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The economics of urban afforestation: Insights from an integrated bioeconomic-health model

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ABSTRACT

Urban afforestation programs are starting to act on the growing body of evidence that nature and greenspace are important determinants of well-being. However, there are a lack of credible investigations into the long-term returns on investment of afforestation inclusive of positive and negative externalities, project-related costs, and dynamic environmental feedbacks. Using the New York City forest canopy as an example, our integrated bioeconomic-health model illustrates that investments in afforestation produce per planted tree net benefits that are significantly lower than previous similarly comparable estimates ($12 vs. $172) and are nonlinear in canopy size. We also show that a reduction in urban air quality, such as those that may be produced by changes in national air quality policies and enforcement, can be mitigated through increased investment in urban afforestation. Our results have significant public policy implications for urban environmental quality initiatives.

1. Introduction

More than half of the world's population now live in cities, and there are projections that urban areas will double in size by the middle of this century (United Nations Population Fund, 2007). As urban populations grow, so does the body of evidence that the natural environment contributes significant ecosystem services to cities that generate well-being and public health co-benefits (Wolf and Robbins, 2015), in addition to important productivity and income effects (Greenstone and Jack, 2015). Trees and urban forests, in particular, have been identified as a meaningful source of urban ecosystem services (McPherson, 2007; Tyrväinen et al., 2005) and have been shown to credibly influence well-being and public health (e.g., Jones, 2017; Jones and McDermott, 2017). Prior literature on forest cover benefits has tended to exploit geographic variation in deforestation or forest canopy loss (e.g., Berazneva and Byker, 2017). The economics of afforestation, or the addition of new forest stock has rarely been investigated, and any established literature routinely ignores bioeconomic feedbacks and costs.

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Following on the heels of a large body of literature that has monetized the benefits of urban trees (see, for example, Mullaney et al., 2015 for a 30 year review) there is now a global urban afforestation push, including cities such as Los Angeles, New York City, London, and Shanghai. A motivating factor for current urban afforestation initiatives is the apparent sizeable monetary benefits of trees (Moffat, 2016). Commonly used estimates of urban forest benefits, such as those produced by the US Forest Service, for example, are based on annual flows of environmental, social, and ecological services provided by trees (Nowak et al., 2016; Sunderland et al., 2012; Peper et al., 2007). These estimates provide what Sunderland et al. (2012) call a one-year "snapshot" of the total benefits of an urban forest. Costs, while rarely included in tree assessments, are generally only measured as the expenditures made on trees in the same year as the assessment. The difference between one-year "snapshot" benefits and costs are often referred to in the forestry literature as "net benefits" of urban trees (Mullaney et al., 2015; Peper et al., 2007). However, what if the one-year "snapshot" net benefit analysis approach is wrong?

In particular, consider that continuous investments are necessary for a healthy standing urban forest. First, trees have to be purchased and planted. Second, trees require ongoing, routine care and maintenance (e.g., pruning, fertilizing, watering, removing dead limbs, etc.). Third, pesticide treatments are necessary in the presence of forest-attacking pests (e.g., emerald ash borer, Hemlock woolly adelig). Finally, more than one planting attempt may be appropriate since the mortality rate of newly planted trees in urban settings is high (Campbell et al., 2014). There are costs associated with each of these activities. If we think of these costs as representing investments in urban tree cover, then the true costs of urban afforestation include not only the one-period expenditures on a tree but also the discounted sum of the over-time investments made in a given tree. To obtain the true net economic benefits of an urban forest, a comparison of the over-time benefits and costs (investments) in tree cover is required. This means that often quoted estimates of urban forest benefits calculated based on one-year "snapshot" analyses (e.g., that the net benefits of an average New York City street tree are $172 (Peper et al., 2007)) are a misrepresentation of true urban forest net economic benefits, leading to a potential misallocation of public resources.

Prior analyses and policy tend to either ignore costs altogether, or include costs in static and non-bioeconomic settings (e.g., Ko et al., 2016; Sunderland et al., 2012; McPherson et al., 2005). As a result, city planners routinely focus on benefits-only estimates or rudimentary net benefits estimates, thereby providing an incomplete picture of the actual returns on investment of afforestation. For example, Los Angeles proceeded with their Million Tree planting initiative because of a report finding that listed $38-$56 in average annual benefits per tree planted (McPherson et al., 2008, 2011). However, such estimates do not consider the dynamic costs of planting and maintaining trees, potential disamenity values, negative externalities of tree cover, water use, or any implementation issues (Pincetl et al., 2013). The relevant question is not whether there are positive benefits of tree planting – it seems evident that there are – but what are the returns of investments in urban afforestation inclusive of short-term planting costs, ongoing maintenance, potential negative externalities, and long-term benefits? This remains an unanswered question.

Another concern of one-period analyses of urban forest benefits is that they do not allow for time dynamics and feedbacks across coupled human and ecological systems. Current period afforestation may measurably improve future urban environmental quality, thereby affecting the future marginal benefit of a planted tree, which would influence the efficient optimal planting time path. This may be particularly important for the air quality and human health benefits of afforestation due to the existence of a dynamic feedback loop between tree pollutant flux and air pollution concentration (Nowak et al., 2006). Ignoring this feedback mechanism would tend to overstate (understate) the air quality public health benefits of trees in cases of declining (increasing) air pollution concentrations. Other feedbacks may also exist for trees and energy savings, trees and CO2 reductions, and trees and aesthetic benefits.

This paper seeks to address the returns of public investments in urban afforestation inclusive of not only a wide array of benefits and costs, but also of the complex dynamic linkages and feedbacks between urban forest management and environmental quality.[1] An integrated bioeconomic-health model of afforestation is constructed that captures the environmental, social, and ecological flows of tree benefits juxtaposed with the costs of planting and maintaining urban trees and potential disamenity value due to tree pollen. Our model can be used to assess the returns on investment of tree planting programs and hence provide the first credible indication of the efficiency of the investments in urban afforestation. The model is parameterized for New York City (NYC), the site of a recently completed large-scale afforestation initiative, and used to illustrate the net benefits associated with various afforestation strategies over a long-term planning horizon.

Three conclusions arise. First, model results indicate that afforestation can provide substantial positive net benefits to society even after accounting for costs and disamenity value from tree pollen. On average, annual net present value benefits range from $10.24 per tree planted (exogenous increase in canopy) to $12.10 per tree planted (endogenous canopy increase). These figures are substantially lower than extant estimates of tree net benefits (e.g., $172) that ignore dynamic afforestation costs and environmental feedbacks. Second, net benefits of afforestation are nonlinear in canopy cover size growth; increasing up to an 8.2% growth in NYC forest canopy and decreasing after that. This result implies that significantly increasing urban forests beyond some threshold is not an efficient policy. Lastly, policy changes that shock urban air quality lead to measurable changes in optimal afforestation policy and depend on the duration and magnitude of the shock. In particular, we demonstrate that because of feedback effects, afforestation can be used to mitigate negative human health outcomes that

[1] By public investment we mean that the urban afforestation project is undertaken and implemented by city planners, and not that the project is completely publically financed. Generally, city governments use combinations of public and private funds to finance afforestation programs (Pincetl et al., 2013). Our focus is not on how these projects are funded, but rather on the net benefits that trees (a quasi-public good) provide to the public over-time.