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Economics of Biological Control in Cabbage Production in two Countries in East Africa

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Abstract

A major constraint of cabbage production in Kenya and Tanzania are insect pests, especially the Diamondback Moth (DBM), which is resistant to almost all commonly used pesticides. In 2001, the International Centre of Insect Physiology and Ecology released an exotic parasitoid, as a case of classic biological control of the pest in East Africa. This paper supplements existing ex-ante impact assessments, conducted during the pilot phase of the project, by presenting the results of a medium term ex-post economic impact assessment. Data were collected in two surveys in 2004/2005 in Central Province, Kenya, and Northern Zone, Tanzania; two major cabbage production areas. The two survey waves were conducted in both dry and rainy season to capture the seasonal variation. The analysis is based on a cross section of 1,291 randomly selected households from both countries. The study used a two-stage damage control production function framework, which treats both pesticide and biological control as damage abatement agents taking into account the endogeneity problem.

Results demonstrate that farmers producing cabbage in areas where biological control is present use significantly less pesticide compared to farmers from areas without biological control. Farmers in Kenya use a higher amount of pesticide than farmers in Tanzania. Pesticide use is negatively correlated with pesticide price, while it is positively correlated with a pest pressure above normal level. Surprisingly, the damage control function shows that farmers from areas with biological control have significantly lower cabbage revenue than farmers from areas without biological control, although a positive impact of biological control on yield was found. However, decreased pesticide use resulted in health benefits for farmers with biological control. Overall, the results support the notion that introduction of classic biological control as a pest control strategy in the two Eastern African countries does not lead to higher net income, but has positive effects on environmental and farmer's health.

Background

Crucifers, especially cabbage, *Brassica oleracea* L. var. *capitata*, belong to the most important vegetables grown in eastern and southern Africa. Cabbage is an important source of vitamins and minerals in a maize-based diet, as well as source of income for smallholder farmers. However, horticultural production is constraint by many problems, with pests being a major one. Among insect pests, the Diamondback moth (DBM), *Plutella xylostella* (L.), is considered as the most destructive worldwide and occurs wherever Brassica crops are cultivated (Talekar and Shelton, 1993). Its damage to cabbage crop results in crop losses and low marketability due to contamination of the heads with larvae or frass. To minimize output losses farmers widely use synthetic pesticides and most farmers in Africa solely depend on their use (Varela *et al*., 2003). The increasing difficulties in DBM control are due to its ability to quickly develop resistance to any pesticides extensively used against it (Gelernter and Lomer, 2000). This challenges farmers in their dependency on chemical control measures, and without alternatives, farmers tend to overuse chemicals shown by high quantity and spray frequency, as well as application of pesticide cocktails (Varela *et al*., 2003). Besides high production costs, other potential implications are the reduction of already small populations of natural enemies, a decline in land and water quality through residues of pesticides and human as well as animal health problems (Brethour and Weersink, 2001; Margni *et al*., 2002). Since chemical control measures are becoming increasingly difficult and uneconomical, biological control is gaining attention (Lubulwa, 1997; Hajek, 2004). Biological control is an alternative to chemical pest control, thus representing a technology, which has the potential to provide resource-poor farmers low-cost natural pest control, to alleviate dependency on pesticides, and via decreasing pesticide use to reduce negative effects on environmental and human health.

A biological control agent, *Diadegma semiclausum*, was introduced by the International Centre of Insect Physiology and Ecology from 2001 onwards in Kenya, Tanzania and Uganda to control for the DBM problem. An economic *ex-ante* impact assessment was conducted during the pilot phase of the project and calculated a benefit cost ratio of 24:1 (Macharia *et al*., 2005). As a supplement, this study represents a short to medium term *ex-post* impact assessment. Specific questions, which are addressed in this study, are (1) Does the introduction of classical biological control affect the output of cabbage production? (2) Does classical biological control result in reduced pesticide use? To answer these questions, study areas in Kenya and Tanzania were selected and data on cabbage production and farmers' health collected following a "with and without" survey design.

Economic impact assessment of classical biological control

Economic impact assessments of classical biological control[1] have been conducted *ex-post* and *ex-ante*, mostly using economic surplus models and conducting cost benefit analyses. Nowadays a production function framework with integrated damage control function is a standard procedure in agricultural production economics and is frequently used in estimations of productivity of pest control measures, mostly of pesticides. In the following a new approach to the economic analysis of biological control is introduced following the production function with damage control framework.

One key feature in the concept of damage abatement is the distinction between inputs in standard factors of production (e.g. land, labor, capital) and in damage control agents (e.g. pesticide, biological control). This distinction is important, because control agents like pesticide and biological control do not enhance productivity directly as standard inputs do, but contribute indirectly to the actual output by preventing output losses. In this study damage control agents considered are pesticides and biological control; the special characteristics of this combination of damage control agents is described in the following

First, population density of biological control agents affects their effectiveness against DBM and their full potential is only reached when they are well established. For this study, information on population density was not available and thus only presence or absence of biological control is considered. Second, the biological control can only control damage caused by DBM and not by other insect pests and plant diseases. Thus, the effect of pesticide and biological control is supplemental and a lower amount of pesticide needs to be applied. Third, it must be accounted for a potential negative impact of pesticide use on biological control, especially the use of broad-spectrum pesticides. Consequently a successful establishment and

[1] Classical biological control is further referred to as simply biological control.

maintenance can be hampered and the level of output losses prevented by biological control can decrease to lower levels. Further, the establishment of biological control can be enhanced by several IPM methods.

Methodology of data collection

The survey followed a two stage sampling design. The first stage involved the selection of major cabbage producing areas with and without biological control: Central Province (Kiambu, Nyeri and Nyandarua District) in Kenya and Northern Zone (Arusha and Tanga Region; and within these regions Arumeru and Lushoto District respectively) in Tanzania. A list of cabbage farmers that was compiled by national extension officers served as sampling frame to randomly select farmers on sub-location/ward level in the second sampling stage. The sampling procedure resulted in a total sample of 1,291 randomly selected farmers covering two cabbage production seasons of which 1,250 complete data sets were retained for the analysis. In Kenya the sample consists of 634 farmers, 496 from areas with biological control and 138 from areas without biological control. In Tanzania the total number of sampled farmers is 616, with 354 from areas with biological control and 262 from areas without biological control.

Data collection was undertaken for two cropping seasons, dry and rainy season using the same structured questionnaire. Information was collected trough face-to-face interviews, for the dry season by a recall survey (October 2004 to March 2005), and for the rainy season (March 2005 to July 2005) by season-long monitoring.

Estimation procedures for production function with damage control function

In the analysis of pesticide productivity, the use of a standard Cobb-Douglas function is criticized for treating pesticide as yield increasing production factor and not capturing knowledge about physical and biological processes of pest control agents. Lichtenberg and Zilberman (1986) explain that using a Cobb-Douglas functional form results in overestimation of productivity of damage control inputs, while productivity of other factors will be underestimated. To address this problem they introduce the concept of damage abatement and propose different specifications of damage control functions.

Until today no agreement on the most suitable specification of the damage control function has been reached. Empirical studies show that results can be sensitive to the functional form (Carrasco-Tauber and Moffitt, 1992; Fox and Weersink, 1995; Pemsl, 2006). Hence, in this study different functional forms are applied and estimated parameters compared. Generally three types of functions are estimated, a standard Cobb-Douglas production function treating pesticide and biological control as conventional production factors estimated for comparison reasons, and two Cobb-Douglas functions with in-build exponential and logistic specification of damage control function, both treating pesticide and biological control as damage abatement agents.[2]

Lichtenberg and Zilberman (1986) note that damage abatement functions may not only include damage control agents, but also other variables, which affect the damage abatement effort. Thus, exogenous variables such as weather conditions and the state of nature interacting with pest prevalence, could be included in the function, but are ignored since they are considered to be not controllable. Since the biological control agent *Diadegma semiclausum* is a natural enemy of DBM, this study explicitly accounts for at least one controllable natural damage abatement agent, so that overall the upward bias in the productivity of pesticides will be reduced.

Additionally, all functions allow for an interaction between pesticide and presence of biological control. Because of the interaction term the interpretation of the coefficients of the variables pesticide and presence requires caution. Following Wooldridge (2003), coefficients of

[2] For specifications see Lichtenberg and Zilberman (1986).

variables which are part of the interaction term need to be computed and cannot be directly interpreted.

A major problem in estimating the above stated production functions is endogeneity of pesticide use in the production function. To address this problem, a two-stage least square (2SLS) estimator is used, and the pesticide use variable is instrumented. Furthermore, production functions and pesticide use function are tested for colinearity and heteroskedasticity, two other potential problems with cross-sectional data. Heteroskedasticity problems detected with the Breusch-Pagen test were corrected for using the Generalized Methods of Moments procedure for 2SLS estimations. All estimations and different tests are addressed using the software package SAS®9.1 and STATA®8.0.

Results

Pesticide use function

In the first stage a pesticide use function[3] is estimated. The dependent variable pesticide cost includes expenditure on insecticides and fungicides measured in US$ per ha and is converted to its logarithmic form. As explanatory variables presence (of biological control), pest pressure, pesticide price, number of products, variety, training, good practices, season and district dummies or an alternative country dummy are included. The district dummies serve to capture the variation in agro-climatic conditions and infrastructural settings that could affect the price and marketing of cabbage. Presence of biological control was not measured at each cabbage plot due to resource constraints, but at division level in Kenya and district level in Tanzania by using information on biological control release points and findings on migration of the parasitoid.

The estimation results suggest that in areas where biological control is present the pesticide expenditure is significantly lower than in areas without biological control. *Ceteris paribus*, the presence of biological control reduces pesticide expenditure by around 34%. Further, pest pressure above normal level, *ceteris paribus*, increases pesticide cost per ha by 23%. Also, a higher pesticide price as well as the use of a higher number of different pesticide products increases pesticide expenditure significantly. Concerning other variables, no conclusions can be drawn since they are not statistically significant. Nevertheless, the signs of the variables denoting use of more tolerant cabbage varieties, participation in agricultural training, use of good practices and rainy season indicate that these factors contribute to reduced pesticide costs, although they are not significant.

The district dummies depict that farmers from Nyeri District, Kenya, spend significantly more on pesticide compared to farmers from both districts of Tanzania (Arumeru and Lushoto) but no significant differences were found between all Districts in Kenya. Using an alternative country dummy in the estimation, results show that Tanzanian farmers use lower levels of pesticides and have significantly lower pesticide expenditure than Kenyan farmers.

Production function with damage control function

At the second stage of the estimation of the production function, the dependent variable output represents the total revenue of cabbage production in terms of cash and in-kind production valued at current prices in US$ per ha converted to its logarithmic form. The output is expected to be directly and indirectly influenced by different input factors like seed, fertilizer, labor, season,

[3] As an entry point of the 2SLS estimation, two alternative pesticide use functions are estimated by ordinary least squares (dependent variables being pesticide cost in US$ per ha and pesticide quantity in kg/l per ha converted to their logarithmic forms). Both functions show a highly significant negative impact of biological control and also other results are similar. Since the pesticide cost function provides a better fit to the data according to the R-squared, it is used for the 2SLS estimations.

age, district dummies / country, pesticide, presence and interaction. The estimation results are presented in Table 1.

Table 1: Estimated parameters for production function

Variable	Cobb-Douglas Coefficient	Cobb-Douglas Std. Error	Damage function specification: Exponential Coefficient	Exponential Std. Error	Logistic Coefficient	Logistic Std. Error
Cobb-Douglas function						
Intercept	4.2366***	0.3735	4.3802***	0.3599	5.1648***	0.5129
Seed	0.2746***	0.0341	0.2841***	0.0348	0.2810***	0.0341
Fertilizer	0.1396***	0.0290	0.1282***	0.0293	0.1418***	0.0289
Labor	0.0626**	0.0274	0.0694***	0.0280	0.0680**	0.0269
Age	0.0227	0.0797	0.0390	0.0813	0.0135	0.0795
Season	-0.1011**	0.0478	-0.0788	0.0486	-0.1033**	0.0478
Districts (Nyeri base)						
Kiambu	0.6569***	0.1125	0.3848***	0.1007	0.6592***	0.1124
Nyandarua	0.7353***	0.0895	0.4567***	0.0740	0.7360***	0.0893
Arumeru	0.3540***	0.0971	0.1106	0.0889	0.3189***	0.0944
Lushoto	0.5427***	0.1000	0.6871***	0.0883	0.5598***	0.1008
Pesticide	0.1273***	0.0399				
Presence	-0.2627	0.1949				
Interaction term	-0.0646	0.0474				
Damage control function						
Intercept					0.1422	0.6408
Pesticide			0.6133***	0.1879	0.0124	0.0097
Presence			0.6981**	0.3409	-0.5240**	0.2385
Interaction term			-0.3776*	0.2285	-0.0103	0.0093
R^2	0.280		0.250		0.282	
Adj. R^2	0.272		0.241		0.273	

N = 1250. Note: Statistical significance at 0.01 (***), 0.05 (**) and 0.1 (*) level of probability. Cobb-Douglas and logistic function are corrected for heteroskedasticity.
Source: own survey

All estimated functions have a sound explanatory power with adjusted R-squared values ranging between 0.24 and 0.28, which is acceptable for cross-sectional data. The direct inputs such as seed cost, fertilizer cost and labor cost are expressed in US$ per ha and are robust over the different specifications. Their significant positive coefficients indicate that higher spending on seed, denoting that farmers either purchased high quantity or better quality of seeds, higher expenditure on organic and/or inorganic fertilizer and aggregated labor costs for different farm activities increase cabbage revenue. The coefficients of the season dummy are negative in all functions showing that the cabbage revenue is lower in the rainy season. Thus, the increase in cabbage quantity produced as a result of favorable environment (e.g. rainfall) does not sufficiently compensate for the decline in market price during the rainy season and results in lower cabbage revenue. The coefficients of age as a proxy for experience in agricultural production and management skills are positive, but not significantly different from zero in all specifications. Nyeri farmers have significantly lower revenue from cabbage production compared to other surveyed districts in Kenya (Nyandarua and Kiambu) and Tanzania (Arumeru and Lushoto).

Analysis of the impact of damage control agents on cabbage output shows that the results are sensitive to the methodological approach. The interaction term is negative for all specifications, indicating a negative impact of pesticide on biological control agents. For the Cobb-Douglas function, the positive pesticide coefficient suggests that an increase in pesticide expenditure is associated with increase in cabbage output. For the exponential and logistic specification the computation of pesticide coefficients results also in positive values, although it is not significant for the latter one. In sum, all the specifications point to the positive role of pesticide input on cabbage revenue. Regarding the impact of biological control, the estimation results show that although the presence coefficients have different signs in the estimated functions (positive in exponential, negative in Cobb-Douglas and logistic), all the coefficients turn to be negative when the interaction term is taken into account and coefficients are computed at the average level of pesticide use. Thus, the estimation results display the common message that farmers from areas with biological control obtain significantly lower cabbage revenue. But compared to conventional pest control strategies, which primarily rely on the use of chemical pesticides, the role of biological control on output depends highly on two major factors. First, the level of establishment of biological control in the cabbage field, and second, the level of DBM's resistance to pesticide. For this study no information was available to establish the fact on these two issues, and hence the low cabbage revenue in areas with biological control might be explained by these two factors. Another explanation could be that in the long-run, a higher cabbage production level in areas with biological control leads to lower cabbage prices and thus to lower cabbage revenue. However, to confirm this empirically goes beyond the scope of this study and would require a "before and after introduction of biological control" comparison, which was not possible at the time of this study since the biological control was established in most areas of Kenya.

In order to explore robustness of the estimated models, production functions were also estimated using a country dummy, and furthermore, exponential and logistic functions were estimated for each survey country separately. Results of this confirm previous results, however, the R-squared value decreases for all specifications as compared to the estimating with district dummies, indicating that the country dummy explains less of the variation in the cabbage revenue. Overall, pesticide shows a positive impact on cabbage revenue in all estimated functions, but presence of biological control indicates a negative impact, which is somewhat contradictory to informal field observations and is being explored further.

Conclusion

This study introduces a new approach in the economic analysis of biological control by using the concept of production function with integrated damage control function with the classical biological control agent, *Diadegma semiclausum*, pesticide, as well as the interaction between these two control agents.

The estimated pesticide use function shows that biological control leads *ceteris paribus* to a 34% decrease in pesticide expenditure. However, estimation results of production functions using different specifications lead to the conclusion that cabbage production with biological control results in lower cabbage revenue than obtained without biological control. This result is contrary to informal observations in the field, which constituted an integral part of the follow-up on the establishment of the biological control, and is being assessed further.

Although not discussed in this paper, further econometric estimation results of a Poisson regression model and a zero-inflated Poisson model support the notion that biological control has a positive impact on household health. Moreover, biological control spread itself and can migrate to other countries, or as in the case of *Diadgema semiclausum* can even prevent damage that DBM causes to other crucifer crops like kale. Therefore also high positive spill-over effects are expected, contributing further to a positive economic impact. However, since biological control is a relatively slow process, complete information on the project impact can usually be obtained only after many years (Van Driesche and Hoddle, 2000) and the results presented here not yet reflect the steady state long-term impact.

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