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Analysis

The welfare impacts of an invasive species: Endogenous vs. exogenous price models

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ABSTRACT

The "fixed-prices" models used to measure damages from invasive species typically overestimate financial impacts. These fixed-price assessments do not address key behavioral modifications that lower costs as people adapt by changing their mix of inputs and outputs given new economic circumstances. Using the invasive emerald ash borer (*Agrilus planipennis*) in Ohio as a motivating example, we develop a computable general equilibrium model that accounts for these behavioral responses. We estimate annual damages from the beetle to be about $70 million, an order of magnitude less than the $400–$900 million in damages estimated using a fixed-price model. Damages are lower because people adapt through price and income adjustments that occur after ash trees are devastated from the emerald ash borer.

1. Introduction

Wood packaging materials are used to transport goods across the globe; over 500 million pallets are made each year for trade, with nearly 2 million pallets in use in the United States (Smith et al., 2003). Wood packaging can shelter unwanted hitchhikers, however, such as non-native species that disrupt local ecosystem services and goods (Hooper et al., 2005). These trade-introduced invasive species destroy key natural resources used to produce market and non-market goods and services (Lodge et al., 2009). For example, gypsy moths which were first introduced to the U.S. to be mated with a native silk worm, have continued to spread through wood materials and have contributed to the destruction of millions of oak trees throughout North America (Mayo et al., 2003; Schultz and Baldwin, 1982). The invasive brown tree snake, introduced into Guam via packing materials, is an invasive species that has caused the death of most of the native forest vertebrates and has caused numerous power outages impacting economic activity (Fritts et al., 2001).

A key challenge to policy making is to estimate how much economic damage occurs due to unwanted hitchhikers carried in wood packaging used in global trade. Current damage estimates reveal a common avoidance of economic realities (Holmes et al., 2010a,b; Kovacs et al., 2010, 2011a,b,c; Pimentel et al., 2005). Current estimates on the costs of invasive species typically use replacement cost methods which may bias potential damages (e.g., Kovacs et al., 2010, 2011b,c; Pimentel et al., 2005). Inherent within these approaches is the assumption that economic behavior does not adjust to changing market conditions from invasive species outbreaks, i.e., prices are assumed fixed or exogenous to the economic system. But people and markets do adjust to biological conditions generating a feedback loop between, and within, systems, which results in endogenous prices (e.g., Finnoff and Tschirhart, 2008).

Herein we demonstrate the importance of endogenous prices for estimating damages from trade-introduced invasive species. Endogenous prices account for the impact on the natural resource market while allowing the interaction between markets to affect additional users through behavioral adjustments to income, output, and substitution effects. Invasive species shift the supply of natural resources, which if used in production, alter factor prices (also see Warziniack et al., 2011). Altered factor prices influence industries through output and substitution effects, and households through income and substitution effects. Using the invasive emerald ash borer (*Agrilus planipennis*) in Ohio as a motivating example, we build a computable general equilibrium model that estimates annual damages to Ohio from the emerald ash borer (EAB) as $70 million, which is several times less than the $377–$967 million in damage estimates using an exogenous price approach (Hushak, 2004; Sydnor et al., 2007). The key reason for the lower damage estimates is economic behavior—people adapt to ash resource shortages, and these costs are tempered through relative price changes within interconnected industries. Our estimates include key price variables and adaptation within the economic system when valuing damages to economic agents.

2. Application of Equilibrium Analysis to EAB Invasion

Our research explores why endogenous prices matter by comparing exogenous price and endogenous price impact estimates for the EAB.

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The invasive beetle, originating from Asia, was first discovered in southern Michigan in 2002. Most scientists hypothesize the EAB entered the United States through solid wood packing material transported in cargo ships and on planes. EAB larvae feeding on the inner bark of the tree destroy its ability to translocate water and nutrients (Poland and McCullough, 2006). Human-accelerated spread of the beetles has continued through firewood sales or harvesting, wooden packing materials, and infested nursery trees. EAB is now found as far east as New York and as far north as Ontario, Canada, causing the death of more than 30 million ash trees in Michigan alone (USDA Forest Service et al., 2009).

The potential consequences facing North America from EAB infestation have generated several studies. Using a fixed-price replacement cost approach, Sydnor et al. (2007) estimate the economic impact to households and to the state due to the removal and replacement of street, park, and private ash trees in Ohio is \$1.8–\$7.6 billion.[1] Kovacs et al. (2010) simulate EAB spread on developed land and use a discounted fixed-price replacement cost approach to estimate the damages to Ohio over the decade (2009–2019) as \$376 million. Assuming ash accounts for 7.5% of logging sales, Hushak (2004) uses the input–output matrix from a social accounting matrix (SAM) for Ohio, along with corresponding multipliers, to obtain annual wood industry (logging, sawmills, and wood processing sectors) impacts from a complete loss of ash as \$207 million.[2] These estimates rely on exogenous price models, omitting key adaptation processes within an economy, which typically leads to an upward bias.[3]

The replacement cost method has been used in situations with little data as it requires only information on price and quantity. Likewise, if an ecological service is unique to an ecosystem and difficult to value, the replacement cost is used as a proxy for benefits of the ecosystem service. The model uses costs as a measure of benefits which biases the value of an ecosystem service, however, because it has no direct link to the surplus welfare measures used in economic welfare analysis (see for example Barbier, 2007; Finnoff et al., 2010; Lodge et al., 2009; McIntosh et al., 2009), Fig. 1.[4]

Input–output (I–O) models are a popular tool for economists wanting to study the interdependencies in the national economy revealed through prices, outputs, investments, and incomes. I–O models have the ability to articulate detailed interrelationships among industries, account for all measures of production, and can measure the multiplier effect of changes in economic activity. Basic I–O models have several disadvantages. The proportion of inputs does not change regardless of the level of production. This can prove problematic if the data is taken from a boom or bust year. For example, in a recession, the labor to output ratio may be higher than expected because employers hold onto labor if they believe a recovery is around the corner. In addition, multipliers in I–O models are created under the assumption that current resources are under-utilized and able to accommodate economic shocks. These shocks may mask displacement effects, however, because most resources already use full employment (Davar, 2000; Oosterhaven, 1988). In addition and similar to the replacement cost approach, the I–O welfare impacts have no relationship to surplus measures because the impacts are measured only in terms of a loss in output.

We address the inadequacies of the previous literature by using a computable general equilibrium (CGE) model that addresses a broader set of issues than the most sophisticated I–O models are equipped to handle. CGE employs *equivalent variation* (EV) as a measure of welfare,

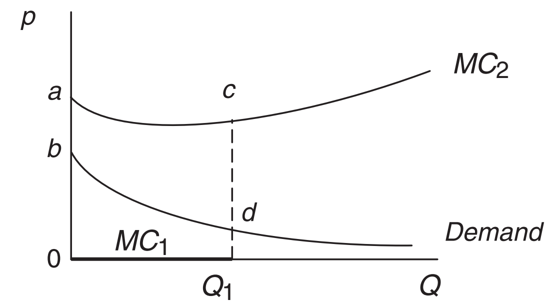

Fig. 1. Replacement cost estimation of ash tree esthetic value: over the lifetime of existing ash trees, the esthetic service they provide is “free” and corresponds to the cost curve, MC_1 that lies along the x-axis, in which individuals demand quantity Q_1. The cost to remove and replace all ash trees in the event of ash death due to EAB corresponds to cost curve MC_2. The replacement cost approach would calculate the area under the MC_2 curve, acQ_1, as the benefit of removing/replacing ash trees esthetic value. However, this overestimates the esthetic value provided by the new trees. The true willingness to pay for this service is really the area under the demand curve for esthetic value or area bdQ_1 (Barbier, 2007). There is no direct connection between replacement costs and a useful welfare measure.

which is ideal to calculate welfare impacts because it measures how economic agents are impacted after a change in prices caused by adjustments to the ash resource base. Following Sydnor et al. (2007) and Hushak (2004), our welfare impacts include industry impacts from a loss of ash harvest used in ash production, and households and state agencies impacts due to the removal (and in some instances, replacement) of dead ash trees. We compare our static and dynamic CGE model results to the previous exogenous price EAB impact estimates from Sydnor et al. (2007) and Hushak (2004).[5] In addition, we allow for both between and within model price restrictions, which highlights the importance of endogenous prices, by varying the degrees of fixed prices within our CGE model (akin to Whalley, 1975).

3. Methodology

Previous impact estimates assume exogenous prices, so that consumers and firms are unable to substitute for other goods or inputs. These restrictive assumptions are relaxed here by allowing consumers the ability to substitute their consumption for cheaper goods as their prices and incomes adjust due to changing market conditions through a multi-sector general equilibrium model. In addition, consumers have the ability to substitute between foreign and domestic goods based on relative world prices. Firms are allowed substitution possibilities over primary factor inputs (labor, capital) and over foreign and domestic intermediate inputs due to changes in factor prices from a loss of the ash stock. Fig. 2 provides a diagrammatic depiction of the CGE model, which allows for inter-industry linkages, factor markets, households, government receipts and expenditures, and trade. Our base model follows previous CGE modeling by De Melo and Tarr (1992), and uses 2003 state of Ohio IMPLAN data.

3.1. Base CGE Model

The CGE model includes fourteen aggregated industries including logging, sawmills, processed wood, finished wood products, building, business services, transportation/storage, furniture, consumer wood goods, recreation, paper, garden stores, parks, and a miscellaneous industry. Table 1 provides the abbreviations for the industries and Appendix A in the supplemental material provides additional industry

[1] Most communities have instituted policies to remove/replace 10% of the ash trees each year, which, according to Sydnor et al.'s (2007) estimates would result in an annual loss of \$180–\$760 million for the state of Ohio (Hood, 2008; Park and Forestry Division, 2007; Washington, 2008).

[2] A SAM is a matrix of interactions in spirit of production relationships in input–output models with greater emphasis on institutional accounts.

[3] The upward bias will usually hold with a replacement cost model. However, this statement does not address the potential for further damages occurring post-replacement, which could lead to replacement costs being a downward biased estimate.

[4] The demand curve may also lie above the MC curve, which would reverse the bias.

[5] Kovacs et al. (2010) does not provide a reference of comparison as we consider the damages from a complete loss of regional ash stock, and not partial ash loss as modeled by Kovacs et al. (2010). But if Kovacs et al.'s (2010) simulation approach was applied to an endogenous price model, we would find significantly different damage estimates than found in the fixed-price replacement cost method.