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*Full Length Research Paper*

# Evaluation of the environmental and economic effectiveness of soil and water conservation practices in Wenago District, Southern Ethiopia

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**Efforts towards soil and water conservation (SWC) goal were started since the mid-1970s and 80s to alleviate both the problems of erosion and low crop yield of Ethiopia. The data were collected through structured questionnaire via face to face interview with 120 sampled household (HH) from Karasodity and Deko villages of Wenago district. The data were analyzed using descriptive statistics and the Heckman two-step econometric estimation procedure. Family size, frequency of extension services, training, and types of SWC practices showed significance and positive relationship with environmental effectiveness (EP) of SWC practices. Access of input, age of the household head, livestock holding and land size were positively related with, and frequency of extension services, access of credit and total land to labor ratio were negatively related with effectiveness of SWC practices on economic level of household (ELHH). Total benefit of SWC practices showed negative relationship with ELHH and statistically significant at p<0.01. It indicated the fact that the benefits from investing in SWC practices accrue over time. There should be work to demonstrate the profitability through providing technical support, access to credit, and provision of efficiently working tools needed for the construction and maintenance of SWC practices.**

**Key words:** Soil and water conservation (SWC), environmental, economic, effectiveness, Heckman

## INTRODUCTION

Land degradation remains one of the biggest environmental problems worldwide, threatening both developed and developing countries and it has been a major global agenda because of its adverse impact on environment and food security and the quality of life (Slegers, 2008). Land degradation, poverty and food insecurity are pervasive and interconnected problems in Ethiopia (Holden and Shiferaw, 2004). Land degradation due to soil erosion and nutrient depletion is considered as the main problem constraining the development of the agricultural sector in Ethiopia (Amsalu and de Graaff, 2007; Tefera and Sterk, 2010).

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Since degradation of land has real economic, social, and human costs with substantial impacts on national economies, it also directly threatens the long-term growth of agricultural productivity, food security, and the quality of life, particularly in developing countries (Shiferaw et al., 2009). The problem is very serious particularly in steep lands where rain fed agriculture constitutes the main livelihood of the people (Hurni, 1988; Shiferaw and Holden, 2001). Recent studies in Ethiopia also indicated that land degradation is a dominant process at the bottom land of the watersheds where there is a saturated soil, in this part of the watershed the soil will be easily removed by sheet and rill erosion and the formation of gullies (Tebebu et al., 2010; Tilahun et al., 2013; Ayele et al, 2015)

Despite the severity of the problem, it is only very recently, in the past three decades, that land conservation has received policy attention in the country (Amsalu and de Graaff, 2007). Soil and water conservation (SWC) in Ethiopia is closely related to the improvement and conservation of biophysical environment, and ensuring sustainable development in agricultural sector and its economy at large (Abera, 2003). In Ethiopia, efforts towards this conservation goal were started since the mid-1970s and 80s (Bekele and Drake, 2003; Shiferaw and Holden, 1998). Since then, different soil and water conserving practices with a variety of approaches have been underway (Adugnaw and Desalew, 2013). The focus was conserving soil, rainwater and vegetation effectively for productive uses, harvesting surplus water, rehabilitating and reclaim marginal lands through appropriate conservation measures and mix of trees, shrubs and grasses based on land potential (Lakew et al., 2005). Effective SWC practices, including physical and biological, are of substantial benefit for attaining and sustaining food security in smallholder farming, through the successful rehabilitation and management of natural resources (Kebede et al., 2013).

Recognizing the threat of land degradation and benefits of SWC practices, the government of Ethiopia is promoting SWC technologies for improving agricultural productivity, household food security and rural livelihoods (Shiferaw and Holden, 1998; Amsalu, 2006, Teshome et al., 2016). The continued use of SWC seemed mainly determined by the actual economic profitability and environmental benefits, and determinant factors for effectiveness.

The positive effects of soil and water conservation (SWC) occur through time and practicing of SWC technologies depends on the ability of the technologies to improve economic and environmental benefits. While there is a bulk of information regarding the adoption of SWC practices, little information is documented on the economic and environmental benefits of the various SWC practices implemented in the study area. The evaluation of the effectiveness of these SWC practices that are alleged to enhance productivity is very important in order to evaluate their performance in reducing land degradation and rehabilitating the land (Yitayal and Adam, 2014). Evaluating the impact of past efforts and proper understanding of the improvement in the livelihood of smallholder farmers' is essential to draw lessons and improve the efficiency of the SWC practices. Therefore, the main objective of the study was to evaluate the environmental and economic effectiveness of SWC practices in Wenago district, Southern Ethiopia.

## METHODOLOGICAL APPROACH

### Description of the study area

The research was conducted in Wenago district, Gedeo Zone, Southern Ethiopia, located at 375 km South of Addis Ababa, the capital of Ethiopia (Figure 1). The District is sub divided into 17 administrative rural kebeles (villages) (GZFES, 2005). Among the village, the study was conducted in Karasodity village and Dako village from April 2015 to March 2016.

### Sample size and data collection methods

A two-stage sampling technique was used when selecting respondents. In the first stage, two kebeles (Karasodity and Deko) were selected purposively based on experience of implementing SWC practices. These numbers of kebeles were considered to be sufficient for drawing valid statistical inferences and manageable to be surveyed with the available finance and time. From each Kebele, one sub watershed was selected purposely based on availability of SWC practices and degraded land adjacently. SWC practices were implemented since 2009 for the purpose of land rehabilitation and to control further degradation through soil erosion by the district and village agricultural offices through mobilizing the community. Majority of the physical SWC practices constructed were soil bunds, fanya juu, half-moons, trenches, micro basins, and cut off drain in area closures, grazing and fallow land. Similarly, the commonly practiced biological SWC include maintaining natural vegetation and tree plantation in area closures, plantation of valley bottoms, and stabilization of physical structures using natural vegetations, vetiver grass and elephant grass. At the second stage, a total of 120 household heads were selected using random sampling technique. The sample comprised of 56 HHs from Karasodity and 64 HHs from Dako Kebele who were within the sub watersheds (30% of total HH from each). Both secondary and primary data were used for this study. The primary data were collected from sample respondents through a structured questionnaire via face to face interview with the heads or working members of households and focus group discussion. The secondary data were collected from district and village agriculture offices.

### Analytical methods

The qualitative and quantitative data were analyzed using descriptive statistics and econometric model. Descriptive statistics such as mean, standard deviation and percentage were used along with the econometric model to analyze the collected data, and SPSS version 20 and STATA version 11 were used for this purpose.

Econometric model was used to assess the environmental and economic performance of SWC practices. The factors that affected

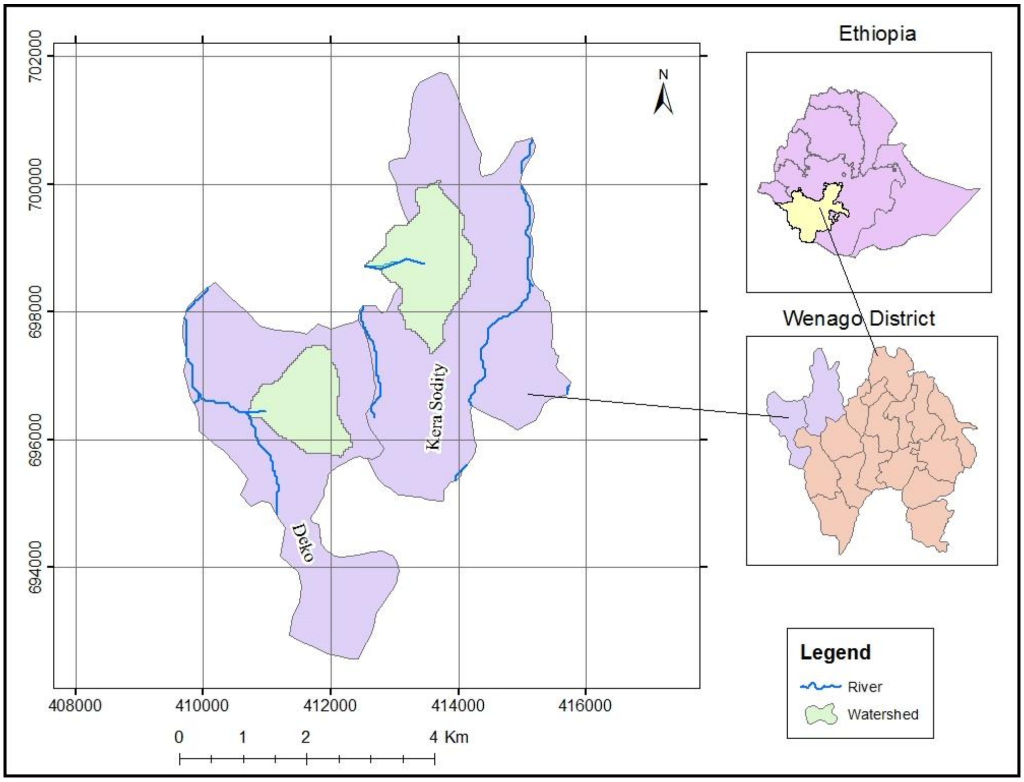


**Figure 1.** Location of the study area.

EP were family size of the household (FS), frequency of extension service (FEXSR), training (TR) and type of SWC practices. Whereas the factors considered to evaluate economic level of HH were access of input (ACCIP), total benefit of SWC (TPSWC), age of the household head (AGHH), livestock holding (LIVSTOCK), land size, frequency of extension services (FEXSR), access of credit (ACCR) and total land to labor ratio.

The Heckman two-step econometric estimation procedure was employed to assess environmental and the economic effectiveness of SWC practices. The first step of the Heckman model was an 'environmental performance'. This equation was used to construct a selectivity term known as the 'inverse Mills ratio' which is added to the second step 'outcome' equation that explains economic level of the household. The inverse Mill's ratio is a variable for controlling bias due to sample selection (Heckman, 1979). If the coefficient of the 'selectivity' term is significant then the hypothesis that an unobserved selection process governs the participation equation is confirmed. Moreover, with the inclusion of extra term, the coefficient in the second step 'selectivity corrected' equation is unbiased. Specification of the Heckman two-equation procedure, which is written in terms of the probability of environmental performance (EP), and economic level of the household (ELHH), is:

The participation equation/the binary probit:

$$Y_{i1} = X_{1i}\beta_1 + U_{1i}; U_{1i} \approx N(0,1) \quad (1)$$

EP = 1 if $y_{1i}>0$

EP = 0 if $y_{1i} \leq 0$

Where: $Y_{1i}$ = the latent dependent variable, which is not observed. $X_{1i}$ = vectors that are assumed to affect the probability of sampled household environmental performance. $\beta_1$ = a vector of unknown parameter in environmental performance equation. $U_1$ = residuals that are independently and normally distributed with zero mean and constant variance. EP = environmental performance. ELHH = economic level of the household.

### The observation equation

$$\text{ELHH} = Y_{2i} = X_{2i}\beta_2 + \alpha\lambda_i + U_{2i}; U_2 \approx N(0, \delta 2) \quad (2)$$

Where: $Y_{2i}$= observed if and only if EP =1. The variance of $X_{2i}$ is normalized to one because only EP, not $Y_1$ is observed. The error terms, $U_1$and $U_2$ are assumed to be bivariat and normally distributed. $Y_{2i}$= regressed on the explanatory variables, $X_{2i}$ and the vector of inverse Mills ratios $\lambda_i$ from the selection equation by ordinary least Squares (OLS). $Y_{2i}$ = the observed dependent variable.

$X_{2i}$ = factors assumed to affect the economic level of the household. $\beta$ = vector of unknown parameter in the economic level of the household equation. $U_{2i}$ = residuals in the observation equation that are independently and normally distrusted with zero mean and variance $\delta^2$.

$$\text{Mill ratios } (\lambda_i) = \frac{F(X_1\beta_1)}{1-F(X_1\beta_1)} \quad (3)$$

Where: $X\beta$ = a density function and $1-F(X_1\beta_1)$ = distribution function.

An econometric Software known as STATA version 11 was

**Table 1.** The summary of definition and measurement of variables in the model.

| Variable name | Description | Expected sign (Relationship) |
|---|---|---|
| **Dependent variable** | | |
| EP | Environmental effectiveness of SWC practices; 1 if a HH is practicing SWC measures continuously, 0 otherwise | |
| ELHH | Economic level of HH : It is continuous dependant variable in the second step of Heckman selection equation | |
| **Independent variable** | | |
| FS | Family size of the household; Number of people in the HH | ± |
| LIVESTOCK | Livestock holding measured in TLU | ± |
| FEXSR | Frequency of extension services; a dummy variable that takes a value of 1 if the household head has access extension service and 0 otherwise. | + |
| TR | Training on SWC received by the farmer; 1 if a HH got training and 0 otherwise | + |
| TPSWC | Types of physical soil water conservation; 1 if a HH practiced physical SWC and 0 otherwise | + |
| TBSWC | Types of biological soil water conservation; 1 if a HH practiced biological SWC and 0 otherwise | + |
| ACCIP | Access of input; 1 if the HH got input for practicing SWC and otherwise 0 | + |
| TPSWC | total benefit of soil water conservation, 1 if yes and 0 otherwise | + |
| AGHH | Age of the household head in years | ± |
| LAND SIZE | HH Landholding in hectare | ± |
| ACCR | Access of credit, 1 if the HH obtained credit and 0 otherwise | + |
| TLLR | Land to labor ratio is measured as the ratio of the area operated to the number of family members (in man-equivalent) | - |
| FI | Farm income | + |

employed to run the Heckman two-step selection model. Before fitting important variables in the Heckman two-step selection model it was necessary to test multicolinearity problem. As Gujarati (2003) indicated, multicolinearity refers to a situation where it becomes difficult to identify the separate effect of independent variables on the dependent variable because of the existing strong relationship among them. In other words, multicolinearity is a situation where explanatory variables are highly correlated.

Multicolinearity was tested using variance inflation factor (VIF) of the variables which is defined as $VIF = \frac{1}{1 - R_{j2}}$. For each coefficient in a regression as a diagnostic statistic is used. $R_{j2}$ Represents a coefficient of determination the subsidiary or auxiliary regression of each independent continuous variable X. As a rule of thumb, Gujarati (2003) stated that if the VIF value of a variable exceeds 10, which will happen if $R_{j2}$ exceeds 0.90, then, that variable is said to be highly collinear. Therefore, for this study, VIF was used to detect multicolinearity problem for continuous variables. On the other hand, for dummy variables contingency coefficient was used.

#### *Definition of study variables and working hypothesis*

**Environmental performance (EP):** It is a dummy variable that represents the probability of environmental performance of the study area. For the household participated in biological and physical SWC practices takes the value of 1 where as it takes the value of 0 for the household having low biological and physical SWC practices performance.

**Economic level of the household (ELHH):** It is continuous dependent variable in the second step of Heckman selection equation. It is measured in terms of birr (1birr = 0.046US$) of the households which is selected for regression analysis and takes positive values.

Wide range of factors influences environmental and economic effectiveness of SWC practices. Hence, potential independent variables that can influence effectiveness of SWC are identified and they are presented in Table 1.

#### *Model specification of economic level of HH*

$$ELHH = \beta_0 + \beta_1(ACCIP) + \beta_2(TPSWC) + \beta_3(AGHH) + \beta_4(LIVESTOCK) + \beta_5(LS) + \beta_6(FEXSR) + \beta_7(ACCR) + \beta_8(LLR) + \beta_9(FI) \quad (4)$$

ELHH = Economic Level of household, ACCIP = access to input, TPSWC = total benefit from soil and water conservation, AGHH = age of house hold, LIVESTOCK = livestock holding, FS = family size, FEXSR = frequency of extension service, ACCR = access to credit, TLLR = total land to labor ratio and FI = farm income)

## RESULTS AND DISCUSSION

### Descriptive statistics

The average household family size was 7.81 persons. The survey result indicated there was significant difference in the family size of the HHs. The mean age was 37.56 years. The HH (household head) age has significant role on the performance of the SWC practices. It could be due to HH with higher age often associated with long years of farming experience to invest more in

**Table 2.** Some of HH socioeconomic characteristics.

| Variable | Mean | Standard deviation | t-value |
|---|---|---|---|
| Age of the household (year) | 37.56 | 9.23 | 36.33 |
| Livestock (TLU) | 6.01 | 3.19 | 16.82 |
| Non-farm income (ETB) | 688.64 | 470.3 | 13.09 |
| Farm income (ETB, Ethiopian birr) | 708.30 | 187.93 | 21.91 |
| Family size (person) | 7.81 | 2.5 | 27.12 |
| Total land to labor (total land per FS) | 0.03 | 0.02 | 14.38 |
| Frequency of extension services | 2.59 | 1.07 | 21.5 |
| Market distance (km) | 20.24 | 7.95 | 22.74 |
| Total land allocated (ha) | 0.24 | 0.13 | 16.39 |

Source: Own Survey data, 2016.

**Table 3.** Determinants of probability of environmental performance.

| Variable | Coef. | Std.err | Z | P>/Z/ | $\frac{dy}{dx}$ (Marginal effect) |
|---|---|---|---|---|---|
| FS | 0.332 | 0.259 | 1.96 | 0.0201** | 0.342 |
| FEXSR | 0.731 | 0.309 | 2.36 | 0.018** | 0.186 |
| TR | 0.958 | 0.577 | 1.66 | 0.097* | 0.0019 |
| TPSWC | 0.33 | 0.317 | 1.96 | 0.020** | 0.023 |
| TBSWC | 11.62 | 0.754 | 8.91 | 0.000*** | 3.27 |

Number of observations = 120 Prob> $\chi^2$ = 0.0000, LR $\chi^2$ (14) = 450.76, Pseudo $R^2$ = 0.2068, Log likelihood = -864.42. ***, ** and * represents significance at 1, 5 and 10% probability levels, respectively. Source: Model output of Own Survey data, 2016.

conservation (Teshome et al., 2013).

The average non-farm income was ETB 688.64 and the farm income ETB 708.30 (Table 2). The sources of income for sample households come from both farm and nonfarm activities. Farm income consists of both incomes from sales of livestock and livestock products and from sales of crops. Non-farm income sources are mainly from petty trade at local market places and daily works.

In the survey area, the average land allocated for production of crops is 0.24 ha per household. There is significant variation in the size of landholding among households. The landholding of farmers in the study area is very small. It is clear that the propensity of retaining conservation structures increases with increasing availability of land resources. The average livestock holding of households in the study area is 6.01 TLU. Cattle, sheep, goats and poultry are the main livestock reared by sample households in both districts. Few equines (mostly donkeys) are also reared in the study area. Distance to market and an all-weather road, which was a proxy for market accessibility was found to have a positive and significant influence on intensity of SWC technology practicing.

## Environmental and economic effectiveness of the SWC practices

Econometric model was used to assess the economic and environmental performance of biological and physical soil and water conservation practices. The factors that affected environmental performance in one hand affected economic level of the household in the other hand.

### *Environmental performances*

**Family size of the household (FS):** As expected, this variable was statistically significant at less than 1% probability level and had a positive effect on the environmental performance (Table 3). The positive and the significant relationship indicated that as the number of family increases some may involve and might reduce labor constraints needed for the construction and maintenance of conservation measures. The marginal effect of the variable also confirms that for every increase in adult equivalent in the household, the probability of improvement of environmental performance increase by 34.2% (Table 3). Teshome et al. (2016) suggested that households who have more persons fulltime involved in agriculture are more likely to invest in and maintain SWC practices. This can be explained by the fact that labor inputs constitute the largest cost factors for SWC line interventions. This result is in agreement with Kebede and Mesele (2014) who reported the positive effect of age shows that with increasing age, farmers accumulate experience about the importance of land management. Similarly, larger family size leads to a lower land-man ratio, which normally should make investment in SWC more attractive (Bekele and Drake, 2003).

**Frequency of extension services (FEXSR):** As expected, this variable had positive relationship with environmental performance and statistically significant at 5% probability level (Table 3) The positive and significant correlation of contact with extension agents in this study implies that farmers having contacts with extension agents tend to understand the problem of soil erosion and the benefits of conservation measures on environment and they are more likely to continually use conservation structures (Adugnaw and Desalew, 2013). Contact with extension services enables farmers to have access to information on new innovations and advisory inputs on establishment and management of technologies.

**Training (TR):** As expected, this variable was statistically significant at less than 10% probability level and had a positive effect on the environmental performance (Table 3). Training delivered by development agents and district experts is one means to create awareness about the problems of erosion and the benefits of SWC measures to motivate farmers to invest in SWC measures. This result is consistent with Teshome et al. (2016) who reported training on SWC is positively related to the actual and final adoption phases of SWC measures, and further revealed that technical support (availability of training and SWC programs) influenced the continued use of SWC measures. The result of the marginal effect indicates that a unit increase in training would increase the probability of the environmental effectiveness of SWC measures by 0.19 %.

**Types of physical soil water conservation (TPSWC):** As expected, this variable had positive relationship with environmental performance and statistically significant at 5% probability level.

**Types of biological soil water conservation (TBSWC):** As expected, this variable had positive relationship with environmental performance and statistically significant at less than 1% probability level. This implies the SWC practices reduced soil erosion, enhanced soil fertility, encouraged water retention and facilitated the growth of vegetation. This result is in agreement with study of Akalu et al. (2014) who revealed that SWC practices have ecological, economic and social benefits. The finding is in line with Kirubel and Gebreyesus (2011) who reported that after the implementation of different SWC measures improves the micro climate of the area as a result of increasing vegetation cover. This is because of increasing vegetation cover in the sub watersheds, which is a direct reflection of the improvement of available water and soil fertility in the area for the greenness of the environment. The result of Amsalu (2006) indicates that farmers were encouraged to continue to use SWC practices perhaps due to effectiveness of the measure in erosion control on steep slopes.

***Economic performance SWC practices***

Studies made on farmers' decision on continued use of soil conservation structures and related theories indicated that wide range of social, demographic, socioeconomic, physical and institutional factors influence effectiveness (Table 4).

**Access of input (ACCIP):** As expected, this variable had positive relationship with household biological and physical soil and water conservation practices and statistically significant at less than 1% probability level (Table 4). Access to input would enhance implementation of soil and water conservation. This implies, as input, SWC tools needed for the construction of SWC measures (e.g., shovels, spades), seed and seedlings for plantation of biological SWC measures. The availability of efficiently working (conservation) tools is also a prerequisite for construction and maintenance of SWC measures (Teshome et al., 2016).

**Total benefit of soil water conservation (TPSWC):** Unexpectedly, this variable had negative relationship with SWC practices and statistically significant at less than 1% probability level. It indicates the fact that the benefits from investing in SWC practices accrue over time. The SWC practices are sometimes not profitable (economically performing) from a private-economic point of view (Kassie et al., 2011; Adimassu et al., 2012). This is because the ecological and social benefits of SWC practices were not quantified in monetary values (Teshome et al., 2014). This implies that these SWC practices are more technically effective than economically efficient (Amsalu and de Graaff, 2007). As Anteneh et al. (2014) noted, to ensure continued use, the conservation component must be profitable to the farmer. Particularly, farmers are very curious about the yield effect of the technology since the structures take up productive land, and maintenance is often labor intensive and costly. In addition, Yitayal and Adam (2014) conclude that SWC interventions may not result in significant improvement on crop productivity and income and hence there is a need to critically evaluate such a program regularly

**Age of the household head (AGHH):** It was a continuous variable measured in number of years. As expected, this variable had a positive relationship with biological and physical soil and water conservation practices and it was found to be statistically significant at less than 1% probability level. The positive and significant relationship indicates that age is a proxy measure of farming experience of household. Therefore,

**Table 4.** Determinants of economic level of the household in the study area.

| Variable | Coef. | Z | P>/Z/ |
|---|---|---|---|
| ACCIP | 0.06 | 2.33 | 0.020** |
| TPSWC | -0.039 | -2.27 | 0.023** |
| AGHH | 0.080 | 4.19 | 0.000** |
| LIVESTOCK | 0.110 | 2.38 | 0.017** |
| LAND SIZE | 15.62 | 8.91 | 0.000*** |
| TOTAL LAND TO LABOR | -124.43 | -11.29 | 0.000*** |
| FEXSR | -0.251 | -1.85 | 0.064* |
| ACCR | -0.364 | -2.19 | 0.029** |
| FI | 0.301 | 1.74 | 0.082* |

Number of observation =120, Censored observation = 38, Uncensored observation = 82 Wald; $\chi^2$ (13) =1509.85, $R^2$ =0.945, Adj $R^2$=0.939. *, ** and *** represents significance at 10, 5 and 1% probability levels, respectively. Source: Model output of Own Survey data, 2016.

as the age of household increase, they would have better knowledge, experience. Similarly, Kebede and Mesele (2014) reported the positive effect of age shows that with increasing age, farmers accumulate experience about the importance of land management. The study of Amsalu and de Graaff (2007) indicated that the likelihood of adoption of conservation practices is more among older farmers than the younger ones, perhaps due to the experiences of older farmers to perceive erosion problems and their limited participation in off-farm activities.

**Livestock:** As expected, this variable had positive relationship with SWC practices and statistically significant at less than 1% probability level. This variable represents the livestock holding of the household in tropical livestock unit. The number of cattle, an indication of economic security, had a positive influence on performance of SWC. Livestock ownership is an important component of the farming system in the area since farming is integrated with crop and livestock production. Therefore, the fact that livestock is considered as an asset that could be used in the production process or exchanged for cash or other productive assets suggests a positive influence on conservation decision (Bekele and Drake, 2003). Our study result is inconsistent with Shiferaw and Holden (1998) who indicated more specialization into livestock away from cropping may reduce the economic impact of soil erosion and lower the need for soil conservation. Amsalu and de Graaff (2007) also showed that the effect of livestock on conservation decision is negative. On the other hand, those farmers who have large number of livestock may have more capital to invest in soil conservation practices. The results of Amsalu and de Graaff (2007) showed that the effect of livestock size with SWC practice decision was significantly negative. Large livestock size discourages conservation investments, perhaps due to the tendency of households to focus more on livestock than on crop production. In addition, temporal yield gains through manure application might reduce potential productivity losses due to erosion, and thus reduce conservation efforts.

**Land size:** As expected, this variable had a positive sign and significant at less than 1% level. The effect of cultivated land size is found to be positive and significant on the performance of SWC. Land shortage which partly aggravated the land degradation problem, because of population pressures on the natural resources base might lead to further land fragmentation, over-grazing, deforestations, steep slope cultivation and absence of fallowing, which in turn increase the accelerated soil erosion. Amsalu and de Graaff (2007) found positive and significant, suggesting that farmers who hold large farms are more likely to invest in conservation. As Teshome et al. (2016) indicated that the potential loss of land for SWC and temporal yield decline do not constrain SWC for large holdings.

**Frequency of extension services (FEXSR):** This variable had negative relationship with economic performance of SWC practices and statistically significant at 10% probability level. The negative and significant correlation of contact with extension agents in this study implies that farmers having fewer contacts with extension agents tend to understand the problem of soil erosion and the benefits of conservation measures and they are more likely to continually use conservation structures. But farmers with better access to information would be more willing to invest in soil conservation measures (Tesfaye et al., 2016). Kebede and Mesele (2014) reported development agents negatively influenced the continued use of SWC technologies by farmers due to their involvement in activities such as rural land-tax estimation. Farmers hesitate to contact the DAs, and thus are less likely to accept the technology to improve the economic effectiveness of SWC practices.

**Access of credit (ACCR):** As expected, this variable had negative relationship with SWC practices and statistically significant at 5% probability level. This indicated the farmers had no access to credit. Tenge et al. (2007) reported that availability of credit facilities is an important incentive for farmers to invest on SWC measures. The study of Tesfaye et al. *(*2016) shows that awareness raising among farmer communities with respect to the benefits of sustainable land use management seems crucial. In another study by Tesfaye et al. (2014) report that among the main driving forces behind farmers' decision to implement soil conservation measures are access to credit to pay for the initial investment costs.

**Total land to labor ratio (TLLR):** As expected, this variable had a negative sign and significant at less than 1% level. Land to labor ratio measured as the ratio of the area operated to the number of family members engaged in farming is used as an indicator of the population pressure. Households with lower land to labor ratio may have incentives to invest in soil conservation. Labor is also one of the crucial inputs for the implementation of soil conservation measures (Tesfaye et al., 2014). The amount of farm labor has an influence on the actual and maintenance of SWC measures. This suggests that households who have more persons fulltime involved in agriculture are more likely to invest in and maintain SWC measures. This can be explained by the fact that labor inputs constitute the largest cost factors for SWC interventions. Derjew et al. (2013) found that higher land labor ratio had negative influence on the use of conservation technologies negatively. Therefore, in this study it is found that higher land to labor ratio negatively related to the use of improved soil conservation technologies.

**Lambda:** According to the model output, the Lambda (Inverse Mills Ratio) or selectivity bias correction factor has positive, but statistically insignificant impact on economic level of the household.

**Rho:** Is the correlation between the error terms of the substantive and selection models. Rho has a potential range between -1 and +1 and can give some indication of the likely range of selection bias. A correlation with an absolute value of 1 would occur if the regression coefficients of the selection model and the regression coefficients of the substantive model were estimated by identical processes (that is, potential selection bias). Conversely, a value of rho closer to zero would suggest that data are missing randomly or the regression coefficients of the selection model and the regression coefficients of the substantive model were estimated by unrelated processes (that is, less evidence of selection bias) (Cuddeback et al., 2004).

## CONCLUSION AND RECOMMENDATION

The Heckman two-step econometric estimation procedure was employed to assess the economic and environmental performance of SWC practices. The study was conducted to evaluate the environmental and economic effectiveness of SWC practices. SWC practices showed statistically significant and positive effect on the environmental effectiveness. Total benefit from SWC practices showed negative relationship with economic level of household. It indicates the fact that the benefits from investing in SWC practices accrue over time. Since farmers would likely continuously use SWC practices if the technology is profitable, the agriculture and natural resources office of the district should work to demonstrate the profitability of the measures. Development agents should practically show how conservation practices increase productivity and profitability by improving their approach. There should be consideration of the determinants affecting environmental and economic effectiveness of SWC such as profitability of SWC practices, social mobilization skill development agents, technical support, access to credit, and provision of efficiently working tools needed for the construction and maintenance of SWC when designing and implementing SWC practices from stakeholders.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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# Economy-wide effects of drought on South African Agriculture: A computable general equilibrium (CGE) analysis

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**South Africa's agricultural sector is comprised of livestock, field crops and fruit in their order of size, in gross value terms. Agriculture in South Africa accounts for a relatively low share in the economy (3% of gross domestic product - GDP), 6% of employment and about 10% of exports (over R144 billion in 2015). Currently (2015/16), South Africa is experiencing the worst drought in over 100 years, which has resulted in significant effects on agriculture, with eight of the nine provinces being declared disaster areas. The motivation of the study was to understand the severity of drought on agriculture as well the impact on the whole economy (to quantify the economy-wide effects/losses emanating from the drought). To quantify these effects a single-country computable general equilibrium (CGE) model was used. Four scenarios were developed: Impact of field crops losses; impact of livestock losses; impact of aggregated agriculture losses; and impact of aggregated agriculture losses plus drought relief. The analysis shows that all scenarios led to a negative impact on GDP, employment and exports while the drought relief was found to have saved some jobs, albeit not significantly.**

**Key words:** Drought, computable general equilibrium (CGE) model, field crops, livestock and fruit, GEMPACK.

## INTRODUCTION

Based on gross value of production, South Africa's agricultural sector is comprised of livestock (e.g. beef, poultry, game, sheep and others) as the biggest sub-sector, followed by field crops (e.g. maize, wheat, sugar, beans, barley, sorghum and oilseeds) and fruit (e.g. fruits, nuts, flowers and vegetables). Agriculture accounts a relatively small share in the economy (3% of GDP), 6% of employment and about 10% of exports (over R144 billion in 2015) (StatsSA, 2015). From a developmental viewpoint, agriculture plays a pivotal role in ensuring food security and providing jobs for low skilled people in the country. Furthermore, agriculture provides raw materials to secondary sectors such as manufacturing and retail which reduces the country's dependency on international

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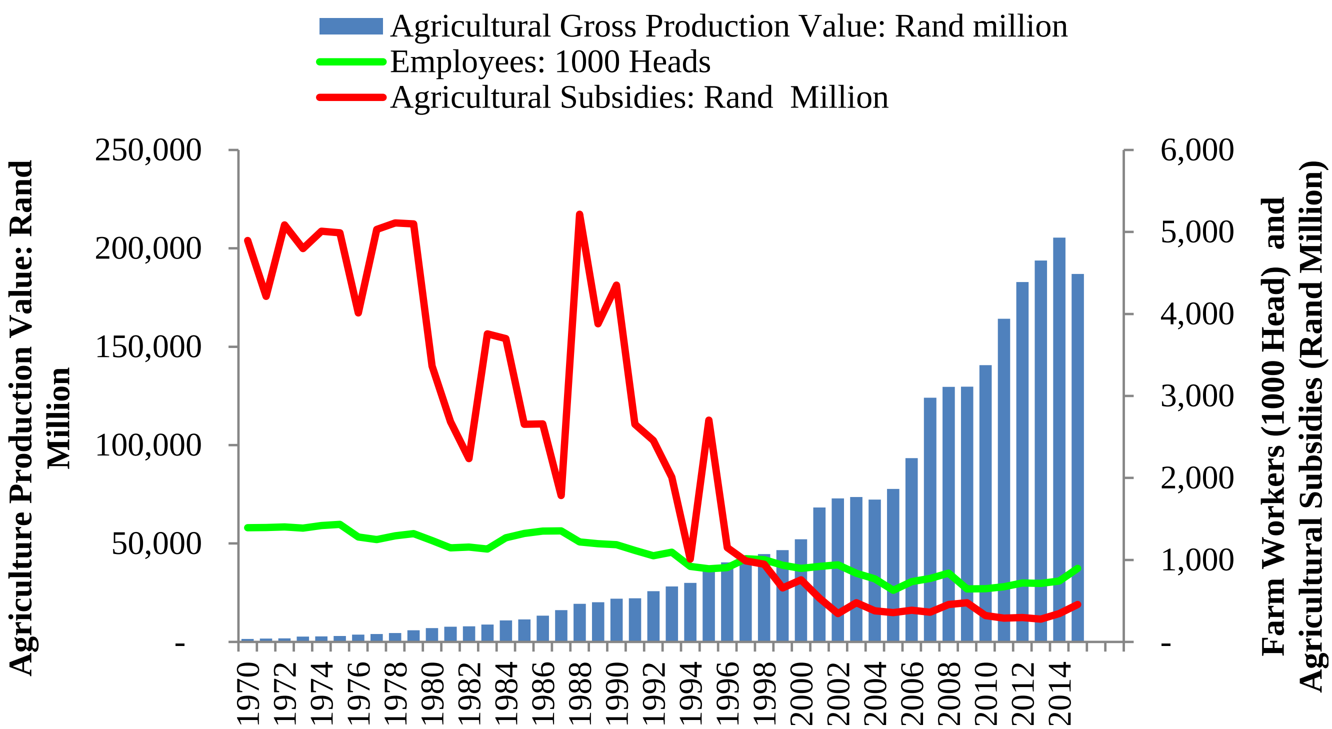


**Figure 1.** South African agricultural trends (production value, employment and subsidies). Source: Adapted from DAFF (2016) and Liebenberg (2013).

markets. Thus any disturbance on the agricultural sector will not only affect food security in the country but it will also affect the competitiveness of secondary sectors and tertiary sectors in the South African economy. Currently (2015/16), South Africa is experiencing the worst drought in over 100 years, which has resulted in significant effects on agriculture, with eight of the nine provinces being declared disaster areas. This drought has resulted in a number of livestock losses, cereal crop losses and in fruit losses. Direct losses, as presented in the simulations, alone amount to billions of Rands. Therefore, this paper seeks to quantify the socio-economic impact of drought on agriculture within a broader context of the economy.

The rationale of conducting the study is to inform policy makers of the economy-wide effects of drought in South Africa focusing on food security impacts, job losses and value lost due to drought. Parallel to evaluating the drought effect, the study also evaluates the drought relief program implemented by government to assist farmers to cope with drought. To better capture the impact, a single-country static computable general equilibrium model - more specifically, the University of Pretoria General Equilibrium Model (UPGEM) model - was used. The approach taken here was used in earlier studies such as Dixon and Rimmer (2002) and Bohlmann et al. (2015). The results show that the economy stands to lose or loses because of drought; the impact on macroeconomic variables, including exports, is minimal but negative.

## OVERVIEW OF THE AGRICULTURAL SECTOR IN SOUTH AFRICA

South African agriculture has experienced significant structural changes over the last 30 years fueled by policy reforms that took place in the mid-1990s. The liberalization of agricultural markets in 1996 provided access to various global markets and consequently stimulated agricultural output, which grew from R52.186 billion in 2000 to over R193 billion in 2013 (Figure 1). Liebenberg (2013) argues that production growth during this period was due to export growth in Europe and Asian markets. Figure 1 also shows trends in farm employment and subsidies. Over the reviewed period, farm employment declined from nearly 1.42 million in the mid-1970s to less than 900 thousand by 1995 and further declined to less than 750 thousand in 2013. Agricultural subsidies have also showed a significant decline from the mid-1980s to 2015 caused by South Africa's trade and market reforms that reduced agricultural protections that is, tariff reduction and agricultural subsidies.

The reduction on agricultural support has exposed agriculture to external shocks such as drought. Smallholder farmers have limited access to irrigation water and possess poor farm infrastructure. As a result of limited farm infrastructure, their capability to withstand drought is very minimal, hence, the current drought has displaced over million smallholder farmers (DAFF, 2016).

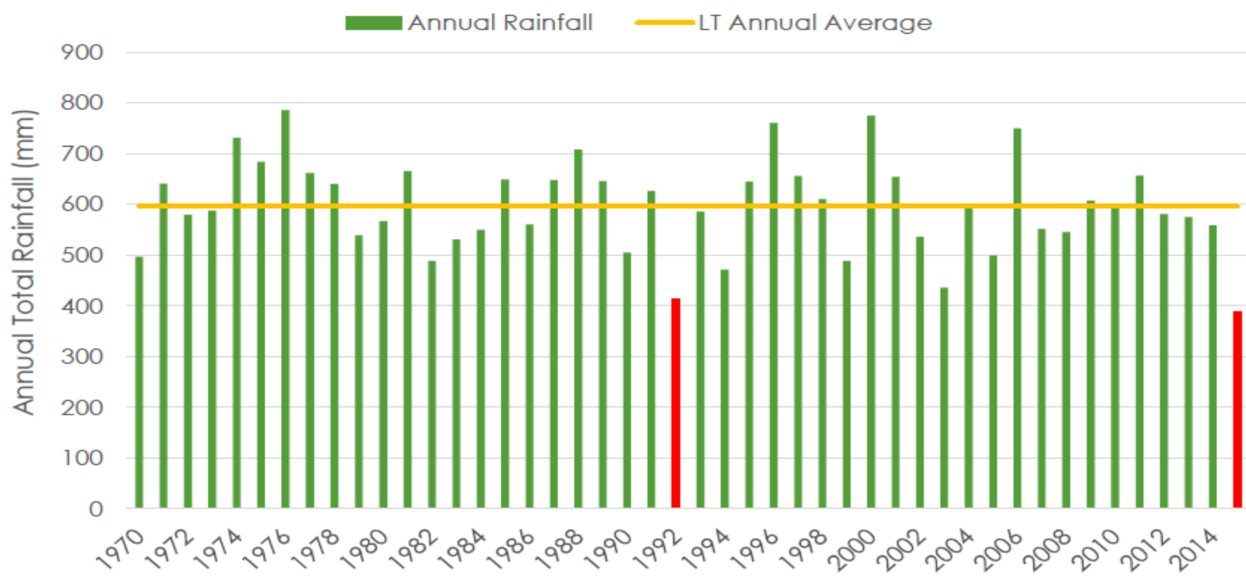


**Figure 2.** South African Annual rainfall. Source: Adapted from BFAP (2016).

Figure 2 shows a trend in the annual rainfall in the country between 1970 and 2015. It is evident that the rainfall received in 2015 season was the lowest throughout the reviewed period. The need to understand the severity of drought on agriculture as well as on the economy as a whole is drawing attention from researchers and policy makers in the country. To better capture the effect of drought on agriculture in the broader economic contexts, a general equilibrium framework is adopted in this study.

## METHODOLOGY

Computable general equilibrium (CGE) models are well-suited to analysing policy questions such as the economy wide impact of drought on agriculture. There are two types of CGE models depending on the number of regional accounts the model has. In cases where there is one regional account the models are known as single country CGE models (for example the UPGEM model) while with two or more regional accounts the model is known as a multi country CGE model (for example the GTAP model). The strength of CGE methodology lies in its ability to capture the various inter-linkages in the real economy in great detail. This inter-linkages ability provides CGE models with a certain advantage over any partial equilibrium models often used in economic analyses of the agricultural sector in South Africa and worldwide. Since data for only one reference year is required for the initial solution to the model, more detail is usually able to be incorporated in the analysis compared to many other econometric methods that require large time-series datasets in order to produce robust simulation results. The large amount of detail to be specified for the agriculture sector in this study, capturing its cost and sales structures along with a number of behavioural parameters, combined with the policy questions within the sector to be addressed in this study, makes CGE the method of choice.

CGE models have also been established as a superior methodology to Input-Output or SAM multiplier models, despite being based on the same underlying set of national accounts (Bohlmann et al., 2015). The ability of CGE models to accurately reflect resource constraints and the impact of relative price changes in the economic decision making process, and ultimately the structure of the economy, are of significant importance in conducting accurate and credible policy analysis.

CGE methodology has been applied in numerous studies to quantify the impact of various shocks to macroeconomic variables in many countries, and a few of these are mentioned next. Berrittella et al. (2004) used a multi-country world CGE model (the GTAP Model) to study the economic implications of climate change-induced variations in tourism demand. Bigano et al. (2006) applied the CGE model to quantify economy-wide effects of two climate change impacts namely, sea-level rise and tourism flows. In a study by Bassanini et al. (1999), a CGE model was applied to simulate the impact of the introduction of an employment conditional scheme in four OECD countries. Using a single-country, static CGE model, Jaafar et al. (2011) quantified the economic impact of pollution tax on the Malaysian economy under the backdrop of trade liberalization. Kaempfer et al. (2007) used a CGE model to examine the consequences of the tariffication of a quota when there are several potential distortions present in a country, including domestic monopoly and wage rigidities.

The UPGEM model used in this study runs on General Equilibrium Modelling Package (GEMPACK) software unlike most other CGE models that run on General Algebraic Modelling System (GAMS) software. This study does not provide a detailed comparison between software packages. A detailed comparison of software packages is documented in Horridge et al. (2013). Also, a detailed explanation of the theory and the structure of the UPGEM model as well as the database was documented in Bohlmann et al. (2015) and Ntombela and Bohlmann (2016).

### Description of the model

According to Adams (2005), there are four basic tasks that distinguish a CGE based analysis from other types of analyses. First, with regards to the theoretical derivation and description of the model, the general equilibrium core of UPGEM is made up of a

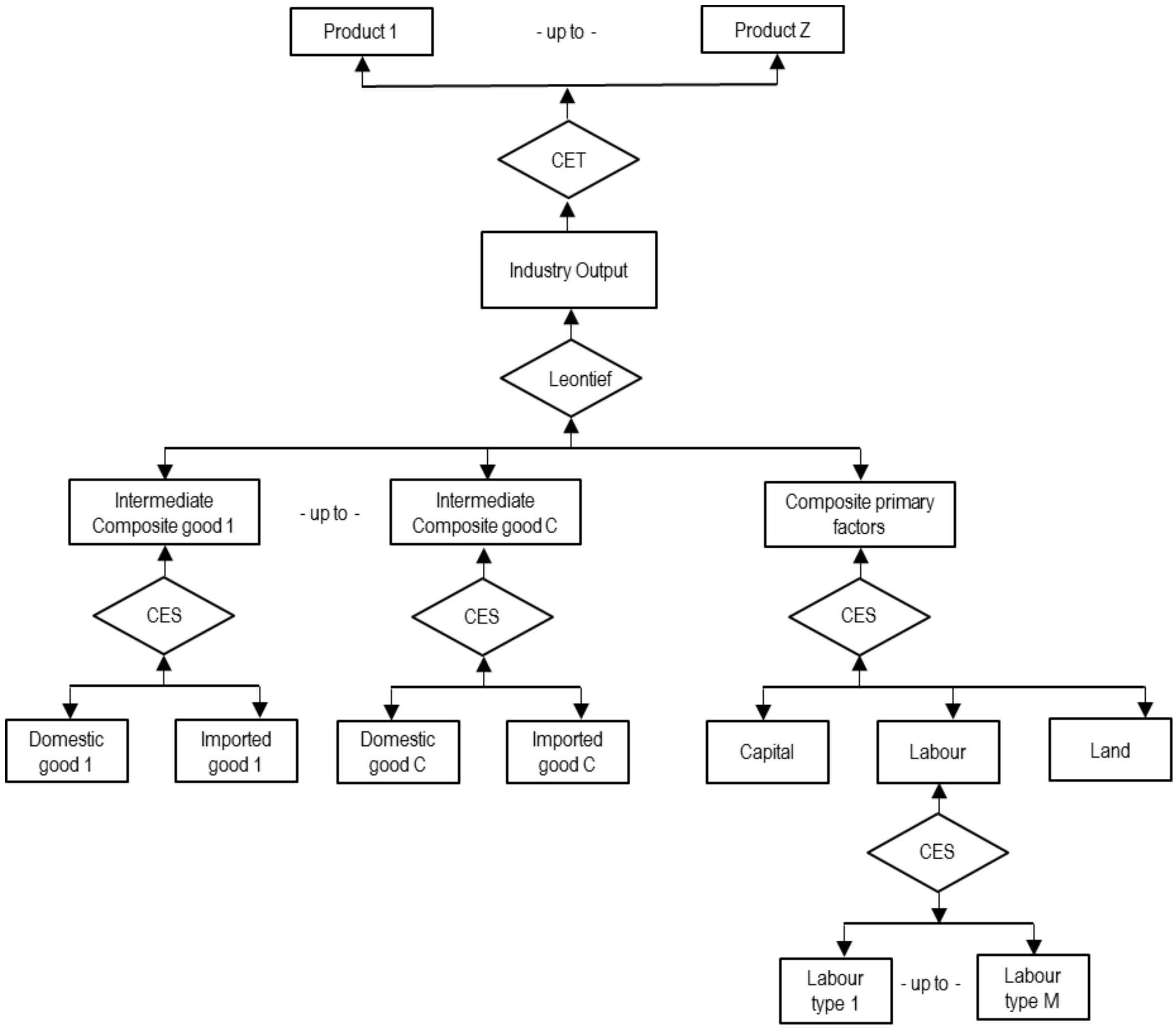


**Figure 3.** Nested production structure of a representative industry in UPGEM. Source: Bohlmann (2015).

linearized system of equations describing the theory underlying the behaviour of participants in the economy. It contains equations describing, amongst others, the nature of markets; intermediate demands for inputs to be used in the production of commodities; final demands for goods and services by households; demands for inputs to capital creation and the determination of investment; government demands for commodities; and foreign demand for exported goods.

The specifications in UPGEM recognize each industry as producing one or more commodities, using as inputs combinations of domestic and imported commodities, different types of labour, capital and land. The multi-input, multi-output production specification is kept manageable by a series of separability assumptions, illustrated in Figure 3. This nested production structure reduces the number of estimated parameters required by the model. Optimizing equations determining the commodity composition of industry output are derived subject to a constant elasticity of transformation (CET) function, while functions determining industry inputs are determined by a series of constant elasticity of substitution (CES) nests. At the top level of this nesting structure, intermediate commodity composites and a primary-factor composite are combined using a Leontief or fixed-proportions production function. Consequently, they are all demanded in direct proportion to industry output or activity. Each commodity composite is a CES function of a domestic good and its imported equivalent. This incorporates Armington's assumption of imperfect substitutability for goods by place of production. In UPGEM all industries share this common production structure, but input proportions and behavioural parameters vary between industries based on base year data and available econometric estimates, respectively.

The second task identified by Adams (2005) is calibration, which incorporates the construction of a balanced database and evaluation of coefficients and parameters. As required for CoPS-style[1] models, the initial levels solution of the model is provided by the base year data. The database, in combination with the model's theoretical specification, describes the main real inter-linkages in the South African economy. As explained in Table 2, the version of UPGEM used in this study is based on a 2011 reference year database that draws mainly from the 2011 supply-use tables published by Statistics South Africa (2015). The core database described in Table 2 contains three sets of information, namely:

[1] CoPs stands for Centre for Policy Studies in Australia where the UPGEM model has its origins.

1. Coefficients, which represent the basic flows of commodities between users, commodity taxes paid by users and margins flows that facilitate the flow of commodities.
2. Behavioural parameters, which are elasticities that influence the degree to which economic agents change their behaviour when relative prices change.
3. Government accounts, which include South African financial accounts with the rest of the world and relevant interest rate parameters.

The third task is solving the model using a suitable closure. In this study, we use a static UPGEM model and select a short run model closure to simulate the effects of drought on the economy. Drought is considered a short term problem caused by a significant decline in rainfall received in 2015/2016. The changes caused by drought in agricultural production are expected to vanish in the long term as the economy converges to a new equilibrium. Figure 4 provides a schematic view of variables selected as endogenous, that is, determined within the model, and those selected as exogenous, that is, determined outside the model. In a short run model closure, we make employment flexible but fix the real wage because economic theory posits that real wages are sticky in the short run. All technological variables are exogenous in the model. Capital stock is fixed but the rate of return on capital is allowed to move. Net trade is also flexible, which enables us to determine the effect of drought on agricultural exports given that agriculture is a net exporter. Demand by final users is fixed to baseline level, that is, private consumption, government consumption and investments are exogenous.

## SIMULATIONS

An intensive simulation process was followed which started with the organizing of the dataset and alignment of sectors. The agriculture sector is split into seven industries namely: Field crops, fruit, livestock, poultry, forestry, fisheries and aquaculture. Then the food sector is split into ten industries namely: Processed meat, fish, fruit and vegetables, crops, sugar, dairy, wine, alcoholic spirits, soft drinks and tobacco. The rest of the industries in the database include: Mining, textile, wood, chemicals, manufacturing, electricity, water, construction, retail, hospitality, transport, communication, business services, government and other unclassified. The final database distinguishes 32 industries and commodities (Table 1).

Figure 5 shows the disaggregation and mapping process, which is informed by two documents namely the Standard Industrial Classification (SIC) and Central Product Classification (CPC), both downloadable from Statistics South Africa (2015)(www.statssa.gov.za).

For simplicity, Table 2 shows an aggregated view of the database highlighting the cost and sale structure of agriculture, food and other sectors within the South African economy. Bohlmann (2016) explains that understanding the cost and sales structure of sectors is imperative for various reasons including, but not limited to the following:

1. From the supply side, understanding the industries that supply intermediate inputs to agriculture and food sectors enable us to know which industries are directly exposed in the short run to any changes experienced by agriculture, such as drought in this case;
2. From the demand side, knowing the final users of products produced by agriculture and food industries allows us to better predict how the drought shock will affect the final users in the economy; and lastly
3. Understanding the primary factors' cost structure, that is, the capital-labour ratio in the overall cost structure of the agriculture and food industries, helps us to better predict the industries' short-run supply elasticities as well as the impact of drought on agricultural employment.

The agricultural sector produced R172 billion worth of products in 2011 across all users in the economy. The agricultural commodities imported in 2011 were worth close to R10 billion less the taxes and subsidies as well as margins which amounted to R24.5 billion. The value of commodities from all sectors within the economy amounted to R5.9 trillion showing that agriculture accounted for just under 3% of the gross domestic product (Table 2). In producing the R172 billion worth of products, the agricultural sector used intermediate inputs worth R109 billion (equivalent to 63% of total production costs), which includes animal feeds, seedlings, fertilisers, agricultural machinery, electricity and water as well as others. In addition, the sector paid nearly R64 billion in compensation for labour and other primary factor costs.

The sales structure of agriculture reveals that R107 billion (equivalent to 57% of total sales) worth of agriculture, forestry and fisheries products are procured by downstream industries, that is food and manufacturing sectors, and used as intermediate inputs. The strong linkages between agriculture and downstream sectors show the importance of this sector in the economy. Agriculture provided live animals worth over R72 billion; grains worth R36 billion; fruits and vegetables worth R38 billion; forestry products worth R20 billion and fishery products worth R3.5 billion to downstream industries for processing. This directly exposes the food and manufacturing industries to the drought problem that is currently facing agriculture. From the sale structure, the rest of agricultural products worth over R100 billion were consumed by export and household users (Table 2).

Recognising the devastating effects of drought on agriculture the South African Minister of Agriculture pronounced in his 2016 budget vote a drought relief of R381 million through the Comprehensive Agricultural Support Programme (CASP) and an additional R400 million through the Land Bank. This implies that the government has acknowledged the need to support farmers in order to cope with drought effects, thus implementing the post drought relief program. It is important to understand that such drought relief is distributed in form of animal feeds, grazing field management and water infrastructure (e.g. boreholes and irrigation equipment). This drought relief will be incorporated in the model to determine its impacts in assisting the country to cope with drought. Once the database was completed and checked using the database balancing tests available in the GEMPACK software and explained in Horridge et al. (2013), the study designed four scenarios (Table 3).

## Analysis of the results

The currency used in the analysis is the South African Rand and the exchange rate during the base year was to the dollar 1UD$ = R7).

Table 4 provides macroeconomic results on the four scenarios. In this model the macroeconomic variables looked at include the GDP, employment, exports, imports and rate of return on capital. It is very clear from Table 4 that across all scenarios, the effects of the drought are significant and negative. In Scenario 3 whereby both Scenario 1 and 2 are combined with additional losses in the fruit industry, GDP declines by nearly 1.5%, employment declines by 1.3%, exports decrease by 3.5% while imports increase by 1.6% and the rate of return to capital increases by 1.5% all against the baseline. The R781 million drought reliefs announced by the Minister of Agriculture, Forestry and Fisheries in 2016 budget vote was captured under policy Scenario 4 and it has a

**Table 1.** Description of industry and product classification used in our database.

| **Industries** | **SIC** | **Description** |
|---|---|---|
| Agriculture | 11; 12 and13 | Agriculture, forestry and fisheries products |
| Processed agriculture | 30 | Processing and preservation of grains, meat, fruits, vegetables, fish, oils and fats, sugar, dairy, wine, spirits and tobacco |
| Manufacturing | 21-29 and 31-39 | Manufacture of textile, paper, petroleum, chemicals and others |
| Utilities | 41 and 42 | Electricity and water |
| Business | 50; 61-65; 71-75; 81-88; 91-99 and 01-09 | Wholesale, retail, hospitality, telecommunications, construction, financials, real estate, public service and others |
| **Commodities** | **CPC** | **Description** |
| Agriculture | 01--04 | Grains, sugarcane, oilseeds, fruits, vegetables, wood, fish and meat products |
| Processed Agriculture | 21 - 25 | Processed meat, gains, dairy, fruit, vegetables, tobacco, wine, spirits and non-alcoholic liqueurs |
| Manufacturing | 11-16; 26-29; 31-39 and 41-49 | Textile, paper, crude petroleum, chemicals, glass, equipments and others |
| Utilities | 17 - 18 | Electricity and water |
| Business | 53-54; 61-68; 71-73; 81-89 and 91-99 | Wholesale, construction, hospitality, public service, financials, business service and others |

**Table 2.** Structure of the agricultural sector within the South African economy (R million).

| **Industry make** | **Agriculture** | **Processed agriculture** | **Manufacturing** | **Utilities** | **Business** | **Total** | **Imports** | **TLSP** | **Margins** | **Total supply** |
|---|---|---|---|---|---|---|---|---|---|---|
| Agriculture | 170680.57 | 1911.43 | 747.84 | 0.00 | 120.36 | 173460.21 | 9906.70 | 6833.21 | 17689.50 | 207889.62 |
| Processed agriculture | 0.00 | 291109.47 | 11350.12 | 0.00 | 10720.29 | 313179.88 | 32545.75 | 62790.39 | 93827.47 | 502343.49 |
| Manufacturing | 0.00 | 2761.10 | 1508312.06 | 0.00 | 18224.64 | 1529297.80 | 705629.59 | 152960.95 | 413593.03 | 2801481.37 |
| Utilities | 0.00 | 0.00 | 0.00 | 144040.07 | 0.00 | 144040.07 | 1576.96 | 5173.82 | 0.00 | 150790.85 |
| Business | 1966.26 | 2424.99 | 121020.23 | 311.93 | 3623248.12 | 3748971.55 | 135250.00 | 69938.63 | -525110.00 | 3429050.18 |
| Total make | **172646.84** | **298207.00** | **1641430.26** | **144352.00** | **3652313.41** | **5908949.50** | **884909.00** | **297697.00** | **0.00** | **7091555.50** |
| Intermediate use | **Agriculture** | **Processed agriculture** | **Manufacturing** | **Utilities** | **Business** | **Total** | **Households** | **Exports** | **Others** | **Total Demand** |
| Agriculture | 19992.14 | 63078.90 | 20033.07 | 12.58 | 4078.97 | **107195.66** | 77748.80 | 22913.82 | 31.35 | 207889.62 |
| Processed agriculture | 20930.92 | 58471.40 | 4923.40 | 80.45 | 27956.04 | **112362.22** | 353379.23 | 34949.96 | 1652.08 | 502343.49 |
| Manufacturing | 39337.44 | 33201.46 | 771718.61 | 37044.03 | 510172.56 | **1391474.09** | 481333.07 | 675006.78 | 253667.43 | 2801481.37 |
| Utilities | 2129.24 | 4955.42 | 40874.16 | 20206.96 | 29559.51 | **97725.29** | 49750.05 | 1343.87 | 1971.64 | 150790.85 |
| Business | 26703.58 | 59255.98 | 274371.59 | 13998.48 | 1190831.20 | **1565160.82** | 780912.78 | 163374.57 | 919602.00 | 3429050.18 |
| Total inter inputs | **109093.31** | **218963.17** | **1111920.82** | **71342.50** | **1762598.28** | **3273918.08** | **1743123.93** | **897589.00** | **1176924.49** | **7091555.50** |
| **Primary factors** | **Agriculture** | **Processed agriculture** | **Manufacturing** | **Utilities** | **Business** | **Total** | | | | |
| Labour Costs | 19753.13 | 36136.68 | 265976.29 | 23857.00 | 975280.32 | 1321003.42 | | | | |

**Table 2.** Cont'd.

| | | | | | | |
|---|---|---|---|---|---|---|
| Capital Costs | 21667.55 | 42633.03 | 224003.05 | 49674.65 | 875733.04 | 1213711.32 |
| Net Production Taxes | -20.94 | 474.12 | 2063.19 | -522.15 | 38701.77 | 40695.99 |
| Land Costs | 22153.79 | 0.00 | 37466.91 | 0.00 | 0.00 | 59620.69 |
| Total prim factor costs | **172646.84** | **298207.00** | **1641430.26** | **144352.00** | **3652313.41** | **5908949.50** |

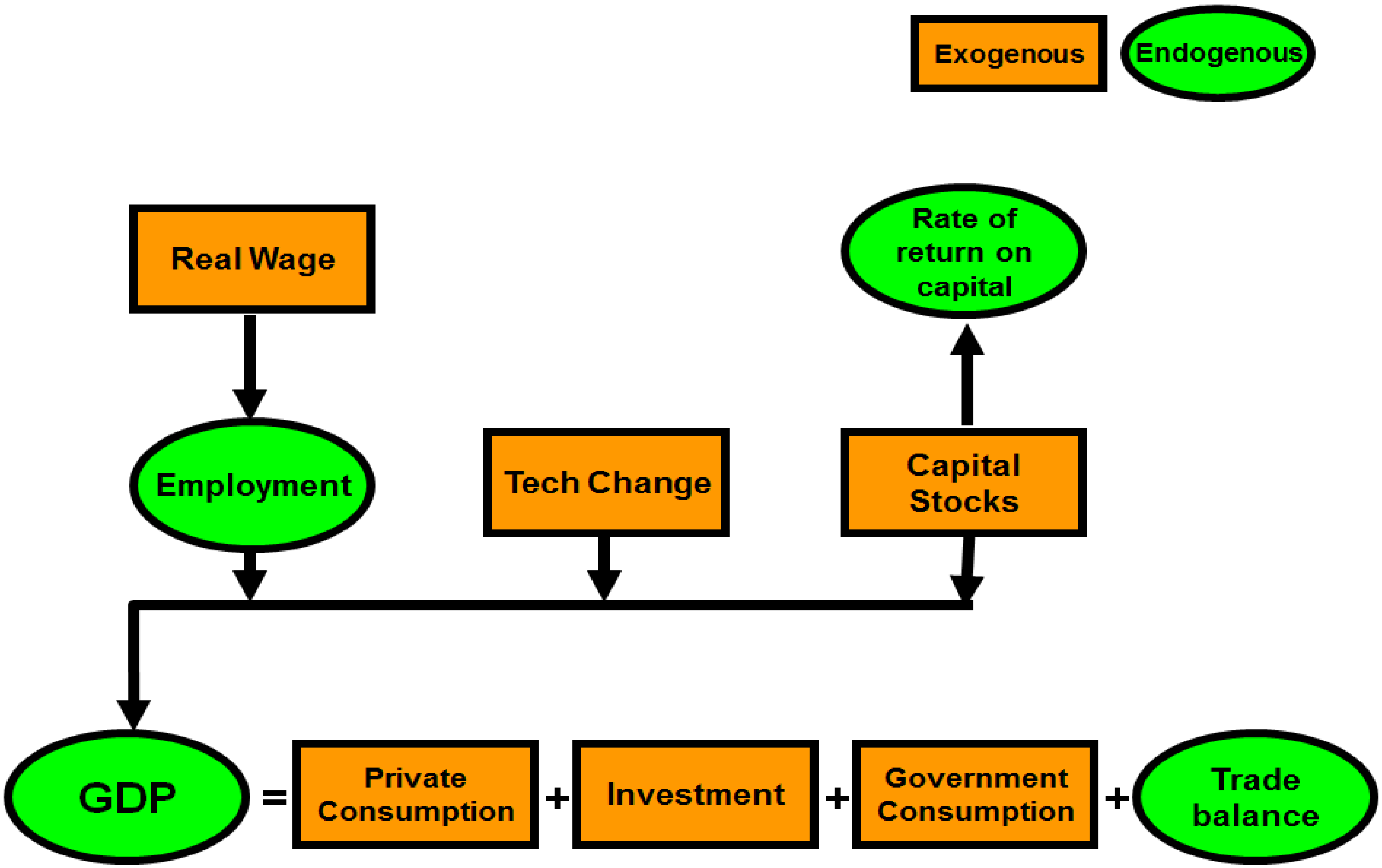


**Figure 4.** Causation in the short-run model closure. Source: Adapted from Horridge et al. (2013).

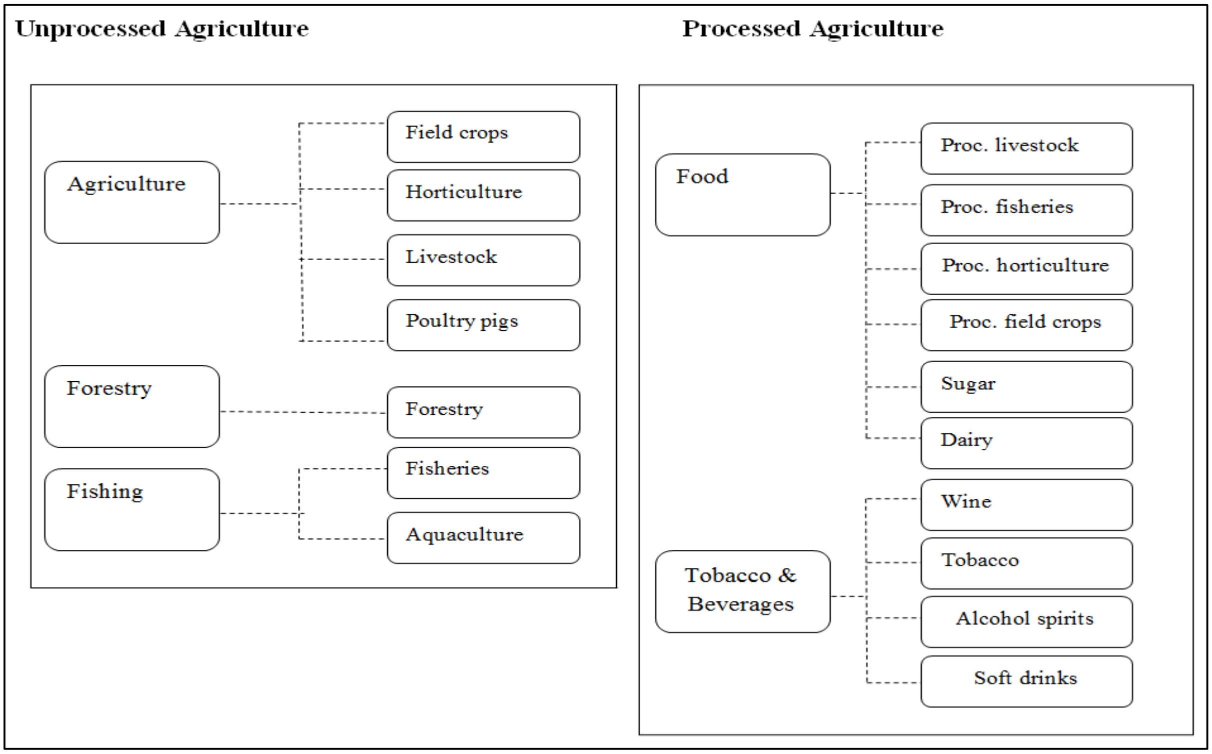


**Figure 5.** Mapping process to disaggregate agriculture and food industries. Source: Ntombela and Bohlmann (2016).

**Table 3.** Scenarios formulated to capture the effects of drought on the economy.

| Scenarios | Aim | Description | Shock imposed on the model |
|---|---|---|---|
| Scenario one | To assess impact of drought on field crops only | Scenario is informed by industries' estimation on production output. A weighted average decline from maize, sugar, wheat, seeds and other grains is calculated to be 23% below baseline | -23% on Field Crops production |
| Scenario two | To assess impact of drought on Livestock only | Scenario is informed by industries' estimation on production output. A weighted average decline from read and white meat is calculated to be 8.65% below baseline | -8.65% on Livestock production |
| Scenario three | To assess impact of drought on the aggregated agricultural sector | A weighted average decline in fruit is calculated to be 0.05% below baseline. It also includes reductions from Scenario 1 and 2 | Scenario 1 and 2 plus -0.05% on fruit production |
| Scenario four | To assess impact of drought on aggregated agricultural sector plus impact of drought relief | Scenario 3 plus drought relief program | Scenario 3 plus drought relief program, that is, R781 million investment in agriculture sector |

Source: Own classification.

minimal effect on the economy given the severity of drought.

Scenario 1 and 2 isolate the effects caused by decline only in field crops and livestock respectively. From this, it is evident that the significant impact of drought stems from significant decline in field crops products including grains, sugar, barley, tobacco, which are in turn used as intermediate inputs in secondary industries.

The changes in macroeconomic variables are always better captured when they are presented in terms of actual levels. Table 5 presents the macro results in levels (quantities) form. Although the drought relief is minimal

**Table 4.** Macro results: percentage changes.

| Parameter | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|
| GDP | -1.177 | -0.385 | -1.494 | -1.493 |
| Employment | -0.983 | -0.327 | -1.264 | -1.263 |
| Exports | -2.685 | -0.848 | -3.366 | -3.365 |
| Imports | 1.216 | 0.421 | 1.609 | 1.602 |
| Rate of return on capital | 1.146 | 0.429 | 1.528 | 1.529 |

Source: UPGEM simulation.

**Table 5.** Macro results: quantities.

| Parameter | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 | Relief impact |
|---|---|---|---|---|---|
| GDP | -34 518 208 560 | -11 291 002 800 | -43 814 956 320 | -43 785 629 040 | +29 327 280 |
| Employment | -140 927 | -46 880 | -181 212 | -181 069 | +143 |
| Exports | -24 100 264 650 | -7 611 554 720 | -30 212 845 740 | -30 203 869 850 | +8 975 890 |
| Imports | 10 141 057 140 | 3 725 466 890 | 14 238 185 810 | 14 176 242 180 | -61 943 630 |

Source: UPGEM simulation.

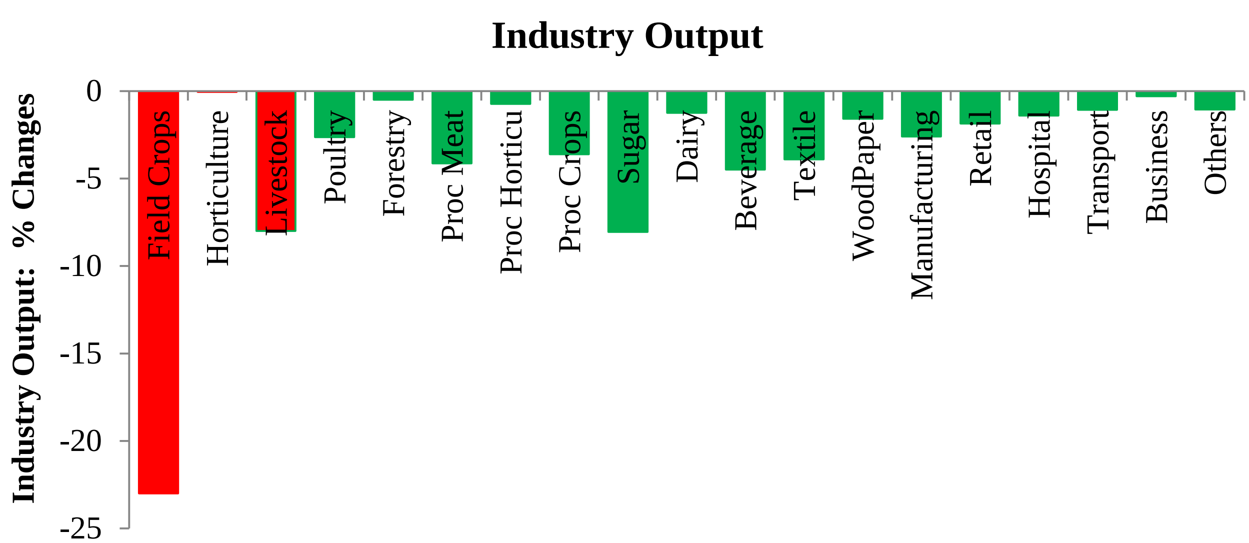


**Figure 6.** Industry output micro results. Source: UPGEM simulation.

but it has helped rescue nearly 150 jobs from the already lost 181 212 jobs in Scenario 3.

Figure 6 presents results showing the impact of drought on individual industry output. The output in primary agriculture was exogenously decreased by 23% in field crops, less than 1% in fruit and nearly 9% in livestock and collectively such decline resulted in further declines in secondary and tertiary industries. On average, the output of all economic industries declined by 3.5% below the average output with exception in sugar and textile industries, which lose over 5% production each.

Figure 7 provides industry results indicating that drought is causing a significant decline in exports especially in primary agricultural exports. For example, the 31% decline in maize production results in more than 70% decline in field crops products. The 22% decline in sugar cane reduces sugar production by 26%.

Figure 8 shows the decline in industry employment due to drought. All industries lost employment with food and agricultural industries suffering the most. It can be seen from Figure 6 that the biggest employment losses will be found in the field crops, livestock and sugar. These three depend mostly on rain fed pasture or on rainfall for planting. It is important to note that the impact of drought


**Figure 7.** Industry exports: Micro results. Source: UPGEM simulation.

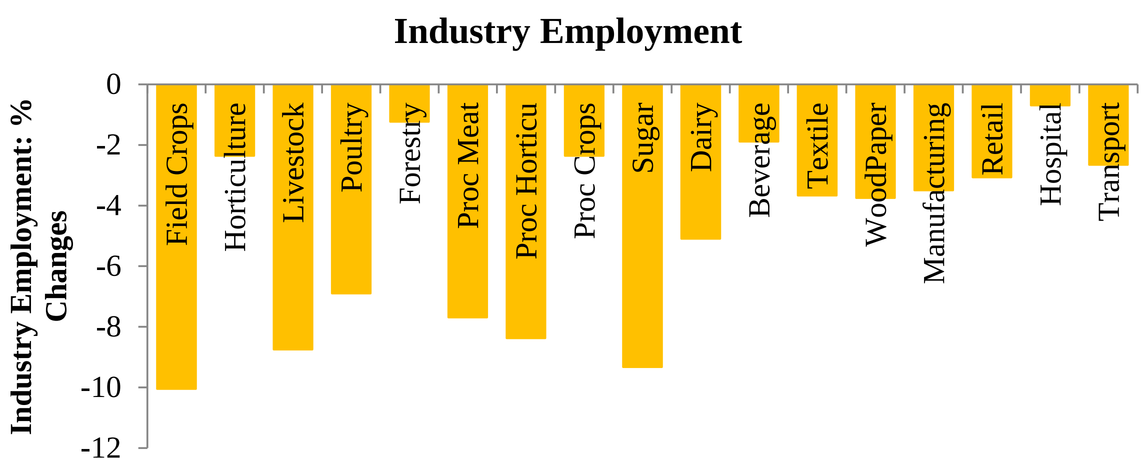


**Figure 8.** Industry employment micro results. Source: UPGEM simulation.

on employment in all sectors stands to be negative.

## Conclusions

In this study we employed the UPGEM model to estimate the impact of drought on the South African economy. The UPGEM model is a CGE-based model that is made up of a linearized system of equations describing the theory underlying the behavior of participants in the economy. Its CGE-based structure enables the capturing of the various inter-linkages in the real economy in great detail, which in turn makes this model well-suited to analyzing policy questions such as the economy wide impact of drought on agriculture.

Four scenarios are analysed namely: (1) Impact on field crops only; (2) Impact on livestock only; (3) Impact on aggregated agriculture output; and (4) Impact on aggregated agriculture output plus impact of drought relief. It was found that all scenarios reflected a negative impact on aggregate GDP, employment and exports. In Scenario 4, drought relief was found to have saved some jobs, albeit not significantly. The overall conclusion from this study is that the 2015/16 drought has resulted in a negative impact in South Africa's economy. The intervention by government mainly through the Department of Agriculture, Forestry and Fisheries' drought relief has assisted in saving some of the jobs that could have been lost due to drought. The amount injected as drought relief is clearly not enough, which speaks to fiscal constraints that South Africa as a country faces under the currently difficult economic climate. One of the lessons learnt from this drought is that more concerted effort by all stakeholders is required to prevent potential catastrophic implications of any future droughts.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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# Contracts for Grain Biosecurity and Grain Quality

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**The export of grain from Western Australia depends on a grain supply network that takes grain from farms to port through Cooperative Bulk Handling (CBH) receival and storage sites. The ability of the network to deliver pest free grain to port and ship depends on the quality of grain delivered by farmers and the efficacy of phosphine based fumigation in controlling stored grain pests. Unfortunately, over time, common stored grain pests have developed resistance to phosphine. There is some evidence that phosphine resistance, develops on farm due to inadequate biosecurity management. This paper considers the design of farm biosecurity contracts using a principal agent approach. An optimizing non-linear programming model with different effort levels of Cooperative Bulk Handling (principal) and farmer (agent) is developed to determine: (i) whether the farmer's effort level affect the CBH's profit function, and (ii) whether increasing monitoring effort by the CBH has an impact on farmer's performance on farm. Results show that; (i) the optimal effort level of farmer is higher for perfect information assumption than moral hazard one. Meanwhile, (ii) under moral hazard assumption, when Bulk Handler is engaged in intensive monitoring level, the farmer is engaged in a higher level of effort. Price premium represents the incentive for farmers, while cost-reduction represents the incentive for Grain Bulk Handler.**

**Key words:** Principal-agent model, biosecurity contracts, asymmetric information, stored grain, effort levels, farmer, grain bulk handler.

## INTRODUCTION

Biosecurity hazards stemming mainly from invasive alien pests and exotic diseases impose a threat over the production systems worldwide (Vitousek et al., 1996). Such hazards can potentially result in significant economic losses; especially for agricultural producers in regions infested with pests or diseases. The consequences might extend over individual farmers to have epidemic effect on the agricultural market through non-sustainability in supply and higher prices in demand. Such epidemic impacts are non-ignorable. For example, the annual costs of arthropods are estimated to account for $15.9 billion in US, $0.96 billion in UK, $0.94 billion in Australia, $1.0 billion in South Africa, $16.8 billion in India and $8.5 billion in Brazil. What makes the problem more complicated and have more potential to increase rapidly is the expansion in trade globalization (Pimentel et al., 2001).

Meanwhile, food safety and quality have become significant concerns for consumers' worldwide (Gaaloul et al., 2011). Therefore, achieving and maintaining high quality food standards have been progressed dramatically. In terms of remarkable progress in food

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quality approach, the cereal industry has occupied a major portion of such a devastating improvement. Such concerns can have a significant impact on the supply markets; especially when cereals represent a major produce and export as in Australia (Arvanitoyannis and Traikou, 2005; Bertolini, Bevilacqua, and Massini, 2006).

Wheat is Australia's most important grain crop, worth around $7 billion each year (Australian Bureau of Statistics, 2016). Western Australia (WA) wheat exports were valued at a record of $3 billion in 2014/15; accounts for 46% of Australia's wheat exports; (Department of Agriculture and Food, 2016). Engaging in investment (high-quality storage infrastructure) and actions (effective fumigation) can ensure a standard of grain biosecurity that avoids significant loss of grain value through quality deterioration; and assists in maintaining the pest-free status of Australia's grain exports. This may result in enhancing the Australian grain access to markets with stringent standards for stored-grain pests.

As grain moves from farms to port through a transport and storage network, ensuring that grain biosecurity commences on farm and continues at each stage of the network, is vital to the grain supply chain and its final quality. Managing stored grain biosecurity (defined here as ensuring that grain is pest-free for export) depends significantly, on the effective use of phosphine fumigation in sealed stores; in particular for the management of stored grain on farm and through the grain storage and transport network. Since 1984, stored grain industry in WA has been heavily reliant on phosphine to meet export market demand for pest and residue free grain. However, data shows a slow increase in frequency of weak phosphine resistance however, strong resistance, which has recently been detected in intercepted quarantine goods (Chami et al., 2011).

The significance of grain infestation or phosphine resistance problems stems from grain collection in bulk/pool means that, any minor infestation can influence costs of the grain bulk handler and farmers. The potential expansion of phosphine resistance across the grain network may result in its replacement with other fumigants as Carbon Dioxide, which costs 5 to 10 times as much as phosphine (The State of Queensland, Department of Primary Industries and Fisheries, 2008). Meanwhile, other fumigants can have residues in grain as chemicals and pesticides. Hence, phosphine resistance problem may turn up to a food, if not cured at early stages that might have a major impact on global trade. In an economic model of trade losses that can result from non-efficient pest treatment by phosphine, a $1.3 billion was estimated for an outbreak with Karnal Bunt in Western Australia; one of the most threatening grain pests. Some other pests can lead to yield reduction or increase in production and management/monitoring costs (Australian Grains Industry Alliance, 2008).

A simple systematic grain supply network consists of farmers and grain bulk handler (in our case, is represented by the CBH). A farm operating under a Quality Assurance (QA) scheme is expected to applybiosecurity best practice as specified by the assurance scheme contract between the involved parties, in a most likely principal agent relationship. BFIQ (Better Farm Intelligent Quality) is a QA scheme initiated by the CBH in WA since 2008 to 2009. BFIQ (now called CBH QA) aims to meet export standards and indirectly, benefit farmers by increasing the price-premium for their grain (Safe Quality Food Institute, 2010). In this context, CBH QA provides international customers with additional QA by emphasizing that, the required quality has been achieved on farms through managing/monitoring the planting, harvesting, storage and transport of grain to reduce quality deterioration. Meanwhile, CBH QA helps the industry to manage grain safety and quality risks and hence; reduces management and monitoring costs; and probably enlarges profit level.

In terms of economics and management, three pronged strategy is considered. First, within CBH use existing infrastructure to ensure that, neither infestations nor resistance emerges; second, provide farmers with an incentive to deliver insect free and residue free grain to CBH stores; and third, develop monitoring methods that are able to identify outbreaks of strongly resistant grain beetles quickly and cheaply, to isolate and eradicate the outbreak (Newman, 2011). The paper in hand focuses on the last two strategies.

The aim of this paper is to discuss the possibility of grain quality improvement through contracting between the involved parties; assuming risk-neutrality of different parties. Any downgrading of grain quality because of low effort level of one or more farmers will be shared among all farmers in terms of lower premium levels, which is similar to public good problem. Farmers exert independent effort levels but share an interconnected price. Therefore, the paper determines two issues: (i) whether the farmer's biosecurity effort level exerted on farm affects CBH's profit function, that is, better farmer performance increases CBH's profit; and, (ii) whether an increase in the monitoring effort by CBH has an impact on farmer's biosecurity effort on farm. The study is structured as follows. Section 2 reviews the principal-agent theory under asymmetric information. Section 3 reviews some case studies on the application of the principal-agent model in the presence of asymmetric information problems. Section 4 develops the farm biosecurity contract model. Section 5 gives results, and Section 6 concludes.

## Literature review on principal-agent theory under asymmetric information

The marketing contract between principal and agent(s) plays an important role in controlling product quality and safety. On one hand, the principal seeks a continuous supply of safe and good quality products to reduce transaction costs incurred with faulty products. On the other, the agent(s) requires income stability, market security and access to technology and capital. Thus, contracts serve two purposes: they coordinate exchanges in the production process, while providing a portion of control and risk-sharing between the contracting parties/members.

Agents(s) accepting a contract are expected to conform to all requirements of the contract. Nevertheless, it is hard for the principal to measure quality and/or observe directly product properties at delivery time. Accordingly, establishing compliance is difficult. The problem with food risks, when growers/agents know in advance that their production process and final product quality cannot be directly noticed by processors/principals. This results in growers /agents probable use of poor practices, with the probability increasing with the profits to be gained through opportunistic behaviour. Therefore, the difficulty of detection or enforcement of contracts allows the grower/agent to promise the delivery of a safe product but does not fulfil this promise even under contract-terms; representing a moral hazard problem.

Moral hazard or incentive problems stem from asymmetric/imperfect information among members of a firm as agents' actions cannot be observed and hence cannot be contracted upon. Inspection and penalties can to an extent influence grower's behaviour. As penalty increases, the financial risk of breaking rules increases and hence, compliance also increases. Babbage (1835) emphasizes the need for accurate evaluation of the agent's performance in an attempt of setting-up efficient contracts. The general principles of agent's remuneration are linking a considerable part of the agent's wages, to the firm's profit and allocating more advantages for all contributed improvements. However, Barnard (1938) is the first one to define a general theory of incentives in management. He highlights the need to stimulate desired effort levels of the agent and to create the principal relationships within the firm to tackle the necessary imperfectness of incentive contracts. Arrow (1963a) introduces the idea of moral hazard borrowed from the insurance world to the literature on the control of management. Williamson (1975) uses the case of symmetric but non verifiable information between two parties, to develop his transaction costs theory. Grossman and Oliver (1983) model the principal agent relational pattern and hence, achieve the significant context of modern literature on incomplete contracts that stems from asymmetric/imperfect information (Laffont and Martimort, 2002).

Heuth et al. (1999), proposes four possible remedies for the problem of asymmetric information. First, try to monitor the grower/farmer's activities by direct observation in the field. This option could work, if principal's observations could fully reflect the actual performance of the grower according to a previously stated plan. Second, try measuring product's quality and link some portion of the farmer's payment on realized quality. Third, try to find ways to gain more control over farmer's quality related activities by directly specifying one or more inputs that can have direct impact, the final quality. Fourth, by making farmers responsible for bad quality products such as to make the farmer's last payment directly related to downstream price; this will make farmers residual claimants for their poor performance (Heuth et al., 1999).

Our analysis is related to previous literature on principal agent models; addressing food safety through marketing contracts. Harris and Raviv (1976) address a principal agent relationship in which the agent provides a productive input (e.g effort) that cannot be observed by the principal directly. Their results relate to a very specific kind of imperfect monitoring of the agent's action which allows the principal to detect any shirking by the agent with positive probability. Holmstörm (1979) studies efficient contractual agreements between a principal and an agent under different assumptions about what can be observed, and hence contracted upon. He found that when the procedures alone are observable, optimal contracts will be the second best as a result of a moral hazard problem. Therefore, he concluded that contracts can generally be improved by creating additional information systems (as in cost accounting), or by using other available information about the agent's action or the state of nature (Holmstörm, 1979). Meanwhile, Elbasha and Riggs (2003) show that regardless of the orientation of the legal system, the levels of efforts exerted by the principal and the agent are suboptimal when efforts are complements, and ambiguous when efforts are substitutes. The impacts of a policy that forces agents to provide the principal with information about food preparation and handling can improve social welfare, if information is complementary to efforts (Elbasha and Riggs, 2003).

Principals have many strategies for ensuring growers/farmers' delivery of safe food ingredients including the reduction in measurement error through improved diagnosis and motivating suppliers to provide safety signals. In some supply chains, such strategies are either not possible or very expensive. Therefore, designing careful contracts can be a relative inexpensive alternative; while promising a potential for safe food improvement (Starbird, 2005a). Also, Starbird (2005b) uses principal-agent theory to explain the interaction between sampling inspection, failure costs (penalties), and food safety. The sampling inspection policy, the internal failure cost, and the external failure cost were found to have a significant effect on the buyer's willingness to pay for safer food and, hence, on the supplier's willingness to exert the effort required to deliver safe food.

In response to a spinach *E. coli* outbreak in 2006, Western Growers initiated the California Marketing

Agreement that requires all signatory leafy greens handlers to buy product only from farmers, who follow the newly developed Leafy Greens Good Agricultural Practices (GAP). As a result, direct relationships with farmers/agents were based on compliance with production practices and have allowed processors/ principals to become much more involved than before in the production practices (Liang and Jensen, 2008). In contrast, when a principal makes an effort that can impact a product's quality and can be by consumers, this will weaken the grower's/farmer's incentive to apply effort in quality control (Olmos et al., 2011).

Especially relevant to this study are the studies that highlight how the marketing contract between principals and growers/farmers affects agricultural production. Several studies have explored the effects of contracting using theoretical and empirical approaches. Liang and Jensen (2008) finds that, the optimal premium is higher and the base payment is lower under the contract with a marketing agreement and the processor earns less under the contract with a marketing agreement.

Until now, however, no formal studies of agricultural contracts have examined the relationship between grain bulk handler (CBH Ltd as the principal) and grain farmer (as an agent) in a principal-agent context within a grain supply chain, with the objective of improving final grain quality. Hence, the contribution of this paper is to determine two issues: (i) whether the farmer's effort level affects CBH's profit function, that is, better farmer performance increases CBH's profit; and, (ii) whether increased monitoring effort by the CBH has an impact on farmer's biosecurity effort on farm. The objective of the model proposed in this paper is to examine how a monitoring strategy, as one of the sated above remedies for asymmetric information problems can influence the behaviour of growers/farmers with respect to grain production quality. Such kind of information may help in designing efficient incentive contracts in the context of the principal agent theory.

## METHODOLOGY

The current contract between grain producers and bulk handler is outlined in the Grain Operations Harvest Guide (CBH, 2011). The ability of grain handler, such as CBH, to contract for grain that is insect and other contaminant free is complicated by twin problems, asymmetric information and moral hazard. Asymmetric information implies that the farmer knows how the grain has been managed in storage and on farm, but CBH cannot observe that directly. The related problem of moral hazard is where the farmer does not have an incentive to manage stored grain according to industry best practice. There is a widespread evidence that standards of stored grain management for biosecurity are not universally applied (Taylor and Slattery, 2010). The problem that CBH faces is one of a principal agent one; where CBH devises a grain supply contract that pays producers a price premium for clean grain. Indirectly this may induce farmers to increase their biosecurity efforts on farm. However, to reinforce this reaction, CBH must also engage in grain sampling for live insects and pests at receival sites.

The Principal-Agent model in this paper assumes that a profit maximising risk neutral bulk handler (CBH) procures grain from a group of farmers. The aim of CBH is to maximise profit by selling grain to the world market at price $P_W$, less biosecurity costs. CBH's expected costs depend on the effort level exerted by farmers to deliver clean grain, monitoring costs for CBH and the price premium paid as an incentive for farmers to deliver un-infested (clean) grain. The CBH is trying to reduce the costs incurred within a grain supply network by reducing/eliminating infested grain access to bulk storage and transport network. Prices paid to farmers by CBH are constrained by farmers' participation and incentive constraints.

### Model Overview

A mathematical grain quality model based on the Principal-Agent theory is used to discuss how the effort level exerted on farm can have an effect on the final grain quality and farmer's net profit, gained from selling grain to CBH. The grain quality model is written and solved in General Algebraic Modelling System (GAMS; GAMS Development Corporation 2006). Three scenarios for a grain quality model will be discussed in the following section. The three scenarios formulate the relationship between a farmer and CBH in a principal-agent context over a single year. The farmer and CBH can choose an effort level that ranges between zero (no-effort) and one (all effort required to reach grain high quality).

According to the effort level chosen, grain quality varies. At one hand, the effort level on farm is stimulated by price premiums received by farmers after grain delivery and inspection at CBH. The farmer's effort includes biosecurity activities performed to reach grain-quality desired in a BFIQ context. At the other hand, the CBH effort level is stimulated by higher profits received from exporting good-quality grain overseas. Free of infestations grain results in higher price premium/profit for CBH and vice-versa. CBH's effort includes monitoring activities to inspect the quality of grain delivered by farmers. Grain price with/without premium paid to farmers is constrained by participation and incentive constraints. Monitoring costs at CBH plus grain-price paid to farmers influence the objective function.

### *Scenario 1: Optimal contract design under symmetric information*

The assumption of complete information entitles that the farmer's effort level is verifiable by CBH, and hence, CBH can compensate the farmer directly for his effort. The farmer knows in advance (before signing the contract with the CBH) that she will be paid according to her effort level. Effort is represented by an index such that $0 \leq e_f \leq 1$

The economic decision variables of the model are the farmer's effort and its corresponding price premium paid by CBH. GAMS software is used to trade-off between different verifiable/observable biosecurity effort levels exerted on farms and the corresponding farmer's price premiums paid by CBH. The difference between world prices paid to CBH for grain exported overseas minus the prices paid to farmer either with/without price premium (according to grain quality) minus the cost of infestation incurred by CBH will make up the CBH profit maximization problem.

Therefore, the profit maximization problem from the point of view of CBH can be set out as follows:
Maximise with respect to ($e_f$, $p_f$):

$$\left(p_w - e_f\,(1+\theta)p_f - \left(1-e_f\right)p_f - \left(1-e_f\right)c^{inf}\right) \quad (1)$$

Where ($p_w$) is the world wheat price less the expected price paid for high quality grain ($e_f\,(1+\theta)p_f$) and the expected price paid for low-quality grain ($\left(1-e_f\right)p_f$) less the cost of infestation that CBH incurred, because of low grain quality ($(1-e_f)c^{inf}$). The farmer's incentive to apply effort depends on the profit derived from selling grain to CBH. There are two constraints: a participation constraint and an incentive constraint. The participation constraint (or individual rationality constraint) that ensures farmer's expected profit is not reduced by contracting with CBH is:

$$e_f(1+\theta)p_f + (1-e_f)p_f - c_f(e_f) \geq 0 \quad (2)$$

The *incentive constraint* ensures that expected profit is not reduced by increasing effort. This constraint is the derivative of the participation constraint:

$$\theta p_f \geq c_f^{'}(e_f) \quad (3)$$

The first best effort level under perfect information when CBH can verify farmer's effort is given by the first order condition:

$$\left(c^{inf} - c_f^{'}(e_f)\right) = 0 \quad (4)$$

The equation above implies that the first best will be obtained by equating the CBH's marginal value; represented as savings in infestation minus the cost that should have been paid in case the farmer puts lower/no effort level instead, with the farmer's marginal cost of doing effort.

***Scenario 2: Optimal contract design under asymmetric information and cbh's zero monitoring cost***

The model setup remains the same but due to asymmetric information; the farmer's effort is non-verifiable (Laffont and Martimort 2002). However, CBH can monitor (inspect) grain and pay the farmer according to grain quality. CBH does not incur any monitoring cost to detect a farmer's effort; therefore, CBH chooses to put the highest effort level to monitor the farmer's performance. The economic decision variables of the model are the effort level of the farmer and its corresponding price premium paid by CBH plus the monitoring effort level done by CBH to detect grain quality and to pay the farmer accordingly.

GAMS software is used to trade-off between different non-verifiable effort levels exerted on farms, the monitoring effort at CBH and the price premiums paid to farmer. The main objective of the model is to find the optimum effort level of the farmer and CBH that will increase the CBH profits. CBH profit is reduced by prices paid to farmers either with/without price premium (according to grain quality), plus the cost of grain infestation. Therefore, the profit maximization problem from the point of view of CBH can be set out as follows:

*Maximise with respect to* ($e_f$ , $p_f$):

$$\left(p_w - e_m\, e_f\,(1+\theta)\,p_f - e_m(1-e_f)p_f - (1-e_f)c^{inf}\right) \quad (5)$$

The CBH's profit is the world price ($p_w$) for exported grain minus a high price (price premium) paid to the farmer ($e_m\, e_f\,(1+\theta)\,p_f$) after monitoring her effort level to be satisfactory minus the non-premium price paid to the lower farmer's effort observed by CBH ($e_m(1-e_f)p_f$) minus the cost paid by CBH as a consequence of having infested crop ($(1-e_f)c^{inf}$). The optimal effort level (second-best) exerted under asymmetric information assumption where the farmer's effort level is unverifiable but CBH can detect grain quality without incurring extra cost is given by the following necessary condition:

$$\left(c^{inf} - c_f^{'}(e_f) - e_f\, c_f^{''}(e_f)\right) = 0 \quad (6)$$

The equation above implies that the second best will be obtained by equating the CBH's marginal value represented by savings in the cost of infestation it should have paid otherwise with the farmer's marginal cost of doing effort plus a third term. The third term of the equation represents how much the change in the rate of farmer's effort will change the farmer biosecurity cost on farm. A small change in farmer's effort level will result in higher impact on CBH's marginal profit

***Scenario 3: Optimal contract design under asymmetric information and CBH's payable monitoring cost***

The third scenario which is the more complicated case deals with the farmer and CBH under moral hazard assumption; where the farmer can manipulate her effort level. CBH needs to exert some effort to monitor the farmer's performance; while it incurs monitoring cost. However, CBH will not always succeed in detecting her accurate level of effort. Consequently, CBH might commit type I (classifies non-infested crop as infested) or type II (classifies infested crop as non-infested) errors when judging a farmer's performance. The possibilities are summarised in Table 1. The economic decision variables of this scenario are the effort level of the farmer and its corresponding price premium paid by CBH, plus the monitoring effort level of CBH.

The profit maximization problem from the point of view of CBH can be set out as follows:

*Maximise with respect to* ($e_f, e_m, p_f$)*:*

$$\{p_w - \left(\alpha^s(e_f\,, e_m)(1+\theta)p_f\right) - \left((1-\alpha^s)(e_f\,, e_m)\right)p_f - c^{inf}(e_f\,, e_m) - c_m e_m\} \quad (7)$$

CBH profit is reduced by the price paid to farmer plus the monitoring cost and the cost of infestation.

The probability of CBH paying the price premium is:

$$\alpha^s(e_f\,, e_m) = e_f\, e_m + (1-e_f)(1-e_m) \quad (8)$$

The probability of not paying a premium to the farmer:

$$1-\alpha^s(e_f\,, e_m) = e_f(1-e_m) + (1-e_f)e_m \quad (9)$$

The expected cost of infested grain is:

$$c^{inf}(e_f\,, e_m) = (1-e_f)e_m\, c^{inf}{}_0 + (1-e_f)(1-e_m)c^{inf}{}_1 \quad (10)$$

The first term on the right hand side of the equation is an expected cost when an infested crop is detected and is segregated. The second term is the expected cost when infested crop is not detected and is allowed to infest a batch of grain at the receival site. It is expected that:

$$c^{inf}{}_0 < c^{inf}{}_1 \quad (11)$$

**Table 1.** Grain status detection events.

| Farm biosecurity state | CBH detects grain status | |
|---|---|---|
| | **Detected** | **Not detected** |
| Insect Free | $e^f e^m$ | $e^f(1-e^m)$ |
| Infested | $(1-e^f)e^m$ | $(1-e^f)(1-e^m)$ |

**Table 2.** Model parameters.

| Parameter or function | Value of parameter or function ($/tonne) |
|---|---|
| Export Wheat Price 2008 ($\boldsymbol{p_w}$) | 326 |
| Farmer's Reserve Wheat Price ($\boldsymbol{p^f}$) | $0.7\, p_w$ |
| $\boldsymbol{C_f(e^f) = \beta_0 \left(\frac{1}{1-e^f}\right)^{\beta_1}}$ | $\beta_0 = 6.17;\ \beta_1\ 0.365961$ |
| $\boldsymbol{C_m(e^m) = \phi_0 \left(\frac{1}{1-e^m}\right)^{\phi_1}}$ | $\phi_0 = 10;\ \phi_1 = 0.5$ |
| $\boldsymbol{C_0, C_1}$ | $C_0 = 30, C_1 = 120$ |

That is, when infestation is detected and infested crop is segregated from other non-infested crop, losses or costs incurred by the CBH will be less than when it is not detected and infestation will permeate the whole crop. The condition for an optimal selection of biosecurity effort of the farmer and the monitoring effort of CBH is given by:

$$\frac{c^{inf}\, e_m + c_m'\, e_m}{c^{inf}\, e_f + \gamma c_f''(e_f)} = \frac{\alpha^s(e_m) - 2\gamma}{\alpha^s(e_f)} \qquad (12)$$

The previous equation shows that the marginal expected cost of infested crop is equal to the corresponding increase in the probability of crop being assessed as 'non-infested'.

For a given monitoring scheme for CBH, the farmer exerts the following effort:

$$-c^{inf}\, e_f - c_f'(e_f) - h(e_f, e_m) c_f''(e_f) = 0 \qquad (13)$$

Where;

$$h(e_f, e_m) = -\frac{\alpha^s(e_f,\ e_m)}{\alpha^s(e_f)}$$

#### Parameter values for the model

The model has a relatively small number of parameters (Table 2); most are straightforward, such as the WA grain price. The price of rejected grain or infested grain is set as a parameter in relation to the WA grain price. The only non-linear elements in the model are the costs of farmer biosecurity efforts and CBH monitoring efforts. These functions are calibrated from available data (Taylor and Dibley, 2009, CRC70096). The cost of infested grain involves two terms: when infested grain is identified, then it can be separated and treated at a relatively low cost. However, a more substantial cost is incurred when infested grain is not detected and is combined in a larger batch; to impose a significant problem to the whole grain bulk.

#### Model output

The model's optimal solution includes effort level exerted by farmer and CBH. The more effort done on farm, the less effort will be required at CBH and better grain quality will result and vice-versa. Each model scenario generates different profit for CBH. Given the grain prices paid to farmers (with/without premium), CBH's profit associated with each grain-quality scenario (i.e. objective function value) is calculated. Optimal effort levels for farmer and CBH and their resulting profit values for various grain-quality scenarios are then compared to address the research questions.

## RESULTS

The effort levels within the three scenarios and their associated returns are compared to highlight the effect of the asymmetric information problem between CBH and farmer (Figures 1 and 2). The results give a clear message that, asymmetric information reduces the profits of both the farmer and CBH. New technology that reduces the cost of monitoring to CBH is beneficial as it reduces CBH costs; and induces a higher level of biosecurity effort by the farmer.

Consider the perfect information result (Scenario 1); CBH is able to detect infested grain at no cost; and therefore selects $e_m$ =1. Also CBH is able to contract on the level of farmer's effort. Results (of scenario 2 and 3 ) show a more complicated case; where CBH depends on a price premium $\theta$ (or cost-discount) to provide farmer

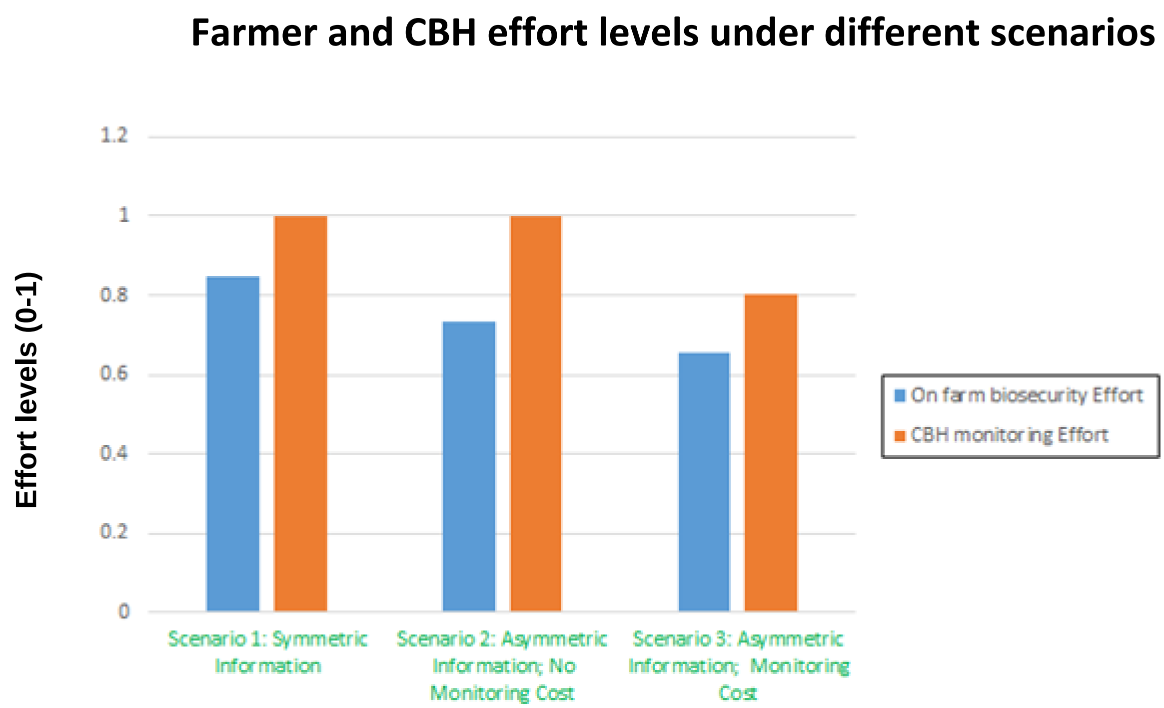


**Figure 1.** Effort levels exerted by farmer and CBH under scenarios 1, 2 and 3.

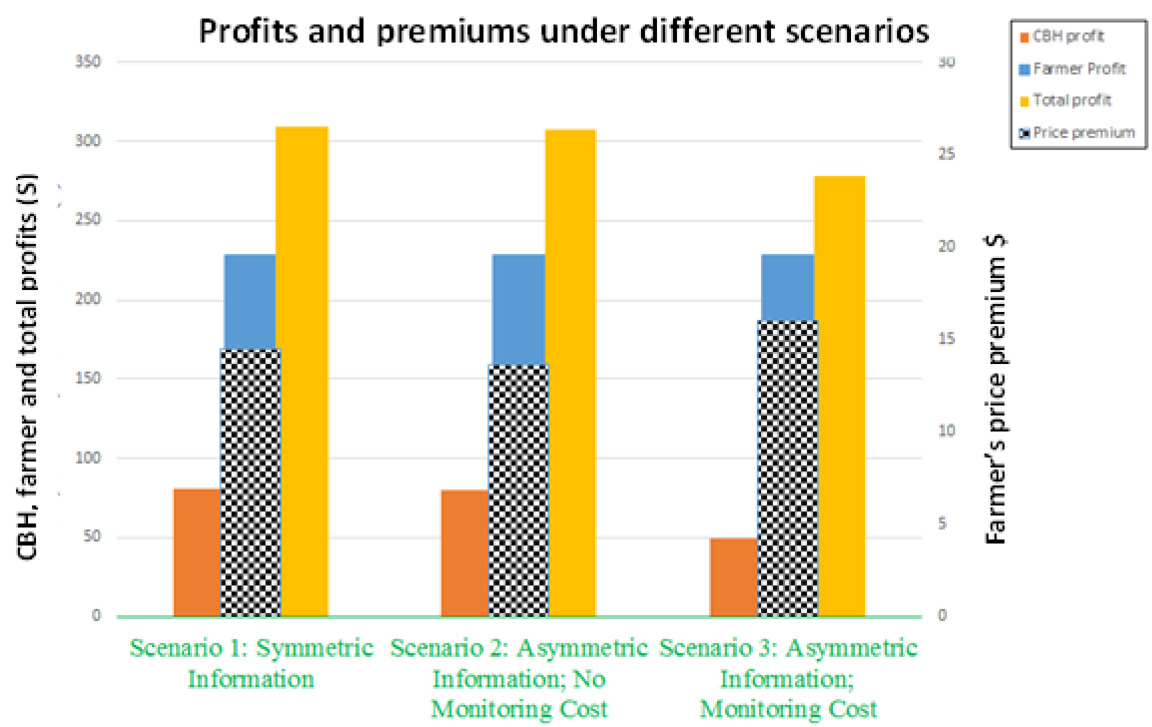


**Figure 2.** Farmer's Price premium and farmer and CBH's profits under scenarios 1, 2 and 3.

with an incentive to deliver insect-free grain. However, the incentive for on farm effort declines in Scenario 3; when the cost of CBH monitoring dictates that CBH engages in imperfect monitoring and occasionally mis-classifies grain as infested (when not-infested) and vice-versa. These errors of classification reduce the incentives of farmers to exert biosecurity effort.

Figures 1 and 2 illustrate the cases of different information types and effort levels that the biosecurity contract model produces. CBH as the principal offers a contract to a farmer, which includes a price premium; when clean grain is detected. The contract fixes a level of monitoring of grain quality and targets a level of farm effort; that entails labor and material costs related to managing biosecurity on farms. Figure 1 shows clearly the decrease in farmer's effort level on farm between the three scenarios.

Under asymmetric information, there is a probability of mis-classification of wheat quality by CBH which exerts the least biosecurity effort level. This reaction reflects how significant it is to have the correct monitoring effort level at CBH; that gives more confidence to farmer where effort level will be correctly rewarded and paid for. In addition, a comparison between the three scenarios show the lower monitoring effort level of CBH because of the accompanied monitoring cost. A technological advancement that may result in reducing monitoring cost for CBH, may lead to higher grain quality and more profits for farmer and CBH.

Figure 2 indicates the lower CBH profit level under scenario 3 because of the higher incurred losses with the asymmetric information scenario between CBH and farmer; which cannot be correctly detected with the high monitoring cost. Farmer's profit has not been actually changed between the three scenarios. This might be a significant reason of farmer's manipulation; who does not need to exert much effort if the profit will not be affected. A fair system of evaluating farmer's effort can be a stimulator to deliver a high quality grain to CBH. A higher price premium paid to farmer under scenario 3 shows a good way of encouragement to deliver grain that is pest free; but does not guarantee it. Better evaluation methods for grain quality may help encourage higher biosecurity effort levels on farms.

## DISCUSSION AND CONCLUSION

The main findings of the paper can be summarized as follows: (1) Asymmetric information, relating to grain quality and in particular the effort level that the farmer applies to grain biosecurity management on farm, imposes a cost on CBH and hence; reduces its profit. (2) The CBH's ability to monitor grain's quality delivered to their receival sites encourages the farmer to exert more biosecurity effort on farm. The results of the three scenarios described under grain quality model show that, asymmetric information between CBH and farmer reduces the CBH's profits. New technology that reduces the cost of monitoring to CBH is beneficial as it induces a higher detection level at CBH; and consequently a higher effort level on farm and a resulting good quality of grain. The contract between CBH and farmer includes a price premium related to the freedom of grain from any pests. The level of effort on farm entails labour and material costs related to managing biosecurity on farm.

This paper presents some provisional results on the design of contracts for grain quality. The realistic scenario; where farm effort is non-verifiable and CBH monitoring is costly requires that CBH pays a price premium to the farmer of around 5% over the reserve price. Farmer's and CBH's monitoring practices are considered substitutable. The more effort exerted by farmer on farms, the higher the grain quality will be and the less effort required by CBH, and vice-versa. The model can be further developed by including contracting over farm grain store investment. This would then allow farmers to signal their intention to store grain in a way that reduces the probability of infestation. In addition, some other factors that result in grain quality deterioration; rather than misuse of phosphine, might be included to measure for their impacts on the grain network.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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