Evaluating Vector-Virus-Plant Interaction in Regional Supply of Peas and Lentils: A Limited Dependent Variable Analysis

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Introduction

The Palouse area, which encompasses parts of eastern Washington and northern Idaho, is one of the leading pea and lentil producing regions in the US (USDA, 2007). These crops are exposed to PEMV (*Pea enation mosaic*) and BLRV (*Bean leaf roll*) viruses, which are usually vectored by the pea aphid, *Acyrthosiphon pisum* (Harris). Pea aphid outbreaks and associated epidemics of PEMV and BLRV virus can significantly reduce yields (Clement et al., 2010).

An analytical model is formulated to depict the effects of pea aphid and virus outbreaks on yields under optimal planting and pesticide use decisions, given that the levels of pea aphid outbreaks and virus epidemics can be endogenous (Marsh et al., 2000). Our profit maximization based model allows planting and pesticide use decisions to affect prevalence of the aphid and the viruses. Analytical results are derived to show the effects of aphid outbreaks on pest damage-adjusted yield under optimal planted acreage and pesticide use.

Empirically we apply a simultaneous equations model (Roodman, 2009) to investigate the interactions among pesticide use-adjusted crop yields, aphid infestations, and virus outbreaks. The four equations are: per acre yield of peas, per acre yield of lentils, infestations of aphid, and outbreaks viruses.

The data set defines 5 levels of pea aphid abundance severity ranging from 0, corresponding to no aphid presence, to 4, corresponding to peak counts averaging >100 aphids per plant in 76–100% of the fields (Clement et al. 2010). The records of viruses (PEMV and BLRV) are combined into a single binary variable with 1 indicating virus outbreak and 0 for no virus outbreak (Clement et al. 2010). To reflect the categorical nature of our data we imposed ordered probit and probit specifications on the equations where aphid and virus are the dependent variables respectively. Following Clement et al. (2010) and Burrows (1983), we include temperature and rainfall as exogenous variables in the aphid and virus growth functions.

Objectives

- The primary objective of this study is to examine the effects of aphid and virus outbreaks on the yields of peas and lentils under optimal planting and pesticide use decisions while incorporating possible effects of climatic conditions on the likelihood of virus and pea aphid outbreaks.

- Set up a theoretical model to show the effects of aphid and virus outbreaks on yields under optimal pesticide use when aphid growth is in part endogenously determined.

- Compare our empirical results from simultaneous equations system with single equation estimation.

Selected Citations

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Analytical Model

Following the logic of Sexton et al. (2007), the profit maximization problem is set up as follows:

$$Max \quad \pi = PY(\theta)D(A,V)x_1 - w_1x_1 - w_2x_2$$
$$s.t. \quad A = A(x_1,x_2,\theta) \quad and \quad V = V(A)$$
$$\frac{dA^*}{d\theta} = \frac{\partial A^*}{\partial x_1}\frac{dx_1^*}{d\theta} + \frac{\partial A^*}{\partial x_2}\frac{dx_2^*}{d\theta} + \frac{\partial A^*}{\partial \theta}$$
$$\frac{dY(\theta)D^*}{dA^*} = \frac{dY(\theta)D^*/d\theta}{dA^*/d\theta} = \frac{Y'D^*}{dA^*/d\theta} + Y(\theta)\left(\frac{\partial D^*}{\partial A} + \frac{\partial D^*}{\partial V}\frac{dV^*}{dA}\right)$$
$$\frac{dY(\theta)D^*}{dV^*} = \frac{Y'D^*}{dV^*/d\theta} + Y(\theta)\left(\frac{\partial D^*}{\partial V} + \frac{\partial D^*}{\partial A}\frac{dA^*}{dV}\right)$$

Where :
x_1 – Planted acreage
x_2 – Pesticide use
A – Aphid abundance
V – Virus Ourbreak
Y – Yield
D – Crop Yield Damages Control [0:1]
θ – Climatic Conditions

The equations above allow one to decompose the effects of aphid and virus on damage adjusted yield into two parts: the direct effect caused by aphid and virus, and the indirect effect through change of climatic conditions. It can be shown that the direct effect is always negative. However, the sign of the indirect effect can only be determined unambiguously under two cases without making assumptions on relative magnitudes of the component terms.
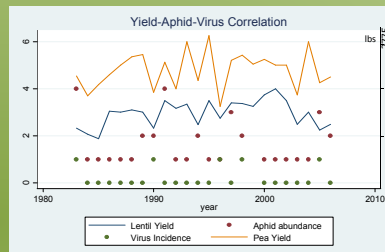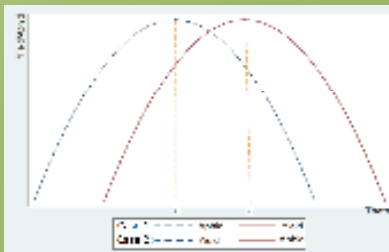
Case 1:
$$\frac{\partial A^*}{\partial \theta} < 0 \quad \frac{\partial^2 \pi}{\partial x_1 \partial \theta} < 0 \quad \frac{\partial^2 \pi}{\partial x_2 \partial \theta} > 0 \quad \frac{\partial^2 \pi}{\partial x_1 \partial x_2} < 0 \quad Y' > 0$$

Case 2:
$$\frac{\partial A^*}{\partial \theta} > 0 \quad \frac{\partial^2 \pi}{\partial x_1 \partial \theta} > 0 \quad \frac{\partial^2 \pi}{\partial x_2 \partial \theta} < 0 \quad \frac{\partial^2 \pi}{\partial x_1 \partial x_2} < 0 \quad Y' < 0$$

In both of the two cases, the total effect will be negative.

Yield-Aphid-Virus Correlation

Empirical Method

We apply the Full Information Maximum Likelihood (FIML) (Roodman, 2009) method to examine interactions among pea and lentil planting decisions, pea aphid infestations, and outbreaks of *PEMV and BLRV* viruses in the Palouse region of WA.

The model is specified as:

$$\begin{cases} Y^P = \beta_{10} + \beta_{11}Acr^P + \beta_{12}Temp + \beta_{13}V + e_1 \\ Y^L = \beta_{20} + \beta_{21}Acr^L + \beta_{22}Temp + \beta_{23}V + e_2 \\ A = \Phi_A(\beta_{31}Acr^P + \beta_{32}Acr^W + \beta_{33}Rain + \beta_{34}Temp + e_3) \\ V = \Phi_V(\beta_{40} + \beta_{41}A + e_4) \end{cases}$$

Where the third equation is specified as an ordered probit, and fourth equation is specified as a probit.

Data and Summary Statistics

Variable	Mean	Std. Dev.	Min	Max
Pea Planted (thousand acres)	94.33	19.87	65	126
Lentil Planted (thousand acres)	78.19	15.27	48	112
Wheat Planted (thousand acres)	2591.481	346.5983	2100	3700
Pea Yield (lb per acre)	1868.905	538.031	1288	2775
Lentil Yield (lb per acre)	965.19	232.30	595	1366
Max Temp. (F)	64.64958	1.743618	61	67.02
Min Temp. (F)	51.54375	1.51207	48.05	54.08
Rainfall (mm)	14.03083	3.368483	7.78	20.8
Virus	.2083333	.4148511	0	1
Aphid	1.583333	1.017955	0	4

The crop data come from The National Agricultural Statistics Service
The weather data come from Western Region Climate Center

Results

Variable	FIML Result	Single Equation Result	
PEA YIELD EQUATION			
Pea Planted	0.0113***	0.002***	
	(15.87)	(12.76)	
Virus	-0.5321***	-0.3754***	
	(-3.78)	(-4.35)	
Mean Temp.	-0.03*	-0.043*	
	(-2.35)	(-2.26)	
Constant	18.835***	12.21***	Adj-R-Squared:
	(9.786)	(3.371)	0.832
LENTIL YIELD EQUATION			
Lentil Planted	0.0473***	0.023***	
	(15.87)	(19.78)	
Virus	-0.212***	-0.18**	
	(-3.78)	(-2.63)	
Mean Temp.	-0.0027	-0.0058	
	(-0.39)	(-0.86)	
Constant	23.437***	20.965***	Adj-R-Squared:
	(10.25)	(6.75)	0.832
APHID EQUATION			
Wheat Planted	0.00440**	0.0038**	
	(3.27)	(2.43)	
Pea Planted	-0.00298	-0.001	
	(-0.44)	(-0.09)	
Rainfall	-0.164*	-0.104	
	(-2.37)	(-1.19)	
Min Temp.	0.317***	0.08	Pseudo R Squared:
	(7.06)	(0.38)	0.14
VIRUS EQUATION			
Aphid	0.0569**	0.57**	
	(2.22)	(1.93)	
Constant	-0.946	-1.84**	
	(-1.55)	(-2.87)	
	P(LR>chi-Squared(4))		Pseudo R Squared:
	0.033**		0.14
t-statistics in parentheses		p***<0.01, p**<0.05, p*<0.10	

Conclusions

- Analytical results show two conditions under which the total effect of aphid on yield can be signed unambiguously without additional assumptions on the magnitudes of component parts of the indirect effect and the direct effect. Both cases correspond to the situation where $\theta_1 < \theta < \theta_2$. In this interval direct effect of changes in climatic conditions on yield is enhanced with the indirect effect of climatic change via increasing or decreasing damages from aphid and viruses.

- Empirical results show that the presence of virus causes a 0.5 pound loss to the pesticide use-adjusted pea yield and a 0.2 pound loss to lentil. The effect of virus is inconsequential relative to total yield which points to effectiveness of pesticide use.

- The LR test for the simultaneous equations model is significant (P-value 0.033), justifying the use of this approach for estimating the inter-relationships among crop productivity, vector insect infestation, and virus outbreaks.

Acknowledgement