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Microdata and the Valuation of Natural Capital

Jonathan Colmer and John Voorheis

4.1 Introduction

The theoretical basis for valuing natural capital and the ecosystem services they provide is well established (Weitzman 1976; Hartwick 1990; Heal 1998; Daily et al. 2000; Arrow et al. 2004; Nordhaus 2006; Arrow et al. 2012; Fenichel and Abbott 2014). However, despite substantial progress in our understanding of ecology and significant advances in quantifying natural capital, the valuation of natural capital has lagged behind.

How much society values the stock of natural capital and the flow of ecosystem services that it provides is ultimately an empirical question, the answer to which is critical for evaluating trade-offs between environmental conservation and use (Krutilla 1967; Fisher et al. 1972) and for assessing the question of whether society is following a sustainable economic program (Fenichel and Abbott 2014; Fenichel et al. 2018). The critical challenge to

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valuing natural capital is determining the appropriate prices to use when evaluating these question. When there are missing or incomplete markets—as is often the case for many critical natural capital stocks—economists have to rely on nonmarket valuation approaches.

Addressing the challenge of valuing natural capital is pivotal to ongoing policy efforts and natural capital accounting. Credible valuation of natural capital is critical to the integration of environmental data into national economic accounts. Therefore, refining natural capital valuation methodologies is not just an academic exercise, but critical for providing evidence that can be used in frameworks that recognize and safeguard the value of the natural environment in policy-making and economic activity.

In this paper we consider the extent to which advances in the availability of microdata might help to relax some of the measurement constraints associated with the valuation of natural capital, and in turn open the door to new methodological and accounting frameworks that incorporate spatial and individual heterogeneity in valuations.

We first discuss some of the current conceptual challenges associated with natural capital accounting, and explore the potential role that microdata could play in helping to address these challenges. Second, using a new microdata infrastructure—the Environmental Impacts Frame (Voorheis et al. 2023)—we provide a case study to illustrate the empirical relevance of these challenges, in the form of evidence on the distribution of urban tree cover across individuals in the United States.

4.2 Conceptual Challenges

In this section we discuss several key conceptual challenges that natural capital accounting currently faces and discuss the potential role that microdata could play in helping to address these challenges.

4.2.1 Aggregation Bias and Natural Capital Accounting

To date natural capital accounting has focused largely on producing national accounts at the national level; however, such approaches make very strong assumptions about aggregation, commonly used in other accounting practices, which are unlikely to apply in the context of natural capital. A major conceptual challenge relates to the spatial context of natural capital.

Natural capital accounting has traditionally relied on a “law of one price.” This is the approach taken when aggregating physical and financial capital stocks; however, unlike natural capital, physical and financial capital stocks are generally tradable commodities that can be easily transported and exchanged, meaning that values can be aggregated using a common price. The assumption of a common price is more plausible in such settings because the location of physical or financial capital is less likely to affect its value. By contrast, many stocks of natural capital are immobile and depend

critically on their location—natural capital is spatially dependent. If a stock of natural capital is concentrated in one area rather than another, the people living there will value it more highly than the national average (Addicott and Fenichel 2019). This relative scarcity will lead to a divergence between the total value of natural capital and the sum of its parts.

Spatially resolved microdata provides a platform with which to link spatially explicit natural capital stocks with detailed and comprehensive population and economic data. This can facilitate the definition and measurement of relevant economic jurisdictions, or “market extent,” which in turn will facilitate the description, quantification, and valuation of natural capital across locations. This is critical because, as first noted by Smith (1993) differences in market extent are likely far more important than differences in marginal valuations.

4.2.2 Heterogeneity in Valuations within a Location

Concern about aggregation bias extends to heterogeneity in how individuals value natural capital within a market. While working with more spatially granular data can help to mitigate heterogeneity across locations, aggregation bias remains if there is heterogeneity in valuations across individuals within a location. Such differences in valuations may arise, for example, due to differences in income or preferences.

Here, confidential microdata provide descriptive details on the distribution of income, wealth, race and ethnicity, age, and other socioeconomic characteristics that will aid researchers and policymakers in understanding how the population within a “natural capital” jurisdiction varies compares to other jurisdictions. This will help to understand the extent to which marginal valuations of natural capital may vary between jurisdictions, as well as the potential for heterogeneity in valuations within a jurisdiction.

4.2.3 Missing Markets

The previous two conceptual challenges presume that accounting prices for natural capital are available or identifiable. In practice, identifying the appropriate prices needed is the core challenge associated with any natural capital valuation or natural capital accounting exercises.

The main constraint is the absence of observable prices for nonmarket goods and services. Even if prices for a given stock of natural capital were observed at two points in time, the prices used to value a change in wealth must be constant and formed as a convex combination of the two observed prices (Fenichel et al. 2016, 2018).

Restricted-use microdata provide no direct solution to this problem; however, by providing comprehensive economic and sociodemographic context at the individual level, combined with spatially explicit information on quantities of natural capital stocks, they provide necessary information about the economic program. When combined with appropriate methodologies and

research designs, such data facilitate the identification of marginal valuations based on the actual choices and trade-offs that individuals and society make (Fenichel and Hashida 2019). Further, large sample sizes mean that heterogeneity in valuations can in principle be recovered when significant heterogeneity in populations exists within or between natural capital jurisdictions.

4.3 The Environmental Impacts Frame

While advances in technology have improved our understanding of *where* natural capital is located, there remain large gaps in our understand about *who* benefits from natural capital, as well as the consequences for health and well-being. As discussed above, the benefits of natural capital are unlikely to be evenly distributed across individuals within a population, resulting in misleading inferences when using aggregated data sources.

To help mitigate these constraints, we have developed a new prototype microdata infrastructure to facilitate individual-level analyses in the United States—the Census Environmental Impacts Frame (EIF). The EIF uses confidential Census Bureau microdata drawn from surveys, administrative records, and decennial censuses to provide detailed panel data on demographics, economic circumstances, and address-level residential histories for nearly all residents of the United States from the late 1990s forward. These rich microdata (containing more than six billion observations) present new opportunities to advance our understanding of the environmental conditions people face, why differences in exposure to environmental conditions arise, and the distributional consequences of exposure to hazards and amenities in the United States.

The EIF is a modular infrastructure, rather than a single combined file. There are two core modules constructed from confidential data at the Census Bureau: a demographic “spine,” which contains basic demographic information, such as race, age, sex, date, place of birth, and date of death, for the relevant universe of individuals, and an annual residential history file for individuals in the spine, allowing researchers to track individuals over time and space.²

The EIF exists to facilitate the description and analysis of exposure to environmental amenities and hazards at the individual level. The core components described above—the demographic spine and the residential histories—provide the foundation for an exciting and extensive research agenda. Using the EIF, it is possible to incorporate and analyze any environmental data that can be geospatially resolved. As such, the EIF allows researchers to develop a systematic and comprehensive understanding of environmental exposures at a high spatial resolution over a relatively long time series. In the

2. See Voorheis et al. (2023) for more details on how these modules are constructed.

following section we leverage the EIF to highlight the conceptual challenges discussed and illustrate how the EIF could be used to alleviate (at least in part) some of these issues.

4.4 Urban Tree Canopy in the United States

Urban tree canopy cover—the layer of leaves, branches, and stems that cover land surfaces in urban areas—is an important variety of natural capital in the United States. Urban trees have been argued to provide many important benefits: absorbing carbon dioxide; providing shade and lowering air temperatures; supporting stormwater infrastructure by absorbing large amounts of water and reducing runoff; improving air and water quality; providing wildlife habitats that increase local biodiversity; and providing aesthetic, social, mental health, and cultural benefits.

We incorporate high-resolution data on urban tree canopy cover from the National Land Cover Database (NLCD) into the Environmental Impacts Frame for the year 2016. The NLCD provides satellite-derived data on tree cover at a 30×30 m grid and reports the share of each pixel that is covered in by tree canopy. Because this resolution is in many cases smaller than individual parcels, we aggregate the NLCD data to the census block level, and assign this block-level average canopy measure to each individual's location in the 2016 EIF as their exposure to canopy.

Figure 4.1 displays the distribution of canopy cover across the United States. As discussed in section 4.2.1, when natural capital is heterogenous across locations and immobile (as trees are wont to be), a common price cannot be used. Trees are locally non-excludable and have a relatively low marginal cost associated with providing services such as cooling and pollution abatement. This has the additional implication that, all else equal, trees might generate more natural capital services in in more densely populated areas.³ We see that there is substantial spatial variation in canopy cover across the United States, and so the accounting price may vary substantially.

However, much of this variation may conflate regional differences. Given the density of population in urban areas, understanding variation in urban canopy cover is of particular interest. To avoid comparisons between rural and urban tree cover, we restrict our analysis to Core-Based Statistical Areas (CBSAs), geographic areas defined by the Office of Management and Budget (OMB) that contain urban areas and highly integrated adjacent communities. Using this data we provide a systematic description of how urban tree canopy cover varies across space and individuals and relate what we observe to the conceptual issues raised in section 4.2.

We first provide systematic evidence on how much variation in canopy cover exists across and within-CBSAs in the United States and how within-

3. Of course, forests and larger agglomerations of trees create different services.

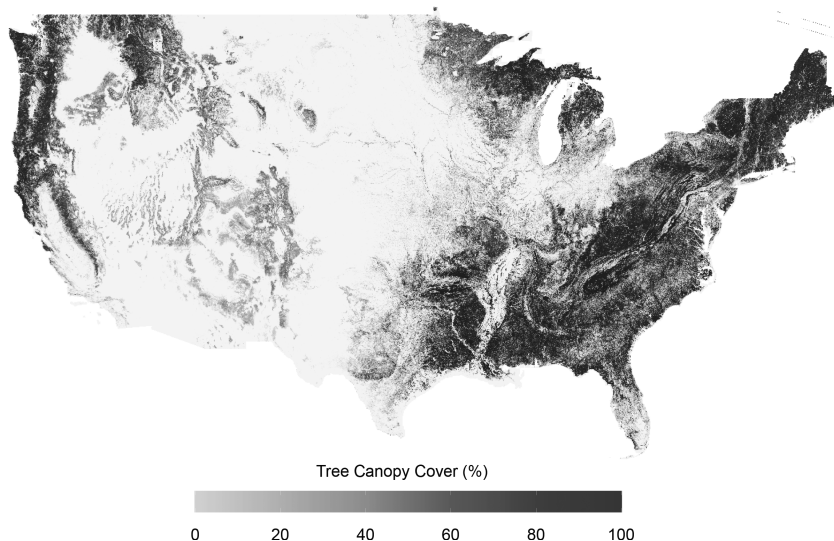


Figure 4.1 Tree canopy cover in the United States

Source: NLCD

Notes: This figure shows tree canopy coverage in the contiguous United States for the year 2016. Data is derived from multi-spectral satellite imagery. The raster data is available at a 30 meter resolution but aggregate to a 480 meter resolution in the figure for visualization purposes. Each 30 m grid cell reports the estimated share of land that is covered by tree canopy. Percent coverage increases visually in the figure from light to dark.

CBSA variation in canopy cover correlates with with several key measures of environmental quality. We document that there is substantial variation in urban tree canopy cover across the United States. The between-census block-group standard deviation in urban canopy cover is 18.73. The 90–10 gap is 47.33—an individual living in a census block-group at the 90th percentile of the urban canopy distribution has canopy cover that is 47.33 percentage points higher than an individual living at the 10th percentile of the urban canopy distribution. We show that there is substantial variation in canopy cover even with CBSAs. The within-CBSA standard deviation is 14.05. The within-CBSA 90–10 gap is 31.21—an individual living in a census block-group at the 90th percentile of their CBSA’s urban canopy distribution has canopy cover that is 31.21 percentage points higher than an individual living in a census block-group at the 10th percentile of their CBSA’s urban canopy distribution (figure 4.2).

Second, we show that this variation in urban canopy cover is associated with meaningful variation in exposure to a number of socioeconomically important margins of environmental quality. One important margin is the role that canopy plays in reducing surface temperatures. Temperatures can vary substantially over short distances due to differences in land cover, which

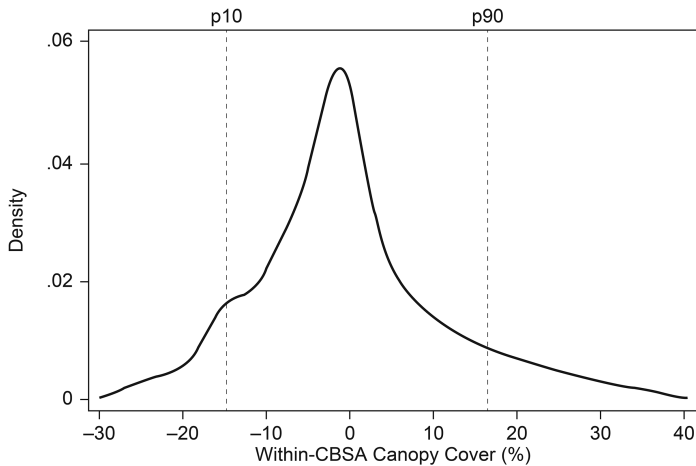


Figure 4.2 The within-CBSA distribution of tree canopy coverage in the United States

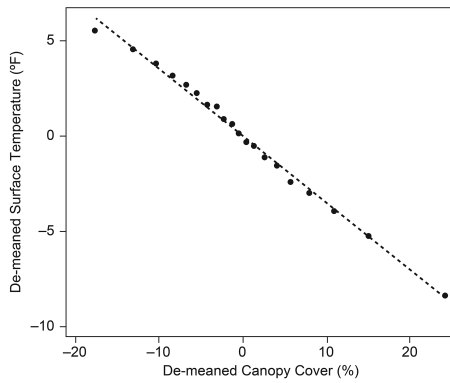
Source: NLCD

Notes: This figure presents a kernel density plot of the within-CBSA distribution of tree canopy coverage for the contiguous United States in 2016. The left dashed line is the 10th percentile of the within-CBSA distribution (-14.59). The right dashed line is the 90th percentile of the within-CBSA distribution (16.61). The within-CBSA 90–10 gap is 31.21 percentage points.

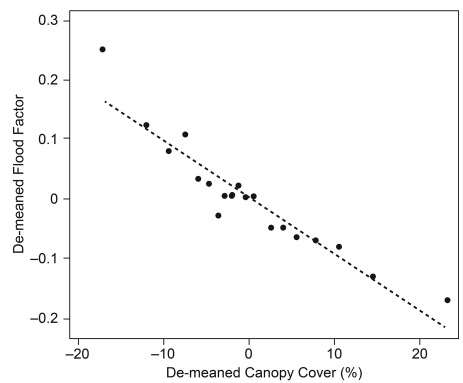
affects local surface energy balance—a phenomenon known as the urban heat island effect (Grimmond 2007). Pavement and concrete reflect less sunlight and absorb more heat than natural landscapes, such as trees and vegetation. Consistent with this we document that there is a strong negative association between canopy cover and surface temperature within CBSAs. On average, individuals living in census block-groups with 10 percentage point more canopy cover than their CBSA mean are exposed to summertime surface temperatures that are 3.5°F (approximately one standard deviation) lower than the CBSA mean (figure 4.3a). Chakma et al. (2023a) document the existence of persistent racial disparities in surface temperatures, canopy cover, and imperviousness and show that these disparities exist at every percentile of the national income distribution. Chakma et al. (2023b) show that the mortality effects of temperature are much higher in neighborhoods with greater imperviousness and that half of the black-white gap in temperature-driven mortality can be explained by differences in imperviousness.

We also estimate a strong negative correlation between canopy and flood risk. Urban tree canopy cover reduces flood risk by intercepting rainfall through the collection of water on branches and leaves, increasing the soil’s capacity to absorb and retain water, and by physically slowing down the flow of water. All of these considerations reduce the burden on drainage systems.

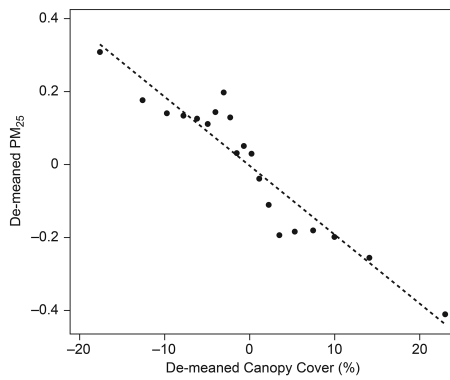
A. Summer Surface Temperature



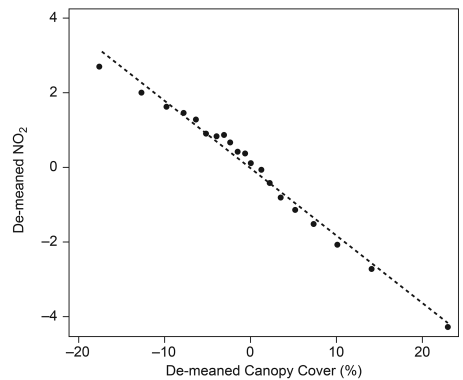
B. Flood Risk



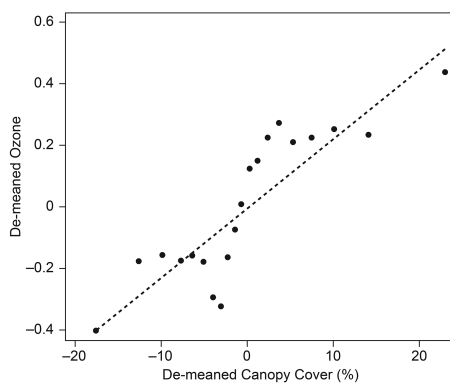
C. Fine Particulate Matter (PM_{2.5})



D. Nitrogen Dioxide (NO₂)



E. Ozone



Source: NLCD, Landsat, First Street Foundation Floodfactor, the Environmental Impacts Frame, Di et al. (2020), Requia et al. (2020), and van Donkelaar et al. (2021).

Notes: These figures report the bivariate relationship between within-CBSA variation urban tree canopy cover and within-CBSA variation exposure to environmental risks in 2016. The unit of analysis for the underlying analysis is an individual.

We estimate that, on average, individuals living in census block-groups with 10 percentage points more canopy cover than their CBSA mean are exposed to a flood risk score that is 0.1 points (approximately one standard deviation) lower than their CBSA mean (figure 4.3b). Wing et al. (2022) calculate that annualized US flood losses are currently US\$32.1 billion on average and are projected to rise to US\$40.6 billion by 2050 under the RCP4.5 scenario.

Finally, in Figures 4.3c, 4.3d, and 4.3e we explore the relationship between urban canopy cover and different types of air pollution. In figure 4.3c we estimate a strong negative correlation between canopy cover and fine particulate matter ($PM_{2.5}$). Fine particulate matter consists of extremely small airborne particles (30 times smaller than the diameter of a human hair), often generated from combustion sources, that can penetrate deep into the lungs and bloodstream, posing significant health risks. Urban canopy has the potential to affect $PM_{2.5}$ concentrations through direct air filtration (leaves and bark trap and absorb $PM_{2.5}$ particles from the air), and cooling (cooler air can potentially hold fewer particles and reduces energy demand). On average, we estimate that individuals living in census block-groups with 10 percentage points more canopy cover than their CBSA mean are exposed to fine particulate matter that is 1.89 micrograms per cubic meter ($\mu g/m^3$) (approximately one standard deviation) lower than the CBSA mean. This association reflects a non-trivial difference in exposure. Deryugina et al. (2019) estimate that a $1\mu g/m^3$ increase in $PM_{2.5}$ exposure for one day causes 0.69 additional deaths per million elderly individuals over the following three days. This estimate likely reflects a lower bound. Deryugina and Reif (2023) estimate that the long-run effects of acute exposure are higher and calculate that the effect of chronic exposure on life expectancy are seven to eight times larger than the long-run effects of an acute exposure. Colmer et al. (2021) estimate that reductions in early childhood $PM_{2.5}$ exposure are associated with substantial increases in later-life W-2 earnings and document that disparities in exposure play a non-trivial role in shaping broader patterns of economic opportunity and inequality in the United States.

In figure 4.3d we also estimate a strong negative correlation between urban canopy cover and nitrogen dioxide (NO_2). NO_2 is a highly reactive gas, which forms primarily from the burning of fossil fuels. It contributes directly to smog, reacts with sunlight and other compounds in the atmosphere to form secondary pollutants such as ozone, and acts like a catalyst to transform primary emissions into secondary particulates, increasing the total amount of particulate matter in the air. Similar to particulate matter, urban canopy cover can affect NO_2 concentrations through direct air filtration and cooling. We estimate that, on average, individuals living in census block-groups with 10 percentage points more canopy cover than their CBSA mean are exposed to nitrogen dioxide concentrations that are 1.81 parts per billion (approximately one standard deviation) lower than the CBSA mean. These are meaningful differences. Meng et al. (2021) estimate that, on average, a $10\mu g/m^3$ increase in previous day ambient NO_2 concentration was associ-

ated with a 0.46 percent increase in all-cause mortality.⁴ Khreis et al. (2017) conduct a meta-analysis of 21 studies and generate a summary estimate for the likelihood of developing asthma at some point during childhood. They calculate an odds ratio of 1.05 per $4\mu\text{g}/\text{m}^3$, i.e., a 5 percent increase in risk.

In figure 4.3e we estimate the opposite relationship—a strong positive correlation between urban canopy cover and ozone concentrations. Ozone forms through complex chemical reactions between nitrogen oxides (NO_x) and volatile organic compounds (VOCs) in the presence of sunlight. The consequences of urban canopy cover for ozone is unclear. On the one hand, trees absorb nitrogen dioxide, primary components of ozone. By lowering air temperature, tree cover could also reduce the efficiency of ozone formation. On the other hand, trees directly emit natural volatile organic compounds (VOCs), a critical precursor to ozone formation. Our empirical pattern suggests that, all else constant, the VOC channel is dominant in our context. We estimate that, on average, individuals living in census block-groups with 10 percentage points more canopy cover than their CBSA mean are exposed to ozone concentrations that are 0.22 parts per billion (approximately one standard deviation) lower than the CBSA mean. The epidemiological literature tilts toward larger damages from fine particulates and NO_x vs. ozone (Turner et al. 2016, Qian et al. 2017), but without a more detailed comparison of dose response functions that account for the complex relationships between pollutants, it is unclear whether the increased damages from ozone would be offset by improvements in PM_{2.5} and NO_x.

These facts are helpful for documenting, at least in part, the potential economic value associated with urban canopy cover. However, showing how quantities vary does not provide any insight into the valuation of this form of natural capital or the extent to which valuations may vary within a location. An important margin that may shape differences in valuations is income. Natural capital Engel curves, if they existed, would tell us how demand varies with income holding prices and preferences fixed. However, absent prices, Engel curves cannot be estimated for nonmarket goods and services. Instead, we explore the extent to which canopy cover exposure varies with income, a revealed preference, but reduced form and likely inconsistent approximation for how demand may vary throughout the income distribution.

A common approach to evaluating the role the income plays in shaping differences in environmental quality is to use a place-based average of the household income; however, the use of even granular place-based data severely limits what one can learn about the potential for differences in willingness to pay for natural capital within locations. In our existing and

4. Assuming 1 atmosphere of pressure (1,013.25 hPa) and an average temperature of 12°C, we convert $\mu\text{g}/\text{m}^3$ into parts per billion (ppb), using a conversion factor of $1.967\mu\text{g}/\text{m}^3 = 1$ ppb. $10\mu\text{g}/\text{m}^3 = 5.085$ ppb.

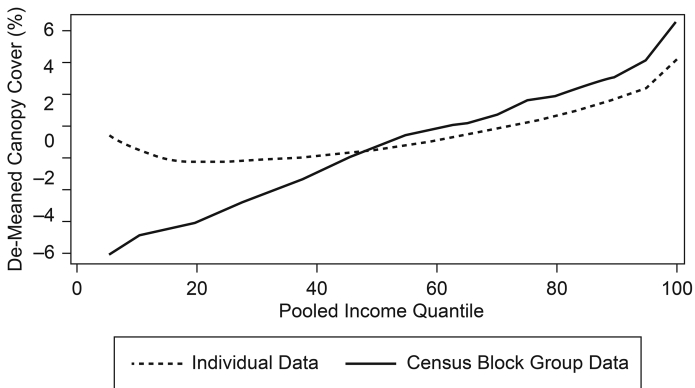


Figure 4.4 Aggregation bias and the canopy–income relationship

Source: NLCD and the Environmental Impacts Frame.

Notes: This figure shows how within-CBSA variation in canopy cover varies across the individual-level national income distribution (dotted line) and the distribution of census block-group average income per capita (solid line). We document a much flatter canopy–income profile when using the distribution of individual income than when using the distribution of census block-group average income per capita, indicating that there are other place-based factors correlated with place-based income that result in biased inferences about the importance of income in shaping exposure to urban canopy cover.

ongoing work we repeatedly document that substantial variation in income within even narrowly defined geographies results in misleading inferences being made about people when using place-based data (Chakma et al. 2023a; Colmer et al. 2023; Voorheis et al. 2023)—a problem known as aggregation bias. Here, we illustrate this in the context of the relationship between income and canopy cover. In figure 4.4, we show that within-commuting zone variation in canopy cover exposure is relatively flat through the first half of the individual-level national income distribution before increasing moderately at higher income levels. Individuals at the 90th percentile of the individual-level income distribution experience canopy cover that is 2.7 percentage points higher than individuals at the 10th percentile of the individual-level income distribution. By contrast, using the distribution of income per capita across locations, we see that there is a much stronger association between place-based average income and canopy cover. We estimate that individuals living in neighborhoods at the 90th percentile of the block-group income distribution experience canopy cover that is 8.6 percentage points higher than individuals living in neighborhoods at the 10th percentile of the block-group income distribution, more than tripling the individual-level gap. This is largely driven by differences in the relationship in the bottom half of the income distributions. These differences imply that there are other neighborhood-level factors or amenities correlated with income at the neighborhood level that are not as strongly correlated with the individual-level

income distribution. Using place-based data results in a potentially incorrect interpretation of the canopy cover–income relationship. If one were to personify places, rather than using person-level data, one would come to vastly different inferences about the empirical relevance of income for predicting canopy cover exposures.

That there is less variation in exposure to canopy cover within the individual-level income distribution suggests that within-location heterogeneity in income may not be a first-order determinant of willingness-to-pay for natural capital in this context. We caveat again, however, that these simple relationships do not convey direct information on willingness-to-pay, or the extent of heterogeneity in willingness-to-pay within census blocks; nevertheless, this finding suggests that the scope for heterogeneity along margins of income are more limited than one may infer from place-based data. This is not because there is limited heterogeneity in income within census block-groups—within-location heterogeneity is what leads to differences in the two canopy–income relationships (figure 4.4). By contrast, it suggests that there may be little scope for individual income as an important determinant of demand for natural capital. Colmer et al. (2023) provide causal evidence that even large changes in individual income lead to only small changes in demand for air quality. Whether this is because the true marginal willingness to pay for air quality is low, or because information frictions or other market failures distort revealed measures of marginal willingness to pay, remains unclear.

This highlights the third conceptual challenge that natural capital valuation faces—missing markets. Microdata are not able to do anything directly to address this constraint. Accounting prices are not observed and so can't be “provided” in the same way that data on earnings or housing prices can be made available. The granular variation provided by microdata does, however, create opportunities to credibly estimate accounting prices in a systematic and comprehensive way. This is beyond the scope of this paper, but the application of thoughtful research designs and/or structural models could be used to identify not only average accounting prices or willingness to pay estimates, but also distributions of these economic quantities.

4.5 Conclusion

In this paper we have raised the prospect of leveraging microdata (and in particular a new restricted-access environmental microdata infrastructure being developed at the Census Bureau) as an input to improve and expand measurement inputs necessary for natural capital accounting exercises. The availability of new microdata products creates opportunity for researchers to expand methodologies and accounting frameworks with individual-level data in mind.

We provide several illustrations of how microdata can help to address con-

ceptual issues and inform natural capital accounting exercises. Restricted-access microdata can be helpful in defining the extent of the relevant economic jurisdictions when engaging in nonmarket valuation exercises, and address issues of heterogeneity in valuation within locations. Combined with appropriate research designs and structural models, restricted-access microdata containing individual-level information about income, wealth, locational choices, alongside information on exposure to natural capital, can be used to learn about willingness to pay for natural capital, as well as heterogeneity in willingness to pay. By facilitating the production of new facts and necessary structural estimates, microdata have the potential to improve the natural capital accounting endeavor by grounding estimates in the experiences and well-being of individuals, providing new and improved evidence which can inform decisions around how to manage the relationships between people, businesses, and the environment.

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Comment Corbett Grainger

Can we improve estimates of the value of natural capital by using high-resolution data on the population and the distribution of environmental amenities? Under what circumstances does the spatial unit of analysis affect our estimates of the value of natural capital? In their chapter, Colmer and Voorheis (this volume) use high-resolution data from the census, paired with remotely sensed estimates of tree canopy cover, to illustrate the potential importance of individual-level data in such valuation applications.

In this comment, I discuss how high spatial resolution, individual-level data could be important in natural capital applications. There are two inter-related factors that I will focus on: the degree of variation of the environmental good over space, and the extent to which demand for the environmental good varies with population characteristics.

Heterogeneity over Space

Some amenities vary significantly even within a small geographic area. Air pollution and urban tree canopy, two examples from Colmer and Voorheis (this volume), both vary significantly between cities but also within a given

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