Ecological Economics 126 (2016) 1–13

Contents lists available at ScienceDirect

Ecological Economics

journal homepage: www.elsevier.com/locate/ecolecon

Analysis

The macroeconomic cost of catastrophic pollinator declines

Dana Marie Bauer [a,*], Ian Sue Wing [b]

[a] George Perkins Marsh Institute, Clark University, Worcester, MA 01610, USA
[b] Department of Earth and Environment, Boston University, Boston, MA 02215, USA

ARTICLE INFO

Article history:
Received 27 November 2011
Received in revised form 8 January 2016
Accepted 31 January 2016
Available online 1 April 2016

Keywords:
Ecosystem services
Pollination
Valuation
Agriculture
General equilibrium model

ABSTRACT

We develop a computable general equilibrium (CGE) approach to assess the macroeconomic impacts of productivity shocks due to catastrophic losses of pollination ecosystem services at global and regional scales. In most regions, producers of pollinator dependent crops end up benefiting because direct output losses are outweighed by increased prices, while non-agricultural sectors experience large adverse indirect impacts, resulting in overall losses whose magnitudes vary substantially. By comparison, partial equilibrium analyses tend to overstate the costs to agricultural producers, understate aggregate economy-wide losses, and overstate the impacts on consumers' welfare. Our results suggest an upper bound on global willingness to pay for agricultural pollination services of $127–$152 billion.

1. Introduction

Pollination is a valuable ecosystem service which provides a variety of benefits including food and fiber, plant-derived medicines, ornamentals and other esthetics, and genetic diversity, as well as contributions to overall ecosystem resilience (Naban and Buchmann, 1997; MEA, Millennium Ecosystem Assessment, 2003). Mounting evidence of long-run declines of both managed and wild insect pollinators at local and regional levels has raised concerns over potential risks to global food security and economic development, particularly in countries where agriculture is a large portion of the economy (Kluser and Peduzzi, 2007; Steffan-Dewenter et al., 2005; Allen-Wardell et al., 1998). Acute declines in pollinator populations and species diversity have occurred in Europe and North America (Biesmeijer et al., 2006; NRC, National Research Council., 2007; vanEngelsdorp et al., 2008; Potts et al., 2010), and been linked to pests, diseases, habitat destruction, and agricultural intensification (Cunningham, 2000; Kremen et al., 2002; Priess et al., 2007; Winfree et al., 2009; Le Feon et al., 2010; vanEngelsdorp and Meixner, 2010). Of particular concern is the fact that these trends coincide with agriculture's increasing dependence on pollination services globally (Aizen et al., 2008, 2009; Aizen and Harder, 2009; Garibaldi et al., 2009), which has fueled fears of a global pollinator crisis (Steffan-Dewenter et al., 2005).[1]

There has been a flurry of recent effort to quantify the economic benefits of pollination as an ecosystem service, elucidate the implications of pollinator declines for the supply of this service, and assess the economic and broader societal impacts of adverse supply shocks. Studies have sought to address this last issue in the context of agriculture by estimating the proportions of crops in a specific region that depend on pollinators, and calculating losses in terms of the value of the corresponding production at risk and the partial equilibrium impact on consumer surplus (Losey and Vaughan, 2006; Gallai et al., 2009a). This approach has been adopted by the United Nations Food and Agricultural Organization (FAO, Food and Agriculture Organization of the United Nations, 2009; Gallai and Vaissiere, 2009).

In the present paper, we highlight the implications of extending this economic valuation methodology to a general equilibrium (GE) setting. Specifically, we develop and test a novel approach that incorporates measures of the pollinator dependence of different crops into the sectoral production functions of a multi-region, multi-sector computable general equilibrium (CGE) model. Following Gallai et al. (2009a) and others (Barfield et al., 2012; Brading et al., 2009; Gallai and Vaissiere, 2009; Losey and Vaughan, 2006), we simulate catastrophic losses in both wild and managed pollinators implicitly as exogenous reductions in the productivity of crop sectors by the fraction of pollinator-dependent production.[2] The resulting price and quantity adjustments across domestic and international markets for crop as well as non-crop commodities elucidate the full welfare impacts of lost pollination services as well as

* Corresponding author at: George Perkins Marsh Institute, Clark University, 950 Main Street, Worcester, MA 01610-1477 USA.
E-mail addresses: dbauer@clarku.edu (D.M. Bauer), isw@bu.edu (I. Sue Wing).

[1] Globally, 75% of primary crop species and 35% of crop production rely on some level of animal pollination (Klein et al., 2007), while in the United States, more than half of primary crop species and 20% of primary crop production rely in part on animal pollination services (Bauer and Sue Wing, 2010).

[2] Because of the global scale of our analysis and a corresponding lack of detailed regional data, we are not able to explicitly model the ecological relationships between animal pollinators and crop production. The catastrophic loss of all pollination service inputs provides an upper bound on potential economic losses.

http://dx.doi.org/10.1016/j.ecolecon.2016.01.011
0921-8009/

the economic channels through which they operate. Our goals are four-fold: (1) provide a more robust upper-bound estimate of the global value of pollination services broadly defined; (2) examine both the direct (crop sector) and indirect (non-crop sector) impacts that could result from lost pollination services; (3) highlight the heterogeneity of potential economic losses among global regions, including the influence of global trade; and (4) compare and contrast our GE results to those provided by individual-market partial equilibrium (PE) approaches.

The remainder of the paper is organized as follows. In Section 2, we begin with a brief survey of the methods used by previous studies to estimate the value of pollination services. Our own methodology is described in Section 3, which outlines the construction of our scenarios of pollination service losses as crop sector productivity shocks, gives an overview of the CGE model's structure, database and calibration, and explains its relationship to the partial equilibrium analyses. Section 4 presents the results of our simulations, and draws comparisons with partial equilibrium assessments to yield insights into the potential spillover effects of lost pollination services on production in agricultural and non-agricultural sectors, relative price changes, and, ultimately, consumers' welfare. Section 5 concludes with a summary of our findings and suggestions for future research directions.

2. Background

To provide context for our analysis, it is useful to first consider the methods used by earlier economic valuation studies of pollination services supplied to agriculture. Three major approaches tend to be used: (1) calculation of the value of total annual crop production that can be directly attributed to animal-mediated pollination (e.g., Robinson et al., 1989; Morse and Calderone, 2000; Losey and Vaughan, 2006; Brading et al., 2009; Barfield et al., 2012), (2) estimation of the impacts on social welfare, in particular changes to consumer and producer surplus (e.g., Southwick and Southwick, 1992; Kevan and Phillips, 2001; Kasina et al., 2009; Winfree et al., 2011), and (3) summation of replacement costs, whereby purchased inputs—including the rental of commercial bee colonies or the use of non-animal alternatives (e.g., hand pollination or mechanized pollen dusting)—substitute for natural (i.e., wild) pollination services (e.g., Allsopp et al., 2008; Burgett, 2009; Burgett et al., 2010; Caron, 2010).

The key characteristic of these methods is the partial equilibrium (PE) focus on individual markets with no accounting for the consequences of potential linkages among them, in either backward (effects on upstream sectors' revenue by changing demand for the use of their products as inputs) or forward (effects on downstream sectors' costs by changing the supply of the product used by them as an input) directions (Bauer, 2014). This is evident from the separable manner in which valuation approaches (1) and (2) above are calculated. Letting i and r index crops and regions, the potential value of production loss (VPL) is simply the pollinator-dependent share of agricultural revenue (Gallai et al., 2009a):

$$VPL_r = \sum_i \left(D_i \times P_{i,r} \times Q_{i,r}\right) \tag{1}$$

where D is the crop-specific pollinator "dependency ratio"—which measures the impact of a loss of animal pollination in terms of a fractional reduction in fruit set (and yield) of particular plant species, and P and Q are baseline levels of prices and production specific to each crop and region. Similarly, the loss of consumer surplus (CSL) in crop markets for the simple case of a constant price elasticity of demand, ε, and perfectly elastic supply is (Gallai et al., 2009a; FAO, 2009):

$$CSL_r = \frac{1}{1+\varepsilon}\sum\nolimits_i P_{i,r} Q_{i,r}\left[(1-D_i)^{-(1+\varepsilon)}-1\right]. \tag{2}$$

Recognition of the potential bias from ignoring multi-market interactions when valuing changes in environmental quality or ecosystem services has catalyzed recent applications of multi-market general equilibrium (GE) simulations of the kind we use in this paper (Brouwer et al., 2008; Carbone and Smith, 2008; Carbone and Smith, 2008, 2010; Delink et al., 2011; McDermott et al., 2013). The principal advantages of such approaches are their ability to: (1) consistently track changes in prices and demands across multiple interrelated markets, (2) summarize the macroeconomic effects of shocks by utilizing theoretically consistent measures of the change in aggregate economic welfare, and (3) test the consequences of different possibilities to substitute other inputs for ecosystem services. Even so, the application of GE approaches to the issue of pollinator declines is still in its infancy.

A recent study by Gallai et al. (2009b) analyzes the distributional consequences of pollinator declines when there are market interactions. They construct a stylized analytical general equilibrium model with two firms—each of which produces a single good, but only one of which requires inputs of pollination services—and two consumers endowed with factors of production. Distributional impacts vary with property rights regimes: both consumers suffer and there is an unequivocal welfare loss under an equal distribution of property rights, while the consumer without the pollination endowment can experience a welfare gain under an asymmetric distribution of property rights.

In a key paper, Monck et al. (2008) use a CGE model of the Australian economy to assess the impact of an invasion of the *Varroa* mite—a major honey bee pest. Australia is the only major developed economy that remains able to rely on a large feral (i.e., wild) honey bee population for the majority of its pollination services because it has not yet experienced *Varroa*'s destructive effects. Their model divides the economy into multiple crop sectors and two pollination services sectors—one combined with honey production and one that is pollination-only—and simulates the market impacts of counterfactual scenarios of *Varroa* incursion with and without pollination industry preparation. Results suggest that while investment in a managed pollination services industry is costly, overall benefits can be gained by moderating the short-run impacts of a *Varroa* incursion on the overall supply of pollination services.

Our study extends Monck et al.'s approach to multiple pollinators and multiple regions. We develop a static multi-region, multi-sector CGE simulation of agricultural production and international trade. Catastrophic wild and managed pollinator declines are modeled as exogenous neutral shocks to the productivity of four key crop sectors, and the direct crop sector and indirect non-crop sector effects of global and localized pollination service losses are investigated. For the sake of transparency, our analysis is deliberately stylized with respect to the ecological underpinnings of pollinator declines. We do not inquire into their origins or how they manifest themselves across pollinator species, nor do we capture local or regional pollination deficits or overabundance, but focus instead on what might happen to heterogeneous but interlinked agricultural-economic systems should such catastrophes reduce pollinator-dependent crop production capacity.

3. Methods

3.1. The Numerical Model

As summarized in Table 1, our simulation model divides the world into 18 regions that mirror FAO's member country groupings. Production in each region is divided into 13 broad industry groupings, which are made up of four crop sectors, the major markets for their outputs (e.g., processed food products), and their inputs (e.g., fuels, and chemicals such as fertilizer and pesticides). Our structural specification of the world economy builds on the template developed by Rutherford and Paltsev (2000). Each regional consumer is modeled as a representative agent with nested constant elasticity of substitution (CES) preferences and endowments of three factors of production: labor, capital and arable land. Each industry sector is modeled as a representative