the energy and environmental policies, in large producing countries will affect both the ethanol market, and the domestic and international sugar markets. This study concluded that domestic sugar and ethanol market prices in Brazil do impact the world sugar and ethanol price, and Brazil holds a competitive advantage in the world ethanol market.

Gallagher et al., (2006) estimated an econometric model for comparing the cost advantage between the U.S. corn-ethanol industry and Brazil's sugarcane-ethanol industry. They further conducted a time-series analysis of the cost advantage measure to see how sugar and corn market cycles, random weather shocks, and financial policy changes, impact the international competitiveness of the ethanol markets in these two countries. They conclude that the U.S. would typically be an ethanol importer, but that it could take an occasional or cyclical export position in the ethanol market. The results of this study seem to relate to the recent ethanol exports increase from the U.S. in the years 2010 and 2011.

Elobeid and Tokgoz (2006) studied the ethanol market in regard to both energy (gasoline in this case) and crop markets, specifically those related to corn and sugarcane markets. The importance of the crop markets in ethanol production come from the fact that the price of a feedstock like corn and sugarcane accounts for the major cost for an ethanol plant. The results from this study indicate that an increase in gasoline prices affects the U.S. and Brazilian ethanol markets differently because of the characteristics of their respective vehicle fleets. On the other hand, an increase in the U.S. corn price decreases the profit margin for ethanol plants and leads to a reduction in ethanol production, as a result, the U.S. domestic ethanol price increases, making ethanol imports from Brazil relatively more attractive. In addition, if there is a shock that increases the world price of raw sugar, it results in diversion of more sugarcane into sugar relative to ethanol production in Brazil.

Martinez-Gonzalez, Sheldon and Thompson (2007) illustrate the impact of trade distortions on U.S. imports of ethanol from Brazil. They use a two-stage least squares model to estimate a partial equilibrium trade model based on annual data from 1975 to 2006. This study calculated the deadweight losses from the derived export supply and import demand elasticities including the distortions in trade. The results of this study conclude that the elimination of trade distortions is beneficial for the U.S-Brazil ethanol trade.

The availability of literature regarding international trade in the bio-fuel sector, as impacted by climatic influence on the feedstock production is limited. However, to create a background for this study, certain studies are of relevance which explore the impacts of climate change on corn and sugarcane yields respectively. This allows for a better understanding of specific climate variables, which are further incorporated in the econometric model for this study.

Deressa, Hassan and Poonyth (2005) enlist some important temperature and precipitation requirements for the sugarcane harvest period, which is a critical phase impacting the overall yield and sugar content. The study region for this analysis is the sugarcane producing sub-tropical wet climate area of KwaZulu-Natal, in South Africa where sugarcane production is rain fed. This area is similar to the Sao Paulo region of Brazil, in terms of the sub-tropical climate. This study indicates that during the sugarcane harvest period, low temperatures are beneficial, especially in the range of 18-22ºC. This study explains this range based on an early study by Humbert (1968), stating that low temperature levels allow for sucrose accumulation, which increase the sugar content, but very low temperatures, below 10ºC rupture cells and causes heavy damage to the crop. Further, the former study also reveals that total harvesting season precipitation > 94mm, is not favorable for sugarcane production. This negative relationship between increased precipitation beyond 94mm, and net revenue could be attributed to possible outbreak of pests and insects, for the above mentioned specific study area.

Studies that specifically deal with impacts of climate variables on feedstock production for corn based ethanol, and linking it to the ethanol trade are also rare. Therefore, some studies that expand on specific climate requirements by the corn crop in a particular growing season are mentioned below. These studies provide a reference for creating climatic variables in the import supply function of ethanol, in this study. Neild and Newman (1990) studied the growing season characteristics and requirements of corn crop in the U.S Corn Belt. This study specifies certain temperature and precipitation requirements for the corn crop in the study area. In the Corn Belt, the number of freeze-free days during the year characterize the growing season. During the growing season, corn can survive short exposures to higher temperatures that range from about 32 F (0^0C) to over 112 F (45^0C). Less growth is observed with initial growing temperatures of near 41 F (5^0C) to near 95 F (35^0C). The precipitation requirements for higher yields in the Corn Belt vary from 18 to 20 inches (45 to 50 cm). It is important to note that these requirements are specifically critical during the growing season.

In another study by Goldblum (2009), the potential county-scale impacts of climate change on corn were evaluated for Illinois, USA. The study identified specific monthly climate variables (mean daily temperature and precipitation) to which corn yield is sensitive. Further, a comparison was drawn between monthly regional General Circulation Model (GCM) predictions, and the monthly climate variables to which corn yield is sensitive, in order to predict crop yield under future climate. The results of the study indicated that corn yield is negatively correlated with July and August temperatures in much of the state of Illinois, and positively correlated with July and August precipitation in most of northern and southern Illinois, respectively. This study concluded that with the regional GCM predictions indicating increased summer temperatures and summer drought in Illinois, corn yields will most likely witness a decline under the future conditions.

3. OBJECTIVES

1) To develop a working econometric model for assessing the impacts of climatic indicators and market variables on U.S - Brazil ethanol trade and,
2) To analyze the direction of impact of climatic indicators and market variables on the net ethanol export supply function of Brazil and the net ethanol import demand function of U.S over a 30 year study period from 1980-2009.

4. THEORETICAL FRAMEWORK

The theoretical background of this study is based on standard trade theory. Figure 6 illustrates a partial-equilibrium trade depiction of production and trade of ethanol. This is the case of two large countries (U.S. and Brazil), which can influence their terms of trade. Also, in this study the market operates under free trade given there are no trade distortions, in accordance with the facts presented earlier. In this case, climatic factors play an important role in affecting ethanol trade. This is represented by the diagrammatic example (Figure 6) that follows. The left hand panel diagram shows the exporting country Brazil, assuming that historically Brazil has been a net exporter of ethanol. The center panel diagram shows the world market and the right panel diagram shows the U.S market, assumed to be a net importer. Since the export supply of ethanol in Brazil is affected by weather conditions, an unfavorable climate reduces the excess supply. In the left-hand panel, equilibrium in the world market prior to reduction in export supply from Brazil is given by price P_W. This generates the U.S. excess derived demand for ethanol ED. In combination with Brazil's excess supply curve ES, the initial international equilibrium is given by price Pw.

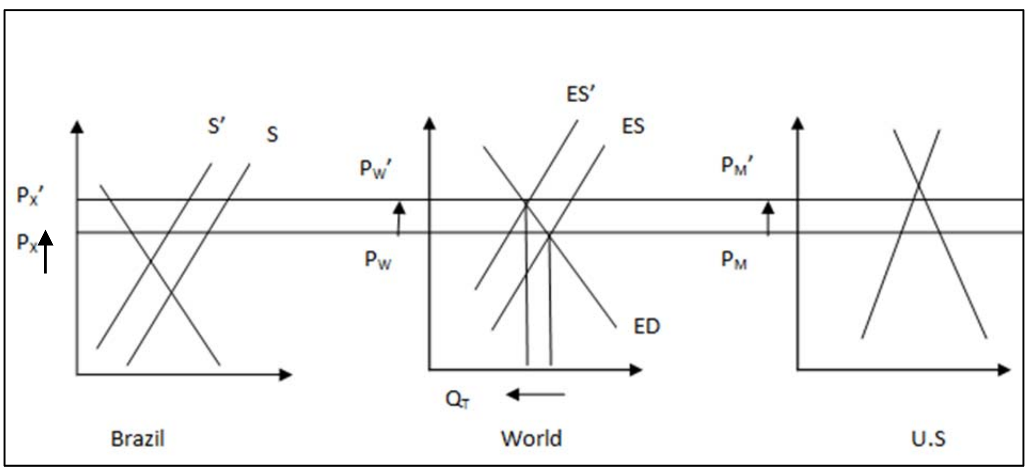


Figure 6. A partial-equilibrium trade model for production and trade of ethanol.

Assuming that an unfavorable weather for sugarcane production in Brazil, shifts the excess supply curve ES to ES', world price increasing to Pw', U.S. price of ethanol rising to P_M', and the Brazilian price increasing to P_X'. The quantity traded in the world also declines. In this manner, the climatic conditions that affect the supply of ethanol in Brazil (depends on sugarcane production), impact the entire world market of ethanol, assuming no trade distortions, which is the current scenario, as mentioned earlier. The internal price in both countries and the world market are both impacted by the reduction in supply, which may occur on account of a drought, high temperatures, or other weather related conditions, impacting the yield of sugarcane for ethanol production. The extent of the decline however depends on the elasticities of supply and demand in both countries, and the severity or favorability of climatic factors. This study assumes only Brazil and U.S as the two large countries in ethanol production, and that the impact of rest of the world or smaller countries on ethanol price will be minimum.

5. Methods and Data

5.1. Data description

This study contributes to a prior study by Martinez-Gonzalez, Sheldon and Thompson (2007), by estimating an export supply function for Brazil (Represented by Net Brazilian exports), and an ethanol demand function for U.S (Represented by Net U.S imports), as affected by the market variables (Price of ethanol, price of sugar, price of corn, price of oil, Real exchange rate, Real gross domestic product of Brazil), and the climatic variables which impact the production of corn and sugarcane based ethanol in the U.S and Brazil respectively. An important observation with regard to the price for ethanol used in the model (*Peth)* is that the actual price used is the U.S ethanol price. Ideally the Brazilian anhydrous ethanol price should have been used as the world price (Martinez-Gonzalez, Sheldon and Thompson, 2007), but there were data availability limitations for historical annual data for Brazil, and the U.S ethanol price has been used as the international price in the model. This study assumes that Brazil and U.S are the two large countries in ethanol production and their prices largely impact the international ethanol price (Martinez-Gonzalez, Sheldon and Thompson, 2007). The index used for deflation of nominal variables is the U.S Consumer Price Index (Year 2000=100). The description for the market variables of interest is provided in Table 2.

Table 2. Sources of Market Variables Employed to Estimate the Model

Variable [notation in model]	Sources [Units]
Price of ethanol [Peth,t]	Nebraska Ethanol Board, Energy Information Administration (EIA), and Kansas State University, 2002 [dollars per gallon]
Net Brazilian exports [Et]	Uniao da Industria de Cana de Açúcar (ÚNICA), Walter, Dolzan and Piacente, 2006 [million gallons]
Net U.S. imports [It]	U.S. Department of Energy, 2011 [million gallons]
Price of sugar [Psug,t]	World Bank, 2012 [dollars per pound]
Price of oil [Poil,t]	Hofstrand and Johanns, 2012 [dollars per barrel]
Price of corn [Pcorn,t]	Hofstrand and Johanns, 2012 [dollars per bushel]
Real gross domestic product_Brazil per capita [RGDPPCBr,t,]	Economic Research Service-U.S. Department of Agriculture (ERS-USDA) [real dollars]
Exchange rate [ER]	Economic Research Service-U.S. Department of Agriculture (ERS-USDA) [real per dollar]

Climatic Variables of Interest

The main climatic variables of interest to this study are: average annual maximum and minimum temperatures, and average annual precipitation. The secondary weather indicators of interest specific to sugarcane are: days of winter temperature < 18ºC, whether or not total winter precipitation > 94 mm, days of summer temperature > 35ºC, whether or not total summer precipitation < 354 mm (Deressa, Hassan and Poonyth, 2005), while indicators specific to corn are: days of summer temperature > 35ºC, and whether or not total summer precipitation < 450 mm (Neild and Newman, 1990).

It is important to note that in South East Brazil, the main plant and harvest season is in the months of October and November (Vaughan, 2003), and therefore the secondary indicators of interest, are narrowed down to: days of winter temperature (months of October and November) < 18ºC, and whether or not total winter precipitation > 94 mm. Also, it is to be noted that whether or not total summer precipitation < 450 mm for corn production, and whether or not total winter precipitation > 94 mm for sugarcane production, are binary variables. Therefore, the sensitivity of corn and sugarcane to these two variables, were represented as absolute numbers for the total summer precipitation for corn, and total winter precipitation for sugarcane production, respectively.

Selection of Weather Stations for Climatic Variables

For Brazil, the area of interest is the South East Sao Paulo state, and for the U.S, it is the Midwestern state of Iowa. The state of Sao Paulo produced about 17,676 million gallons of ethanol, accounting for 67% of the total production in the country in 2009 (Valdes, 2011), while Iowa produced about 3,537 million gallons of ethanol (USDA, 2011) in the year 2010, contributing to 53% of the total U.S ethanol production. Four weather stations from both production regions are chosen on the basis of availability of weather observations, and proximity to the largest production areas of corn and sugarcane, in the respective study regions.

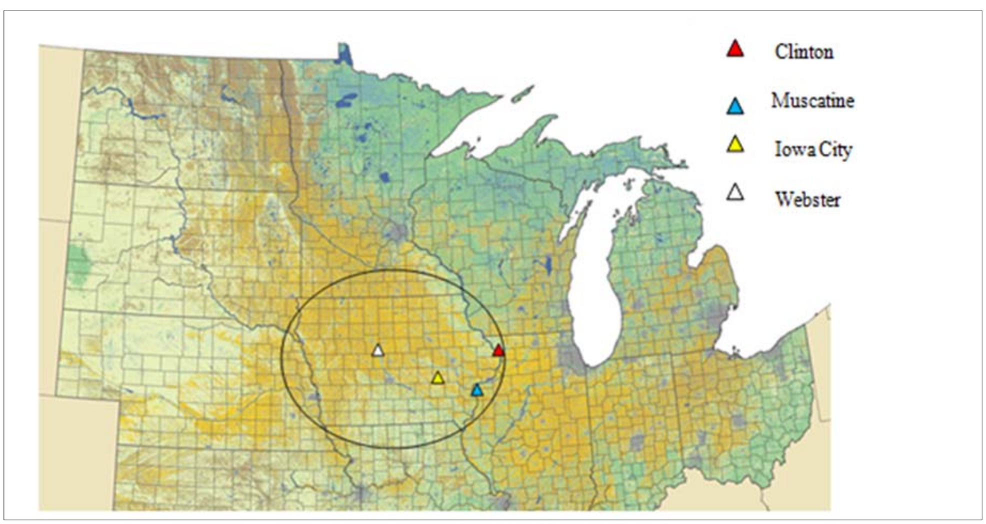


Figure 7. Weather Stations in Iowa- U.S for developing climatic variables for corn production.

Historical observations for daily maximum and minimum temperature, and precipitation are obtained from 1980-2010. The source of this data is the GHCN daily legend (Global Historical Climatology Network) for individual weather stations, from the National Climate Data center of the National Oceanic and Atmospheric Administration (NOAA, 2012). Further, the observations from each of these stations, for the climatic variables of interest, are averaged to represent a local climate for the study regions. For Iowa, the weather stations are: Iowa City, Clinton, Muscatine, and Webster. For Sao Paulo, the weather stations chosen are: Sao Paulo, Bauru, Campinas, and Presidente Prudente. These weather stations are depicted in Figures 7 and 8 respectively.

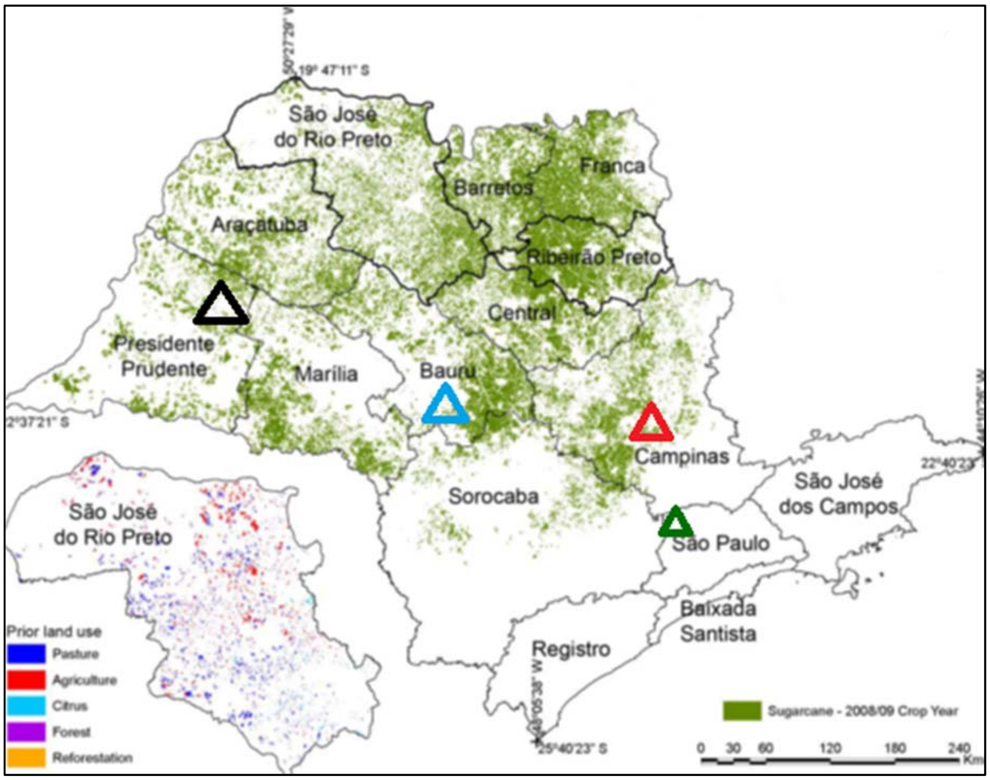


Figure 8. Weather Stations in São Paulo state- Brazil for developing climatic variables for sugarcane production.

5.2. Model Estimation

Estimation of the Export Supply and Import Demand Model

A partial equilibrium 2SLS (2 Stage Least Squares) model is set up in SAS, to estimate the impact and significance of market variables and climatic indicators on the ethanol trade between the two countries of study. Before estimating the model, different instrumental variables used for estimating the export supply and the import demand are tested for autocorrelation, using a Durbin Watson statistic. These details are mentioned in the results section. The two equations to be estimated are as follows:

$\ln E_t = \alpha 0 + \alpha 1$ lnPeth,t-1+ $\alpha 2$ ln E,t-1+ $\alpha 3$ lnPsug,t + $\alpha 4$ ln Tmax_Brazil,t + $\alpha 5$ lnTmin_Brazil,t + $\alpha 6$ lnPrcp_Brazil,t + $\alpha 7$ lndays_tmin_winter_below18_ Brazil,t + $\alpha 8$ lntot_prcp_winter_ Brazil,t + $\alpha 9$ lnER,t + $\alpha 10$ lnRGDPPCBr,t + $\alpha 11$ln Poil,t + εt (1)

lnIt = $\beta 0$ + $\beta 1$ lnPeth,t + $\beta 2$ lnPoil,t + $\beta 3$ ln Pcorn,t + $\beta 4$ lnTmax_Iowa,t + $\beta 5$ ln Tmin_Iowa,t + $\beta 6$ lnPrcp_Iowa,t + $\beta 7$ ln tot_summer_prcp_Iowa,t + $\beta 8$ ln days_tmax_summer_above35_Iowa,t + υt (2)

Equation (1), estimates the export supply function of Brazil represented by E_t, and equation (2), estimates the import demand function of U.S represented by It. The exogenous variables used as instruments are: the price of oil, the price of sugar, the price of corn, the real GDP per capita of Brazil, the lagged price of ethanol, the lagged level of exports, and the climatic variables (Tmax_Iowa, Tmin_Iowa, Precipitation_Iowa, days of summer temperature >35ºC (Iowa), total summer precipitation (Iowa), Tmax_Brazil, Tmin_Brazil, Precipitation_Brazil, days of winter temperature (for months of October and November) < 18ºC (Brazil), and total winter precipitation (Brazil)). The descriptive statistics for important variables are provided in Table 3. Before the analysis was carried out, a unit root test was conducted and the series showed stationarity with the Dickey fuller test, for both dependent variables. The lagged dependent variable, and the lagged price of ethanol used to estimate the export supply curve for Brazil are both included to control for serial correlation. Using the Durbin Watson statistic, Durbin h statistic for lagged dependent variable (Durbin, 1970), and the autoreg procedure in SAS to check for serial correlation, individual results were obtained for the export supply (Table 4) and import demand (Table 5) functions.

Table 3. Descriptive Statistics of market and climatic variables

Variable	Obs.	Minimum	Maximum	Mean	Std. Deviation
Price of ethanol ($/gal)	30	2.20	1.43	0.30	1.10
Net Brazilian exports (mn gal)	30	1352.36	248.27	341.66	2.64
Net U.S. imports (mn gal)	30	731.14	76.25	177.59	0.001
Price of sugar ($/lbs)	30	0.04	0.29	0.10	0.05
Price of corn ($/bu)	30	1.45	4.78	2.46	0.68
Price of oil ($/barrel)	30	10.87	94.04	27.78	19.24
Real GDP-Brazil per capita (real$)	30	3612.51	5210.18	4272.97	389.46
Exch. rate (real/$)	30	1.12	3.52	1.88	0.65
Tmax_Iowa (Celcius)	30	13.90	17.75	15.86	0.88
Tmin_Iowa (Celcius)	30	3.10	6.78	4.52	0.84
Prcp_Iowa (mm)	30	523.75	1418.23	911.07	181.15
Tmax_ Brazil (Celcius)	30	25.08	29.40	27.66	1.31
Tmin_ Brazil (Celcius)	30	12.73	18.80	16.86	1.42
Prcp_ Brazil (mm)	30	14.30	2218.75	1050.03	473.25

The reporting of R2 or the adjusted R2 is not advisable when using 2SLS, as they tend to be biased. The Hausman test of exogeneity showed a p-value, which is not significant at 95% confidence level, and this indicated the exogeneity of instrumental variables[1].

6. Results

The results from the econometric model indicate the impact and direction of the market and climatic variables on ethanol trade. From the estimation of Brazilian exports as the dependent variable in the export supply function, it is clearly evident that there exists a positive relation between exports and world price of ethanol, as mentioned in Table 4. This supports the assumption of trade model between large countries, that a favorable world price boosts exports. Also, since the equations are in log form, we can also obtain the price elasticity of export supply. As shown in Table 4, the own price elasticity of export supply is 2.62. Also, exports show a positive relation with exchange rate, as well as the real GDP of Brazil.

Table 4. Estimation of the Export Supply Function (*Et*) for Brazil

Parameter	Estimate	Approx. Std Err	Pr > |t|
Intercept	-24.6738	45.9501	0.5982
ln price of ethanol (-1)	2.6284	1.436	0.0848*
ln net Brazilian exports (-1)	0.6317	0.1793	0.0026**
ln price of sugar	0.3725	0.9343	0.6951
ln Exchange Rate	1.0737	1.0995	0.3425
ln real gross domestic product_ Brazil	0.7854	3.7772	0.8377
ln price of oil	-0.1571	0.6044	0.798
ln Tmax_Brazil	6.4020	6.4046	0.3315
ln Tmin_Brazil	-1.6753	2.273	0.4712
ln Prcp_ Brazil	-0.2822	0.2431	0.2617
ln days_tmin_winter_below18_ Brazil	0.6915	1.0653	0.5249
ln tot_prcp_winter_ Brazil	0.4708	0.5869	0.4335

Durbin ***h*** Statistic (Serial Correlation Test for lagged dep.) = 0.1845 Pr > h (0.4268)[2].
**significant at 0.05 level, *significant at 0.10 level.

[1] Hausman Test Statistic: 1.19, Pr > ChiSq: 0.9996: Indicates the instrumental variables are exogenous.
[2] Durbin ***h*** statistic is not significant with a *p*-value of 0.4268, indicating no autocorrelation.

With regard to the climatic variables, some interesting patterns are noticed. Ethanol exports show a positive correlation with annual average of daily maximum temperature, and a negative relation with the annual average of daily minimum temperature and precipitation. With regard to the seasonal variables, there exists a positive relation between exports and days of winter temperature below 18^0C, as expected. This is because during the harvest season, a lower temperature in sugarcane crop allows for sucrose accumulation, and increases the sugar content for ethanol production, as mentioned earlier. Also, there is a positive relation shown between total winter precipitation and exports. One of the important discussion points with regard to the export supply is that among the different market and climatic variables, only the lagged price of ethanol, and the lagged dependent variable are statistically significant at 0.05 and 0.10 significance levels. The statistically significant estimates for the above two parameters, indicate the strong impact of prices on the export supply, which is further enunciated by the fact that the export supply is price elastic as indicated by the price elasticity. Further, it is to be noted that although the climatic factors are also important in terms of influencing production in an exporting country like Brazil, the impact of these variables is more evident in an importing country like the U.S., which can be supported by the results for the import demand function, as described in Table 5 and the discussion that follows.

From Table 5, it can be noted that the signs of the coefficients in the import demand function are also as expected. There is a negative relation between imports and the world price of ethanol, and the own-price elasticity of import demand is -5.1216. Also, there is a positive relation between price of oil and the import demand. Further, the import demand shows a positive relation with the price of corn, which implies that as corn prices increase, it is cheaper to import fuel ethanol. Among the climatic variables, the import demand shows a negative relation with average annual daily maximum temperature and average annual precipitation. The average annual daily minimum temperature shows a positive relation with import demand. Among the seasonal variables, the import demand shows a negative relation with summer precipitation, which is also in accordance with the fact that higher summer precipitation, would lead to better corn yields, and therefore promote ethanol production and reduce dependence on imports. Also, there is a negative relation between numbers of days in summer exceeding 35 degrees and the import demand.

With regard to statistical significance among the market variables, only the price of oil was significant at the 0.05 level. Comparing with the export supply that showed no statistical significance with regard to oil prices, we can conclude that the prices of oil make a significant impact on the import demand when compared to the export supply. Also, the import demand is price elastic and the export supply is price inelastic with regard to oil prices. The climatic variables showed significant results with regard to the average annual daily minimum temperature in Iowa (at 0.05 level), and numbers of days in summer exceeding 35 degrees in Iowa (at 0.10 level). This finding indicates that minimum temperatures exert an important influence on corn production, which in turn impacts the import demand. Although literature cites that, higher temperatures lead to a reduction in corn yield, the climatic data for Iowa indicates that such an occurrence was very rare in the period of study, and therefore did not negatively impact the import demand.

From the above discussion, the conclusive findings suggest some important points. When compared to the export supply of ethanol for Brazil, the import demand of ethanol for U.S is significantly influenced by climatic changes, especially with regard to average annual minimum temperatures. Also both the export supply and the import demand of ethanol for Brazil and U.S respectively, are price elastic in nature. Further, the price of oil exerts a significant influence on the import demand when compared to the export supply.

Table 5. Estimation of the Import Demand Function (*It*) for U.S.

Parameter	Estimate	Approx. Std Err	Pr > |t|
Intercept	48.3837	36.6059	0.2012
ln price of ethanol	-5.1216	4.2691	0.2443
ln price of oil	4.81714	1.5284	0.005**
ln price of corn	0.2341	1.7921	0.8973
ln Tmax_Iowa	-15.469	10.2747	0.1478
ln Tmin_Iowa	6.3543	2.9101	0.0411**
ln Prcp_Iowa	-3.5329	3.076	0.2643
ln tot_summer_prcp_iowa	-0.4971	1.1292	0.6645
ln days_tmax_summer_above35_Iowa	-0.2991	0.1615	0.0788*

Durbin Watson Statistic (Serial Correlation Test) = 1.1083[3].
**significant at 0.05 level, *significant at 0.10 level.

CONCLUSION

The outcome of this research highlights the impact of both the market and climatic variables on ethanol trade between the U.S and Brazil, which are countries with large production, consumption, as well as exporting and importing capacities. The results suggest that climatic factors play an important role in the feedstock production for ethanol in these two countries. In South East Brazil, both low temperature and increased precipitation during winter, showed a positive relation with ethanol exports. With regard to import demand in U.S, it showed a negative relation with both increased summer precipitation, and days of summer exceeding 35^0C. The conclusive findings indicate that compared to the export supply of ethanol from Brazil, the import demand of ethanol for U.S. is significantly influenced by climatic changes, especially with regard to average annual minimum temperature and high summer temperature. Also both the export supply and the import demand of ethanol for Brazil and U.S respectively, are price elastic in nature. Further, the price of oil exerts a significant influence on the import demand when compared to the export supply.

This study provides an initial framework for developing future studies that incorporate multiple climatic variables besides temperature and precipitation, that impact plant growth and yields at critical stages of production. Also, it paves way for developing predictive models, using future climate projections for incidents of extreme weather events like drought, floods, and storms, to predict the movement of trade for bio fuel commodities like ethanol which use agricultural inputs as raw materials. This research will also be a motivation for

[3] Durbin Watson significance critical value (n=30 observations, 8 parameters): 0.854 (dL) and 2.141(dU). Test statistic falls within the limits, indicating no serial correlation.

conducting international trade policy studies for bio-fuels like ethanol by incorporating climate change variables. This is crucial as energy policies of developed countries will witness significant changes as they try to switch from fossil fuel intensive sources to alternative sources of energy like ethanol.

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