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Invasive Species Impacts on Human Well-being Using the Life Satisfaction Index

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Invasive alien species are known to be disruptive to the natural environment and can lead to sharp reductions in environmental quality, thereby affecting social welfare. However, little is known about how subjective well-being, in particular, is impacted by invasive species. This is troubling because it precludes credible empirical considerations of the full-range of social externalities when setting invasive species management policy. To address this knowledge gap, this paper provides the first estimates of invasive species impacts on subjective well-being using the life satisfaction ("happiness") index. The approach is applied to the invasive emerald ash borer (EAB), a particularly virulent ash tree attacking pest in North America. Using a repeated cross-sectional fixed effects design, the impact of EAB detection on life satisfaction (LS) is estimated for individuals living in 189 counties in 15 US states over 2005–2011. Results suggest that after EAB detection, LS is reduced by 0.127 on a 4-point scale [95% CI: −0.002, −0.252]. The magnitude of impacts are greatest after a 5-year lag and are largest among young adults (18–24 years).

1. Introduction

Invasive alien species may impact human well-being indirectly through disruptions to the natural environment and the provision of ecosystem services. Invasives disturb established ecological conditions such as native fauna habitats, vegetation coverage and composition, and water and air quality (Pyšek and Richardson, 2010; Pejchar and Mooney, 2009). The United Nations Environment Program (2016) has stated that environmental shocks created by invasive species are "a huge threat to human well-being" and the World Health Organization (2015) has warned that the ecological impacts of invasive species are an ongoing threat to how people live and interact in their communities.

In an age of increasingly coupled human and natural systems, where human and environmental interactions (and vice versa) are becoming more impactful due to factors such as global climate change and the increased connectedness of people and goods, there is a growing realization of the need for research on invasive species impacts that are more inclusive of impacts that are indirect, multi-dimensional, in the periphery, or occur over varying time horizons (e.g., Jones, 2016; Liu and Piper, 2016; Walsh et al., 2016; Donovan et al., 2013, 2015). This line of inquiry is concerned with creating a broader empirical basis of the "cascades of effects" (European Environment Agency, 2012) of invasives on human well-being in order to better inform invasive species management and ecological policy.

However, there is a gap in this literature on the empirical relationship between invasive species and subjective well-being, also known as life satisfaction or the "happiness" index. This is troubling because life satisfaction is an important empirical approximation to subjective welfare or "experienced utility" (Kahneman et al., 1997). The association between environmental quality and life satisfaction has been documented across many studies (e.g., Möllendorff and Hirschfeld, 2016; MacKerron and Mourato, 2009; Welsch, 2006, 2007) and is considered by the OECD to be a useful input into setting environmental policy priorities (Silva et al., 2012). The absence of credible empirical evidence on invasive species and life satisfaction limits the usefulness of benefit-cost analyses of proposed management policies and hinders our understanding of the full-range of invasive species spillover effects.

The objective of this research is to provide the first estimates of life satisfaction impacts attributable to invasive species by exploiting a large natural experiment that resulted in a sharp degradation to environmental quality within a relatively short period of time across the eastern US. The invasive emerald ash borer (*Agrilus planipennis*), or EAB hereafter, has destroyed tens of millions of North American ash trees (*Fraxinus* spp.) since first being detected in the US in 2002, sharply reducing the size and composition of US forest cover (Herms and

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McCullough, 2014). The short duration over which EAB spread has occurred, the degrees of randomness inherent in its spread, and the large disruption it has had on urban forest canopies, provides a quasi-experimental setting in which to evaluate the impact of EAB on life satisfaction.

Natural experiments or quasi-experiments exploit exogenous sources of variation in treatment, such as quasi-random EAB spread, that are independent of outcome, strengthening identification. While falling short of causality, quasi-experimental research designs nevertheless have the potential to effectively eliminate (or significantly reduce) environmental endogeneity such as residential sorting, environmental confounding, or avoidance behaviors, providing “causally-consistent” effect estimates (Graff Zivin and Neidell, 2013). The natural experiment provided by EAB has been previously used to study the relationship between invasive species and health (Donovan et al., 2013, 2015) and invasive species and time use allocation (Jones, 2016). Ours is the first application to life satisfaction and hence to evaluating the broader subjective welfare implications of EAB across the US. A nationally-representative dataset containing information on individual life satisfaction from the US Centers for Disease Control and Prevention (CDC) is investigated using a fixed effects repeated cross-sectional design that compares life satisfaction in EAB detected counties to concurrently non-EAB detected counties after controlling for observable respondent characteristics and unobservable time-invariant county-level heterogeneity.

2. EAB Impacts on Environmental Quality

EAB is a small phloem-feeding borer beetle native to Asia that was accidently introduced into the Midwestern US in 2002 likely through international trade of ash and ash by-products. Adult EAB lay eggs in the conductive tissue of ash trees and the larvae feed on the inner layers of bark, disrupting the transfer of nutrients and water through the tree. At sufficient EAB density, the tree is unable to continue functioning and thus dies.

Nearly all EAB develop within one year, but a biennial life cycle has been observed in areas with low EAB densities (Siegert et al., 2010). Larvae are extremely tolerant to cold temperatures (up to −30 °C) and appear to attack all North American ash species, including both stressed and relatively healthy trees. Natural predators to EAB such as woodpeckers and wasps have thus far proven to be largely ineffective at reducing the EAB population. In addition, eradication and containment efforts (including insecticide use) have proven largely ineffective at controlling spread, though research is ongoing (McCullough and Mercader, 2012). Given the practical challenges involved in stopping or even slowing EAB spread in the US, experts believe that the entire stock of some 8 billion North American ash may be threatened (Sydnor et al., 2011).

The impact of EAB on environmental quality is not contemporaneous with initial infestation. Adult ash typically die within 4–7 years after initial infestation, though saplings or highly stressed trees can die in as little as one year (Herms et al., 2014; Poland and McCullough, 2006). Therefore, the greatest magnitude of impacts of EAB on environmental quality are likely to be lagged by several years after initial detection; a phenomena that has been observed in other cases of invasive species (e.g., Strayer et al., 2006; Crooks, 2005). Once ash begin to die, however, the effects on urban forest canopies, in particular, are devastating since ash can comprise 10–40% of total urban tree cover (USDA Forest Service, 2015). Moreover, trees provide many benefits to society.

Trees are an important and recognized source of ecosystem services. Trees reduce storm water runoff, intercept rainfall, provide shade, and capture air pollutants. The public health and well-being contributions of trees and forests is an active and fruitful area of research (e.g., Nilsson et al., 2011). Tree cover is known to impact community identity and pride and is associated with community capacity and trust (Elmendorf, 2008). Forests and trees are sources of recreational opportunities and have been associated with improved physical and mental health outcomes (De Vries et al., 2011; Tyrväinen et al., 2005). For example, Hansmann et al. (2007) found that individuals visiting an urban forest were significantly less likely to suffer from headaches and stress and were more likely to feel well-balanced. Ellaway et al. (2005) discovered that individuals living in greener, more forested areas were three times more likely to be physically active than residents in less green areas. In light of the evidence linking trees to well-being, the Forestry Commission of England has taken an active role in promoting trees and forests for the purpose of improving the health and quality of life of UK residents (O'Brien, 2005). The sudden loss of hundreds if not thousands of trees in a community due to EAB, as is common across eastern US areas, could have significant impacts on well-being and life satisfaction.

The nature of the threat to well-being posed by EAB is accentuated by the fact that ash trees are one of the most common urban and suburban tree species in the US (McCullough, 2013). Ash often border streets and occupy space in parks and residential yards. Given the ubiquitous status of ash and their close proximity to where millions of people live and work, the impacts of losing most if not all ash trees to EAB is potentially significant. Buildings that were once shaded in the summer may no longer be so; ash forested parks, urban green spaces, and areas of recreation may now lack or have severely reduced forest coverage; or the tree(s) in the front or back yard may now be gone.

The evidence to-date suggests that EAB has significant effects on individual outcomes. Donovan et al. (2013) found that EAB detection was associated with 21,193 excess cardio-respiratory deaths over 2002–2007, which they hypothesized was due to changing forest conditions. More recent work suggests that women are at greater risk of cardio-respiratory disease after detection of EAB (Donovan et al., 2015). Behavioral habits may also be affected by EAB. For example, Jones (2016) found that individuals spent less time outdoors engaged in recreation and exercise and more time working after EAB was detected. These studies indicate the significant effects of EAB on health and behavior. However, if EAB also lead to broad-based changes in subjective well-being and perceived quality of life, then the potential damages of this invasive species would grow tremendously to include known factors associated with life satisfaction such as income, unemployment, education, and self-esteem. What is lacking is credible empirical evidence that invasive EAB is associated with changes to life satisfaction.

It is not a priori clear whether changes to life satisfaction would be positive or negative. Life satisfaction could increase after EAB if, as found in Jones (2016), people are working longer hours and thusly earning higher incomes. Income is known to be positively associated with life satisfaction (Frijters et al., 2004). Employment also provides increased opportunities for building interpersonal relationships and social networks, which could also positively impact well-being. On the other hand, if individuals in EAB infested areas spent less time outdoors and engaged in less recreation, as found in Jones (2016), then life satisfaction may be negatively affected. Additionally, witnessing many community trees being taken down could also engender feelings of grief or remorse, potentially negatively affecting life satisfaction. The magnitude and direction of EAB-induced changes in life satisfaction is an open empirical question that this study seeks to address.

3. Data

The study area under investigation consists of all US counties where EAB was detected between 2005 and 2011. Data on dates and location (county and state FIPS) of initial EAB detection from 2003 to 2016 were provided by the USDA Animal and Plant Health Inspection Service (USDA APHIS). All EAB detections are made at the county level and detected counties are considered to be infested indefinitely.

During the 7 year study period, EAB was detected in 256 counties across 15 US states and the District of Columbia (Fig. 1). Spread of EAB during this time had a random component to it as evidenced in Fig. 1 by the presence of outlier detected counties and on account of the fact that some counties are completely surrounded by EAB and contain ash, yet no EAB have been found. The quasi-random dimension of EAB