From:	Tim Trohimovich
To:	Cnty 2025 Comp Plan; Jeffrey Delapena; Rebecca Messinger; Glen Yung; Michelle Belkot; Wil Fuentes; Matt Little; Sue Marshall
Subject:	Re: Comments on the Comprehensive Plan Update for the Oct 1 public hearing
Date:	Wednesday, September 30, 2026 10:32:33 AM
Attachments:	image.png image.png image.png Blame_the_exurbs_not_the_suburbs_Explori.pdf Guide for authors - Energy Policy.pdf Guide for authors Landscape and Urban Planning - ISSN 0169-2046 ScienceDirect.com by Elsevier.pdf Agricultural_land_fragmentation_the_spat.pdf Lyubich_UCBerkeley_JMP Role of People and Places emissions.pdf AER Reviewer Guidelines.pdf

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Dear Councilors and Staff:

Tim Trohimovich, AICP
Director of Planning & Law
Futurewise
1201 3rd Ave #2200, Seattle, WA 98101
(206) 343-0681
tim@futurewise.org

From: Tim Trohimovich <Tim@futurewise.org>
Sent: Wednesday, September 30, 2026 10:25 AM
To: Cnty 2025 Comp Plan <comp.plan@clark.wa.gov>; Jeffrey Delapena <jeffrey.delapena@clark.wa.gov>; Rebecca Messinger <rebecca.messinger@clark.wa.gov>; Glen Yung <glen.yung@clark.wa.gov>; Michelle Belkot <michelle.belkot@clark.wa.gov>; Wil Fuentes <wil.fuentes@clark.wa.gov>; Matt Little <matt.little@clark.wa.gov>; Sue Marshall <sue.marshall@clark.wa.gov>
Subject: Comments on the Comprehensive Plan Update for the Oct 1 public hearing

Dear Councilors and Staff:

Enclosed please find Futurewise's comments on the comprehensive plan update. Thank you for considering our comments. We will be sending the the referenced documents in another email.

Please contact me if you require anything else.

Tim Trohimovich, AICP (he/him)
Director of Planning & Law

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September 30, 2026

The Honorable Sue Marshall, Council Chair
Clark County Council
PO Box 5000
Vancouver, Washington 98666-500

Dear Council Chair Marshall and Councilors Yung, Belkot, Fuentes, and Little:

Subject: Comments on the Comprehensive Plan Update
Sent via email: comp.plan@clark.wa.gov; jeffrey.delapena@clark.wa.gov; rebecca.messinger@clark.wa.gov; glen.yung@clark.wa.gov; michelle.belkot@clark.wa.gov; wil.fuentes@clark.wa.gov; matt.little@clark.wa.gov; sue.marshall@clark.wa.gov;

Thank you for the opportunity to comment on the 2025 Comprehensive Plan Update. Futurewise works throughout Washington State to support land-use policies that encourage healthy, equitable, and opportunity-rich communities, and that protect our most valuable farmlands, forests, and water resources. Futurewise has members and supporters across Washington State including in Clark County.

Summary of the Recommendations

Futurewise has the following comments and recommendations:

- Futurewise recommends aligning the County's greenhouse gas (GHG) emissions reduction targets with the City of Vancouver's reduction targets and to adopt policies and regulations consistent with the State of Washington Department of Commerce's *Clark County 2022 Greenhouse Gas Emissions Analysis*. This is necessary to comply with the climate element requirements of the Growth Management Act (GMA). Please see page 2 of this letter for more information.
- Because urban area expansions are not needed, the comprehensive plan cannot expand the urban growth areas (UGAs). Expanding the UGAs would violate the Growth Management Act (GMA). Please see page 4 of this letter for more information.
- The UGAs must not be expanded onto agricultural lands of long-term commercial significance. This is necessary to comply with the GMA. Please see page 4 of this letter for more information.
- Draft a supplemental EIS with appropriate up-zoning to accommodate affordable housing targets. While the UGAs have sufficient capacity for housing

and population, they should add additional affordable housing types. A draft supplemental EIS will provide the analysis needed to provide more affordable housing within the existing urban growth areas. Please see page 6 of this letter for more information.

- Adopt an Agriculture 40 (AG-40) zone to better protect working farms. This will help maintain the agricultural industry in the county and to protect access to fresh and healthy food. Please see page 7 of this letter for more information.
- Prohibit cluster land divisions in Agriculture zones. Cluster subdivisions do not protect farmland; they ultimately reduce the agricultural land base over time. Please see page 8 of this letter for more information.

Detailed Recommendations

Align greenhouse gas (GHG) emission reduction targets with the City of Vancouver's reduction targets and adopt policies and regulations consistent with Commerce's *Clark County 2022 Greenhouse Gas Emissions Analysis.*

RCW 36.70A.020(14) and RCW 36.70A.070(9) provide that "[i]t is up to each jurisdiction to create a program 'with a demonstrated ability to reduce emissions' in a manner which achieves" the state adopted greenhouse gas emission reduction targets.[1] These targets are in RCW 70A.45.020(1)(a) and (c) and call for net zero greenhouse gas emissions by 2050. The City of Vancouver calls for a goal that the city be carbon neutral by 2040 which we certainly support.[2]

Either way, the County must comply with RCW 36.70A.070(9)(d)(ii). In the *Thurston County* decision analyzing the GMA's greenhouse gas reduction requirements, the Growth Management Hearings Board concluded that the legislature in RCW 36.70A.070(9)(d)(ii) "has directly required" the greenhouse gas emissions reduction subelement to be consistent with the State of Washington

[1] *South Sound Bird Alliance, Gordon White, Robert Metzger, and Futurewise v. Thurston County*, Growth Management Hearings Board Western Region (GMHBWR) Case No. 26-2-0013c, Final Decision and Order (Aug. 17, 2026), at 17 of [69] last accessed on Sept. 29, 2026, at: https://eluho2022.my.site.com/casemanager/s/eluho-document/a0Teq00001YYbDzEAL/20260817-final-decision-and-order. This decision was not appealed and is now final.

[2] City of Vancouver, Washington, *Our Vancouver Our Future 2026-2045 Comprehensive Plan* p. 170 (Adopted June 1, 2026) and last accessed on Sept. 28, 2026, at: https://www.cityofvancouver.us/wp-content/uploads/2026/06/Our-Vancouver-Comprehensive-Plan-Final_accessible_26.05.28.pdf#page=22.11.

Department of Commerce's Guidance for Climate elements or "a demonstration of equivalency based on 'scientifically credible projections and scenarios.'"[3]

Thurston County adopted different policies than those recommended by Commerce.[4] As the Board concluded:

> Here the County did not provide any scientifically credible projection analyzing how much GHG emission reduction its adopted policies would achieve. In the absence of such analysis, the County had no basis to conclude that its adopted policies for GHG emissions reduction would be equivalent to or better than those identified by Commerce. The County has not calculated the GHG emission reductions its policies will achieve. The County did not provide the required equivalency analysis and, therefore, failed to meet the requirements of RCW 36.70A.070(9)(d)(i).[5]

As Futurewise's Comment Letter to the Clark County Planning Commission (July 30, 2026) documented on pages 10 to 19, Clark County has also not proposed to adopt the policies recommended by Commerce. We have not been able to find any scientifically credible projection analyzing how much GHG emission reductions the Clark County climate policies would achieve. This violates the requirements of RCW 36.70A.070(9)(d). Further, the scientifically credible projections must also include greenhouse gas emissions from the urban growth area expansions and rural, agricultural, and forestry growth projections. Rural residents have substantially higher greenhouse gas emissions, particularly higher transport-related direct greenhouse gas emissions, than residents in the urban growth

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[3] *South Sound Bird Alliance, Gordon White, Robert Metzger, and Futurewise v. Thurston County*, GMHBWR Case No. 26-2-0013c, Final Decision and Order (Aug. 17, 2026), at 17 of [69]. In the *South Sound Bird Alliance* the 2023 Commerce Guidance was applicable. Now, the Wash. State Dep't of Commerce, *Climate Element Planning Guidance* (Dec. 2025 Version 1.0) is in effect and this guidance is available at: https://www.commerce.wa.gov/growth-management/climate-planning/climate-planning-guidance/ and enclosed at the link on the last page of this letter and was enclosed in a separate email with the filename: "2025 Climate Planning Guidance.pdf" sent along with Futurewise's Comment Letter to Planning Commission (July 30, 2026).

[4] *South Sound Bird Alliance, Gordon White, Robert Metzger, and Futurewise v. Thurston County*, GMHBWR Case No. 26-2-0013c, Final Decision and Order (Aug. 17, 2026), at 19 of [69].

[5] *Id.*

areas.[6] The transport-related direct emissions of rural residents are three times those in larger cities, and 1.5 times those in the suburbs.[7]

As Futurewise's Comment Letter to the Planning Commission (July 30, 2026) recommended, Clark County should adopt the policies and regulations recommended by Commerce's *Clark County 2022 Greenhouse Gas Emissions Analysis*.[8] Futurewise's Comment Letters to the Planning Commission on July 30, 2026 and August 20, 2026 also included recommendations for the resiliency element necessary to comply with the GMA requirements to address the adverse impacts of climate. We also recommend the County adopt those recommendations too.

There must be no expansion of urban growth areas (UGAs) or de-designations of agricultural resource lands.

The Washington State Supreme Court wrote "we hold a county's UGA designation cannot exceed the amount of land necessary to accommodate the urban growth projected by [the Washington State Office of Financial Management] OFM, plus a

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[6] Jeffrey Wilson, Jamie Spinney, Hugh Millward, Darren Scott, Anders Hayden, and Peter Tyedmers, *Blame the exurbs, not the suburbs: Exploring the distribution of greenhouse gas emissions within a city region* 62 ENERGY POLICY 1329, pp. 1334 – 35 (2013) enclosed at the link on the last page of this letter and in a separate email with the filename: "Blame_the_exurbs_not_the_suburbs_Explori.pdf." Energy Policy is a peer reviewed journal. Energy Policy Guide for authors webpage p. *14 last accessed on Feb. 3, 2026, at: https://www.sciencedirect.com/journal/energy-policy/publish/guide-for-authors and enclosed at the link on the last page of this letter and in a separate email with the filename: "Guide for authors - Energy Policy.pdf;" Eva Lyubich, *The Role of People versus Places in Individual Carbon Emissions* 115 AMERICAN ECONOMIC REVIEW 1439, p. 1443 (2025) "If suburban and rural households lived in a place with the average place effect of the principal city closest to them—a scenario that captures in spirit how households' exposure to place effects might shift in response to regulations that limit urban sprawl and encourage upzoning and infill development—I estimate that their emissions from residential energy use and commuting would decrease by about 15 percent." Enclosed at the link on the last page of this letter and in an email with the filename: "Lyubich_UCBerkeley_JMP Role of People and Places emissions.pdf." The American Economic Review is peer-reviewed. American Economic Review Reviewer Guidelines last accessed on Sept. 28, 2026, at: https://www.aeaweb.org/journals/aer/reviewers and at the link on the last page of this letter and in a separate email with the filename: "AER Reviewer Guidelines.pdf."

[7] Jeffrey Wilson, Jamie Spinney, Hugh Millward, Darren Scott, Anders Hayden, and Peter Tyedmers, *Blame the exurbs, not the suburbs: Exploring the distribution of greenhouse gas emissions within a city region* 62 ENERGY POLICY 1329, p. 1335 (2013).

[8] Wash. State Dep't of Commerce Growth Management Services, *Clark County 2022 Greenhouse Gas Emissions Analysis* pp. 25 – 26, pp. C-1 – C-7 (v3.5.1) last accessed on Sept. 28, 2026, at: https://deptofcommerce.app.box.com/s/7ldu8wigqhvfikj4omrovl4szfpt7d8s and at the link on the last page of this letter and in a separate email with the filename: "CountyGHGAnalysisReport_Clark_20260618.pdf" and sent along with Futurewise's Comment Letter to Planning Commission (July 30, 2026).

reasonable land market supply factor."[9] A comparison of the total 2023-2045 housing unit needs in the *2025 Population, Housing and Employment Allocation – Issue Paper 5* with the "2023 VBLM Capacity" shows that existing capacity can accommodate or is within a few housing units of accommodating the planned housing growth.[10] This is confirmed by Commerce's comment letter on the proposed Clark County comprehensive plan.[11]

And the cities and unincorporated urban growth areas will likely need to increase their capacity for low-rise multifamily and mid-rise multifamily dwellings to meet the affordable housing requirements which will increase the housing capacity in the cities and unincorporated urban growth areas.[12] Further, Vancouver, Camas, and Washougal were required to adopt their new middle housing zoning by December 31, 2025, further increasing their housing capacity.[13] So, there is no need to expand the county's urban growth areas. Without a need to expand the urban growth areas, Clark County lacks the legal authority to expand the UGAs.[14]

Further, the *Clark County Agricultural Lands Study* documents "that 98 percent of the 101,844-acre Agricultural Land Base (99,900 acres) is classified as having Prime or Statewide Importance soils. A nearly identical share, 96 percent (31,400 acres), is found within the existing 32,589-acre Agricultural Designations. This near-universal prevalence indicates that from a soil-capability perspective, the

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[9] *Thurston Cnty. v. W. Washington Growth Mgmt. Hearings Bd.*, 164 Wn.2d 329, 352, 190 P.3d 38, 49 (2008).

[10] Clark County Comprehensive Plan 2025 Update Planning for growth 2025 – 2045 *2025 Population, Housing and Employment Allocation – Issue Paper 5* prepared by Community Planning p. 5; Clark County 2025 Allocation based on VBLM and HAPT Method A p. *1 last accessed on June 17, 2026, at: https://clark.wa.gov/sites/default/files/media/document/2024-02/Allocation%20Housing_Method%20A.pdf and at link on the last page of this letter with the filename: "Allocation Housing_Method A.pdf."

[11] State of Washington Department of Commerce letter to Clark County Re: 2026-S-14100 and 2026-S-14101 60-day Notice of Intent to Adopt - Periodic Update to Clark County's Comprehensive Plan and Development Regulations p. 2 (Sept. 22, 2026).

[12] Washington States Department of Commerce, Local Government Division Growth Management Services, *Guidance for Updating Your Housing Element: Updating your housing element to address new requirements* p. 36 (Aug. 2023, updated Jan. 2026) last accessed on June 17, 2026, at: https://www.commerce.wa.gov/growth-management/housing-planning/housing-guidance/ and at the link on the last page of this letter with the filename: "1220_Book2_Housing Element Update_230823 Final_updated 260112.docx" and sent along with Futurewise's Comment Letter to Planning Commission (July 30, 2026).

[13] Washing State Department of Commerce Middle Housing Update Deadlines last accessed on April 23, 2026, at: https://deptofcommerce.app.box.com/s/bv7g03x1h176hwy2lgm8chraykr8ki50 and at the link on the last page of this letter with the filename: "Middle Housing Update Deadlines by Year - Updated May 2025.pdf."

[14] *Thurston Cnty. v. W. Washington Growth Mgmt. Hearings Bd.*, 164 Wn.2d 329, 351 – 52, 190 P.3d 38, 48 – 49 (2008).

vast majority of lands identified in the study area are physically well-suited for agricultural production."[15] The other factors also show that these lands qualify as agricultural lands of long-term commercial significance.[16] The Land Use Element and Future Land Use Map must retain the existing agricultural lands of long-term commercial significance designation.

The land that Ridgefield and La Center are requesting to pave over forever are prime agricultural lands and farmlands of statewide importance and meet the other criteria for agricultural lands of long-term commercial significance.[17] Consequently, these lands cannot be legally dedesignated under WAC 365-190-040(10)(c). Since the lands cannot be dedesignated legally, they cannot be legally added to the UGAs unless the land added has been protected for agricultural use through the adoption of a purchase or transfer of its development rights.[18]

In the past Clark County was able to dedesignate agricultural lands of long-term commercial significance that continued to meet the criteria and have them annexed before the Growth Management Hearings Board and the courts found that these dedesignations violated the Growth Management Act. That is no longer possible because dedesignations and urban growth area expansions do not take effect until after the Growth Management Hearings Board appeals are resolved.[19] So, dedesignations that violate state law are now a waste of time and money as they will be appealed and overturned and cannot be annexed during the appeal period.[20]

Draft a supplemental EIS with appropriate up-zoning to accommodate affordable housing targets.

We recommend that the County prepare a supplemental environmental impact statement (EIS) to up zone areas within the existing urban growth areas to provide for more affordable housing types. While the UGAs have sufficient capacity for housing, population and employment, they should add additional capacity for affordable housing types. This should include housing affordable to families earning extremely low incomes (0% to 30% of area median income

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[15] ECOnorthwest, *Clark County Agricultural Lands Study* pp. 62 – 63 (Clark County Planning & Development Department: Nov. 2025) last accessed on Sept. 28, 2026, at: https://clark.wa.gov/sites/default/files/media/document/2025-11/final-agricultural-lands-study-technical-report-2025.11.04-1.pdf and at the link on the last page of this letter with the filename: "final-agricultural-lands-study-technical-report-2025.11.04-1.pdf."
[16] *Id.* pp. 66 – 73.
[17] *Id.* pp. 62 – 73.
[18] RCW 36.70A.060(5).
[19] RCW 36.70A.067.
[20] RCW 36.70A.067.

[AMI]), very low incomes (31% to 50% of AMI), low incomes (51% to 80% of AMI), and moderate incomes (81% to 120% of AMI) as the Growth Management Act requires in RCW 36.70A.070(2).

The comprehensive plan should better protect agricultural lands of long-term commercial significance.

The Growth Management Act requires Clark County "*to assure the conservation of agricultural lands and to assure that the use of adjacent lands does not interfere with their continued use for the production of food or agricultural products.*[21] Adopting an Agriculture 40 (AG 40) zone for agricultural lands of long-term commercial significance and prohibiting cluster subdivisions on agricultural lands would significantly improve protection for working farms.

Adopt an Agriculture 40 (AG-40) zone to better protect working farms.

Clark County's BERK report documents that the 20-acre minimum lot size and non-agricultural uses allowed by the Agriculture (AG-20) comprehensive plan designation and zone fails to conserve agricultural land of long-term commercial significance because they allow "non-productive rural uses."[22] "Given onsite development or other non-productive rural uses (e.g. dwellings, manicured lawns associated with dwellings, etc.) there is a greater area zoned AG and a lesser area inventoried by [the Washington State Department of Agriculture] WSDA in agricultural use. WSDA inventoried acres make up between 15-27% of the AG 10 zone area [which is now zoned AG-20]."[23] The BERK report also found based on the Census of Agriculture that "1.5% of the [Clark County] farms are large, representing 72% of the total commodity outputs. ... The loss of large farms corresponds to a loss in commodity totals. In 2007 dollars, the value of agriculture dropped from $62.3 million in 1997 to $52.7 million in 2007, and again to $45.9 million in 2012."[24] Converting large farms to small farms and 20-acre estates with

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[21] *King County v. Central Puget Sound Growth Management Hearings Bd. (Soccer Fields)*, 142 Wn.2d 543, 556, 14 P.3d 133, 140 (2000) emphasis in original.
[22] BERK Consulting, *Clark County Comprehensive Plan 2016 Update Planning for Growth 2015 – 2035: Clark County Agriculture and Forest Land Supplemental Mapping and Data Analysis – Issue Paper 9* p. 18 (June 23, 2016) last accessed on Sept. 28, 2026, at https://www.clark.wa.gov/sites/default/files/dept/files/community-planning/2016-update/Plan%20Adoption/Final%20documents-maps/Issue%20Paper_9_Supplemental%20Resource%20Land%20Info_2016_0623_CLEAN.pdf enclosed at the link on the last page of this letter and in a separate email with the filename: "Issue Paper_9_Supplemental Resource Land Info_2016_0623_CLEAN.pdf" and enclosed in a separate email with Futurewise's Comment Letter to Planning Commission (July 30, 2026).
[23] *Id.* at p. 18.
[24] *Id.* at p. 6.

manicured lawns as the AG-20 zone allows will not conserve agricultural lands and encourage the agricultural economy as the GMA requires. Clark County should increase the minimum lot size to 40 acres and remove the nonagricultural uses from the comprehensive plan designation and zone.[25]

Prohibit cluster land divisions in Agriculture zones.

Clustering is not an effective method of protecting working farms. A peer-reviewed study of clustering in comparison to other techniques showed that it does not protect farmland long-term.[26] Clustering because it only protects a portion of the farmland leads to a reduction in parcel sizes.[27] Smaller parcels can be difficult to farm long-term. "Contiguity with other protected land can be an important factor in the long-term farming status of a particular parcel of land."[28] Cluster programs cannot maintain continuity with other protected land and can

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[25] Arthur Nelson, *Preserving Prime Farmland in the Face of Urbanization: Lessons from Oregon* 58 JOURNAL OF THE AMERICAN PLANNING ASSOCIATION 467, 471 – 74 (1992) enclosed at the link on the last page of this letter with the filename: "Preserving Prime Farmland in the Face of Urbanization Lessons from Oregon JAPA.pdf." The Journal of the American Planning Association is a peer-reviewed journal. Journal of the American Planning Association - Instructions for authors webpage pp. 3 – 4 of 9 enclosed at the link on the last page of this letter and in a separate email with the filename: "JAPA Instructions for Authors.pdf" Both documents emailed with Futurewise's Comment Letter to Planning Commission (July 30, 2026).

[26] Elizabeth Brabeca and Chip Smith, *Agricultural land fragmentation: the spatial effects of three land protection strategies in the eastern United States* 58 LANDSCAPE AND URBAN PLANNING 255, p. 262 (2002) last accessed on Sept. 28, 2026, at: https://d1wqtxts1xzle7.cloudfront.net/107339839/viewcontent-libre.pdf?1699891797=&response-content-disposition=inline%3B+filename%3DAgricultural_land_fragmentation_the_spat.pdf&Expires=1790652373&Signature=Ve-7dufCwmoKxnGMiisokoQneDZgxSF2JVnmfPY20iz2qs3PH6SCOzp8Jtl6i34q0dL1ADrectCKdMb-4R1ZjKhsqsZ7apxh5ru9-eaJY~EvHiTnkXVpzHKz4D46nmj4sb1jqZBnXt3rOZJJHX5tyiv109cGpoQfmDtB-UW97965jgF463OZSpsPL-RsxgbW0uYOXBY7-B7WBMSZbvzjI3SDRhJ5JO4epA~zQRQ4Qi-dVaLcmXoMliH6eXiULGdc~hlpgW~h8LnNPsLg9IJcnRZZJzhDPM8GySJ2YwRkpsodKfBXO6rImxKVXHlZRaYr-~NgYNZRHAAvePfWeLtW8A__&Key-Pair-Id=APKAJLOHF5GGSLRBV4ZA and available at the link on the last page of this letter and another email with the filename: "Agricultural_land_fragmentation_the_spat.pdf." Landscape and Urban Planning is a peer-reviewed journal. Landscape and Urban Planning Guide for authors p. *6 last accessed on Sept. 28, 2026, at: https://www.sciencedirect.com/journal/landscape-and-urban-planning/publish/guide-for-authors#about-the-journal-peer-review and available at the link on the last page of this letter and in a separate email with the filename: "Guide for authors Landscape and Urban Planning - ISSN 0169-2046 _ ScienceDirect.com by Elsevier.pdf."

[27] Elizabeth Brabeca and Chip Smith, *Agricultural land fragmentation: the spatial effects of three land protection strategies in the eastern United States* 58 LANDSCAPE AND URBAN PLANNING 255, p. 263 (2002).

[28] *Id.* 263.

lead to situations where farmland is located close or even surrounded by residential cluster subdivisions.[29]

> The most significant weakness in the cluster program is the issue of preservation of the agricultural land base: only 6% of the original agricultural land base has been protected through the use of clustering, and only an average of 36% of an original parcel is protected under the requirements of the program. Thus, the effect of the cluster program is increasing fragmentation and loss of the land base.[30]

As this peer-reviewed study shows, cluster subdivisions will not maintain the agricultural land base in Clark County. Cluster subdivisions should not be allowed on agricultural lands of long-term commercial significance.

Thank you for considering our comments. If you require additional information, please contact me at telephone 206-343-0681 or email: tim@futurewise.org.

Very Truly Yours,



Tim Trohimovich, WSBA No. 22367
Director of Planning & Law

Enclosures at this link and in another emails:

https://futurewiseorg.sharepoint.com/:f:/g/IgAIkOZVzGs9QYtZ5F3NHbVpAfX-lUuvva5bsIfPoIDLFgA?e=nMPFbe

[29] *Id.* 263.
[30] *Id.* 266.



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University of Massachusetts Amherst

From the SelectedWorks of Elizabeth Brabec

February 15, 2002

Agricultural land fragmentation: the spatial effects of three land protection strategies in the eastern United States

Elizabeth Brabec, *University of Massachusetts - Amherst*
Chip Smith, *University of Michigan - Ann Arbor*

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Agricultural land fragmentation: the spatial effects of three land protection strategies in the eastern United States

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Abstract

Fragmentation of agricultural land by urban sprawl affects both the agricultural production capacity of the land and its rural scenic quality. In order to assess the resulting fragmentation of the three most common types of agricultural land conservation tools in the United States, this study analyzes the spatial form of three land protection strategies: a purchase of development rights (PDR) program, a clustering program and a transfer of development rights program. By assessing a series of measures of success such as total acreage protected, size of parcels, contiguity and farming status, the study compares the effectiveness of programs that have been in place for approximately 20 years, analyzing the extent to which each program prevents or enhances fragmentation. The analysis shows that although the number of acres protected is an important factor in program success, the amount of protected land remaining in active farming is additionally influenced by any development rights that may remain with the land, the use of a variety of tools to reduce the likelihood of parcel isolation, and the adjacency and contiguity of protected parcels. © 2002 Elsevier Science B.V. All rights reserved.

Keywords: Land conservation; Agriculture; Land protection; Metropolitan agriculture; Fragmentation; Urban sprawl

1. Introduction

Urban sprawl, caused by the continued flight of homeowners out of cites to relatively inexpensive land and housing in the urban fringe, has placed a tremendous pressure on farmland resources in the United States (Heimlich and Brooks, 1989). With the fragmentation of farms in the urban fringe has come a loss of the traditional farming economic base, and a change in the character and visual quality of rural communities (Heimlich, 1989; Lapping et al., 1989). To combat this loss and fragmentation of farmland, many communities in urbanizing areas of the United States are adopting a variety of tools to protect farms, farmland and the rural landscape. The primary responses by communities have been two-pronged: governmental or non-profit agencies purchase significant tracts of land, and local governments impose zoning and other regulatory requirements on the development of the land (American Farmland Trust, 1997). While analysis of the numbers of acres protected by each type of tool has been completed in the past, the varying effects on fragmentation of these regulatory and acquisition programs have not been analyzed or compared (Daniels, 1997).

The issues for farmland fragmentation are two-fold. First, there is the issue of regional fragmentation: the erosion of the farmland base leading to a loss of sufficient farm support operations and facilities, which raise operating costs (Lapping, 1979; Pfeffer and

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Lapping, 1995). Second is the issue of parcel fragmentation:

> ''Development in rural/urban fringe areas creates other farm management problems. Without strict zoning regulations farmland often becomes parcelized as entire farms or parts of farms are sold to developers. This parcelization of farmlands leads to a ''checkerboard distribution of farmlands, i.e. many noncontiguous fields. Farming such scattered plots is problematic. For example, field surveillance to monitor crop growth and pest populations is difficult, as is the movement of farm equipment because of transportation problems. Under these conditions consolidation of landholdings to achieve efficient scales of operation is nearly impossible.'' (Pfeffer and Lapping, 1995, p. 85)

This study examines the use of the three dominant land conservation tools used in the urban fringe and urbanizing rural areas—transfer of development rights, purchase of development rights (PDR) and cluster development—to determine the effect of each type of program on fragmentation of agricultural land. The following analysis provides a brief description of each land preservation program, a history of the program in each community and then the results of the spatial analysis conducted for the targeted agricultural land.

2. A description of the programs reviewed

Three communities were chosen in the eastern United States as case studies for analysis: Montgomery County, Maryland, and the towns of Riverhead and Southampton on Long Island, in New York state. These communities were chosen based upon three primary factors which affect the ability to assess the long-term effects of a land protection strategy. First, all three have had active farmland preservation strategies and tools in place for approximately 20 years, a sufficient period of time to develop a clear analysis of the impact of the tools on the farmland resource. Secondly, while all three communities use a variety of land conservation tools, each community's strategy relies significantly on one tool as the major leader in protection efforts: Montgomery County, Maryland relies primarily on transfer of development rights; Riverhead, New York on PDR; and Southampton, New York on cluster development. Thirdly, all three communities have active farming economies located in or on the fringe of major metropolitan areas, therefore, each farmland protection strategy and its tools must deal with significant development pressures.

2.1. Transfer of development rights in Montgomery County, Maryland

A transfer of development rights (TDR) program is typically a broadly applied, regional program which defines an area to be protected from development (sending area) and an area where development will be allowed to occur (receiving area). Since the program allows landowners to transfer the rights to develop one parcel of land to another parcel of land, the parcel from which the development rights are being transferred can no longer be developed, or developed only in a limited way.

In theory, a TDR program that is mandatory in the sending area should result in a low rate of farmland fragmentation. Since all of the parcels in the sending area transfer development rights outside of the area, little to no fragmentation should result. Thus, TDR programs have been touted as a primary tool for protecting agricultural land (Lapping et al., 1989; Merriam, 1978).

In 1980, Montgomery County became one of the first municipalities in the nation to adopt a countywide TDR program for agriculture preservation through its 1980 master plan (M-NCPPC, 1980). The county articulated a number of public policies underlying the TDR program, among them: a desire to control public costs associated with sprawl by channeling growth to existing population centers and setting aside lands for agriculture preservation; a goal of ensuring the continued viability of farming for regional food supplies; and a desire to maintain rural open space and the rural character of the area (M-NCPPC, 1980).

The county delineated an agricultural reserve (the sending area) of approximately 96,000 acres in the northern portion of the County. The extent of the agricultural reserve was based on soil quality, existing agricultural use, amount of existing development, size of farm parcels, and the threat of projected future development (M-NCPPC, 1980) with the goal of preserving a ''critical mass'' of farmland. Within the

boundaries of the reserve, the TDR program was mandatory, and created easement restrictions on property from which development rights were transferred. In establishing the program, the county allowed landowners to sell development rights at the rate of one development unit per 5 acres, but decreased the allowable building density in the sending area to 1 unit per 25 acres (Montgomery County Code, 1997, Article 28, Section 59-C-9.6). The county allotted one development right for every 5 acres of land (no fractional development rights) regardless of the quality of land, proximity to existing development, or other factors. Once a landowner transferred the development rights, the county acquired a permanent easement on the land, limiting residential development and restricting that parcel to agricultural uses except for the residual 1 unit per 25 acres which the landowner retained (M-NCPPC, 1980).

The county created approximately 15,000 development rights on land within the Agriculture Reserve. As of 1997, 6629 development rights had been removed from the underlying parcels and 5123 transferred to receiving areas (leaving 1506 development rights that had been removed, but not transferred). Approximately 2170 development rights remain attached to the underlying land in the form of small, pre-existing parcels or the 1 unit per 25 acres underlying right the county permits for actual development in the area.

Today the county's active farms are primarily located in the northern portion of the county, in the agricultural reserve. Agricultural production remains a strong segment of the economy in Montgomery County, with approximately US$ 28.6 million of agricultural products produced in 1997, up from US$ 27.7 million in 1992 (US Census, 1997). Crops, including field and nursery crops, are the major agricultural land use with a value of almost US$ 20 million in 1997 (US Census, 1997). Field analysis indicates that these crops are predominantly cereal and grain crops, with nursery and row crops composing a minor portion of the production. Livestock production, although still a strong component of the agricultural economy, is valued just under US$ 9 million (US Census, 1997).

Of the approximately 96,000 acres that make up the agricultural reserve in Montgomery County, 30,062 acres are protected under the TDR program, alongside an additional 15,000 acres of public lands and 9058 acres of land protected under the county's other four preservation tools (see Fig. 1). Judging from these figures, the TDR program has been the most aggressive in terms of preserving the farmland base in the county and provides a point of comparison for the predominant PDR program in Riverhead and the Southampton cluster development program.

2.2. Purchase of development rights in the town of Riverhead, New York

A PDR program typically uses public funds—tax revenues or municipal or state bonds—to fund the purchase and retirement of development rights on agricultural land. They are a commonly used farmland preservation tool, and are touted as being highly efficient at farmland retention (Lapping et al., 1989), equitable for landowners (Daniels, 1991), and generally a permanent preservation solution (Daniels, 1991). Since the tool is voluntary on the part of the landowner, a PDR program does not hold the inherent protection against fragmentation of a TDR program. In addition, the tool's most often cited drawback is its expense (Daniels, 1991; American Farmland Trust, 1997; Nelson, 1994), therefore, its potential to avoid fragmentation is tied to the amount of public funds that are available for development rights purchase.

The town of Riverhead is an historic agricultural community on the eastern end of Long Island. Riverhead has abundant, high quality agricultural soils and is one of the most important agricultural areas in New York state. However, thus far, Riverhead has experienced only a fraction of the tourism and resulting resort economy that has come to define Southampton, located on its southeastern border. Of Riverhead's more than 46,000 acres, and 16,862 acres are in agricultural use, although only 14,584 acres are zoned for agriculture. Approximately 12,300 acres, or 84% of the agricultural zone, are currently engaged in agricultural production, while the remainder are engaged in other uses such as golf courses, camps and private hunting reserves.

Riverhead's agricultural economy is focused primarily on row crops and nurseries. Of the total land in agricultural production, 1970 acres are in nursery production, 1924 in potatoes, 3211 in row crops and 1610 in sod. According to the 1997 census for the

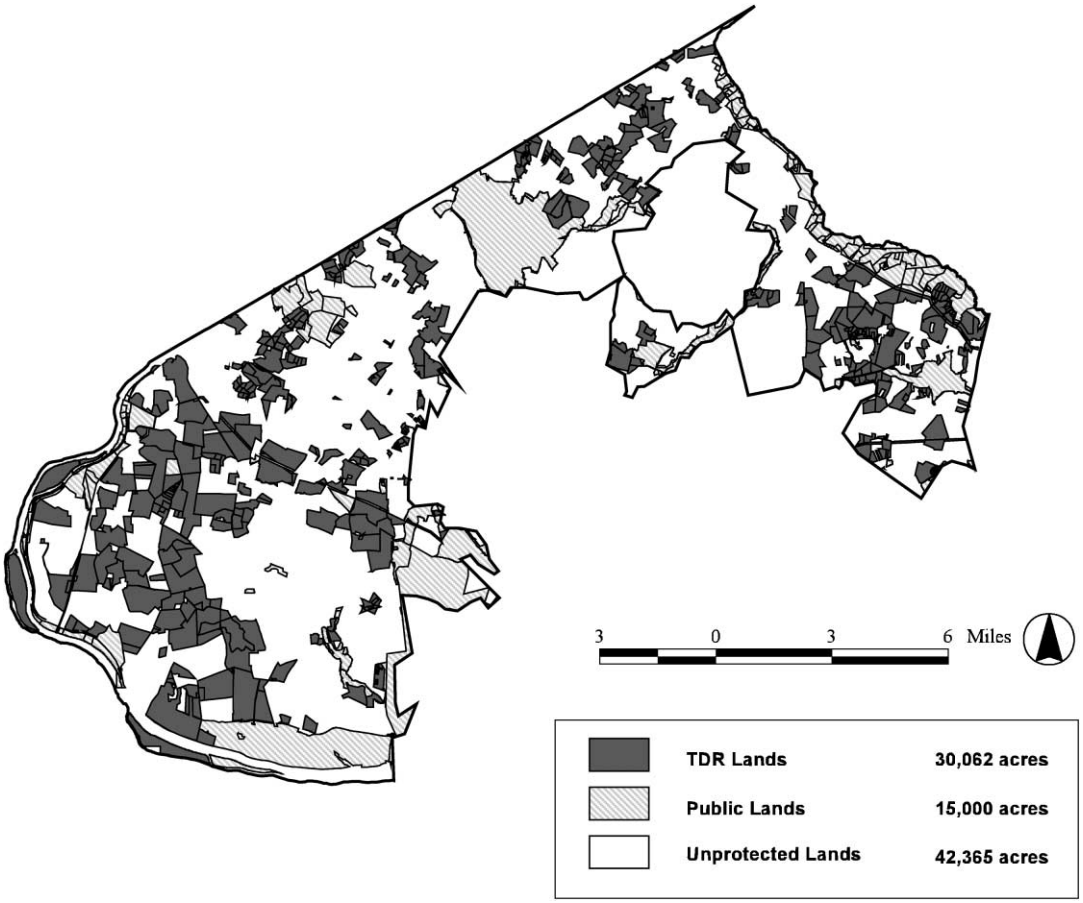

Fig. 1. Montgomery County's agricultural reserve area showing protected and unprotected lands.

entire area of Suffolk County, the agricultural economy relies on crop production, which includes potatoes, vegetables and orchards. The number of farms producing livestock is very small, producing only US$ 12 million compared to the US$ 155 million produced by crops (including nursery and greenhouse crops).

Unlike its neighbor Southampton, Riverhead depends primarily upon the Suffolk County PDR program to preserve agricultural land (see Fig. 2). Though Riverhead has established a town PDR program, the town has only purchased the development rights on two agricultural parcels. By contrast, the county PDR program has purchased the development rights on 70 parcels, preserving 3889 acres to the 61.5 acres preserved through the town program. Other tools have not been used effectively in Riverhead's strategy to add to the protected pool of farmland. Local land trusts have not been active in Riverhead in the purchase of farmland or farmland development rights as they have in Southampton. While, the town has a transfer of development rights program on the books, it is not mandatory in the sending area, and the town has only designated a very small receiving zone, resulting in the lack of use of this tool.

The county PDR program, one of the nation's first PDR program, was implemented in 1977 (American Farmland Trust, 1997). According to the Suffolk County Planning Department, between 1977 and 1996, US$ 40 million was spent to fund the acquisition of development rights, preserving over 7000 acres of land in the county. Another US$ 9 million was spent in conjunction with partnerships between Suffolk County, town governments and non-profits to purchase

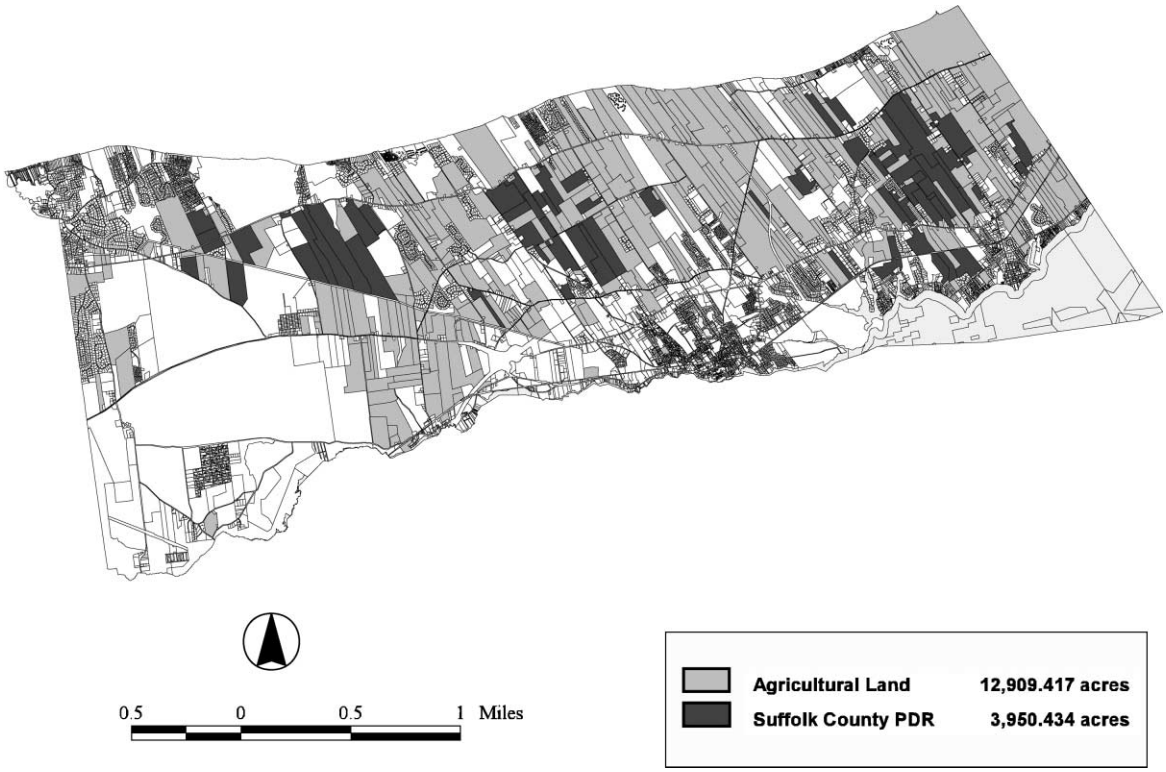

Fig. 2. The town of Riverhead showing extent of agricultural land, along with county PDR parcels.

development rights and conservation easements (Suffolk County Planning Department, 2000). The amount of land preserved in Riverhead by the county PDR program represents more than half of the total land preserved in the county through the program.

The county program used five factors in determining where to buy development rights: soils, current land use, contiguity of farmland, development pressure and the price of land (Suffolk County, 1996). Highest priority for acquisition was given to land in designated county Agricultural Districts, parcels over 10 acres in size and those with high-quality agricultural soils. In addition, parcels under consideration for purchase must have been engaged in active farming for at least 2 years prior to purchase.

2.3. Cluster program in Southampton, New York

In contrast to the regional focus and planning inherent in transfer and PDR programs, cluster development programs typically deal with development on a site by site basis. While cluster programs may be mandated in a prescribed geographical area, development and preservation decisions are made on an individual site basis, providing the opportunity for significantly more fragmentation than in transfer or purchase programs, a tendency noted in previous reviews (Arendt, 1997; American Farmland Trust, 1997). Cluster programs work with the underlying zoning density, reducing minimum lot sizes and requiring that a portion of the site remain as open space. Obviously, the percentage of open space required to be set aside in any cluster program is a major determining factor in the overall effectiveness of that program, as is whether the program is mandatory or voluntary, and the degree of discretion granted to the statutory review body. In terms of the potential for fragmentation, the question of whether protected open space on adjacent clusters is contiguous is critical.

Fragmentation of the remaining open space into a patchwork that has limited use as agricultural land or

habitat is also a critical issue (Whyte, 1964; Arendt et al., 1994; Dramstad et al., 1996). Although, it is a very popular tool, clustering is not regarded by farmland protection advocates as a front-line means to protect agricultural land bases (Arendt, 1997; American Farmland Trust, 1997). Previous reviews have suggested that clustering may be better designed for preserving niche farms on the urban fringe that produce high-value specialty crops for sale to urban areas (Arendt, 1997) and as a means to protect rural character and scenic quality (Daniels, 1997; Arendt, 1991), even though clustering may produce development results that are visually and functionally incompatible with surrounding land uses (Arendt, 1991).

The town of Southampton, located on the eastern end of Long Island, has been an agricultural community since its settlement in the late 1600s. By the 1970s, tourism and second home development were beginning to fragment the existing farming areas. Mandated in the 1970 master plan for the town, residential clustering was adopted in 1979 and substantially revised in the early 1980s. The town defined an agricultural overlay district, that coincided with the concentrations of agricultural land in the town and prime agricultural soils. By mandating the use of planned residential development (PRD) subdivisions within the agricultural overlay district, the town granted the planning board the discretion to require that a subdivision cluster the development units on the portion of the parcel containing the least productive soils. The percentage of open space to be set aside in the subdivision was governed by a sliding scale based on the minimum lot size of the underlying zoning (see Table 1).

Table 1
Prime agricultural soil preservation guidelines in the town of Southampton for the various development densities allowed in the agricultural overlay zone (Town of Southampton, 1989)

Zone	Minimum lot size requirements	Required percentage of prime soil preservation (%)
R-10	0.23 ac	35
R-15	0.34 ac	35
R-20	0.46 ac	35
R-40, CR-40	0.92 ac	35
R-60, CR-60	1.37 ac	35
CR-80, R-80	1.84 ac	50
CR-120, R-120	2.75 ac	65
CR-200	4.59 ac	65

Despite intense development pressure, farming continues in the town. Paradoxically perhaps, the most important farming areas are also located in the areas of highest land value located in the southeastern portion of the town adjacent to the prime beaches, comprising the highly desirable resort hamlets of Sagaponack, Bridgehampton and Water Mill. Cropping patterns provide evidence of the shift from traditional farming to metropolitan niche farming: row crops, particularly potatoes are being edged out by truck farming and nurseries as the predominant agricultural products.

Land in the agricultural overlay zone in the town of Southampton is protected under three different

Table 2
A breakdown of protected land by acres in the agricultural overlay zone, town of Southampton

Land type or protection tool	Total acres	Percent of total area	Average parcel size (acres)
Total land in farming use	6397.1	48.8	11.0
Total protected	2274.6	17.8	18.5
Subdivision reserve areas	755.7	5.8	13.7
County PDR	669.4	5.1	30.4
Town PDR	757.1	5.8	30.3
Local land trusts	149.1	1.1	3.4
Unprotected	4122.5	31.0	8.2
Total land not in farming use	6704.2	51.1	–
Protected	97.8	0.9	8.9
Developed and vacant land	6575.6	50.0	1.7
Public land	30.8	0.2	1.6
Total agricultural overlay	13101.3	100	–

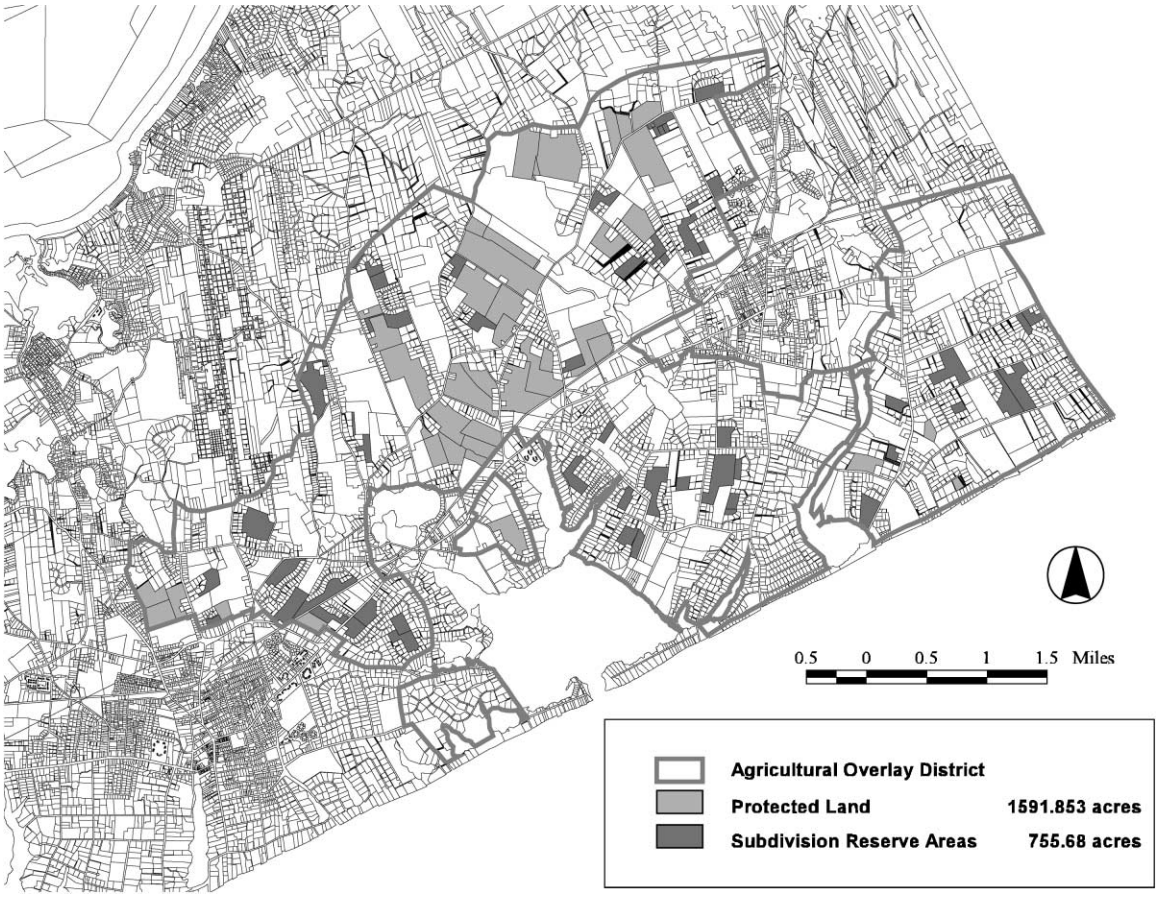

Fig. 3. The agricultural overlay zone in the eastern portion of the town of Southampton showing protected land and subdivision reserve areas.

tools: planned residential development (cluster), county and town PDR, and local land trusts. As of 1997, total preserved land accounted for 18% (2372 acres) of the total land acreage within the agricultural overlay, while unprotected land accounted for 4123 acres, or 31%. The remaining 6576 acres (50%) were developed (see Fig. 3 and Table 2).

3. The effects of the three programs on resource fragmentation

In order to compare the effect of the land protection tools and programs on fragmentation of the farmland resource, each major tool was analyzed according to the two major issues of fragmentation: (1) the erosion of the farmland base leading to a loss of sufficient farm support operations and facilities; and (2) the issue of parcel fragmentation. These two issues give rise to three measures or indicators of fragmentation in the resource, described below.

First, to assess the issue of the erosion of the farmland base, the total number of acres protected by the program was determined according to each of its associated tools. In order to allow the comparison of programs with widely differing amounts of resource land, this number was compared to the total number of acres of targeted land, giving a relative percentage of land protected.

Second, to assess the issue of parcel fragmentation, two measures were analyzed: parcel size and parcel contiguity. The average protected parcel size was assessed as a key indicator of the continued viability of the protected parcels for farming. Parcel size is an

indicator for large-scale, traditional farming enterprises, and is often relied upon as an indicator of fragmentation and degradation of the resource (Daniels, 1997; Gerard, 1984). However, in metropolitan fringe areas, there is some indication that parcel size may not be as important an indicator of continued farm production, due to a change in focus from field crops to high yield specialty crops (Pfeffer and Lapping, 1995; Scarfo, 1990).

Contiguity, or the degree to which the protected parcels connect to other protected parcels, creating a large agglomeration of land available for farming (Lapping et al., 1989) is a key measure of fragmentation. Other reviewers have noted that isolated farm parcels that are not contiguous with other farmed parcels often experience negative impacts such as complaints from neighbors and lack of support that negatively affect farming operations (Bryant and Johnston, 1992; Scarfo, 1990) in addition to the management issues associated with farming isolated parcels of land.

Finally, to test the effects of fragmentation on active farming, all protected lands for the three major tools were checked for active farming status through a field inventory conducted during the summer of 1999.

3.1. Regional fragmentation: total acreage protected

The three tools show a wide variety in the total number of acres protected over the lifetime of the program (see Table 3). However, since the total acreage targeted for protection in each jurisdiction varies so dramatically, the percent of the total acreage protected and the average acres protected per year provide a clearer indication of the preservation potential of each program.

In these respects, the TDR and PDR programs are the clear forerunners, protecting 31 and 23% of their respective land areas over the life of the program (see Table 3). However, when comparing the average acres protected per year, the TDR program at 1768 acres to the PDR program's 195 acres illustrates the TDR program's potential to protect large acreages of farmland. The cost of acquiring the development rights to large amounts of farmland (to acquire the amount of farmland preserved under Montgomery County's TDR program would require an almost 10-fold increase over the Riverhead totals) could make the goal of preservation almost prohibitive. It is interesting to note that in Montgomery County, an additional 10% of the land base (9058 acres) above that protected by TDR has been protected through the use of state and county PDR programs. The failure of clustering to protect a significant amount of the farmland base is underscored by the small amount (6%) protected in the Southampton program.

3.2. Parcel fragmentation

3.2.1. Size of parcels

Parcel sizes vary widely under the three tools, again with the TDR and PDR programs showing the most congruency. The greatest difference between these two tools is in the size of unprotected parcels, which in Montgomery County was 47.7 acres and in Riverhead, 28.5 acres. This reflects the fact that the PDR program has targeted the largest parcels for protection, leaving many of the smaller parcels for either future protection or development.

Pre-protection parcel sizes are relevant to the analysis only in terms of comparison between the cluster program and the other two programs. In Southampton, pre-protection parcel sizes ranged from the smallest at 6.6 acres to the largest at 71 acres. The mean pre-development or pre-protection parcel size was 37 acres, compared to 74.1 in Montgomery County

Table 3
Comparison of land protection achieved in acres for the three preservation programs: transfer of development rights, PDR and cluster

Program	Date of program inception	Total acreage targeted for protection[a]	Protected acreage[b]	Percent of total acreage protected (%)	Average acres protected per year
TDR, Montgomery County	1980	96485	30062	31	1768
PDR, Riverhead	1977	16862	3889	23	195
Cluster, Southampton	1979	13093	771	6	41

[a] Acreage contained within the target protection zone.
[b] Acreage permanently protected by the program: TDR by 1997, PDR by 1999; cluster by 1998.

Table 4
Comparison of parcel sizes across the three programs: transfer of development rights, PDR and cluster

Program	Affected parcel size		Unprotected parcel size[a] (mean acres)
	Pre-development or protection (mean acres)	Protected (mean acres)	
TDR, Montgomery County	74.1	74.1	11.3
PDR, Riverhead	51.1	51.1	37.5
Cluster, Southampton	37.0	13.7	8.5

[a] Parcels in agricultural use.

(50% larger) and 51.1 acres in Riverhead (28% larger). In Southampton, the relatively small pre-development parcel size exacerbated the results of the mean protected development parcel. At 13.7 acres, the mean protected development parcel was less than half the size of the original parcel (see Table 4). Loss of parcel size is an inherent result of the clustering tool since only a portion of the affected parcel is protected from development, while in TDR and PDR, the entire affected parcel is protected.

3.2.2. Contiguity

Contiguity with other protected land can be an important factor in the long-term farming status of a particular parcel of land. In addition to the measure of adjacency of protected land is the question of how the tools and coordinated farmland protection strategies achieved an aggregation of protected parcels across the targeted protection area. Two measures are key: adjacency of a protected parcel with another protected parcel, and secondly, the extent to which those protected parcels form a large mass of contiguous protected land. In assessing the results of the aggregations, the key factor is the average size of the resulting aggregations (see Table 5) and the overall percentage of protected land that remains isolated from other protected land (see Table 6).

In reviewing the adjacency of protected parcels in the three programs, the TDR and PDR showed the strongest results, with 91 and 75% of parcels adjacent to other protected parcels under the same program (see Table 7). In Southampton, only 36% of the protected parcels were adjacent to other subdivision reserve areas, and 46% were adjacent to only unprotected parcels. This result illustrates the failure of discretionary review to ensure contiguous protected land in a cluster program. Exacerbating the issue of adjacency in Southampton, 17% of the protected parcels (8 of the 47 subdivision reserve areas) were completely surrounded by residential subdivisions.

Due to its large target protection area, Montgomery County's TDR program produced the largest aggrega-

Table 5
Aggregations of protected land achieved by the various tools and three preservation strategies of the study sites

Program	Percent of aggregations	Total acres	Average percent of parcels	Mean size of aggregation in acres	Maximum acres of aggregation	Minimum acres of aggregation
Montgomery County						
TDR	59	27406.2	10.0	464.5	11675.1	3.9
PDR	20	7758.8	6.25	387.9	2183.0	48.8
TDR and PDR	59	36963.1	12.7	626.5	14906.7	3.9
Riverhead						
PDR	12	2952.3	4.0	246.0	857.0	21.7
Southampton						
Cluster	18	275.9	2	30.7	56.7	9.7
PDR and land trust	75	1165.5	4.4	68.6	261.9	4.7
Cluster, PDR and land trust	27	1606.7	3.8	54.2	142.8	4.7

Table 6
Relative area of the protected parcels that were aggregated and isolated by the tools used in the three study sites

Program	Percent of parcels	Total acres	Mean size of parcels (in acres)	Percent of protected area by tool
Montgomery County				
TDR				
Aggregated	593	27406.2	46.2	91
Isolated	50	2655.6	53.1	8
Total	643	30061.8	–	100
PDR				
Aggregated	125	7758.8	62.1	86
Isolated	18	1299.6	72.2	14
Total	143	9058.4	–	100
Riverhead				
PDR				
Aggregated	48	2952.3	61.5	75
Isolated	22	981.1	44.6	25
Total	70	3933.4	–	100
Southampton				
Cluster				
Aggregated	18	275.9	15.3	36
Isolated	30	496.9	16.6	64
Total	48	772.8	–	100
PDR and land trust				
Aggregated	75	1165.5	15.6	88
Isolated	8	161.5	20.3	12
Total	83	1327.0	–	100

tions of protected land. However, it is clear from Table 6 that the farmland protection strategies that use more than one tool—Montgomery County and Southampton—achieve a positive effect in protected land aggregation. In Southampton, aggregations of protected land increased in total acreage almost six-fold, while the average aggregation size increased by 43%. Montgomery County's aggregation size increased by 25%.

When looking at the effects of the individual tools (Table 7), the TDR program showed a positive effect on fragmentation, resulting in the aggregation of 91% of the parcels into protected areas with an average size of 465 acres. The PDR programs also fared well, aggregating 86% of the total protected land area in Montgomery County, 75% in Riverhead, and 88% of the PDR and land trust parcels in Southampton. The parcel aggregations in Montgomery County and

Table 7
Breakdown of percentage of parcels contiguous with other protected parcels or unprotected land in agriculture

Program	Contiguous with other protected parcels[a]		Contiguous with only unprotected parcels (%)
	Same program (%)	Other programs (%)	
TDR, Montgomery County	92	2	7
PDR, Riverhead	78	–	20
Cluster, Southampton	38	19	46

[a] A parcel may be contiguous with more than one type of protected parcel.

Table 8
Breakdown of programs detailing accessibility of preserved lands

Program	Accessible by (percent of parcels)		
	Road (%)	Protected (mean acres) (%)	Unprotected land in farm use (%)
TDR, Montgomery County	88	60	2
PDR, Riverhead	66	43	7
Cluster, Southampton	67	15	17

Riverhead communities averaged 387 and 246 acres, respectively.

The cluster program in Southampton did not fare as well. Of the protected parcels, 64% were isolated, with an average protected aggregation of only 30 acres. The additive effect of other tools in reducing fragmentation is particularly obvious here, since the average aggregation size rose to 54.2 acres with the addition of county and town owned PDR parcels and acquisitions by local land trusts.

3.3. Farming status

In order to test the effects of fragmentation on active farming, all protected lands for the three major tools were checked for active farming status. Farming status was determined for Montgomery County from tax parcel information with field checks. In Riverhead and Southampton, status was based solely on field observations.

All three farmland preservation tools showed high rates of active agricultural use. In Riverhead, 97% of PDR protected land were in active farm use (see Table 8). Parcel size had a direct effect on the agricultural status of land in Riverhead. Analysis of the parcels identified that 40% of parcels under 5 acres were actively farmed, 92% of parcels between 10 and 25 acres were actively farmed and 96% of parcels larger than 25 acres were actively farmed; there are no PDR parcels between 5 and 10 acres. This analysis indicates that in Riverhead parcel size is factor in agricultural status: the larger the preserved parcel, the greater the likelihood it remains in agricultural use (Tables 9 and 10).

Table 9
Comparison of lands in active farm use

Program	Protected land in active farm use			Not in active farm use mean parcel size (acres)
	Acres	Percent (%)	Mean parcel size	
TDR, Montgomery County	24641	82	77.7	16.6
PDR, Riverhead	3786	97	59.2	32.6
Cluster, Southampton	709	92	13.7	8.9

Table 10
Summary comparison of land protection for the three programs[a]

Program	Total acres protected	Percent of land base protected (%)	Average protected parcel size (acres)	Percent of protected parcels in active agriculture (%)	Percent of protected land in aggregations (%)
TDR, Montgomery County	30062	31	74.1	82	91
PDR, Riverhead	3889	23	51.1	97	75
Cluster, Southampton	771	6	13.7	92	36

[a] In the TDR program, the land parcel retains development rights at the rate of 1 unit per 25 acres after transfer.

In Southampton, 92% of all subdivision reserve areas were actively farmed. For the purposes of this study, land in agricultural production includes equestrian land (153 acres), land used by commercial nurseries and orchards (45 acres), and farmland producing row or specialty crops (511 acres). The status of two SRA parcels (11.5 acres) was undeterminable due to the visual and/or physical inaccessibility of the lots from public property. It is important to note that in addition to equestrian uses, several of the subdivision reserve areas were used as wildflower meadows, both of which take land out of traditional agriculture. Riding arenas and academies, while popular, have a high ratio of built structures and impervious surfaces, therefore, these uses do not preserve the prime agricultural soils as intended by the goals of the program.

In Southampton, larger parcels are more likely to be farmed than smaller parcels. Half of parcels under 5 acres were actively farmed; 91% of parcels 5–10 acres in size were actively farmed; 79% of parcels 10–20 acres were actively farmed; and 100% of parcels larger than 20 acres were actively farmed. One explanation for the dip in percentage of parcels actively farmed in the 10–20 acres category is that 10 acres may be too large to be leased for efficient truck farming and 20 acres too small to support efficient row crop production.

The analysis of active farming status in Montgomery County indicates one flaw of TDR program as applied in the county. While 82% of the protected land continues in agricultural use, it is the lowest percentage of the three programs. Part of the reason for this can be found in the mean parcel size of land not in active farm use, 16.6 acres. This supports the finding that the remaining development right of 1 unit per 25 acres encourages the creation of smaller parcels that have a residential function.

4. Conclusions

Avoiding fragmentation—the isolation of farmland parcels—is a key aspect of any farmland preservation strategy. Therefore, it is critical to understand the triggers and the effects of fragmentation inherent in any farmland preservation strategy. The results of this initial investigation into the spatial forms produced by three farmland preservation programs identify several key triggers of fragmentation.

At the regional level, when looking strictly at the numbers of acres of farmland protected by the three programs, transfer of development rights appears to be the most successful agricultural land protection method. Montgomery County's transfer of development rights program resulted in a higher rate of land conservation than either of the other two programs—31% of the land base from transfer of development rights in Montgomery County, compared to 23% from PDR in Riverhead and 6% for Southampton's cluster program. The most significant weakness in the cluster program is the issue of preservation of the agricultural land base: only 6% of the original agricultural land base has been protected through the use of clustering, and only an average of 36% of an original parcel is protected under the requirements of the program. Thus, the effect of the cluster program is increasing fragmentation and loss of the land base.

However, the number of acres protected provides only an initial indication of the success of any of the three programs in avoiding land fragmentation. The success or failure of each program is clarified by the amount of protected land that continues to remain in active farming. The PDR program resulted in 97% of the preserved parcels in active agricultural production, compared to 82% for the transfer of development rights program. This is due at least in part to the remaining development rights in the transfer program (at the rate of 1 unit per 25 acres) that allow for further subdivision of the land into residential estates, a popular commodity in the metropolitan real estate market. Even in Southampton, where the parcel sizes are much smaller, the active agricultural use is 92%, underscoring the importance of severing all future development rights from the protected parcel.

As important to the issue of fragmentation is the question of how the farmland preservation programs achieve contiguous blocks of protected farmland. Again, the transfer of development rights program in Montgomery County is the most successful in achieving large contiguous blocks. However, the results also underscore the importance of developing a coordinated strategy utilizing a variety of farmland protection tools. Two of the case studies, Montgomery County and Southampton, which used a variety of tools for protecting farmland showed both a dramatic

increase in size of protected areas and reduction of protected parcel isolation when all of the farmland protection tools are included in the analysis. Meanwhile, Riverhead did not have a variety of active tools. While the PDR program in Riverhead used adjacency in its selection criteria, isolated parcels remained a problem in the program.

Further, research and comparison between programs is certainly needed, however, this analysis illustrates key criteria for effectively reducing fragmentation in a farmland protection strategy. First, an emphasis on protecting large parcels is critical to reducing fragmentation as much as possible during the protection process. Secondly, using adjacency and contiguity criteria in making preservation decisions improves the ability to protect large contiguous blocks of land and are key in ensuring that farming can continue effectively in the targeted area. In this respect, severing all development rights from the land will ensure the continued viability of farming, lessening the potential of conversion to residential uses. In cluster programs, effectiveness is also influenced by the amount of review discretion granted to the site plan approval board, and the threshold of open space protection required in the ordinance. Finally, the analysis and comparison of the three land preservation strategies reinforces the importance of utilizing and coordinating a variety of protection tools to achieve optimum protection of the land base.

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Blame the exurbs, not the suburbs: Exploring the distribution of greenhouse gas emissions within a city region

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HIGHLIGHTS

- Household survey data and GPS-verified travel data are used to estimate GHG emissions.
- Residential location impacts both transportation and housing-related GHG emissions.
- Results reveal spatial variability in direct GHG emissions at the sub-regional scale.
- No significant difference in total direct GHG emissions between urban and suburban respondents.
- Travel related GHG emissions are significantly higher among those living in the exurbs.

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ABSTRACT

This research investigates whether where we live matters in terms of contributions to direct greenhouse gas (GHG) emissions. Using results from the Halifax Space Time Activity Research (STAR) project, we estimate GHG emissions for 1920 randomly selected respondents in Halifax Regional Municipality, Nova Scotia, Canada. The unique data set allows us to report direct GHG emissions with an unprecedented level of specificity at the sub-regional scale using household energy-use survey data and GPS-verified travel data. We report results and investigate statistical differences between communities and urban–rural zones (inner city, suburban, and inner and outer commuter belts). Results reveal considerable spatial variability in direct GHG emissions across the study area. Our findings indicate that individuals living in the suburbs generate similar amounts of GHG emissions (20.5 kg CO_2e person^{-1} day^{-1}) to those living in the inner city (20.2 kg CO_2e person^{-1} day^{-1}), challenging a widely held assumption that living in the urban centre is better for sustainability. However, individuals in more rural areas have significantly higher transport-related GHG emissions than those living in the inner city and suburbs. Our results underscore the importance of understanding the spatial distribution of GHG emissions at the sub-regional scale.

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1. Introduction

Influencing where people live is a strategy available to municipalities for reducing household greenhouse gas (GHG) emissions. The objective has been to increase the population density of the urban core and curb urban sprawl (Parshall et al., 2010; Weisz and Steinberger, 2010). The rationale is based on a poorly tested, yet widely held, assumption that people living in the urban core have lower environmental impact lifestyles than do their suburban and rural counterparts (Hoornweg et al., 2011). The premises held that square-footage of houses are smaller in inner city zones, and that individuals are less vehicle-dependent than those living in the suburbs and rural fringes of urban regions. However, the relationship between the built environment and travel mode choice remains poorly understood (Ewing and Cervero, 2010). Furthermore, as most sustainability and land-use planning studies are urban-focused, the policy debate has focused on an urban (inner-city) versus suburban dichotomy. The suburbs are perceived as the locus of 'unsustainable' development and living, compared to the urban core (Hoornweg et al., 2011). In the North American context, however, the rapidly-developing "exurbs" of the urban fringe (Davis et al., 1994; Lamb, 1983; Nelson, 1991; Taylor, 2011) extend far into the quasi-rural commuter belt, and it is therefore also important to compare GHG emissions of exurbanites to those of urban and suburban residents.

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The notion that where we live influences our environmental impact has been an important meta-theme within the "smart growth" planning movement. Understanding of the distribution of GHG emissions across urban regions is, however, poor at best. Few studies report GHG emissions or carbon footprints at the sub-regional or sub-municipality scales. Lack of data at finer spatial scales presents a significant limitation for sustainability analysis (Wilson and Grant, 2009). Lenzen et al. (2004) and Haq and Owen (2009) estimate both energy consumption and carbon footprints at the sub-city level by linking input-output analysis with household spending survey data. Druckman and Jackson (2008) for the United Kingdom, and Weber, Matthews (2008) for the United States, estimate GHG emissions of households by income category and other household characteristics using models that link household expenditure data to energy consumption. Neither study specifies a geographic region, but their models could support a sub-regional analysis. In absence of input-output data, VandeWeghe and Kennedy (2007) estimate residential GHG emissions by census tract for the Toronto Census Metropolitan Area (Canada) based on household fuel payments and transportation survey data. Wilson et al. (2013) presents the most refined analysis to date, estimating the ecological footprint, including the carbon footprint, by Census Dissemination Area (400–700 people) for Oakville, Ontario (Canada). Ecological footprint values were derived using household energy use data, square footage data, household spending data, and commuting survey data.

The literature provides convincing evidence that environmental impacts vary substantially at the sub-city level. What is of interest, however, is to discern whether such variation is repetitive and predictable, and here the results are mixed. Wilson et al. (2013) found substantial variability in ecological footprints within what one might expect to be a relatively homogeneous group (the study community, Oakville, is a bedroom community of Toronto and considered a suburb in its entirety). In Oakville, higher footprint households tended to concentrate along the waterfront and green spaces indicative of higher-income households. Lenzen et al. (2004) found that energy requirements of subdivisions are higher nearer the city centre. Haq and Owen (2009) noted neighborhoods reporting the largest carbon footprints were in either the inner city or rural areas. VandeWegh and Kennedy (2007) found census tracts located in the suburbs had the highest per capita GHG emissions. All of these efforts, however, quantify the environmental impact of households based, in part, on spending data or other indicators. To the best of our knowledge, no studies have estimated GHG emissions (or similar measurement units, i.e. carbon footprint) based directly on energy use information collected at the household level.

The objective of the present analysis is to understand spatial variation in direct greenhouse gas emissions across an urban region based on household-specific energy use data and GPS-verified personal travel data. The unique dataset allows us to report direct GHG emissions with an unprecedented level of specificity at a sub-regional level. The analysis reports direct GHG emissions using for 1920 respondents living in Halifax Regional Municipality (HRM), Nova Scotia, Canada.

Results are reported by community, confirming variability in direct GHG emissions across HRM. In addition, results are reported by urban–rural zones, highlighting differences in direct GHG emissions between urban, suburban, and rural commuter zones.

2. Data and methods

2.1. Data

Our study employs data from the Halifax Space-Time Activity Research (STAR) project, which represented the world's largest deployment of global positioning system (GPS) technology for a household activity survey (Bricka, 2008). The Halifax STAR project sampled 1971 randomly selected households in HRM, or about one household in 78, between April 2007 and May 2008 (Time Use Research Program (TURP), 2008). HRM is the provincial capital of Nova Scotia and the largest municipality in Atlantic Canada, spanning almost 5500 square kilometers, with a population of over 390,000 people in 2007 (Statistics Canada, 2012). In many ways, HRM is highly representative of Canadian mid-sized metropolitan areas, having a diverse and moderately prosperous economy with population growth of about 0.5% per year. The study area has a clearly-defined downtown area that has experienced little inner city decay, and income variations across the region are modest. Low-density exurban sprawl is particularly evident in a commuter belt within 50 km of downtown Halifax, while very few people reside in the fully rural area beyond 50 km (Millward and Spinney, 2011a).

The Halifax STAR project collected time diary and questionnaire data over 373 days of data collection, with a cooperation rate of 25% and overall response rate of 21% (Millward and Spinney, 2011b). The primary sampling frame was all residential households with listed telephone numbers. A pre-notification letter was used to make initial contact with each household, followed by a recruitment telephone call. Using computer-assisted telephone interview (CATI) software, recruited households completed a brief intake questionnaire to collect age and other information for all household members. The age information was used to randomly select the secondary sampling unit; a single household member over the age of 15 who was randomly selected as the "primary respondent", and was assigned a consecutive pair of diary days (e.g. Thursday–Friday, Friday–Saturday, etc.). Throughout the 48-h reporting period, the primary respondent carried a GPS-device (Hewlett Packard iPAQ hw6955) that was programmed to collect GPS data every 2 s and automatically send that information back to a central server for processing. The "day after" the two-day reporting period, both questionnaire and two-day time diary data were collected using specially-designed computer-assisted telephone interview (CATI) software. The CATI software enables interviewers to visualize the GPS data, travel routes, and precise start and end times for all "stops" (i.e. stationary locations lasting at least two minutes). See Time Use Research Program (TURP), 2008, 2010a, and, 2010b for a detailed description of the sampling strategy, survey methods, and data user guide. The STAR survey was modeled after Statistics Canada's (2006) General Social Survey (GSS) Cycle 19, which asked questions about personal characteristics, household characteristics, neighborhood features, socio-economic data, and subjective dimensions of well-being. The STAR survey supplemented those questionnaire items with questions regarding electricity consumption, home heating, and energy efficiency behaviors, among others.

Using ArcGIS 9.3®, the geographic coordinates (latitude and longitude) of each household's residential location within the study area were "spatially joined" with communities (based on municipal administrative boundaries) and urban–rural zones (delimited operationally on the basis of both urban form and commuting linkages to the urbanized area). Given the measurement of transportation-related GHG emissions is based primarily on average travel distance, the zones defined by Millward and Spinney (2011a) are used in this study. These zones are based on street network travel distance outwards from "downtown", and, therefore, offer a more functional approach to examine the extent to which GHG emissions vary within the study region. The "inner city" of HRM is defined as the area within a 5 km travel distance of Halifax and Dartmouth's "downtown" areas. The "suburbs" are adjacent developed areas with city water and sewer services, mostly lying between 5 and 10 km from downtown. The "inner

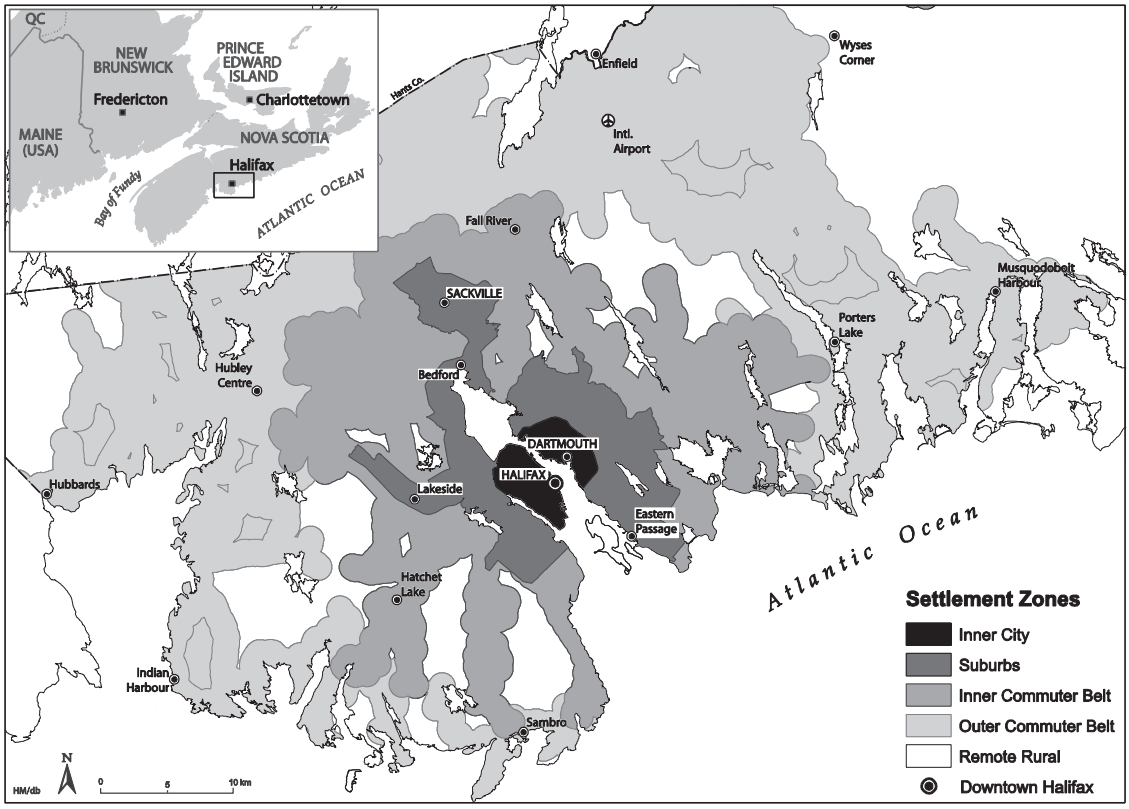

Fig. 1. Urban–Rural Zones in the Halifax Regional Municipality.

Table 1
Summary statistics for select survey items by urban–rural zone.

	Inner city *Mean (S.D.)*	**Suburbs** *Mean (S.D.)*	**Inner commuter belt** *Mean (S.D.)*	**Outer commuter belt** *Mean (S.D.)*
Age of respondents	55.3 (14.2)	52.6 (13.9)	48.7 (11.0)	48.9 (12.1)
Persons per household	2.5 (1.1)	2.7 (1.1)	3.1 (1.2)	2.9 (1.2)
Heated square feet	1983 (1128)	1979 (820)	2237 (915)	2177 (786)
Heated square feet per person	920 (626)	848 (505)	836 (514)	857 (443)
Number of household vehicles	1.4 (0.7)	1.7 (0.7)	2.1 (1.0)	2.0 (0.7)
Car-dependency (km/day)	25.8 (38.5)	32.6 (42.7)	49.3 (50.6)	53.2 (52.1)
Percent light duty vans and trucks (%)	21	31	34	38

commuter belt (ICB)" comprises unserviced communities lying between 10 and 25 km travel distance to downtown while the "outer commuter belt (OCB)" lies between 25 and 50 km to downtown. Millward and Spinney (2011a) define a fifth zone, "remote rural", which encompasses areas beyond 50 km travel distance to downtown, or lacking road access, but due to a lack of sample, we do not report GHG emissions for this zone (Fig. 1).

The STAR sample approximates a proportional distribution for gender, days of the week, and the months of the year. Spinney and Millward (2011) provides a detailed description of the sample. A few of the more pertinent survey items to the study are summarized and presented in Table 1 using measures of central tendency and dispersion that are stratified by urban–rural zone. The survey items that are summarized in Table 1 are respondents' ages; persons per household; housing size (heated square footage); heated square footage per person; number of household vehicles, "car-dependency" that is measured using daily mean travel distance (km) in a private vehicle or taxi; and the prevalence of light duty vans and trucks (bigger vehicles) as a percentage of vehicle fleet of respondents.

If we consider adjacent successive urban–rural zones as an ordinal classification of increasing distance from downtown, both household size and the number of persons per household increases as we move away from the inner city toward the inner and outer commuter belts. The heated square footage of households per person, however, decreases with increasing distance from the inner city. The mean heated square feet of housing increases with increasing distance from the inner city, but when the size of the home is adjusted for the size of the family, there appears to be an inverse relationship between heated square feet per person and increasing distance from the inner city. Both dwelling size and family size increase with distance from the inner city. There is a steady decline in the age profile with increasing distance from the inner city; average age decreases from a high of 55 years old in the inner city to 48 years old in the inner and outer commuter belts. More pronounced is the pattern of increasing car dependency (km traveled per day) with increasing distance from the inner city, and decreasing opportunities for alternate travel modes. About one-quarter of inner city respondents are car dependent. That value rises to about one-third in the

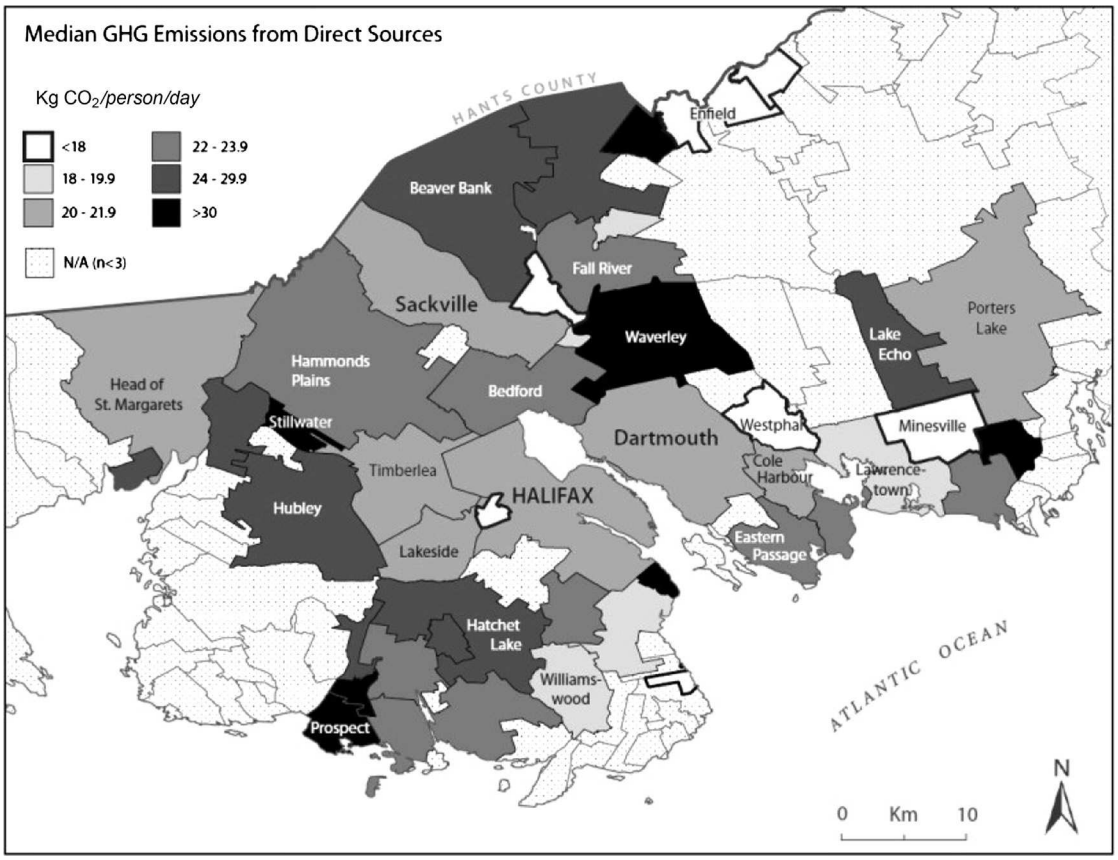

Fig. 2. Spatial distribution of median GHG estimates by communities.

suburbs, to almost one-half in the inner commuter belt, and exceeds one-half in the outer commuter belt. Not surprising then, the average number of vehicles per household also increases with increasing distance from the inner city, where the average is 1.4 vehicles per household and that number reaches its maximum in the inner commuter belt at 2.1 vehicles per household. In the same vein, there is a modest, but steady, increase in the prevalence of light-duty vehicles with increasing distance from the inner city to the rural countryside. Overall, however, we found little distinction in prevalence of light-duty vehicles between the inner and outer commuter belt zones.

2.2. Methods

Shelter-related and transportation-related direct GHG emissions were estimated per respondent per day in kilograms carbon dioxide equivalents (kg CO_2e person^{-1} day^{-1}). Shelter-related GHG emission estimates are based on respondent-recall of electricity bills, home heating bills, and amount of wood burned. Respondents were asked to consult bills, although we are not able to verify which houses did and did not. We reported shelter-related emissions per respondent by dividing the total household emissions by the number of household members. We confirmed results with an expert from the provincial energy efficiency agency, which resulted in 15 cases being screened out of our analysis, because of unreasonably high shelter-related energy use. For transportation-related direct GHG emissions, we estimated personal transportation based on distances traveled, using household activity survey data. Trip distances were computed using the shortest path between GPS-verified origins and destinations. Thirty-six respondents had incomplete travel data and were screened out of our analysis. Also, we do not include air travel in our estimation of GHG emissions, because many of the out-of-country coordinates were not captured in the STAR survey. In Nova Scotia, air travel (domestic aviation) represents approximately 7% of total transport-related GHG emissions (Environment Canada, 2010). For a more detailed description of specific methods and assumptions used to estimate direct GHG emissions, see Wilson et al. (in press).

Each respondent's residential location was used to summarize the spatial distribution of direct GHG emissions across the 62 communities within the study area. Communities, in this context, do not reflect a specific population size. Rather, they represent longstanding geographic areas with meaningful similarities in both perceptions and interpretations of both place and context. Median direct GHG emissions were calculated for communities with three or more sampled households and mapped using ArcGIS 10® to illustrate the spatial distribution of emissions. In addition, shelter-related, transportation-related, and total direct GHG emissions were assigned to urban–rural zones. Statistical Package for the Social Sciences (SPSS, v.15.0) software was used to measure the median and inter-quartile range (IQR) for GHG emissions by urban–rural zones. Medians were chosen in preference to means, because each of the three emission variables exhibit skewed distributions, which was confirmed by the Kolmogorov–Smirnov *Z* test. We tested two-tailed significance of differences among adjacent successive urban–rural zones using a Mann–Whitney *U* test. The *U*-test is a non-parametric difference-of-ranks test that tests whether two independent samples of observations are drawn from the same distribution, and it is employed in preference to the two-sample *t*-test because the distributions of the variables under scrutiny are skewed.

3. Results

In total, direct GHG emissions were estimated for 1920 respondents. We omitted 51 of the 1971 households due to incomplete or

problematic data specific to this research. Statistical analysis of the STAR household data indicates the median total direct GHG emissions for HRM is 21 kg CO_2e person^{-1} day^{-1}, with a range of 101 kg, and inter-quartile range of 14 kg. On average, provision of electricity and home heating contribute 78% of direct GHG emissions with a mean of 14.6 kg CO_2e person^{-1} day^{-1}, which is significantly higher ($p = < 0.001$) than emissions associated with personal transportation, which account for the balance of direct GHG emissions and average 4.1 kg CO_2e person^{-1} day^{-1}.

3.1. Greenhouse gas emissions by community

A total of 44 communities have three or more households with estimates of direct GHG emissions (Fig. 2). We found variability in direct GHG emissions across the HRM, with median values ranging from 13.9 to 35.8, and a median value across all communities of 21 kg of CO_2e person^{-1} day^{-1}. In general, median GHG emissions per person tend to increase as we move toward the perimeter of the HRM, although that pattern does not appear consistent. For example, the communities of Stillwater and Waverley both have very high emissions (> 30 kg CO_2e person^{-1} day^{-1}) while the community of Westphal has very low median emissions (< 18 kg CO_2e person^{-1} day^{-1}) (Fig. 2). The overall pattern is that communities in the commuter belt tend to have higher values than the inner-city or suburbs, and it is noteworthy that all communities with median direct emission values over 24 kg CO_2e person^{-1} day^{-1} lie in the exurban commuter area. Relatively high per capita daily emission values (> 24) are noted for wealthier commuter-belt communities, such as Waverley, Stillwater, and Oakfield, while relatively lower emission values (< 20) in the commuter belt tend to occur in medium or low-medium income areas, such as Enfield, Lawrencetown, and Williamswood. These community-level patterns echo results produced previously by Wilson et al. (2013) for the town of Oakville, Ontario. However, some community-level median emission values are based on few observations, which prevents significance testing. To allow such testing, we turn to an examination of zonal differences along the urban–rural continuum.

3.2. Greenhouse gas emissions by urban-rural zone

To further elucidate the spatial distribution of shelter-related, transportation-related, and total direct GHG emissions across the study area, we present median and IQR emissions per person per day by urban–rural zone in Table 2. In addition, in Table 2, we report Mann–Whitney U test results of differences between adjacent successive urban–rural zones.

Results in Table 2 indicate that total emissions increase away from the urban core; median daily direct GHG emissions for respondents living in the inner and outer commuter belt zones are approximately 11% higher than for respondents living in the inner city zone. Interestingly, there is little difference (< 2%) in median direct GHG emissions between the inner city zone and the suburban zone, and any difference appears purely due to chance. For total direct GHG emissions, the only significant difference ($p = 0.003$) between adjacent successive zones is for the suburbs and ICB, the suburbs being lower. Basically, the results in Table 2 illustrate that as we move away from the inner city zone, there is a decrease in shelter-related emissions and an increase in transportation-related emissions.

Results in Table 2 indicate that the overall median transportation-related GHG emissions are 4.1 kg CO_2e person^{-1} day^{-1}. Our sample indicates that private vehicle use contributes about ninety-nine percent (99%) of direct GHG emission associated with personal transportation. Transportation-related GHG emissions increase from the inner city (2.2 kg CO_2e person^{-1} day^{-1}) to the suburbs (4.0 kg CO_2e person^{-1} day^{-1}), and another increase to the inner commuter belt (6.2 kg CO_2e person^{-1} day^{-1}). Despite another increase (0.9 kg CO_2e person^{-1} day^{-1}) from the inner to the outer commuter belt, values for these two zones are not significantly different (Table 2). Any increase in transportation-related emissions moving outwards from the inner city appears to be offset by significantly reduced shelter-related emissions. Results in Table 2 indicate that significantly lower shelter-related emissions were reported in the suburbs (14.6 kg CO_2e person^{-1} day^{-1}) compared to the inner city (16.2 kg CO_2e person^{-1} day^{-1}), and significantly lower again in the inner commuter belt (13.6 kg CO_2e person^{-1} day^{-1}). Just like travel-related emissions, shelter-related emissions are not statistically different between respondents living in inner and outer commuter belts.

Table 2
Median direct greenhouse gas emissions, kg CO_2e person^{-1} day^{-1}.

Zone	*N*	Total direct GHG *Median (IQR)*	Transportation-related GHG *Median (IQR)*	Shelter-related GHG *Median (IQR)*
Overall	1920	20.8 (14.1)	4.1 (7.0)	14.6 (10.0)
Inner city	382	20.2 (12.6)	2.2 (3.9)	16.2 (10.5)
Significance		0.382	< 0.001	0.026
Suburbs	1039	20.5 (13.5)	4.0 (6.1)	14.6 (10.0)
Significance		0.003	< 0.001	0.023
Inner commuter belt	334	22.9 (15.4)	6.2 (9.1)	13.6 (9.5)
Significance		0.944	0.513	0.818
Outer commuter belt	165	22.0 (19.6)	7.1 (11.4)	13.4 (8.2)

4. Discussion

The present analysis complements previous sub-city environmental impact analyses by reporting direct GHG emissions using household-specific energy use data and GPS-verified travel data for 1920 respondents living in HRM. Our unique dataset allows us to report direct GHG emissions with an unprecedented level of specificity at a sub-regional level. The data demonstrate a wide range in direct GHG emissions by respondent, reflective of the sampling strategy and consistent with trip diary data. Data collection occurred over a 1-year period. Depending on the time of year, households could have very different home energy use demands. Further, with respect to personal transportation, large ranges in travel distances are consistent with trip diary surveys (Kang and Scott, 2010). While individual travel events may appear to be atypical for the person undertaking them (e.g., the case of visiting a distant relative), taken in aggregate they accurately represent variability in GHG emissions based on people's activities, which take place at disparate locations. Not all trip purposes are repetitive (as is the case for travel to and from work). Rather, there exists considerable variability in activities and travel across days of the week (Kang and Scott, 2010).

Our analysis is not without its limitations. For example, it reports GHG emissions per respondent, because the travel data are based on a personal, wearable, GPS collection device. Conceptualizations of urban regions in terms of households may be a more functional unit. It would also help mitigate issues of attribution of transportation-related GHG emissions if other household members are present in the vehicle. For example, what is the appropriate approach to split the associated GHG emissions if the trip purpose is taking a child to sports practice or if a child is present on a shopping trip? A potential research direction could be to incorporate out-of-home activity diary data from other household

members, which could be used to identify if and why other household members are present in the vehicle. Using trip purpose by travel segment could provide a useful mechanism for mitigating attribution issues.

Although studies suggest that indirect emissions contribute 40–65% of total GHG emissions associated with typical Western lifestyles (Benders et al., 2006; Kok et al., 2006; Moll et al., 2005; Nansai et al., 2008; Weber and Matthews, 2008), our analysis does not include indirect GHG emissions. Indirect GHG emissions refer to the emissions that result from earlier stages in the life cycle of the goods and services that we consume and correlate strongly with income (Benders et al., 2006; Druckman and Jackson, 2008; Lenzen et al., 2004; Weber and Matthews, 2008). We considered including indirect emissions by allocating regional input–output data to households by income category, using household expenditure survey data. We decided not to, however, to avoid estimating sub-city results by extrapolating from national-level data. Further, HRM does not appear to have a high concentration of higher-income households in one specific zone. In the sample, all zones reported a median personal income range category of $40,000–$59,999. Future research will look at including indirect GHG emissions.

Our results illustrate the patterning of GHG emissions within a city region at an exceptional spatial scale. These fine-resolution results offer planners and policy makers a unique perspective regarding variation in GHG emissions at a sub-city level. The community-level mapping, for example, revealed considerable variation in emissions at the local level, consistent with other sub-city analyses of environmental impacts (Haq and Owen, 2009; VandeWeghe and Kennedy, 2007; Wilson et al., 2013) and challenges the notion of a simple gradient in increasing emissions moving outward from the urban core. Although peripheral communities tend to show higher median total emissions, these medians also seem to relate to income levels, with wealthier communities showing higher values (Wilson et al., in press). Small sample sizes in many rural communities, however, prevented the use of significance testing.

Shelter-related emissions per person decrease as we move away from the inner city toward the outer commuter belt. While houses become bigger as we move outward from the inner city, to the commuter-belt zones, the STAR sample indicates there are more people per household (Table 1). When we factor in number of persons per household, therefore, the square footage per person is very similar in all zones except the inner city, where it is noticeably larger. This may reflect the “empty-nest” characteristic of many inner-city households, compounded by under-sampling of renters, such as students and those with lower incomes.

We feel reporting results by urban–rural zone to be a more useful approach for analyzing direct GHG emissions at the sub-city level than reporting by community. The zones organize the municipality based on urban form and distance to the regional centre, which are both widely perceived factors influencing energy consumption patterns. Categorizing HRM by zone can support policy and planning decisions that cater to different challenges and opportunities faced by each zone to reduce GHG emissions. For example, public transportation either does not service or poorly services the inner and outer commuter zones, limiting travel options. Also, the housing stock in the urban core is typically older than in the suburban and commuter zones, presenting different challenges to reducing shelter-related GHG emissions. The lack of significant differences between inner and out commuter belt zones in direct, transportation-related, and shelter-related emissions, plus select survey items, suggesting remarkable similarities among these two regional groups of respondents.

Our results for HRM show little difference in per capita direct GHG emissions between the inner city and the serviced suburbs, challenging a widely-held assumption that inner city living is inherently more sustainable than suburban living. The notion that inner city living is ‘greener’ is partially based on the assumptions that people in the inner city drive less and live in smaller households (square footage). We did find that those living in the suburbs had higher median transportation related GHG emissions. Respondents in the suburbs, on average, traveled more per day as the driver or passenger of a private vehicle (Table 1) and drove bigger vehicles (SUV, van, pick-up) as a percentage of the total vehicle fleet. Median transportation related GHG emissions of respondents living in the inner city are 2.2 kg CO_2e person^{-1} day^{-1} compared to 4.0 kg CO_2e person^{-1} day^{-1} for respondents living in the surburbs. Our dataset, however, does not support the assumption of bigger homes and higher shelter related GHG emissions in the suburbs in comparison to the inner city. Average heated square footage of households was remarkably similar. When we consider square footage per household member, it was less in the suburbs compared to the inner city. Median shelter related GHG emissions of respondents living in the inner city are 16.1 kg CO_2e person^{-1} day^{-1} compared to 14.6 kg CO_2e person^{-1} day^{-1} for respondents living in the surburbs. Lower GHG emissions associated with electricity use and home heating in the suburbs offset the higher transportation related emissions.

In HRM, heating and electricity related emissions dominate direct GHG emissions accounting for 78% of total GHG emissions. The substantial contribution of heating and electricity to overall emissions can be explained in part by Halifax′s reliance on oil and electricity as a primary heating source coupled by the fact that the greenhouse gas intensity of electricity generation in the province is high, over triple the Canadian average. Additionally, in comparison to other regions in Canada, the housing stock is older and there are more single-family dwellings as a percentage of the total housing stock (77% vs. 58%) (Natural Resources Canada (NRCAN), 2010). In comparison, jurisdictions relying on hydro generated electricity and heating primarily with natural gas would have lower associated household GHG emissions. If GHG emissions associated with shelter were lower, the difference in transportation related emissions would be more pronounced in terms of influencing overall emissions. As the province of Nova Scotia moves toward lower-carbon electricity, shelter-related emissions should decline placing greater emphasis on transportation related emissions.

The dynamics driving transportation related GHG emissions are not straight-forward. For example, the notion of a single travel flow from suburbs to inner city for work and shopping in the HRM context is incorrect. In the case of HRM, several major industrial-business hubs are located in the suburbs. Ninety-six percent of new office space between 2008 and 2012 was built in the suburbs indicating a decreasing need to enter the downtown core for work (Our HRM Alliance, 2012). Further, those living in the urban core may travel to suburbs to access services and shopping creating a reverse travel requirement. Assuming that inner city living is inherently more sustainable than suburban living masks that both zones present sustainability challenges that require attention. In the case of HRM, the inner city is dealing with a number of critical issues: high carbon electricity and heating sources, inefficient homes, low population density, large housing size per person, low public transit use, and an infrastructure that favours travel to suburban zones for shopping, services, and potentially even employment.

Efforts to reduce greenhouse gas emissions must also include the exurbanites. Those living in commuter belt zones and on the rural fringe have substantially higher greenhouse gas emissions, and particularly higher transport-related direct GHG, which often get

overlooked in a policy debate that has focused on an urban (inner-city) versus suburban dichotomy. The exurbs of the commuter belt are characterized by low-density, large-lot development, lacking city water and sewer services. Though commuter-dependent, they have the appearance of rurality, and provide sought-after environments for family living (Millward, 2006). However, lack of public transport, and limited options for active transport, lead to greater car-dependency and longer trip distances per person, such that transport-related direct emissions are three times those in the inner city, and 1.5 times those in the suburbs. Interestingly, median transport-related GHG estimates for the inner and outer commuter zones are virtually the same, which is likely due to transport-minimizing accommodations made by outer commuter belt residents, reported by Millward and Spinney (2011a). In particular, respondents in the outer commuter belt make significantly fewer car trips than those in the inner commuter belt, though average trip duration is slightly longer.

5. Conclusion

Policy and planning efforts to reduce the carbon footprints of our cities requires an understanding of the variability in household environmental impacts within a community (Wilson et al., 2013). The STAR data provide a more nuanced perspective on direct GHG emissions than previously available, particularly because they reflect accurate and precise location information. Analysis of these data by urban–rural zones offers a functional categorization around which to frame GHG reduction strategies. Findings challenge the assumption that development patterns outside of the urban core, notably in the serviced suburbs, are inherently less sustainable and/or detrimental to sustainability. The assumptions that those living in the suburbs have bigger homes, bigger cars, and drive more are only partially correct. We did find bigger cars and higher transportation-related GHG emissions, but lower shelter-related emissions appear to offset them. Shelter-related emissions account for 70% of total GHG emissions, on average. We do, however, see a noticeable increase in direct GHG emissions for the inner and outer commuter belts, raising concerns regarding exurban sprawl. The increase can be almost entirely attributed to transportation-related emissions. The results stress the importance of energy use information collected at a household level to inform policy and planning decisions to reduce greenhouse gas emissions at a city level.

While where we live may be important, other factors influence direct GHG emissions. The results of the current study using household level energy use information confirm considerable variability in household GHG emissions across HRM, but also significant predictability between urban–rural zones. Other factors such as income, household size, and respondent age may be better predictors of GHG emissions (Wilson et al., in press), and are interrelated with zonal variations. Research supporting a more nuanced understanding of household GHG emissions within cities, targeting the different challenges and opportunities of different zones, will benefit efforts to achieve GHG reductions.

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2) The manuscript file contains all of the following elements in this order: Title,

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3) The authors listed on the manuscript match the list of authors specified in the submission;
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5) All headings and subheadings are numbered throughout and in the journal's style;
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REVISED SUBMISSIONS

Some general guidance about writing for *Energy Policy*

Energy Policy is a multidisciplinary journal that focuses on policy issues involving energy supply and use, and it has a multidisciplinary readership that includes academics, policymakers and policy analysts. Writing for all these audiences simultaneously demands much from our authors and the editorial process.

The ideal Full-Length Article or Research Note would contain original research and be built around the policy issue on which it intends to shed light. The title should convey the policy relevance of the work rather than the technical content.The abstract also should contain at least one statement about the policy content.

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This section is mandatory. In this required section, concisely state the objectives of the work, provide an adequate background to provide for the context of the work, and indicate the contribution of the work to the energy policy literature. In the introduction, discussions of the background and literature should be limited to that necessary for informing readers about the motivation and significance of a paper. The Introduction should be understandable by most *Energy Policy* readers - a multidisciplinary audience comprising academics, policymakers and policy analysts. As such, the section should be relatively free of disciplinary jargon and acronyms.

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If considered necessary, any background and literature review sections would be placed between the introduction and the methodology sections. Extensive discussions of background information and the literature do not belong in either the introduction or the methodology sections. In general, we recommend that authors who find it necessary to write background and literature review sections to consider minimizing them in length before submitting the final manuscript.

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Strunk Jr., W., White, E.B., 2000. The Elements of Style, fourth ed. Longman, New York.

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[dataset] Oguro, M., Imahiro, S., Saito, S., Nakashizuka, T., 2015. Mortality data for Japanese oak wilt disease and surrounding forest compositions. Mendeley Data, v1. https://doi.org/10.17632/xwj98nb39r.1.

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Coon, E., Berndt, M., Jan, A., Svyatsky, D., Atchley, A., Kikinzon, E., Harp, D., Manzini, G., Shelef, E., Lipnikov, K., Garimella, R., Xu, C., Moulton, D., Karra, S., Painter, S., Jafarov, E., & Molins, S., 2020. Advanced Terrestrial Simulator (ATS) v0.88 (Version 0.88). Zenodo. https://doi.org/10.5281/zenodo.3727209.

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Aims and scope

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Landscape science brings **landscape ecology** and **urban ecology** together with other disciplines and cross-disciplinary fields to identify patterns and understand social-ecological processes influencing landscape change. *Landscape planning* brings landscape architecture, urban and regional planning, landscape and ecological engineering, and other practice-oriented fields to bear in processes for identifying problems and analyzing, synthesizing, and evaluating desirable alternatives for landscape change. *Landscape design* brings plans, designs, management prescriptions, policies and other activities and form-giving products to bear in effecting landscape change. The implementation of landscape planning and design also generates new patterns of evidence and hypotheses for further research, providing an integral link with landscape science and encouraging transdisciplinary collaborations to build robust knowledge and problem solving capacity.

Article types

Landscape and Urban Planning publishes original, empirical research on important international and regional issues in landscape science, with an emphasis on applied work that provides solutions for landscape design. Most manuscript submissions take the form of full-length Research Papers. Shorter Research Notes are also encouraged as described below.

2.1. Research Papers

Given the problem-driven nature of landscape science and the journal's commitment to linking research and practice, most Research Paper submissions will fall within the area of applied research. Purely conceptual or theoretical work will be considered on a limited basis under the Perspective Essay article type (see below). Otherwise, Research Papers focused on modeling and other "basic" research efforts should include at least a small sample of data to demonstrate proof-of-concept. Whether basic or applied, all Research Papers should describe the relevance of the work and its implications for landscape and urban planning, design, management and/or policy. Research Papers are typically between

4000 and 8000 words, including manuscript text and references (use 25-60 references as a guideline). Some exceptions to the upper length limit may be allowed for reports of large-scale interdisciplinary and transdisciplinary projects or for qualitative research where in-text quotations provide evidence in lieu of tables and figures. An abstract (250 words or less), keywords (3-6), and research highlights (3-5) are also required. Tables and figures should be used with economy to convey essential aspects about study concepts and findings. One or two contextual photos may be optionally included as figures to convey to readers the essential nature of the landscape and issues examined in the article. Other informative materials may also be optionally submitted, including Appendices, Acknowledgments, short Author Biographies, Graphical Abstracts, Google Maps (KML files), Embedded Audio and Video files, and Supplementary Material for online-only publication (see Section 3.8 below).

2.2. Research Notes

A Research Note is a concise but complete description of a limited investigation that will not be included in a later paper. It provides one of the following functions: (1) presenting initial proof-of-concept results on new ideas, timely issues, or innovative approaches; (2) reporting replications or extensions of previously published research that does not merit another full-length treatment yet provides results that contribute to a greater understanding of the phenomena under study. Research Notes should typically be limited to 2000 words and a total of 3 tables and figures, yet be sufficiently documented, both by reference to the essential literature and description of methods employed, for readers to be able to assess the scholarly rigor of the research. A Research Note should include a brief (150 words or less) abstract, keywords (3-6), and research highlights (3-5). The title of the submission should be prefaced with the words "Research Note."

2.3. Review Articles

Review Articles examine a coherent and comprehensive set of published research studies or other works (e.g., policies, reports, case studies) covering a subject area of current or emerging interest. They can take one of two forms: (1) Narrative Reviews identify, synthesize, and/or offer critical assessments of the state-of-the-art in knowledge about a subject, highlighting important concepts, variables, and theories under study, problems and knowledge gaps yet to be addressed, and guidance for future research. (2) Analytical Reviews involve systematic assessments of the literature, often using bibliographic database search and retrieval systems such as Scopus or Web of Science, alone or in combination with full-text searching, mining, and analysis software. These include Systematic Reviews and meta-analyses that follow a standardized format aimed at building a base of knowledge for evidence-based design (e.g., http://www.environmentalevidence.org/EBConservation.htm). They also include quantitative, bibliometric techniques such as citation analysis and qualitative analyses of content themes aimed at identifying the structure of and trends in knowledge about an area of inquiry. Review Articles are typically between 6000 and 10,000 words in length, including references and tables. Please include an abstract (250 words or less), keywords (3-6), and research highlights (3-5), and follow APA 6th Edition guidelines (Section 6.26) for referencing documents included in your analysis.Review Articles need to explicitly indicate the originality and need for the review, cover a wide and international range of literature and provide a brief assessment of previously published reviews related to the topic.

2.4. Perspective Essays

Perspective Essays present new ideas or frameworks; challenge current thinking, policies, or approaches; or otherwise offer thoughtful reflections aimed at improving our understanding of the interactions between people and natural and built environments and their implications for landscape planning, design, management, and policy. Perspective Essays should be grounded in the existing literature and adequately referenced but with an emphasis on original thought rather than an exhaustive accounting of the ideas of others. Perspective Essays may range from 2000 to 8000 words in length with a limited number of tables and figures. Except for short essays, submissions should be structured with section headings that convey to readers key themes and a logical flow of ideas. An abstract (250 words or less), keywords (3-6), and highlights (3-5) are required.

2.5. Comments and rejoinders

A Comment is a critical or explanatory note on an article published in Landscape and Urban Planning. It may be invited or proposed but must be approved by one of the Co-Editors-in-Chief prior to submission. Comments should typically be of 2000 words or less with a limited number of references. Please include a short abstract (150 words or less), 3-5 highlights, and 3-6 keywords. The title of the submission should be prefaced with the words: "Comment on", followed by the title of the previously published article and the authors' names. Should one or more Comments be accepted for publication, the handling editor may invite the author(s) of the previously published article to write a Rejoinder, which may be published along with the Comments.

2.6. Editorials

The Co-Editors-in-Chief, Associate Editors, Editorial Board members, and invited guests may occasionally provide brief commentaries on significant issues of relevance to the journal's aims and scope, introductory essays to special issues, as well as news and information relevant to the journal and its readers.

2.7. Book Reviews

The editorial team is not accepting books for review at this time. Please consult the online Guide for Authors for future updates.

2.8. Special Issue (SI) policy in Landscape and Urban Planning (LAND)

A Special Issue (SI) in *Landscape and Urban Planning* is a coherent collection of articles on a specific theme of research and scholarship that falls within the aims and scope of the journal and has a broad international appeal. SIs are now published as "virtual" SIs, meaning an article is published in the journal's first available volume/issue once it reaches the final stage, and will be added simultaneously in the SI of the journal (which is an Article Collection of these papers published across different volumes/issues).

SIs are especially intended for those topic areas where there is added value in bringing together multiple papers, leading to increased complementarity and attention for a specific topic area. A principal goal of the SI is to draw upon the outstanding talents and ideas of guest editors who are removed from the day-to-day journal operations and willing to channel a high level of energy and enthusiasm into an effort of finite duration. In this respect, the editors welcome innovative proposals of high quality and relevance from prospective individuals or teams.

1. SI themes

Typically, an SI addresses a theme of research that is too large and/or too complex to be thoroughly examined from the perspective of a single article within the scope of a regular issue. Such themes can fall into one of two categories. An **emerging theme** addresses a novel or rapidly evolving area of inquiry that is gaining momentum within science, technology, policy, or society, and has clear implications for landscape and urban planning. Such themes typically engage pressing challenges, introduce new conceptual framings or methodological approaches, or extend the field into previously underexplored domains. Emerging themes are expected to be agenda-setting and analytically rigorous, while remaining grounded in the journal's integrative focus on ecological, spatial, and governance dimensions. Examples may include the integration of artificial intelligence in spatial planning analytics or the governance implications of digital twins for urban landscape management. An **enduring theme** addresses a foundational and persistent area of inquiry within landscape and urban planning. It engages structural challenges of planning theory, methodology, or knowledge integration that extend beyond short-term topical trends. Such a theme operates at the level of meta-knowledge – advancing understanding of how knowledge in the field is conceptualized, integrated across scales and disciplines, and translated into planning practice (e.g. conceptualizations of social-ecological resilience). The research reported in an SI in either category of themes promises to substantively advance our understanding of the subject area and inspire further exploration.

2. SI article types

An SI is more than a random collection of articles and should exhibit the level of coherence expected of a well-edited book volume. Accordingly, beyond thematic alignment, careful attention must be given to the range and mix of article types. Proposals should therefore include a structured overview of the planned contributions. LAND does not publish SIs based on an open call for contributions or through an invitation to all authors of a specific conference or seminar.

An **emerging theme issue** should be composed mainly of research papers but might also include review articles and/or one or two perspective essays. An **enduring theme issue** could include research papers but might focus more on extending current dialogue with perspective essays, comments and rejoinders. An SI under either thematic category should preferably include a review article that aims to provide a synthetic assessment of the-state-of-the-art of the intellectual field(s) integral to the SI's theme, and is developed or led by a senior author. For further details on article types, see the guidelines on the LAND website.

3. SI contributors and contributions

In order to ensure that an SI has a broad international appeal and provides a diversity of perspectives, the guest editor(s) should make a genuine effort to attract contributors with different professional and/or academic backgrounds, and from different parts of the world. Therefore, proposals developed from specific professional workshops or regional symposia are generally discouraged unless their international relevance and scholarly diversity are clearly demonstrated. An SI typically consists of 6 to 15 papers, including an introductory editorial or review paper by the guest editor(s). If an SI has fewer papers than a normal journal issue, the SI may be published as a "virtual special section" instead of a virtual SI. If fewer than five papers are accepted, the Co-Editors-in-Chief may cancel the SI entirely and proceed to publish those accepted papers as part of regular issues, but will not highlight them as a virtual SI or virtual special section on the journal's website.

4. SI proposal selection procedure and timeline

We encourage research teams to suggest SI proposals to LAND. Proposals are welcome at any time, but twice a year – after May 1 and after November 1 – proposals will be evaluated by the editors-in-chief.

The process of SI proposal selection is systematic and competitive. Proposal authors will be notified of the decision by the Co-Editors-in-Chief within eight weeks after the submission deadlines of May 1 and November 1. Authors whose proposals are conditionally accepted will be given four weeks to revise and resubmit their proposals.

Upon the proposal acceptance, one of the Co-Editors-in-Chief will be designated as the handling editor of the SI, and will work with the guest editor(s) on the SI development to its completion. The assigned Co-Editor-in-Chief has final responsibility for the decisions on all papers to be included and will ensure proper review procedures are maintained, and all papers meet the quality requirements of the journal. Guest editors manage the process of soliciting submissions from the authors they would like to invite, selecting reviewers for all papers submitted to the SI, providing additional review of papers and advice on final decisions. Guest editors are responsible for meeting planned publication schemes and reasonable review time.

5. SI manuscript preparation, submission, review, and revision

The process of SI manuscript preparation, submission and revision is handled by the guest editor(s). Responsibilities include, but are not limited to, identifying authors, building synergy and coherence among all contributions with respect to the SI theme and article types, securing the on-time submissions of all manuscripts, working with the authors on manuscript revisions and making editorial recommendations to the handling editor.

The peer review of SI contributions shall be handled directly by the guest editor(s) with assistance from the LAND editorial team. At each stage throughout the review process, guest editor(s) are responsible for providing editorial recommendations upon which the handling Co-Editor-in-Chief makes a decision and communicates with the author(s). Manuscripts submitted to an SI will be reviewed exclusively by scholars who are not contributors.

6. SI proposal preparation guidelines

A SI proposal, limited to 10 pages, should contain the following contents:

1. **Title and theme** of the SI, indicating whether it fits within the emerging or enduring theme category (see Section 1: SI themes for definitions).

2. **Objectives:** What purposes does the SI intend to serve? Who is the primary audience?

3. **Justifications:** Why should LAND, rather than another journal, dedicate an entire issue to this theme? How innovative and original are the proposed ideas? What is the breadth of appeal (international, disciplinary) and the potential contribution of the proposed SI? What is the added value of publishing these papers as an SI?

   A successful proposal should include a brief survey of related SIs or edited volumes published within the past decade, explaining how the proposed SI differs from and advances beyond existing work. This must include references to relevant scholarly journal articles that serve as the core knowledge domain upon which the proposed SI will be based.

4. **The proposed content and structure of the SI:** Outline the planned composition of the SI, including:

   A list of proposed (potential) contributions, arranged by SI themes and/or objectives.

   Please include paper titles, potential author names, affiliations and a short description (e.g., 1 paragraph) of how each paper contributes uniquely to the overall SI theme and objectives.

   Please also provide the theme of the required review article, lead author and author team.

5. **A realistic time-planning for the SI.** Please note that LAND aims at finishing the publication of an SI within 18 months after submission of the first paper, and that in case of delays, remaining papers will not be published as part of the SI. This procedure aims to help guest editors to implement strict deadlines in the editorial process.

6. **Short CVs** of the proposed guest editor(s) (each limited to two pages; not included in the 10-page proposal limit). Please indicate prior editorial experience. Please note that LAND does not accept proposals led by more than 3 guest editors. From experience, large teams of editors often lead to less consistency in the SI and a lack of responsibility with each of the guest editors.

7. References (not part of the 10-page word limit).

Note: Translated articles originally published in a language other than English will not be considered.

Please submit your proposal to Prof. Christian Albert at the email address albert.landedit@gmail.com and include the term "SI proposal" in the subject line.

Peer review

This journal follows a double anonymized review process. Your submission will initially be assessed by our editors. If your submission is deemed suitable, it will typically be sent to be reviewed by a minimum of two reviewers for an independent expert assessment of the scientific quality. The decision as to whether your article is accepted or rejected for publication will be made by our editors.

Read more about peer review.

Our editors are not involved in making decisions about papers which:

- they have written themselves.
- have been written by family members or colleagues.
- relate to products or services in which they have an interest.

Any such submissions will be subject to the journal's usual procedures and peer review will be handled independently of the editor involved and their research group. Read more about editor duties.

Authors may submit a formal appeal request to the editorial decision, provided it meets all the requirements and follows the procedure outlined in Elsevier's Appeal Policy. Only one appeal per submission will be considered and the appeal decision will be final.

Special issues and article collections

The peer review process for special issues and article collections follows the same process as outlined above for regular submissions, except, a guest editor may send the submissions out to the reviewers and may recommend a decision to the journal editor. The journal editor oversees the peer review process of all special issues and article collections to ensure the high standards of publishing ethics and responsiveness are respected and is responsible for the final decision regarding acceptance or rejection of articles.

Open access

We refer you to our open access information page to learn about open access options for this journal.

Ethics and policies

Ethics in publishing

Authors must follow ethical guidelines stated in Elsevier's Publishing Ethics Policy.

Submission declaration

When authors submit an article to an Elsevier journal it is implied that:

- The work described has not been published previously except in the form of a preprint, an abstract, a published lecture, academic thesis or registered report. See our policy on multiple, redundant or concurrent publication.
- The article is not under consideration for publication elsewhere.

- The article's publication is approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out.
- If accepted, the article will not be published elsewhere in the same form, in English or in any other language, including electronically, without the written consent of the copyright-holder.

To verify compliance with our journal publishing policies, we may check your manuscript with our screening tools.

Authorship

All authors should have made substantial contributions to all of the following:

1. The conception and design of the study, or acquisition of data, or analysis and interpretation of data
2. Drafting the article or revising it critically for important intellectual content.
3. Final approval of the version to be submitted.

All authors are accountable for all aspects of the work, to ensure that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Corresponding author

Authors must appoint a single corresponding author to communicate with the journal during the editorial process. This individual submits the manuscript and all required documentation to the journal, and serves as the primary contact between the journal and the co-authors. It is important that all contact details of the corresponding author are kept up to date throughout the submission and publication process.

Only the corresponding author's affiliation will be used to determine eligibility for a publishing agreement, and possible discounts related to it. Affiliations of other co-authors are not relevant for eligibility.

Group authorship

Group authorship refers to the attribution of an article to a defined and named group of authors whose members have contributed to the work. Examples include research consortia, clinical trial groups, collaborative networks, task forces or working groups, expert panels or consensus groups, and participatory research groups.

- Group authorship must be declared on the title page *at submission.* When available, the submitting author should include the group under "Collaborative Author Groups" in the submission system.
- A corresponding author who agrees to coordinate all communications on behalf of the group must be designated.
- The group name will be included in the author list in the published article (e.g., "on behalf of the [Consortium Name]").
- All group members associated with the work should be listed in a dedicated section, preferably an appendix.
- All listed authors must follow the journal's authorship and authorship change policies.
- The group must maintain a transparent internal process for determining authorship and resolving disputes. All authorship disputes must be resolved within the group.

Changes to authorship

The editors of this journal generally will not consider changes to authorship once a manuscript has been submitted. It is important that authors carefully consider the authorship list and order of authors and provide a definitive author list at submission.

The policy of this journal around authorship changes:

- All authors must be listed in the manuscript and their details entered into the submission system. Changes can only be made prior to acceptance, and only if approved by the journal editor. This includes additions, deletion, or rearrangement of author names.

- Requests to change authorship must be made by the corresponding author using the Authorship Change Request form. The corresponding author must provide the reason for the request to the journal editor with written confirmation from all authors, including any authors being added or removed, that they agree with the changes. Requests which do not comply with the instructions outlined in the form will not be considered.

- This journal does not allow authorship changes after acceptance. This includes additions, deletions, or the rearrangement of author names, including changes to the corresponding author.

- The review process may be paused while a change in authorship request is being considered.

- Change requests made by the authors without the Authorship Change Request form or editor approval may result in the rejection of the manuscript, or retraction if the article has already been published.

Declaration of competing interests

All authors must disclose any financial and personal relationships with other people or organizations that could inappropriately influence or bias their work. Examples of potential competing interests include:

- Employment

- Consultancies

- Stock ownership

- Honoraria

- Paid expert testimony

- Patent applications or registrations

- Grants or any other funding

- Affiliation with the journal as an Editor or Advisory Board Member

The declarations tool should always be completed.

Authors with a journal affiliation to declare should enter the following text under “Other Activities” within the declarations tool and should inform the journal and publisher prior to completing the submission process:

Given their role as [AUTHOR JOURNAL ROLE TITLE], [AUTHOR NAME] had no involvement in the peer-review of this article and has no access to information regarding its peer-review. Full responsibility for the editorial process for this article was delegated to another journal editor.

Editorial disclosure statements will be included as a footnote and/or in the declaration of competing interest section of the article.

Authors with no competing interests to declare should select the option "I have nothing to declare".

The resulting Word document containing your declaration should be uploaded at the "attach/upload files" step in the submission process. It is important that the Word document is saved in the .doc/.docx file format. Author signatures are not required.

Funding sources

Authors must disclose any funding sources who provided financial support for the conduct of the research and/or preparation of the article. The role of sponsors, if any, should be declared in relation to the study design, collection, analysis and interpretation of data, writing of the report and decision to submit the article for publication. If funding sources had no such involvement this should be stated in your submission.

List funding sources in this standard way to facilitate compliance to funder's requirements:

Funding: This work was supported by the National Institutes of Health [grant numbers xxxx, yyyy]; the Bill & Melinda Gates Foundation, Seattle, WA [grant number zzzz]; and the United States Institutes of Peace [grant number aaaa].

It is not necessary to include detailed descriptions on the program or type of grants, scholarships and awards. When funding is from a block grant or other resources available to a university, college, or other research institution, submit the name of the institute or organization that provided the funding.

If no funding has been provided for the research, it is recommended to include the following sentence:

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of generative AI use

Authors must declare the use of generative AI tools in the manuscript preparation process upon submission of the paper.

Generative AI and AI-assisted technologies ("AI tools") have been rapidly adopted in research and scholarly publishing, offering significant benefits while requiring clear standards for responsible and transparent use.

Authors preparing a manuscript for this journal may use AI tools to support them. However, these tools must never be used as a substitute for human critical thinking, expertise and evaluation. AI tools may only be applied with human oversight and control.

Please read Elsevier's detailed author policy on the use of AI tools, as stated in Elsevier's generative AI policies for journals.

Ultimately, authors are responsible and accountable for the contents of their work. This includes accountability for:

- Carefully reviewing and verifying the accuracy, comprehensiveness, and impartiality of all AI-generated output (including checking the sources, as AI-generated references can be incorrect or fabricated).
- Editing and adapting all material thoroughly to ensure the manuscript represents the author's authentic and original contribution and reflects their own analysis, interpretation, insights and ideas.
- Ensuring accuracy and originality of any AI generated images and provide appropriate attribution where relevant.
- Ensuring the use of any tools or sources, AI-based or otherwise, is made clear and transparent to readers. If AI tools have been used, we require a disclosure statement upon submission; please see example below.
- Ensuring the manuscript is developed in a way that safeguards data privacy, intellectual property and other rights, by checking the terms and conditions of any AI tool that is used.

Finally, authors must not list or cite AI tools as an author or co-author on the manuscript since authorship implies responsibilities and tasks that can only be attributed to, and performed by, humans.

The use of AI tools in the manuscript preparation process must be declared by adding a statement at the end of the manuscript when the paper is first submitted. The statement will appear in the published work and should be placed in a new section before the references list. An example:

Title of new section: *Declaration of generative AI and AI-assisted technologies in the manuscript preparation process.*
Statement: *During the preparation of this work the author(s) used [NAME OF TOOL / SERVICE] in order to [REASON]. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the published article.*

The declaration does not apply to the use of basic tools, such as tools used to check grammar, spelling and references. In addition, authors are not required to disclose the use of AI tools or features within specialist disability-related assistive technology, provided these are used solely for accessibility purposes.

If you have nothing to disclose, you do not need to add a statement.

Please note: to protect authors' rights and the confidentiality of their research, this journal does not currently allow academic editors and reviewers to upload an unpublished manuscript into a generative AI tool, as is stated in Elsevier's generative AI policies for journals. However, AI tools may be used in a supportive capacity by editors and reviewers to improve structure and language of the review report or editorial decision letter or to conduct a background literature search. Elsevier is actively evaluating compliant AI tools and may revise this policy in the future.

Preprints

Preprint sharing

Authors may share preprints in line with Elsevier's article sharing policy. Sharing preprints, such as on a preprint server, will not count as prior publication.

We advise you to read our policy on multiple, redundant or concurrent publication.

Use of inclusive language

Inclusive language acknowledges diversity, conveys respect to all people, is sensitive to differences, and promotes equal opportunities. Authors should ensure their work uses inclusive language throughout and contains nothing which might imply one individual is superior to another on the grounds of:

- age
- gender
- race
- ethnicity
- culture
- sexual orientation
- disability or health condition

We recommend avoiding the use of descriptors about personal attributes unless they are relevant and valid. Write for gender neutrality with the use of plural nouns ("clinicians, patients/clients") as default. Wherever possible, avoid using "he, she," or "he/she."

No assumptions should be made about the beliefs of readers and writing should be free from bias, stereotypes, slang, reference to dominant culture and/or cultural assumptions.

These guidelines are meant as a point of reference to help you identify appropriate language but are by no means exhaustive or definitive.

Reporting sex- and gender-based analyses

There is no single, universally agreed-upon set of guidelines for defining sex and gender. We offer the following guidance:

- Sex and gender-based analyses (SGBA) should be integrated into research design when research involves or pertains to humans, animals or eukaryotic cells. This should be done in accordance with any requirements set by funders or sponsors and best practices within a field.
- Sex and/or gender dimensions of the research should be addressed within the article or declared as a limitation to the generalizability of the research.
- Definitions of sex and/or gender applied should be explicitly stated to enhance the precision, rigor and reproducibility of the research and to avoid ambiguity or conflation of terms and the constructs to which they refer.

We advise you to read the Sex and Gender Equity in Research (SAGER) guidelines and the SAGER checklist (PDF) on the EASE website, which offer systematic approaches to the use of sex and gender information in study design, data analysis, outcome reporting and research

interpretation.

For further information we suggest reading the rationale behind and recommended use of the SAGER guidelines.

Definitions of sex and/or gender
We ask authors to define how sex and gender have been used in their research and publication. Some guidance:

- Sex generally refers to a set of biological attributes that are associated with physical and physiological features such as chromosomal genotype, hormonal levels, internal and external anatomy. A binary sex categorization (male/female) is usually designated at birth ("sex assigned at birth") and is in most cases based solely on the visible external anatomy of a newborn. In reality, sex categorizations include people who are intersex/have differences of sex development (DSD).

- Gender generally refers to socially constructed roles, behaviors and identities of women, men and gender-diverse people that occur in a historical and cultural context and may vary across societies and over time. Gender influences how people view themselves and each other, how they behave and interact and how power is distributed in society.

Depending on the focus of a paper, sex and/or gender may or may not be relevant to the content of the paper. We recognize that beliefs, attitudes, and laws relating to sex and gender may vary. These articles do not attempt to dictate author beliefs but rather require that, where relevant to an author's research or paper, the author must provide clear explanations of how the paper and research define and use sex and gender.

Image manipulation

We accept that authors sometimes need to adjust images for clarity but any manipulation of images for the purpose of deception or fraud will be seen as scientific ethical abuse and will be dealt with accordingly.

Authors must adhere to this journal's policy for graphical images:

- No specific feature within an image may be enhanced, obscured, moved, removed or introduced.

- Adjustments of brightness, contrast, or color balance are acceptable if, and only as long as, they do not obscure or eliminate any information present in the original image.

- Nonlinear adjustments such as changes to gamma settings must be disclosed in the figure legend.

- Use of AI tools to create or manipulate primary research images is not permitted. This includes images that represent experimental or observational data, such as western blots, microscopy images, histology images, or patient images. Please read our policy on the use of AI tools in figures, images and artwork, which can be found in Elsevier's GenAI Policies for Journals.

To verify compliance with the above, this journal may send your images to a secure third-party tool to enable screening for image irregularities. Our editors may ask you to provide original data or images if any questions arise as a result of the screening. The final decision as to whether images are acceptable will be taken by our editors.

Authors are encouraged to carefully check all images before submission and to connect all the data in any figures to the original, unprocessed data.

Jurisdictional claims

Elsevier respects the decisions taken by its authors as to how they choose to designate territories and identify their affiliations in their published content. Elsevier's policy is to take a neutral position with respect to territorial disputes or jurisdictional claims, including, but not limited to, maps and institutional affiliations. For journals that Elsevier publishes on behalf of a third party owner, the owner may set its own policy on these issues.

- Maps: Readers should be able to locate any study areas shown within maps using common mapping platforms. Maps should only show the area actually studied and authors should not include a location map which displays a larger area than the bounding box of the study area. Authors should add a note clearly stating that "*map lines delineate study areas and do not necessarily depict accepted national boundaries*". During the review process, Elsevier's editors may request authors to change maps if these guidelines are not followed.

- Institutional affiliations: Authors should use either the full, standard title of their institution or the standard abbreviation of the institutional name so that the institutional name can be independently verified for research integrity purposes.

Studies in humans

Authors must follow ethical guidelines for research involving humans, their data, and/or their biological materials (e.g. organs, tissues). Authors should ensure that they adhere to the following:

- All studies must be performed in compliance with relevant laws, regulations, and institutional guidelines and that the appropriate institutional committee(s) has/have approved them. For instance, medical research involving humans should be carried out in accordance with the World Medical Association Declaration of Helsinki: Ethical principles for medical research involving human participants and should follow the International Committee of Medical Journal Editors (ICMJE) recommendations for the conduct, reporting, editing and publication of scholarly work in medical journals and aim to be representative of human populations in terms of sex, age and ethnicity. Sex and gender terms should be used correctly, as outlined in the "Reporting Sex- and Gender-based analyses" section of this journal's Guide for Authors.

- Informed consent must be obtained for research with human participants, including their data or biological materials. Consent must be given without coercion, and the privacy rights of human participants must always be observed. If your study contains human participants, please read Elsevier's full human research policy for further information.

    - Authors should be aware that written (or electronic) consent is required for certain studies under national laws. In studies where only verbal informed consent was obtained, authors should include justification for the absence of written consent, the name of the approving ethics committee, and a statement on how verbal consent was recorded.

    - Consent for publication should also be obtained.

- Authors must obtain and retain explicit written consent for any identifiable participant materials (e.g. case details, videos, recordings, images, photographs, and illustrations). All participant information must be de-identified: do not include names or personal identifiers (e.g., initials, ID numbers, DOB)

- Images should be used only when scientifically necessary and with explicit consent, and nonessential identifying details must be removed. If identifiers are altered to ensure anonymity, authors must confirm that scientific meaning is not affected. Fully anonymized images (e.g., x-rays, scans) that contain no identifying marks and are not accompanied by identifying text do not require formal consent, though informing the patient is good practice. Case reports always require consent. Simply obscuring identity (e.g., eye bars or blurring) is not sufficient without consent.

- Written consents must be retained by the authors. They should not be provided to this journal unless this is specifically requested in exceptional circumstances, for example, when a legal issue arises. Only then should you provide copies of the consents, or evidence that all relevant consents were obtained.

- Appropriate consents and safeguards should be in place for research with vulnerable populations, as described in Elsevier's human research policy. In many countries, additional ethical approval may be needed for research with those who lack the capacity to consent (e.g. children or those with mental health or neurological conditions including dementia).

- For the full policy, see "Consent requirements for case reports, personal information, and images."

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The Role of People versus Places in Individual Carbon Emissions[†]

By Eva Lyubich*

There is substantial spatial heterogeneity in household carbon emissions. I leverage movers in two decades of administrative Decennial Census and American Community Survey data to estimate place effects—the amount by which carbon emissions change for the same household living in different places—for almost 1,000 cities and roughly 61,500 neighborhoods across the United States. I estimate that place effects account for 14–23 percent of overall heterogeneity. A change in neighborhood-level place effects from 1 standard deviation above the mean to 1 below would reduce household carbon emissions from residential energy and commuting by about 40 percent. (*JEL* D12, D15, L94, Q41, Q54, R11, R23)

Increased carbon and other greenhouse gas emissions since the onset of the industrial revolution have caused global average temperatures to rise by over 1°C (1.8°F) relative to preindustrial levels (NASA 2020). In 2015, the United States signed the Paris Accord, a global agreement aimed at mitigating the potential damages from climate change by limiting overall warming to below 2°C. In search of opportunities for decarbonization, researchers and policymakers have pointed to substantial spatial heterogeneity in household carbon emissions, suggesting that perhaps higher-emissions places could adopt features of lower-emissions places, such as density and high-quality public transportation infrastructure, in order to lower household carbon emissions (e.g., Jones and Kammen 2014; International Energy Agency 2021; Pomponi et al. 2021; Wagner 2021).

*US Census Bureau (email: eva.lyubich@census.gov). Rema Hanna was the coeditor for this article. Any opinions and conclusions expressed herein are those of the author and do not represent the views of the US Census Bureau. The Census Bureau's Disclosure Review Board and Disclosure Avoidance Officers have reviewed this data product for unauthorized disclosure of confidential information and have approved the disclosure avoidance practices applied to this release (Release authorization numbers: CBDRB-FY24-CES014-016, CBDRB-FY24-CES014-017, and CBDRB-FY24-CES005-017). I am grateful to Reed Walker, Pat Kline, Emmanuel Saez, and Joe Shapiro for their guidance and support throughout this work. I also thank the editor and three anonymous referees for their constructive feedback. This article has benefited tremendously from comments and suggestions from Alan Auerbach, Matilde Bombardini, Stephanie Bonds, Severin Borenstein, David Card, Lucas Davis, Karl Dunkle Werner, Ben Faber, Meredith Fowlie, Cecile Gaubert, Kendall Houghton, Hilary Hoynes, Jon Kolstad, Enrico Moretti, Andrés Rodríguez-Clare, Raffaele Saggio, Jim Sallee, Elif Tasar, Danny Yagan, Katherine Wagner, Randall Walsh, Chris Walters, and seminar participants at the University of California, Berkeley. I am grateful to the National Science Foundation Graduate Research Fellowship Program (DGE 1752814), the Berkeley Opportunity Lab and Smith Richardson Foundation, and Washington Center for Equitable Growth for financial support. The collection of data used in this study was partly supported by the National Institutes of Health under grant number R01 HD069609 and R01 AG040213, and the National Science Foundation under awards SES 1157698 and 1623684. I thank Matt Mullins for editing assistance.

[†]Go to https://doi.org/10.1257/aer.20230346 to visit the article page for additional materials and author disclosure statement(s).

However, differences in mean carbon emissions across places reflect a combination of local amenities, household characteristics, and taste-based sorting. The relative contributions of these pieces is a central determinant of whether place-based interventions that change urban form would lead to significant reductions in carbon emissions. For instance, if places with large single-family homes and car-oriented transportation infrastructure are high-emissions because the people who live there dislike multifamily homes and public transit, then deregulating zoning or building new rail lines would have little impact on household emissions. Conversely, if the lack of denser housing and transit options is a constraint on household choices, rather than a reflection of their preferences, then interventions that change these local public amenities have the potential to decrease carbon emissions for many households at once.

In this paper, I decompose variation in household carbon emissions into a component driven by household characteristics and a component driven by place effects, that is, the amount by which the same household's carbon emissions would differ from place to place due to differences in the underlying features of those places. To do so, I construct a longitudinal panel of residential and transportation energy use for over 1 million individuals from 20 years of restricted-access Decennial Census and American Community Survey (ACS) (US Census Bureau 2000, 2010, 2001–2019). The longitudinal nature of these data allows me to link individual survey respondents over time and across places. I use a mover design, examining changes to household carbon emissions for over 250,000 movers across roughly 1,000 cities and 61,500 neighborhoods, to estimate place effects and their contribution to heterogeneity in carbon emissions.

I begin my analysis by documenting observational patterns of city- and neighborhood-level variation in household carbon emissions in my sample. While previous work has shown evidence of substantial variation in household carbon emissions (e.g., Jones and Kammen 2014; Ummel 2014; Green and Knittel 2020), the level of geographic granularity in publicly available data has limited researchers to predicting neighborhood-level carbon emissions from national data projected onto local place and household characteristics. In contrast, detailed geographic identifiers in the administrative Census Bureau microdata make it possible to directly estimate neighborhood-level means. I estimate that on average, households living in cities with emissions 1 standard deviation above the mean emit 50 percent more than those living in cities 1 standard deviation below the mean. Similarly, households in neighborhoods 1 standard deviation above the mean emit, on average, just under twice as much as those in neighborhoods 1 standard deviation below the mean. Accounting for variation driven by observed household characteristics such as household size and income decreases the dispersion across place estimates by less than 10 percent.

The heterogeneity that remains after accounting for observable household characteristics reflects some combination of unobserved household characteristics and causal place effects. Unobserved household characteristics might include preferences for spending time in a private yard versus a public park, risk tolerances for biking versus driving, sensitivities to hot or cold temperatures, or simply environmental consciousness. Place effects could stem from a variety of local amenities and supply-side factors that determine patterns of household energy use. They could reflect aspects of urban form such as public transportation, bike and pedestrian infrastructure, highway networks, density, or zoning regulations. They could

also be driven by natural amenities such as climate. Lastly, they could arise from supply-side factors that determine fuel shares and electricity emissions factors, both of which shift the amount of carbon emitted for a given level of energy use.[1] I show how place effects can be interpreted through the lens of a consumer energy demand model in which average energy demand, energy demand elasticities, energy prices, and average emissions factors vary across places.

My empirical strategy uses movers to estimate the contributions of place effects and household characteristics to heterogeneity in household carbon emissions. The mover design accounts for unobserved differences between households by comparing carbon emissions for the same household living in different places. Consider the following thought experiment. Imagine two households identical in every observable way—same household size, same income, same education levels, etc. One lives in a dense, urban neighborhood well-served by public transit, while the other lives in a car-dependent suburb with large homes. The urban household likely generates lower carbon emissions. But is that because the place itself determines emissions or because the urban household has different unobservable characteristics, like stronger environmental preferences, that led it to select into the lower emissions neighborhood? If I observe the same household move between neighborhoods, any resulting change in that household's emissions can no longer be attributed to fixed unobserved household preferences or characteristics, and I can use those changes to infer differences in place effects. In order for estimates from the mover design to be unbiased, the central assumption is that mover destinations are uncorrelated with changes to unobserved determinants of household carbon emissions. A crucial advantage of undertaking this analysis with Census Bureau microdata is that I observe, and can control for, many time-varying household characteristics that could correlate with both potential emissions and destination choices and thereby confound estimates of place effects. In other words, the identifying strategy does not allow for households to move in response to a sudden shift in environmental preferences, but it does allow for households to move in response to changes in income, the number of children, and age-based or life cycle preferences, because I observe these characteristics.

For the first set of results, I use an event study to estimate how much carbon emissions change after households move, as a share of the mean difference between their origin and destination. Intuitively, if spatial heterogeneity is driven in part by underlying differences between places, when a household moves, I should see its emissions shift toward the mean of its new location. The larger the shift, the more important the role of place. I find that, on average, when households move to a new city, their carbon emissions change by about 85 percent of the mean difference between origin and destination cities. Sorting plays a larger role in neighborhood-level variation than in variation across cities, but the role of place remains meaningful; when households move to a new neighborhood, their carbon emissions change by 53–60 percent of the mean difference between their origin and destination neighborhoods.

[1] For instance, a household in an area with predominantly coal-fired power plants could emit significantly more carbon than a household with identical electricity consumption in an area powered mainly by natural gas or renewable sources. Similarly, many households in the Northeast use heating oil, in part due to legacy equipment choices, which produces substantially more carbon dioxide for the same amount of heating than natural gas.

I explore several dimensions of heterogeneity, finding that my estimates remain stable when restricting the sample to households without significant changes in observable characteristics, when splitting the sample by duration between observations, and when grouping movers based on the magnitude of origin-destination differences in observational mean emissions. The consistency of estimates across these analyses suggests limited systematic sorting of households to places, as such sorting would manifest in a nonlinear relationship between observational means and household emissions. In the absence of systematic sorting, the event study estimates can be interpreted as causal estimates of the effect on emissions of any household moving between any pair of places. While the heterogeneity analysis lends support to this interpretation, the additional assumption of no systematic sorting is quite strong, particularly at the neighborhood level. Under the weaker baseline assumptions, the event study estimates yield unbiased predictions about how household carbon emissions change for any set of observed moves. This is valuable, as it makes it possible to calculate the carbon emissions externality of policies or regulatory restrictions that drive existing patterns of household migration, for instance, policies that restrict housing supply in on average lower-emissions cities.

In the second set of results, I estimate the full nonparametric distribution of household and place effects using a two-way fixed effects model and then do a variance decomposition to estimate the share of overall heterogeneity explained by each component. This approach allows for unrestricted patterns of sorting, but this weaker assumption comes at the cost of limited mobility bias (Andrews et al. 2008): Estimates of place effects are noisy because they can be derived from a small number of movers to and from each place. This imprecision creates an upward bias in the naïve plug-in variance estimate relative to the true variance of place effects, even if estimates of place effects themselves are unbiased. I account for this upward bias using the heteroskedasticity-robust "leave-out" estimator proposed by Kline, Saggio, and Sølvsten (2020). I find low correlations between unobserved household and place effects, even at the neighborhood level. This suggests that sorting on unobserved household characteristics contributes to differences between places through "segregation" of households, but not in a way that is systematically correlated with unobserved neighborhood attributes. City effects explain 14–16 percent of overall heterogeneity, while neighborhood effects explain roughly 22–23 percent of overall heterogeneity. Climate, electricity emissions factors, and energy prices together account for over half of the core-based statistical area (CBSA) variance component. At the neighborhood level, controlling for these factors decreases the place share by less than half, to about 15 percent. While this leaves the majority of overall heterogeneity to other factors, my estimates nevertheless imply the potential for considerable reductions to household carbon emissions from interventions that decrease place effects: I estimate that if a neighborhood went from having a place effect 1 standard deviation above the national mean to having a place effect 1 standard deviation below the national mean, household emissions for residents of that neighborhood would decrease by about 40 percent.

I characterize low- and high-emissions neighborhoods by presenting correlations between estimated tract effects and observable tract-level characteristics. I characterize local amenities using observable characteristics from within the Census Bureau microdata; public-use data on climate and electricity; and commercial data

from Walk Score, a private company that generates estimates of the walkability, transitability, and bikeability of every address in the United States (Walk Score 2021). These data lend unique insight into highly granular variation in neighborhood characteristics. I find that the correlations between amenities and neighborhood place effects for the most part mirror the relationships in the observational data. Low-emissions places have clean electricity and mild climates, and they have amenities characteristic of urban areas. Among the local amenities, density and average home size, proximity to principal cities, and the quality of local bike infrastructure appear to have the most explanatory power.

I conclude my analysis by examining how household carbon emissions would differ if some households were exposed to the place effects of neighborhoods more urban than the one they currently live in. If suburban and rural households lived in a place with the average place effect of the principal city closest to them—a scenario that captures in spirit how households' exposure to place effects might shift in response to regulations that limit urban sprawl and encourage upzoning and infill development—I estimate that their emissions from residential energy use and commuting would decrease by about 15 percent. To put this estimate into context, the Inflation Reduction Act (IRA), which was signed into law in August 2022 and is the largest federal effort to address climate change to date, is projected to decrease economy-wide emissions in 2030 by an additional 15 percent relative to projected reductions from 2005 levels under business as usual.[2]

In many ways, the basic physical design and urban fabric of cities, suburbs, and towns creates the foundational patterns of transportation and residential energy use. Decades of housing, transportation, and land use policies shape these features. The wide distribution of place effects estimated in this paper implies that there may be potential for "place-based climate policies"—policies that aim to reduce household carbon emissions from residential and transportation energy by changing the underlying characteristics of the places people live in—to lead to meaningful reductions in carbon emissions. While this paper does not estimate the causal drivers of place effects, the correlational analysis presented here and many observational and model-based studies (e.g., Shammin et al. 2010; Timmons, Zirogiannis, and Lutz 2016; Ribeiro, Rybski, and Kropp 2019; Pomponi et al. 2021; Ko 2013) provide some hypotheses. Estimating causal relationships between specific amenities and place effects using credible exogenous variation remains an important direction for future research. One might have worried about whether the settings in which such studies can be done are too selected; what if the households that reside in places that make changes to local infrastructure or regulatory restrictions are different from households in places that do not make those changes? The core results of this paper suggest that variation in place effects drives a meaningful share of differences in emissions between places, mitigating some of these concerns about external validity.

[2]Three separate efforts to model IRA reductions have been commonly cited by advocates and lawmakers. The Rhodium Group estimates that under the IRA, emissions will fall 31–44 percent from 2005 levels by 2030, with 24–34 percent reductions under business as usual (Larsen et al. 2022). For the same time frame, Energy Innovation estimates 37–41 percent reductions under the IRA and 24 percent under business as usual (Mahajan et al. 2022), and the REPEAT project estimates 42 percent reductions under the IRA and 17 percent under business as usual (Jenkins et al. 2022).

This paper makes several contributions. A large body of work in labor and urban economics finds significant wage, employment, and productivity benefits from density and integrated land use and transit policies (Tsivanidis 2022; Allen and Arkolakis 2022; Duranton and Puga 2020). These studies suggest that spatial equilibria are inefficient due to agglomeration economies and other externalities but have largely not considered the carbon emissions externality in their analysis. The theoretical justification for using place-based policies in cases where agglomeration economies and other local externalities exist is well-established. Federal intervention can correct inefficient market equilibria and improve welfare by supplementing local government provision of underprovided amenities, offering a "big push" toward an optimal equilibrium when several exist, fostering the growth of productive areas and agglomeration externalities or insuring residents against place-based shocks (Glaeser and Gottlieb 2008; Kline 2010; Kline and Moretti 2014; Glaeser 2013; Austin, Glaeser, and Summers 2018). However, the empirical evidence on the efficacy of place-based policies is mixed. While some studies find that tax incentives targeting areas with lower employment can improve welfare (Busso, Gregory, and Kline 2013; Austin, Glaeser, and Summers 2018; Bilal 2023), others suggest that spatial policies promoting growth in less developed areas may have negligible or even negative aggregate effects on productivity and welfare (Kline and Moretti 2013; Gaubert 2018). Duranton and Venebles (2021) highlight the challenges in evaluating place-based policies, including in the context of urban transport, housing, and infrastructure. The welfare implications of place-based climate policies would crucially depend on their design, implementation details, costs, and household preferences for local amenities; a welfare analysis is beyond the scope of this paper. Carbon emissions are a canonical example of a global externality, but many of the theoretical justifications for place-based policy outlined above could be relevant, given the observed relationship between carbon emissions and factors of urban form, such as density and urban transport. This, together with evidence from this paper that places play an important role in driving household carbon emissions, suggests that further research is warranted.

Methodologically, I build on a large literature in labor examining wage inequality across firms and a growing literature that uses mover designs to estimate place effects on other individual outcomes, e.g., nutritional choices (Allcott et al. 2019), health outcomes and health care utilization (Eid et al. 2008; Finkelstein, Gentzkow, and Williams 2016, 2021), intergenerational mobility (Chetty and Hendren 2018), and wages (De la Roca and Puga 2017; Card, Rothstein, and Yi 2025). This paper is the first to use a mover design to study household energy use and carbon emissions, yielding new insights into spatial heterogeneity in these outcomes. Previous work has highlighted the consequences of spatial heterogeneity in carbon emissions for allocative efficiency (Glaeser and Kahn 2010; Colas and Morehouse 2022) as well as for distributional impacts and the political economy of hypothetical climate policies (Cronin, Fullerton, and Sexton 2019; Sallee 2019; Green and Knittel 2020), but these papers did not examine the causal role of places in their findings. Several papers in the literature have generated estimates of heterogeneous energy demand parameters, but they have necessarily done so in spatially limited and sector-specific contexts (Auffhammer and Rubin 2024; Gillingham 2014; Nowak and Savage 2013; Spiller et al. 2014). The estimates generated in this paper on the relative roles of

place effects versus household sorting could assist in resolving some of the challenges identified in the aforementioned literature around distributional impacts and political economy. For instance, if lock-in of urban form limits the share of household carbon emissions that could be targeted by pricing instruments in the short-to-medium term, estimates of the share of spatial heterogeneity driven by place effects could inform decisions around how much to redistribute carbon dividends when using geography as a tag. And as highlighted previously, they raise an important question as to whether place-based climate policies could serve as a welfare-improving complement to traditional instruments for addressing this global externality.

I. Data and Stylized Facts about Carbon Emissions in the United States

Seventy-five percent of US greenhouse gas emissions are from burning fossil fuels. Of these, 20 percent are from residential energy use (including electricity), and another 20 percent are from light-duty (i.e., passenger) vehicles (US Energy Information Administration 2020b). The focus of this analysis is on carbon emissions from these two sectors; they are a meaningful portion of overall emissions, and they are the forms of emissions that are most directly related to locked-in characteristics of urban form. In the remainder of this section, I first discuss my data and the construction of relevant analysis variables and then provide some descriptive evidence on heterogeneity in carbon emissions in my sample.

A. *Data and Key Variables*

I build a 20-year panel of individual and household-level data using the 2000 restricted-access Decennial Census long form and the 2001–2019 American Community Survey (US Census Bureau 2000, 2010; 2001–2019). The 2000 Decennial Census long form consists of a stratified random sample covering one in six households in the United States. After 2000, the ACS replaced the Decennial Census long form in order to gather detailed information on individuals and households more regularly. The ACS is a stratified random sample covering roughly 0.4 percent of households in 2001–2005 and roughly 1 percent of households in each year after 2005 (US Census Bureau 2014). I link individuals across surveys using protected identification keys, which are unique person identifiers assigned by the US Census Bureau based on names, addresses, dates of birth, other household members, and social security numbers (when available).[3]

For every individual in the panel, I observe measures of residential and transportation energy use and a rich set of demographic, household, workplace, and home characteristics, including detailed geographic identifiers. I supplement the

[3] Neither the Decennial Census nor the ACS asks respondents for their social security numbers. Wagner and Layne (2014) use data with social security numbers to show that the error rate in assigning protected identification keys without social security numbers is below 1 percent. See Bond et al. (2014) for detailed discussion of the assignment algorithm used by the US Census Bureau. Assignment success rates vary across demographic groups—in particular, White and higher-income individuals are more likely to be successfully assigned a protected identification key—but for all demographic subgroups, the success rate is greater than 85 percent. See Bond et al. (2014) for additional discussion of the variation in assignment rates across population subgroups.

Decennial Census and ACS with several external sources of data in order to convert energy expenditures to energy services and emissions, and to characterize places.

Geographic Units of Analysis.—Throughout the study, I analyze spatial heterogeneity at two levels of geographic granularity that roughly represent a city or labor market and a neighborhood.

My first geographic unit of analysis is a core-based statistical area. CBSAs are designated by the Office of Management and Budget and cover the population of metropolitan and micropolitan areas in the United States. Each CBSA is a set of contiguous counties with strong commuting ties and at least one urban core area of at least 10,000 people. In addition to formally designated CBSAs, I define state-level residual CBSAs from unassigned rural areas. My second geographic unit of analysis is a census tract. Census tracts are county subdivisions that typically cover contiguous areas, have populations of 1,200–8,000 people (4,000 on average), and are delineated with boundaries that follow identifiable physical features. They are designed to be relatively stable but are split or merged every 10 years if populations exceed or fall below the 1,200–8,000 window.[4]

Carbon Emissions.—My primary outcome is metric tons of carbon emissions from residential energy and passenger vehicle use, which together account for roughly one-third of US greenhouse gas emissions. I implement the main analysis at the household level: Carbon emissions are given by household residential emissions plus the sum of individual commuting emissions over all individuals in the household.

I estimate carbon emissions from residential energy use from household-reported expenditures on electricity, natural gas, and other home heating fuels in the last year, combined with external data on local annual retail prices and fuel emissions factors. For electricity, I calculate county-level average prices using data from the Annual Electric Power Industry Report (US EIA 2020a). This report contains sales, revenues, and total customers for every major utility in the United States, by sector and state. It also delineates counties contained in each utility's service territory. I calculate county-level retail electricity prices using customer-weighted average prices (revenue divided by sales) across all utilities with service territories containing the county, and I compute household electricity consumption by dividing reported expenditures by my price estimates. I then assign households to one of 12 National Electric Reliability Council (NERC) regions using a tract-level crosswalk from the the Infrastructure Foundation-Level Database (US DHS 2021), and compute emissions using the average annual emissions rates assigned to each region by the Emissions and Generation Resource Integrated Database (US EPA 2021). For natural gas and other home heating fuels, I obtain average retail prices at the state level from the State Energy Data System (US EIA 1960-2019). If a household reports nonzero expenditures on "other home heating fuels," I impute the fuel used

[4]Census geographic definitions vary over time to account for changes in administrative boundaries and populations. To ensure that I don't erroneously identify people who live in places where the designation changed as movers, I use the 2000–2010 census block concordance to assign 2010 geographic definitions to all years in the data, combining blocks in cases where they correspond to a single 2000 block.

from its answer to the question, "What was the primary fuel used for home heating?" Finally, I obtain fuel emissions factors from the Emission Factors for Greenhouse Gas Inventories (US EPA 2018).

I estimate carbon emissions from transportation energy from the sum of individually reported commuting behavior within a household.[5] I estimate commute distance using the geodesic distance between home and place of work census blocks, and I estimated commute speed from estimated mileage and reported time length of commute. I estimate gasoline usage using annual national average fuel economy from the Bureau of Transportation Statistics (2000–2019) accounting for the fact that in general, fuel economy is roughly 30 percent higher on highways than in cities. Finally, I estimate the number of annual commutes using reported weeks worked last year and hours worked last week and convert annual gallons of gasoline to carbon emissions using the motor gasoline emissions factor from the State Energy Data System (US EIA 1960–2019). Individuals who commute by rail, subway, streetcar, bus, bike, or walk and individuals who work from home are assigned an emissions factor based on their mode of transit and data from the National Transit Database (Federal Transit Administration 2002–2019) (see Supplemental Appendix for more details). Altogether, this portion of the outcome captures variation in carbon emissions driven by commute lengths, number of commutes, and mode of transit. I examine the sensitivity of my results to using the National Household Travel Survey (NHTS, Federal Highway Administration 2022) to predict heterogeneous fuel economy and noncommute miles from household and geographic characteristics available in both the census and NHTS. This is not my baseline approach, as it infers how much of variation in vehicle fleets and fuel economy observed in the NHTS is driven by individual preferences versus place-based factors from cross-sectional variation.[6]

Individual and Household Characteristics.—Throughout the analysis, I use demographic and household characteristics to control for variation driven by observable characteristics. Specifically, I control for age, education (completion of a bachelor's degree), sex, race and ethnicity, household income (from salaries and wages, interest, social security, supplemental security, public assistance, retirement, and self-employment), household size, number of children, and homeowner status. I aggregate individual-level demographics to the household level by taking the mean across individuals within a household.

I also observe whether a household lives in a detached single-family home, the number of rooms in a home, and the number of vehicles in the household. These characteristics are intermediate outcomes, which directly affect carbon emissions. They also very likely reflect a combination of household preferences and place characteristics; many places impose restrictions on multiunit homes and/or minimum lot sizes and lack transportation options for households without a car, so household choices

[5] Commuting accounts for about 28 percent of all vehicle-miles traveled and 39 percent of person-miles traveled on transit systems (US Department of Transportation 2015), which means I underestimate carbon emissions from overall personal vehicle use for most people in my sample.

[6] Place-based factors that contribute to variation in vehicle fleets could include social norms, perceptions of safety (e.g., if everyone around you is driving a big car, it is safer for you to drive a big car; certain types of cars may be able to handle adverse weather better), road widths, ease of parking, etc.

are likely to differ from place to place depending on these constraints. Therefore, I do not treat these variables as observable household characteristics when estimating place and household effects, but I do use them later to explore correlates of unobserved place and household heterogeneity.

It is not obvious whether homeownership should be considered an observable household characteristic or part of a place effect. Homeownership rates vary dramatically across CBSAs (Raetz 2021; Mateyka and Mazur 2021), and housing regulations can price people out of homeownership. In these cases, treating homeownership as an intermediate outcome seems appropriate. On the other hand, the choice to become a homeowner simultaneously impacts where people live and factors related to their carbon emissions. For instance, homeowners may want extra space for potential family expansion or space-intensive leisure activities or may choose homeownership in order to be able to install solar panels and have a place to charge their electric vehicle. To be conservative and err on the side of finding a smaller role of place effects, I treat homeowner status as an observable household characteristic in my baseline analysis.

Place Characteristics and Amenities.—I supplement Census Bureau microdata with several external sources of data to characterize amenities at the block, tract, city, and regional level. I focus on amenities that are directly relevant to energy consumption and carbon emissions in the residential and transportation sectors.

To capture variation in climate, I use data on annual heating degree days (HDDs) and cooling degree days (CDDs) at the CONUS Climate Division level (National Oceanic and Atmospheric Administration 2020). The National Oceanic and Atmospheric Administration (NOAA) divides the contiguous states into a total of 344 climate divisions based on regional differences in climates within states. Degree days represent the annual sum of the daily difference between that day's temperature and 65°F and are meant to quantify the heating and cooling requirements of a place.

To account for neighborhood-level variation in transportation and leisure amenities, I use data from Walk Score, a private company that generates estimates of the walkability, transitability, and bikeability of every address in the United States (Walk Score 2021).[7] Walk Score rankings capture proximity to different commercial amenities, such as grocery stores, as well as street characteristics, such as block lengths and intersection widths. Bike Score indexes capture characteristics that make biking more or less accessible, such as the existence of bike lanes, road connectivity, and hilliness. Transit Score ratings capture proximity to different types of transit and the frequency and connectivity of nearby options. For transit, I also observe the number of bus routes and rail routes within one-half mile. Other than route counts, each score is an index from 0–100. I assign over 6 million unique walk score points reflecting data from late 2020 through through early 2021, one to every populated census block in the United States, by matching census block centroids to the nearest walk score latitude-longitude coordinate.

[7] Data can be viewed at www.walkscore.com and were provided by Redfin Real Estate (www.redfin.com).

Finally, I estimate density at the tract level using 2010 census block-level information on area and population. I define urban tracts as those that are characterized as urban by the US Census Bureau *and* surpass the density threshold set for urban centers by the EU-OECD definition of a functional urban area (Dijkstra, Poelman, and Veneri 2019).[8] I define suburban tracts as those contained within a CBSA but not designated as urban. Tracts outside of CBSAs are classified rural.

Sample Restrictions.—I restrict the analysis to individuals who are at least 18 years of age, who are not identified as the householder's child or grandchild, and who are not missing any of the outcome variables or key explanatory or control variables described above. I also impose several additional restrictions related to energy variables. I exclude from the sample households for which residential energy costs are included in rent or gas costs are included in electricity bills because I don't observe expenditures in those cases. I discuss this subsample of households and the potential impact of its exclusion in detail in the Supplemental Appendix. I also exclude individuals in households in which residential energy use is top-coded or whose commute time is top-coded, as the top-coding will obfuscate changes in individual consumption for the highest-demand individuals. Lastly, I exclude individuals if the sum of their household residential energy expenditures is 0, if they are in the bottom 1 percent of nonzero residential energy cost observations, or if they are in the top 1 percent of commute distance observations, as these outliers more likely reflect survey misreporting. My full sample consists of all individuals who meet these restrictions across the 48 continental states and the District of Columbia—almost 17 million people across over 12 million households (Table 1, column 1). I use the full sample to estimate observational geographic and household heterogeneity.

I construct a panel sample by restricting the full sample to individuals for whom I have at least two observations in which they did not indicate that they had moved within the last year. This restriction on very recent migration ensures that I am estimating household carbon emissions at the correct location, as households report their residential energy expenditures over the past year.[9] The panel sample consists of 1,097,000 people across 916,000 households (Table 1, column 2).

Finally, I impose two additional sample restrictions, which are necessary for the implementation of my empirical strategy. First, because residential energy is determined at the household level and place effects are identified from the variation in outcomes of movers between places, I restrict the panel sample to only households consisting of the same full-sample individuals across observations. This ensures that changes in emissions across observations are not driven by changes in the composition of adults in the household. Importantly, this approach does retain households where children are born or grow up and move out between observations, as individuals under 18 are not part of the full sample. Second, I restrict CBSAs and tracts to the "leave-out connected set"—the network of CBSAs or tracts that remain connected to each other by at least one mover after I drop all the observations of

[8] This threshold is 1,500 people per square kilometer.

[9] This restriction applies to all ACS years. The 2000 Decennial Census asked whether respondents had moved within the last five years. Since this is significantly more restrictive, I don't drop these individuals.

Table 1—Sample Statistics

		Panel sample			Mover sample	
	Full	All	CBSA	Tract	CBSA	Tract
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. Demographics						
College	0.25	0.25	0.25	0.25	0.35	0.31
Age	44	46	46	46	43	43
White	0.82	0.89	0.89	0.90	0.89	0.88
Female	0.48	0.48	0.48	0.48	0.45	0.47
Household income	103,400	114,100	114,200	114,900	116,100	115,400
Household kids	1.0	1.0	1.0	1.0	1.0	1.0
Household size	2.8	2.9	2.9	2.9	2.8	2.9
Homeowner	0.75	0.85	0.85	0.85	0.72	0.73
Panel B. Outcomes						
Tons CO_2	15.1	16.1	16.0	16.1	15.0	15.0
Tons CO_2—residential	11.9	12.8	12.8	12.8	11.8	11.9
Tons CO_2—commute	3.3	3.3	3.3	3.3	3.3	3.1
Panel C. Intermediate outcomes						
Detached home	0.72	0.81	0.81	0.81	0.73	0.73
Use electricity only	0.30	0.24	0.24	0.24	0.30	0.28
Commute by car	0.94	0.96	0.96	0.96	0.95	0.96
Commute minutes	25.1	24.9	24.9	24.8	26.0	25.6
Panel D. Place characteristics						
Urban	0.29	0.22	0.23	0.22	0.20	0.25
Suburban	0.62	0.62	0.63	0.63	0.68	0.67
Rural	0.09	0.15	0.15	0.15	0.11	0.08
Walk score	27.2	23.0	23.1	22.4	23.0	25.2
Bike score	35.9	33.4	33.4	33.1	34.1	35.4
Transit score	9.0	6.7	6.7	6.3	6.7	7.9
N bus routes	1.6	1.1	1.1	1.0	1.2	1.3
N rail routes	0.15	0.09	0.09	0.07	0.10	0.10
Cooling degree days	1,359	1,213	1,215	1,205	1,356	1,335
Heating degree days	4,376	4,824	4,815	4,851	4,494	4,518
N people	16,900,000	1,097,000	1,073,000	1,042,000	107,000	290,000
N households	12,600,000	916,000	860,000	833,000	93,000	248,000
CBSAs	1,000	1,000	1,000	1,000	1,000	1,000
Tracts	71,500	70,000	70,000	61,500	54,500	61,500

Notes: Column 1 shows statistics for the full sample. Column 2 shows statistics for the panel sample, with no restrictions that individuals be in the same household or live in a connected geography. Columns 3 and 4 show the panel samples restricted to individuals in a consistent household over time and the CBSA and tract leave-one-out connected sets, respectively. Columns 5 and 6 show statistics for the CBSA and tract mover samples. All sample statistics are weighted using Census Bureau sample weights. Sample counts are unweighted and rounded according to Census Bureau disclosure rules.

any given household (see the Supplemental Appendix for an illustration). I do this after dropping tracts with fewer than 10 full-sample household observations. The leave-out connected sets are constructed separately at the CBSA and tract levels. This means it is possible for a household to be in the CBSA panel but not the tract panel. The leave-out restriction drops a negligible share of (residual) CBSAs and roughly 12 percent of (disproportionately rural) tracts, yielding approximately a 5 percent reduction in the number of households in the sample (Table 1, columns 3 and 4).

CBSA movers are households in the CBSA panel that live in different CBSAs across observations (93,000 households, column 5), and similarly, tract movers are households in the tract panel that live in different tracts (within or across CBSAs)

across observations (248,000 households, column 6). The CBSA panel, tract panel, CBSA movers, and tract movers make up my four primary analysis samples.

B. *Sample Statistics*

Table 1 shows sample statistics for the full sample, unrestricted panel sample, the two geographically restricted panel samples, and the two mover samples.

A comparison across the samples yields three main takeaways. First, households in the panel are on average more likely to be White, have higher income, and are more likely to be homeowners than households in the full sample (columns 1 and 2). This reflects known heterogeneity in protected identification key assignment rates within the Census Bureau (Bond et al. 2014). The panel sample is also 7 percentage points less likely to live in an urban tract, 9 percentage points more likely to live in a detached home, and 2 percentage points more likely to commute by car. The appreciable drop in Transit Score when going from the full sample to the panel is consistent with these differences in urbanity and is likely in part driven by disproportionately dropping households in the densest areas when dropping households whose electricity and/or heating is included in rent, as discussed earlier and also in the Supplemental Appendix. Second, further restricting the baseline panel to the CBSA and tract panels (columns 3 and 4) does not meaningfully change the distribution of demographics, (intermediate) outcomes, or place characteristics. Finally, movers (columns 5 and 6) tend to be younger, more college educated, and have higher income than both stayers and the full sample. Movers also are more likely than stayers to live in urban tracts, less likely than stayers to live in detached homes, and they have higher rates of electric heating and lower emissions from residential energy, making them more comparable to the full sample on all of these dimensions.

Overall, a little under 80 percent of household carbon emissions in my sample are from residential energy, and a little over 20 percent are from commuting.[10] Close to three-quarters of the sample live in a detached, single-family home, a vast majority of the sample commutes by car, and on average, households live within half a mile of only 1 bus route and only 0.1 rail routes.

Table 2 shows additional statistics for the panel samples. I observe the vast majority of households in the panel sample exactly twice, with on average 8–10 years in between observations. Movers tend to be younger than stayers the first time I observe them and are much more likely to have had a child, experience a large change in real household income[11], or transition from renting to owning their home. Households tend to move to places with higher shares of detached single-family homes and worse non-car transportation amenities. The majority of moves are from urban to urban tracts, urban to suburban tracts, or suburban to suburban tracts. Finally, consistent with secular trends of mobility in the United States, households generally move to

[10] Household carbon emissions from residential and transportation energy are roughly evenly split (US Energy Information Administration 2020b). Given that commuting makes up about 30 percent of transportation energy emissions, we would expect a slightly higher than 3:1 ratio of residential to commuting energy. My estimates appear to overstate residential energy use relative to commuting by a few percentage points at most.

[11] I define a large change in income as a greater than 0.5 (in absolute value) change in log income. This approximates a 50 percent increase/decrease in income and corresponds to about the top quarter in absolute income change in my panel sample.

Table 2—Panel Statistics

	Panel sample		Mover sample	
	CBSA	Tract	CBSA	Tract
Panel A. Sample characteristics				
First observed in 2000	0.10	0.10	0.16	0.14
Years between observations	7.9	7.9	10.3	9.8
Panel B. Demographic characteristics				
Age first observed	42.0	42.0	37.1	37.2
Share with large change in income	0.28	0.28	0.45	0.41
Share with change in *N* kids	0.45	0.45	0.55	0.55
Change in *N* kids	−0.12	−0.12	0.08	0.08
Share rent to own	0.11	0.11	0.26	0.26
Panel C. Mover place changes				
Δ walk score			−7.0	−7.1
Δ bike score			−4.2	−4.0
Δ transit score			−2.3	−2.7
Δ *N* bus routes			−0.57	−0.56
Δ *N* rail routes			−0.04	−0.04
Δ tract share detached home			0.05	0.05
% moves urban to urban			0.08	0.14
% moves urban to suburban			0.17	0.14
% moves suburban to suburban			0.44	0.46
Δ cooling degree days			214	136
Δ heating degree days			−331	−188
N people	1,073,000	1,042,000	107,000	290,000
N households	860,000	833,000	93,000	248,000
CBSAs	1,000	1,000	1,000	1,000
Tracts	70,000	61,500	54,500	61,500

Notes: Columns 1 and 2 show panel statistics for the CBSA and tract panel samples. Columns 3 and 4 show panel statistics as well as summary measures of mobility patterns for the CBSA and tract mover samples. All sample statistics are weighted using census sample weights. Sample counts are unweighted and rounded according to Census Bureau disclosure rules.

warmer places. For additional comparisons of movers versus stayers, estimates of the likelihood of moving given shocks to household income, number of children, or changes in homeownership, and the full set of transition probabilities across urban, suburban, and rural places, see the Supplemental Appendix.

C. *Observational Heterogeneity*

Carbon emissions from residential energy and commuting vary immensely across individuals in the full sample (see Supplemental Appendix). This variation is strongly correlated with both geographic and household attributes. At the regional level, carbon emissions vary with climate and with the emissions intensity of local fuel sources. At the more local level, many have observed a relationship between emissions and local amenities that characterize urban form, such as local public transit, bike infrastructure, green space, and density (Ou et al. 2013; Philips, Anable, and Chatterton 2022).

Figure 1 presents average household carbon emissions across urban, suburban, and rural neighborhoods. Households residing in suburban and rural areas have substantially higher emissions than those living in urban areas. While those differences could, in theory, result from sorting based on observable household characteristics

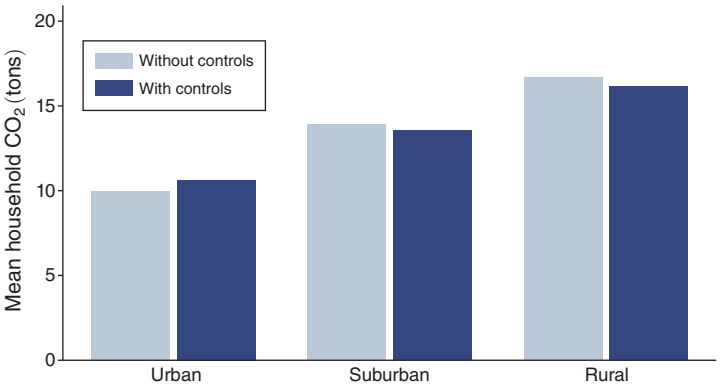

FIGURE 1. HOUSEHOLD CARBON EMISSIONS IN URBAN, SUBURBAN, AND RURAL PLACES

Notes: This figure shows estimates of household carbon emissions by urbanity. Estimates are derived from regressions of log carbon emissions (in metric tons) on indicators for urban, suburban, and rural tracts, with year fixed effects. The specification with controls additionally includes age, gender, race, education, household size, number of children, and homeowner status. I define urban tracts according to Dijkstra, Poelman, and Veneri (2019). I define suburban tracts as nonurban tracts within a CBSA. I define rural tracts as those outside CBSAs. Mean household carbon emissions are precisely estimated and statistically different from one another. The unconditional regression has an R^2 of 0.11; the conditional regression has an R^2 of 0.29.

such as college education, race and ethnicity, household income, or number of children, among others (see Supplemental Appendix), controlling for observable household characteristics only marginally reduces the differences between rural, suburban, and urban areas. There is some sorting of higher-emissions households to suburban and rural areas and lower-emissions households to urban areas, but even after accounting for these differences, households in suburban tracts still emit over 20 percent more per year than observationally similar households in urban tracts, while households in rural tracts emit about 50 percent more.

To examine spatial heterogeneity in more detail, I estimate unconditional and conditional tract-level means, μ_j, using an ordinary least squares regression of log of household carbon emissions onto place fixed effects, year fixed effects τ_t, and in the conditional regression, individual and household observable characteristics $\mathbf{X}_{it}$.

$$\ln CO_{2it} = \mu_{j(i,t)} + \mathbf{X}'_{it}\boldsymbol{\beta} + \tau_t + \varepsilon_{it}. \tag{1}$$

I use an empirical Bayes "shrinkage estimator" to adjust the estimates for statistical noise (see Supplemental Appendix for details). In practice, the distributions and relevant moments are almost identical for the adjusted and unadjusted estimates. Figure 2 presents the adjusted conditional and unconditional distributions of $\hat{\mu}_j$. I estimate that households living in neighborhoods 1 standard deviation above the mean emit on average approximately 1.9 times more than those living in neighborhoods 1 standard deviation below the mean, or 1.8 times more after accounting for differences in observable characteristics. For the remainder of this paper, I refer to means conditional on observable characteristics as "observational means," following the terminology used by Abaluck et al. (2021).

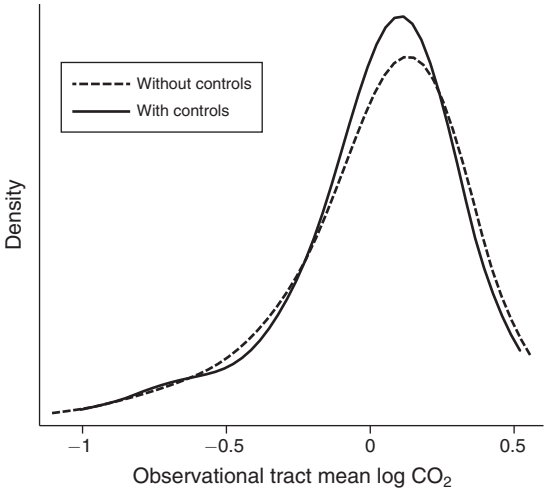

FIGURE 2. HETEROGENEITY IN TRACT-LEVEL CARBON EMISSIONS

Notes: This figure shows kernel density estimates, using a Gaussian kernel function, of tract-level observational mean emissions. The distributions are censored at the top and bottom 1 percent of observations in order to abide by Census Bureau Disclosure Avoidance rules. The dotted line labeled "Without controls" corresponds to the distribution of log CO_2 conditional on year fixed effects only and has a standard deviation of 0.33, while the solid line labeled "With controls" conditions on observable household characteristics and has a standard deviation of 0.30. Both distributions are de-meaned to match the model with controls. Observable characteristics include age, gender, race, ethnicity, education, homeowner status, household income, household size, and number of children.

The remaining heterogeneity in observational means reflects some combination of place-based characteristics and unobserved household characteristics. To illustrate this, I rewrite equation (1) as a two-way fixed effects model:

$$\ln CO_{2it} = \alpha_i + \psi_j + \mathbf{X}'_{it}\boldsymbol{\beta} + \tau_t + \varepsilon_{it}, \tag{2}$$

where ψ_j represents the place-based characteristics and α_i represents the unobserved, fixed, household characteristics. Comparing equation (1) and equation (2) highlights the bias that can arise when inferring place effects from observational means, as $\mu_j = \psi_j + E\left[\alpha_i \middle| i \in j\right]$. In other words, observational means reflect a combination of place effects and an average over the unobserved characteristics of the residents of a place.

The primary objective of this paper is to disentangle these components and quantify the extent to which heterogeneity in household carbon emissions is driven by unobserved household characteristics and preferences, and how much is driven by causal place effects, that is, the amount by which the same household's carbon emissions would differ from place to place due to the underlying features of each place, holding household characteristics fixed. This motivates the mover design, which leverages this exact variation.

II. Model

In the previous section, I demonstrated how a two-way fixed effects model can be used to mitigate biases that arise when making inferences based on observational

means. To provide further insight into the model, I now illustrate how it relates to a standard way of modeling consumer energy demand and discuss the interpretation of place and household effects.

Consider a household, i, living in place, j, that consumes quantity Q of energy in the form of four categories of fuels, f. In the residential sector, it can consume electricity (e), natural gas (n), and other heating fuels (o). In the transportation sector, it can consume motor gasoline (m).[12]

Average demand a_j, price elasticities of demand ρ_j^f, and prices P_j^f are permitted to vary by place. Place-based differences in average energy demand and in price elasticities of demand could stem from a range of fixed and malleable characteristics of places. These characteristics include climate, local public goods and urban form (e.g., density, public transit, pedestrian and bike infrastructure, proximity to highways and availability of parking, and proximity to leisure and commercial amenities), and regulatory characteristics (e.g., zoning restrictions that change the size and density of homes and building codes that change energy efficiency requirements or eliminate natural gas hookups). All of these features could potentially shift energy demand, both on average and in slope.

In addition to place-based characteristics, demand also depends on observable fixed and time-varying household characteristics (such as age, household size, and income) $\mathbf{X}_{it}$, individual fixed unobserved determinants of demand (such as a person's intrinsic risk tolerance for biking on shared roads, aversion to public transit versus traffic, or relative enjoyment of spending time in their own backyard versus a public park) α_i, individual time-varying unobserved determinants of demand (perhaps an increased willingness to bike after reading the latest Intergovernmental Panel on Climate Change report) ε_{it}, and national annual variation τ_t. Taken together, household demand for residential and transportation energy is given by

$$\ln Q_{it} = a_j + \sum_{f \in \mathcal{F}} \rho_j^f \cdot \ln P_j^f + \mathbf{X}_{it}'\boldsymbol{\beta} + \tau_t + \alpha_i + \varepsilon_{it}. \tag{3}$$

If all households within a place used the same proportion of fuel types, it would be simple to express the above equation, with log carbon emissions as the outcome, in terms of a place-based average emissions factor $\bar{\phi}_j$, and to in turn rewrite that expression as the two-way fixed effects model defined in the previous section:

$$\begin{aligned} \ln CO_{2it} &= \ln\left(\bar{\phi}_j Q_{it}\right) \\ &= \underbrace{\ln \bar{\phi}_j + a_j + \sum_{f \in \mathcal{F}} \rho_j^f \cdot \ln P_j^f}_{\psi_j} + \mathbf{X}_{it}'\boldsymbol{\beta} + \tau_t + \alpha_i + \varepsilon_{it}. \end{aligned} \tag{4}$$

In this simplified setting, place effects ψ_j capture the combination of place-based variation in five key factors: average energy demand, fuel price elasticities, fuel

[12] Electric vehicles are a negligible share of driving in my sample time frame. If someone has an electric vehicle, I overestimate their emissions because the electricity they use to charge their vehicle is included in residential energy (if they charge at home), but I also assign them gasoline emissions. As electric vehicles (EVs) become a larger share of the market, observing household vehicle choices, and the place-based role of EV charging networks on these choices, will be critical for future research.

prices, electricity emissions factors, and fuel shares. In reality, fuel shares vary not only across places but also across households. For instance, some states and municipalities are attempting to ban natural gas connections for new construction (O'Brien 2023; Cornfield 2023), but even if natural gas is available as an option, some households may still opt to fully electrify their homes, while others may have a strong preference for cooking on gas stoves.

In the Supplemental Appendix, I examine how the interpretation of the two-way fixed effects model is affected when fuel shares are allowed to vary across individuals. The more complex model includes a term that captures the interaction between fuel emissions factors and a household's fuel shares relative to the place-based average. Because electricity emissions factors vary across places, a household that disproportionately uses electricity will experience a larger drop in emissions when moving from a place with relatively high-emissions electricity to a place with relatively clean electricity, compared to the average household. This lack of separability implies that there is some inherent misspecification in the two-way fixed effects model in this setting.

The model makes two additional simplifications. First, place effects are assumed to be fixed, implying that any time variation, including changes in prices, is absorbed in the place effects, which reflect average differences between places over the sample time frame. Second, while the model allows price elasticities of demand to vary across places, it does not allow for them to systematically vary across households. For example, the model does not allow for different elasticities between high- and low-income households. Allowing for heterogeneity in demand elasticities across household characteristics would introduce additional interaction terms in the error, as elasticities would be interacted with place-specific prices. Together, this interaction along with the interaction between household fuel shares and place-specific electricity emissions factors motivate treating the errors as heteroskedastic.

III. Empirical Strategy

My empirical strategy uses movers to estimate place effects and their contribution to spatial heterogeneity in carbon emissions. The intuition behind the mover design is the following: Suppose high-emissions places are high-emissions because of causal place effects—for example, because there are no alternatives to commuting other than by car or because zoning regulations impose constraints on minimum home sizes and density. If so, there would be households that live in high-emissions places for work or to be near family or near other amenities they enjoy, which may otherwise make lower-emissions residential and transportation choices but are unable to. If those households move from an on average high-emissions place to an on average low-emissions place where lower-emissions alternatives become available to them, their carbon emissions should decrease. Conversely, if spatial heterogeneity is driven by strong preferences, then households currently living in detached single-family homes and commuting by car would continue to do so even given alternate options, and moving from on average high- to low-emissions places should have little effect on household carbon emissions.

I use the mover design to estimate two versions of a heterogeneity decomposition of household carbon emissions. I begin with an event study, which, under

strong assumptions, characterizes the share of differences *between* places attributable to place effects, inferred from movers' changes in emissions relative to origin-destination mean differences. Under weaker assumptions, the event study serves as additional descriptive evidence and model validation for the second decomposition, as well as unbiased prediction of how carbon emissions will change for the set of observed moves. I then estimate the nonparametric distribution of household and place effects and decompose *overall* heterogeneity into variance components. In the following subsections, I first discuss modeling and identifying assumptions, and then I describe each of these decompositions in more detail.

A. *Main Assumptions*

My empirical strategy at its foundation pairs a two-way fixed effect model with a mover design. In order for estimates from this approach to be unbiased, three assumptions need to hold: (i) additive separability of place effects, or constant effects; (ii) nonpersistence of outcomes; and (iii) exogenous mobility, or conditional orthogonality. I discuss each below.

ASSUMPTION 1: *Additive Separability of Place Effects, or Constant Effects.*

A core modeling assumption of the two-way fixed effect design is that the outcome—log carbon emissions—is additively separable in household and place effects. The log specification is statistically appealing, as it reflects the approximate log-normality of the household carbon emissions distribution (see Supplemental Appendix). It is also conceptually appealing, as it implies that place effects increase and decrease carbon emissions proportionally by the same amount for everyone, which aligns with many potential mechanisms through which place effects could arise. For example, it is natural to model climate as scaling residential heating or cooling needs up or down by the same factor for all households, regardless of their baseline energy consumption. If density drives place effects, it is reasonable to expect denser places to decrease the size of homes (and therefore residential energy requirements) or the length of commutes (and therefore transportation energy requirements) by the same factor for all households. Similarly, an increase in transportation alternatives to cars might decrease the share of trips taken by car for all households proportionally.

Nevertheless, the two-way fixed effects model imposes a substantial restriction: It does not allow for heterogeneous treatment effects or match effects. Heterogeneous place effects could arise in various scenarios. For instance, a new public transit option might significantly reduce emissions for relatively low-emissions households, while barely affecting high-emissions households' behavior. Paired with changes in density, this could even produce divergent effects if high-emissions individuals find themselves idling in traffic more due to increased congestion. Alternatively, heterogeneous place effects might arise if low-emissions households make the same consumption choices wherever they live, while high-emissions households respond strongly to changes in amenities. Moreover, Section II reveals that there is an interaction between households' fuel shares and local emissions factors; a household that prefers to use electricity for heating will see a larger drop

in emissions when moving to an area with cleaner electricity than a household that prefers natural gas heating, all else equal. This interaction introduces a degree of misspecification into the two-way fixed effect model, rendering it an approximation. The critical question is whether households systematically sort into locations based on this (or any other) interaction. As long as they do not, the mover design will continue to yield unbiased estimates of average place effects.

To rule out selection on heterogeneous effects, I follow Card, Heining, and Kline (2013) and test whether moves from a low-emissions place to a high-emissions place and moves from a high-emissions place to a low-emissions place are associated with equal and opposite changes in household carbon emissions. To see why symmetry rules out selection on heterogeneous effects, consider differences in potential outcomes across an origin o and destination d, allowing now for there to be an interaction $\eta(\alpha_i, \psi_j)$ between person and place types:

$$E\big[CO_{2it}(d)\big] - E\big[CO_{2it}(o)\big] = (\psi_d - \psi_o) + \eta(\alpha_i, \psi_d) - \eta(\alpha_i, \psi_o).$$

As long as

$$\eta(\alpha_h, \psi_d) - \eta(\alpha_h, \psi_o) \neq \eta(\alpha_l, \psi_d) - \eta(\alpha_l, \psi_o), \tag{5}$$

this type of interaction, paired with selection, would lead to asymmetries between changes in household carbon emissions for moves to higher on average places versus moves to lower on average places. Note that condition (5) holds for a broad class of functions, including the simplest interaction, $\eta = \alpha_i \cdot \psi_j$, since $\alpha_i \cdot (\psi_d - \psi_o) \neq \alpha_j \cdot (\psi_d - \psi_o)\ \forall i \neq j, o \neq d$.[13] Returning to an earlier example, suppose place effects are due to a public transit option that only low-emissions households use. Suppose also that households that wish to use public transit disproportionately move to places where it is available, whereas households that don't want to use public transit disproportionately move to places where it is not available; the subsequent decline in emissions for households moving from a high-emissions place to a low-emissions place will be larger than the increase in emissions for households moving in the opposite direction.

I group places into four quartiles based on observational averages of carbon emissions, and I estimate household carbon emissions for each origin-destination quartile pair, adjusting for annual trends and controlling for demographic and household characteristics. Figure 3 displays the results. For parsimony, the figure shows only moves from the lowest-quartile emissions places to all four quartiles and vice versa, as well as moves within first-quartile places and moves within fourth-quartile places as bounds in gray.

First and foremost, this figure shows that moves across quartiles lead to equal and opposite changes in household carbon emissions. This symmetry suggests that the log-linear two-way fixed effect model of household carbon emissions is a good approximation for the role of place effects and alleviates concern about selection on heterogeneous treatment effects. Second, this figure provides evidence of selection

[13] More generally, equation (5) implies that $\frac{\partial \eta}{\partial \alpha}(\psi_d - \psi_o) \neq 0$, and in turn, $\frac{\partial^2 \eta}{\partial \alpha \partial \psi} \neq 0$. In words, the symmetry check rules out any interaction in which the change between places grows or shrinks with household type.

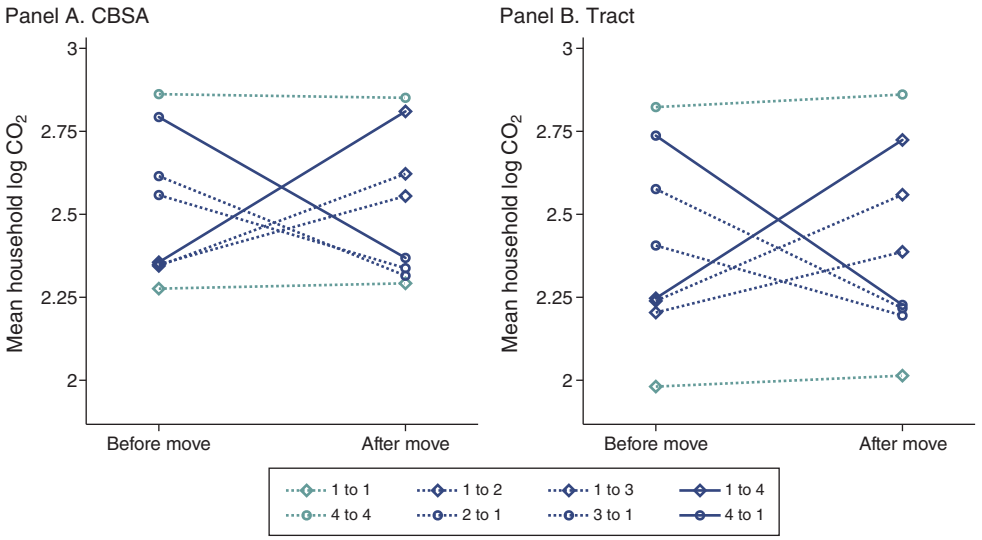

FIGURE 3. CHANGES IN HOUSEHOLD CO_2 WHEN MOVING ACROSS QUARTILES OF MEAN CO_2

Notes: This figure shows average household carbon emissions for movers across places classified into quartiles based on their observational mean carbon emissions in the full sample. Symmetric responses to moves in opposite directions provide support for the log-linear two-way fixed effect model of household carbon emissions because they are consistent with place effects entering log carbon emissions additively. This figure shows only the subset of moves to and from the lowest-emissions places (quartile 1), as well as moves within the highest-emissions places (quartile 4). Estimates are conditional on year fixed effects and the standard set of household characteristics used throughout this analysis. Estimates are weighted by Census Bureau sample weights.

at the tails, particularly for tract-level moves; households that move from the lowest quartile to a different place in the lowest quartile have lower emissions on average than households that move between the lowest quartile and any of the three higher quartiles. Similarly, households that move between places in the fourth quartile have higher emissions than those that move between the fourth and the first, though the difference at the top is less pronounced. Finally, note that households that move between tracts within the same quartile experience a small increase in emissions, consistent with the general trend of households moving to on average higher-emissions places.

ASSUMPTION 2: *Nonpersistent Outcomes.*

As highlighted above, I identify relative place effects from pairwise comparisons of household carbon emissions between origin and destination,

$$E\left[CO_{2it}(d) \mid \alpha_i, \mathbf{X}_{it}, \tau_t\right] - E\left[CO_{2it}(o) \mid \alpha_i, \mathbf{X}_{it}, \tau_t\right] = \psi_d - \psi_o.$$

This expression holds for any two households moving between o and d, which means that it cannot differ from household to household as a result of differences in their residential histories. In other words, the expected change for two households moving between the same origin and destination should be the same even if one of the households previously lived in Houston, while the other previously lived in New

York. Note, however, that the nonpersistent outcomes assumption does *not* rule out that the place someone was born and raised may have a persistent effect on their preferences and carbon emissions. Because I include household effects in the model and only include individuals over the age of 18 in the sample, any persistent effect of place of birth and upbringing on carbon emissions will be captured by the household fixed effect.

ASSUMPTION 3: *Exogenous Mobility or Conditional Orthogonality.*

When the first two assumptions hold, the model serves as a reasonable approximation to the real world, and consequently, random variation in exposure to place identifies place effects. Thus the final, identifying, assumption necessary for this empirical approach to be unbiased is that moves are conditionally exogenous; in other words, household destination choices are not related to changes in unobserved determinants of carbon emissions:

$$E\left[\epsilon_{it} | \alpha_i, \psi_{j(i,t)}, \mathbf{X}_{it}, \tau_t\right] = 0. \tag{6}$$

It is important to emphasize here that the two-way fixed effects model allows for a broad set of sorting behaviors. First, it allows for unrestricted sorting of households on fixed or time-varying observable characteristics. A key advantage of the census microdata is the ability to observe numerous time-varying household characteristics that could potentially bias the estimates if unobserved. Factors such as entering middle age, having children, experiencing a change in income, or becoming a homeowner are all associated with an increase in energy consumption generally (see Supplemental Appendix), and the latter three also significantly increase the probability of moving (see Supplemental Appendix). However, this endogeneity does not bias the estimates, as I observe age, household size, number of children, household income, and homeowner status and am therefore able to separate the effect of these characteristics on household emissions from their influence on a household's choice of new city or neighborhood.

Second, and crucially, the two-way fixed effect model allows for unrestricted sorting on fixed unobservable characteristics. In other words, if households have heterogeneous, but fixed, preferences for neighborhood amenities—for instance, if someone has a particular distaste for public transit, a strong preference for large homes, or a particular love for walking or biking—and their choice of what neighborhood to live in reflects those preferences, estimates of place effects are unbiased by this selection because household fixed effects capture these unobserved but fixed determinants of carbon emissions. The ability to account for, and allow unrestricted sorting on, these time-invariant unobserved preferences is a critical benefit of the pairing of the two-way fixed effect model and mover estimation strategy.

Note also that the fact that I might never observe a very high-emissions household move to a very low-emissions place is not a problem if you accept Assumption 1, that places do not have heterogeneous effects on different types of households. It is sufficient to have a connected network of pairwise moves between places in

order to identify relative place effects, and household effects are identified relative to other households within the same place. Consequently, even if I observe only lower-emissions households moving from Pittsburgh to New York, and only higher emissions-households moving from Pittsburgh to Houston, a comparison of household emissions within Pittsburgh combined with the observed changes to household emissions at their destinations identifies the relevant household and place effects. I have already provided some evidence that place effects do not appear to be heterogeneous in the symmetry check shown in Figure 3. I will provide additional evidence of this when I examine heterogeneity in the event study results, in Section IVA. If this model assumption is violated and there is selection on heterogeneous treatment effects, then the place effects I estimate should be thought of as local average treatment effects for the population moving to those places.

Thus, the main threat to identification stems from the possibility that moves correspond to *changes* in unobserved preferences—either through an idiosyncratic shock or via preference "drift," that is, a gradual evolution in preferences that is not captured by aging. Revisiting the example in the previous paragraph, this would reflect a scenario in which the two households in Pittsburgh were initially similar, but then one household becomes increasingly concerned about climate change and makes lifestyle choices to reduce its carbon emissions, subsequently relocating to New York to facilitate these choices, while the other household's preferences remain unchanged. In this example, the first household's carbon emissions would have changed to some extent even if it had stayed in Pittsburgh, and that portion of the change would be incorrectly attributed to the New York place effect.

A standard approach for ruling out endogenous moves is to test for parallel trends between movers and stayers prior to the move. Unfortunately, I observe the majority of my sample only twice, which makes this impossible. Instead, I use data from the Panel Study of Income Dynamics (PSID; Lyubich 2024), over the same sample period, and assess whether movers in the PSID exhibit any changes to energy expenditures (defined as monthly spending on electricity, home heating, and gasoline) prior to their move. I do not know where households move from or to, so I look separately at households whose energy expenditures are higher after moving and those whose energy expenditures are lower after moving, controlling for household size, income, householder age, and year fixed effects. I find no evidence of pre-trends for either group (see Supplemental Appendix).

In Section IVA, I will also show evidence on preference "drift." If moves were endogenous to evolving preferences, the selection component, and consequently, the parameter estimate, would likely increase with the duration since the move. Some evidence of drift emerges in the baseline analysis, but the magnitude of drift appears to be quite small and becomes insignificant when looking at a restricted sample with no observable major life events.

B. *Event Study Decomposition*

The first decomposition I estimate is an event study, following the approach used by Finkelstein, Gentzkow, and Williams (2016). The event study begins with the two-way fixed effect model defined in equation (2) but summarizes heterogeneity with a single parameter rather than the full distribution of J place effects. For

household i moving from origin o to destination d, the expected change in carbon emissions is given by

$$E\left[\ln CO_{2it}(d) - \ln CO_{2it}(o) \mid \alpha_i, \mathbf{X}_{it}, \tau_t\right] = \psi_d - \psi_o.$$

I then express the change in place effects as a share of the differences between observational means:

$$\begin{aligned}\psi_d - \psi_o &= \frac{\psi_d - \psi_o}{\bar{y}_d - \bar{y}_o} \cdot (\bar{y}_d - \bar{y}_o) \\ &\equiv \theta_{o,d} \cdot (\bar{y}_d - \bar{y}_o).\end{aligned}$$

Incorporating this expression into the two-way fixed effect model yields the event study equation, which I use to estimate θ, the share of between-place differences attributable to place effects:

$$\begin{aligned}\ln CO_{2it} &= \alpha_i + \psi_j + \tau_t + \mathbf{X}_{it}'\boldsymbol{\beta} + \varepsilon_{it} \\ &= \alpha_i + \psi_o + \mathbf{1}_{\{moved\}} \cdot (\psi_d - \psi_o) + \tau_t + \mathbf{X}_{it}'\boldsymbol{\beta} + \varepsilon_{it} \\ &= \tilde{\alpha}_i + \mathbf{1}_{\{moved\}} \cdot \theta \cdot (\bar{y}_d - \bar{y}_o) + \tau_t + \mathbf{X}_{it}'\boldsymbol{\beta} + \varepsilon_{it}.\end{aligned} \tag{7}$$

By characterizing the place share of heterogeneity with a single parameter, θ, the event study approach vastly reduces the dimensionality of the estimation problem. This efficiency comes at the cost of an additional assumption: In order for $\hat{\theta}$ to reflect an unbiased, causal parameter, it cannot be correlated with other parameters in the model. In other words, unlike the two-way fixed effect model, this approach does not permit systematic sorting of certain types of households, either based on observable characteristics or unobservable types, to certain types of places. This is because it infers place types from observational means; if there were sorting of, for example, high-type households to high-type places, $\bar{y}_d - \bar{y}_o$ would grow faster than $\psi_d - \psi_o$ as places grow more different, leading to biased estimates.

The stronger restriction on sorting is more plausible at the CBSA level, in which people are more likely to move for job opportunities or to be close to family, than at the neighborhood level, where choices are more likely to be driven by local amenities. In Section IVA I will provide evidence that estimates of the share parameter are not heterogeneous along several dimensions, suggesting little bias from this stronger assumption. However, even under weaker baseline assumptions, under which event study results can't be interpreted as causal, the results remain informative for two reasons. First, they serve as useful descriptive evidence and additional model intuition and validation for the Kline, Saggio, and Sølvsten (2020)—henceforth, KSS—analysis to come. Second, they yield unbiased predictions about how household carbon emissions will change for any set of observed moves. This is particularly useful, as researchers have highlighted that restrictive zoning and high cost of living in productive areas drives people to higher-emissions

locations (Glaeser and Kahn 2010). The labor and urban literatures have identified that such moves lead to decreased welfare due to loss of agglomeration externalities. The event study specification makes it possible to additionally estimate the carbon emissions externality of these regulatory restrictions.

C. *Variance Decomposition*

The second decomposition is based on the full set of nonparametric fixed effect estimates from the model. Specifically, heterogeneity in household carbon emissions can be decomposed as below, lumping τ_t with $\mathbf{X}_{it}$ for brevity:

$$\begin{aligned}(8)\quad \text{var}[y_{ij}] \;=\; & \text{var}[\psi_j] \;+\; 2 \cdot \text{cov}[\alpha_i, \psi_j] \;+\; \text{var}[\alpha_i] \\ & +\; \text{var}[\mathbf{X}_{it}'\beta] \;+\; 2 \cdot \text{cov}[\alpha_i, \mathbf{X}_{it}'\beta] \;+\; 2 \cdot \text{cov}[\psi_j, \mathbf{X}_{it}'\beta] \;+\; \text{var}[\varepsilon_{it}].\end{aligned}$$

This analysis focuses on the first three terms: the variance component of place effects, the variance component of unobserved person effects, and their covariance, which captures the spatial heterogeneity that results from systematic sorting on unobserved preferences. Each variance component describes the share of *overall* heterogeneity attributable to the relevant component.

In contrast to the event study decomposition, the two-way fixed effects decomposition allows unrestricted sorting of households across places; it imposes no limitations on the magnitude or sign of the covariance terms. This flexibility comes at an econometric cost. A well-documented challenge to estimating variance components in two-way fixed effect models is limited mobility bias (Andrews et al. 2008). Limited mobility bias arises because place effects are estimated based on the outcomes of people who move between different locations; however, for any given place, there might only be a small number of people moving in or out. This can lead to imprecise estimates, which creates an upward bias in the naïve plug-in variance estimate relative to the true variance of place effects, even if estimates of place effects themselves are unbiased. To address this, I estimate variance components using the heteroskedasticity-unbiased leave-out estimator proposed by KSS. The KSS estimator uses a leave-out estimate of standard errors to correct estimates of the variance components for sampling variability.

I implement the leave-out estimator at the household level, leaving out all observations corresponding to a household match. In the mover sample, the KSS estimator is robust to unrestricted heteroskedasticity and serial correlation within each match. Because it is not possible to leave out matches for stayers without dropping all their observations, if there is serial correlation in the error term, KSS estimates of the person variance component in the panel sample are an upper bound on the true value. See the Supplemental Appendix for additional computational details, and KSS for a complete discussion of the leave-out estimator.

IV. Results

This section presents the core results of my paper: estimates of the share of heterogeneity in household carbon emissions attributable to place effects. I begin by

Table 3—Share of Spatial Variation in Mean CO_2 Attributable to Place Effects

	CBSA			Tract		
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. Panel sample						
Place share of mean difs.	0.91	0.86	0.86	0.78	0.60	0.55
	(0.008)	(0.007)	(0.016)	(0.003)	(0.003)	(0.007)
Observations	1,764,000	1,764,000	633,000	1,710,000	1,710,000	613,000
R^2 (adj.)	0.73	0.75	0.77	0.74	0.76	0.77
Panel B. Mover sample						
Place share of mean difs.	0.89	0.85	0.84	0.76	0.57	0.53
	(0.009)	(0.009)	(0.020)	(0.004)	(0.004)	(0.009)
Observations	191,000	191,000	36,000	508,000	508,000	102,000
R^2 (adj.)	0.64	0.70	0.70	0.69	0.73	0.73
Household controls		X	X		X	X
No big life events			X			X

Notes: This table reports event study estimates of the place share of spatial heterogeneity in household carbon emissions. The place share estimate ($\hat{\theta}$) represents the proportion of differences in average carbon emissions ($\bar{y}$) between a mover's origin and destination attributable to place effects. Panel A reports estimates from the panel sample, while panel B restricts the sample to movers only, allowing for systematic differences between movers and stayers. Columns 1 and 4 show estimates from CBSA and tract moves, respectively, with only year fixed effects. Columns 2 and 5 add controls for the standard set of household characteristics. Columns 3 and 6 restrict the sample to households without changes in number of children, income changes exceeding 50 percent, or changes in homeownership. All estimates use Census Bureau sample weights.

showing results from the event study specification, which—even if the stronger assumptions on selection are violated—serve as additional descriptive evidence and can be used to predict how household carbon emissions will change for movers under existing patterns of mobility. I then present results from the variance decomposition of the unrestricted two-way fixed effect model. I conclude the section with a discussion on interpreting the two versions of the analysis.

A. *Event Study Decomposition*

This section presents estimates from the event study derived in Section IIIB:

$$\ln CO_{2it} = \tilde{\alpha}_i + \mathbf{1}_{\{moved\}} \cdot \theta \cdot \left(\bar{y}_{d_{-i}} - \bar{y}_{o_{-i}}\right) + \tau_t + \mathbf{X}'_{it}\boldsymbol{\beta} + \varepsilon_{it},$$

where $\bar{y}_{j_{-i}}$ are sample means estimated from the full sample, leaving out the household observation.[14]

Table 3 presents event study estimates of $\hat{\theta}$, which captures the share of differences between observational place means attributable to differences between place effects. Columns 1–3 show results from regressions examining CBSAs, while columns 4–6 show results from regressions examining tracts. Panel A shows results

[14] To the extent that there is sampling variability in the distribution of observational means, my estimate of the relationship between origin-destination mean changes and individual changes in log CO_2 may be biased. In practice, using a linear empirical Bayes estimator to adjust means for sampling variability does not materially change the results.

estimated from the panel sample, which consists of both movers and stayers; panel B shows results using just the mover sample. Both samples use mover variation to identify place effects, but estimates may differ if the relationship between household characteristics and emissions varies systematically between movers and stayers. For instance, if having children induces divergent preference shocks—prompting movers to seek larger, potentially higher-emission homes, while reinforcing stayers' preference to be within walking distance of friends and local amenities—including stayers in the analysis could underestimate the direct impact of children on movers' emissions, thereby overstating the place effect. Across specifications, the mover sample yields place share estimates that are at most 4 percentage points lower than the panel sample estimates. This implies that movers and stayers have only marginally different responses to changes in observables, and including stayers introduces a small upward bias in the place effect estimates.

Columns 1 and 4 present estimates from a model with just year fixed effects. These estimates show that when a household moves, its emissions change by 89–91 percent of origin-destination CBSA mean differences and 76–78 percent of origin-destination tract mean differences. However, these estimates are confounded by the correlation between household characteristics and location choices. Columns 2 and 5 address this by controlling for observable household characteristics (age, household income, household size, number of children, and homeowner status) that likely influence both emissions and neighborhood choice. This adjustment reduces CBSA share estimates by up to 5 percentage points (to 85–86 percent) and tract share estimates by nearly 20 percentage points (to 57–60 percent). The larger impact on tract-level estimates suggests that, as you would expect, household sorting plays a more significant role in neighborhood-level emissions variation, while CBSA-level moves may be driven more by factors like job opportunities or family considerations. In the Supplemental Appendix, I reestimate columns 2 and 5 controlling for average heating degree days, cooling degree days, and electricity emissions factors. Doing so decreases the CBSA share to 68–70 percent and the tract share to 51–54 percent. While these estimates lend insight into the mechanisms underlying place effects, I focus my main event study analysis on total place effects, which are more relevant for predicting emissions changes from observed migration patterns.

Even after accounting for the rich set of observable characteristics available in the data, household destination choices may still be influenced by unobserved heterogeneous preference shocks. While I cannot rule this out entirely, I explore the potential bias from such selection by restricting the sample to households with minimal observable shocks, motivated by the premise that these households are less likely to have experienced large concurrent unobservable changes. Columns 3 and 6 present results from this "no big life events" subsample, which excludes households that experienced a change in the number of children, a greater than 0.5 log point change in income, or a change in homeownership status between observations. This subsample, comprising approximately 20 percent of the original observations, yields place share estimates at most 5 percentage points lower than the baseline estimates. The fact that households least likely to have experienced unobservable shocks yield qualitatively similar place share estimates to the baseline sample is reassuring and suggests limited bias from shocks to unobserved preference heterogeneity.

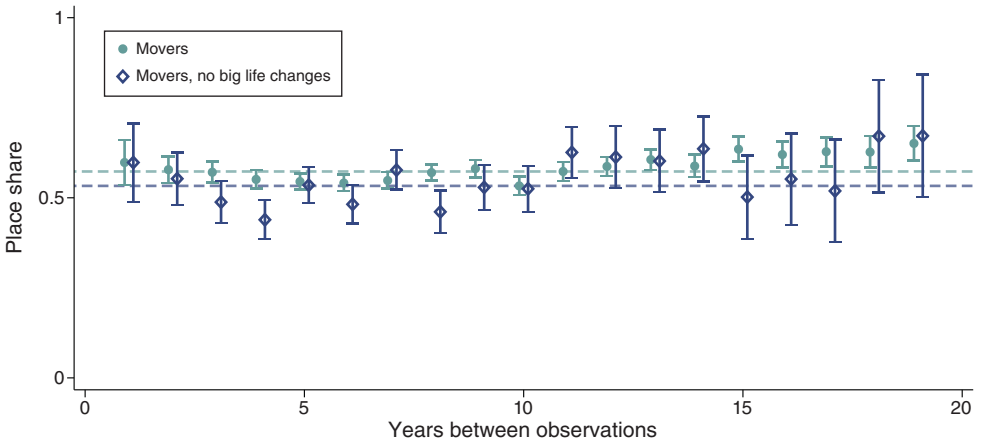

Figure 4. Tract Share of Spatial Variation, by Duration between Observations

Notes: This figure shows event study estimates of the share of spatial variation in mean carbon emissions that can be explained by place effects, by duration between mover observations. In other words, each coefficient is the estimate for place effects generated from the subsample of households that I observe x years apart. Coefficients plotted in light gray are estimated from the model using the full panel of stayers and movers. Coefficients plotted in the dark blue are estimated from the model using the subsample of stayers and movers with no changes in the number of children, less than 50 percent change in household income, and no change in homeownership status between observations. All estimates are weighted using census sample weights.

In addition to unobserved shocks, another potential source of bias arises from "preference drift"—gradual changes in households' preferences over time that are not fully captured by changes in age or other observable characteristics (Card, Heining, and Kline 2013). If such drift exists and influences relocation decisions, place effect estimates would conflate true causal effects with selection, particularly for moves observed after long time intervals. This would manifest as place effect estimates that trend upward with the duration between observations. To explore this possibility, Figure 4 presents tract-level place share estimates by duration between observations, controlling for demographic and household characteristics. The light gray points depict estimates for the baseline mover sample, while the dark blue bars correspond to the restricted subsample of movers with no big life changes between observations.

For the full mover sample, a slight upward trend emerges, with place share estimates for durations in the 15- to 19-year range exceeding the pooled estimate. This pattern dissipates when considering the restricted subsample of movers without observable big life changes; the pooled estimate for this group is not contained within the 95 percent confidence interval for 4 out of the 19 duration-specific estimates, but with no clear trend across durations. The Supplemental Appendix presents analogous CBSA estimates, which exhibit a similar pattern, except the upward trend observed in the longer-duration coefficients becomes insignificant in the baseline mover sample as well.

While these results suggest some preference drift, potentially leading to upward-biased place share estimates, the magnitude appears small relative to observed changes in emissions between places, and this bias appears to be negligible in the sample restricted to households without big life events. One additional result

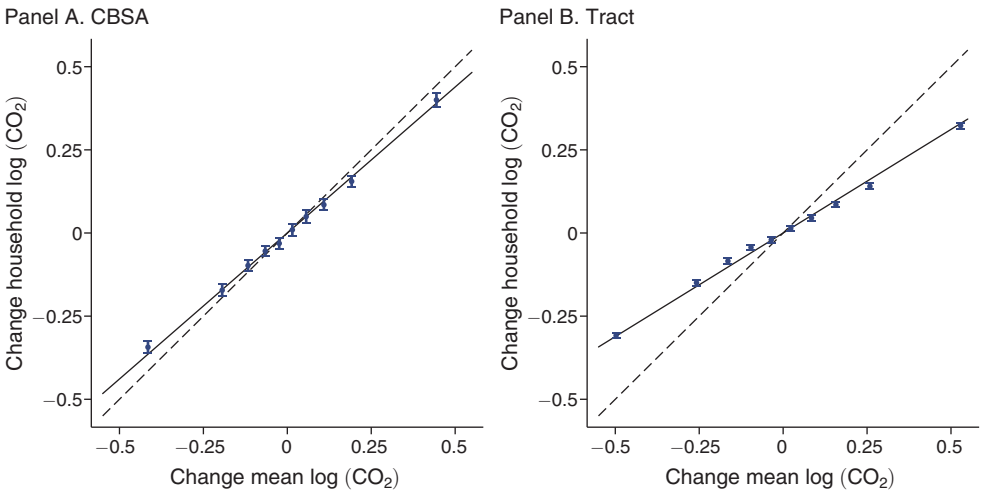

Figure 5. Place Share of Spatial Variation, by Move Type

Notes: This figure shows mover changes in household carbon emissions, by size of origin-destination differences in mean carbon emissions. All estimates are from a model that conditions on changes in observable household characteristics and year fixed effects. I split movers into 10 deciles, according to the size of the (conditional) gap in mean carbon emissions across their origin and destination, and estimate standard errors using bootstrap. Point estimates are shown with 95 percent confidence intervals. The solid lines show the regression estimates from the pooled model, and the dotted line denotes 45 degrees, that is, the scenario in which moving to on average higher- or lower-emissions places leads to a one-for-one increase in own carbon emissions. All estimates are weighted using Census Bureau sample weights.

that emerges from this analysis is that household carbon emissions appear to change instantaneously, suggesting place effects stem from attributes that directly impact emissions rather than gradual influences like peer effects or habit formation.[15]

As a final specification check, I explore heterogeneity across moves of different magnitudes in terms of place mean changes. A potential concern with the results presented thus far is that households choosing to relocate from low-emissions places to high-emissions places (or vice versa) may systematically differ from those moving between areas with similar emissions levels. If a household's choice of destination reveals newly observable information about unobserved preference shocks, the estimates would be biased, mistakenly attributing these shocks to place effects. To explore this possibility, Figure 5 depicts changes in mover households' carbon emissions across deciles of origin-destination mean differences, controlling for demographic and household characteristics. The *x*-axis represents conditional changes in mean emissions between origin and destination, while the y-axis shows to conditional changes in household emissions. The 45-degree line (in gray) represents a scenario in which place effects fully explain variation in carbon emissions across locations. The solid line's slope corresponds to the pooled estimate of the relationship between tract-level mean changes and household-level changes. Standard errors are estimated using bootstrap.

[15] While I don't observe how long ago a household moved, the expected time since moving increases with the duration between observations.

I find that, for both moves across CBSAs and moves across neighborhoods, changes in household carbon emissions as a share of changes in origin-destination means are symmetric and linear across move types. In other words, the share of spatial heterogeneity attributable to place-based differences is consistent for moves from low- to high-emissions places (rightmost points), moves from high- to low-emissions places (leftmost points), and moves between places with similar average emissions (central points). The symmetry and stability of share estimates have several implications. First, this result extends the symmetry check presented in Figure 3, further validating the log-linear model specification and suggesting that the two-way fixed effect model reasonably approximates household carbon emissions. Recall that this implies place effect estimates are unbiased even if I never observe some household types moving to some place types. Second, this result indicates that the event study estimates presented in Table 3 are not driven by a subset of movers or mover destinations, alleviating concerns that estimates primarily reflect changes in the emissions of households who moved to a vastly different destination in response to a large unobserved preference shock. Lastly, this result provides another dimension along which heterogeneity in the estimated share parameter appears to be limited.

In summary, the event study estimates indicate that movers' carbon emissions change by over half of origin-destination differences in neighborhood means (and about 85 percent of origin-destination differences in CBSA means) when they move. Under strong assumptions on sorting, this can be interpreted as a causal share parameter, which would determine the change in carbon emissions resulting from any household moving between any pair of places. I estimate that heterogeneity in the share parameter is limited along several dimensions explored throughout this section—estimates are within a 5 percentage point range of each other across subsamples with vastly different changes to observed characteristics, across different observation time horizons, and across varying move types (between similar versus dissimilar places)—suggesting that perhaps bias from violations of this assumption may also be minimal.

Under weaker assumptions, the event study estimates serve as a useful specification check for the two-way fixed effect model, and perhaps more interestingly, they provide unbiased prediction of how household carbon emissions will change for any *observed* move. Recent research and media coverage have highlighted a pattern of increasing migration from more expensive but on average lower-emissions places to less expensive but on average higher-emissions places (Kolko 2021; Eisen 2019). For instance, in 2019, there was a net migration of about 45,00 people from California to Texas. While not all these moves were from San Francisco to Houston, using these two cities as an illustrative example, carbon emissions in Houston are about 21 percent higher than they are in San Francisco (Jones and Kammen 2014). Combined with the event study findings, this implies that regulatory constraints that restrict housing, increase the cost of living, and drive this pattern of migration increase household carbon emissions by 12 percent or more, imposing a sizable carbon externality.[16]

[16] The 12 percent figure would correspond to treating San Francisco and Houston as neighborhoods. If we were to treat them more like CBSAs, the predicted increase in emissions would be closer to 19 percent.

Table 4—Unobserved Heterogeneity in CO_2: Variance Decomposition

	CBSA				Tract		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Panel sample							
Variance of log(CO_2)	0.31	0.31	0.31	0.31	0.31	0.31	0.31
Share attributable to places	0.16	0.07	0.08	0.17	0.23	0.15	0.15
Share attributable to hhs	0.50	0.50	0.50	0.30	0.36	0.36	0.36
Corr. of place and hh effects	0.01	0.03	0.03	0.02	0.02	0.08	0.11
SD of place effects	0.23	0.15	0.16	0.23	0.26	0.22	0.22
Mover sample							
Variance of log(CO_2)	0.35	0.35	0.35		0.33	0.33	0.33
Share attributable to places	0.14	0.04	0.04		0.22	0.16	0.16
Share attributable to hhs	0.14	0.16	0.17		0.10	0.10	0.10
Corr. of place and hh effects	0.07	0.08	0.08		0.08	0.16	0.18
SD of place effects	0.22	0.12	0.12		0.27	0.23	0.23
Climate + electricity CO_2		X	X			X	X
Price index			X				X
Time-varying fixed effects				X			

Notes: This table reports results from the heteroskedasticity-robust KSS estimation of variance components. For each sample and specification, the table reports the overall outcome variance, the share of variance attributable to place effects (ψ_j), the share of variance attributable to household effects (α_i), the correlation between place effects and household effects (which captures how much households sort on unobserved characteristics), and the bias-corrected standard deviation of place effects. All specifications include year fixed effects and the standard set of household controls used throughout the paper. Columns 1 and 5 report the baseline variance decompositions at the CBSA and tract levels. Columns 2 and 6 add controls for local mean heating degree days, cooling degree days, and log electricity emissions factors. Columns 3 and 7 additionally control for a price index, constructed from lagged fuel shares interacted with national retail prices. Finally, column 4 computes time-varying CBSA place effects using five-year periods (2000–2004, 2005–2009, 2010–2014, and 2015–2019), using stayer observations across periods to identify time variation in place effects, while movers, as before, identify cross-sectional variation.

B. *Variance Decomposition*

In this section, I weaken the restriction on sorting imposed by the event study and present estimates from the variance decomposition shown in equation (8):

$$\begin{aligned}\text{var}\left[y_{ij}\right] \;=\; &\text{var}\left[\psi_j\right] \,+\, 2\cdot\text{cov}\left[\alpha_i,\psi_j\right] \,+\, \text{var}\left[\alpha_i\right] \\ &+\, \text{var}\left[\mathbf{X}_{it}'\beta\right] \,+\, 2\cdot\text{cov}\left[\alpha_i,\mathbf{X}_{it}'\beta\right] \,+\, 2\cdot\text{cov}\left[\psi_j,\mathbf{X}_{it}'\beta\right] \,+\, \text{var}\left[\varepsilon_{it}\right].\end{aligned}$$

For each sample and specification, Table 4 presents the overall variance of the outcome, log(CO_2); the share of variance attributable to each of the unobserved heterogeneity components (place effects, ψ_j, and household effects, ψ_i); the correlation between the unobserved heterogeneity components; and the bias-corrected standard deviation of place effects. The top panel presents estimates from the entire panel of movers and stayers, while the bottom panel presents estimates from the mover-only sample.

Columns 1 and 5 present the baseline analysis, which includes year fixed effects and the standard vector of household controls. I estimate that CBSA effects account for 14–16 percent of overall heterogeneity (column 1), and tract effects account for 22–23 percent of overall heterogeneity (column 5). Columns 2 and 6 introduce

controls for mean heating degree days, cooling degree days, and log electricity emissions factors, excluding their impact on household emissions from estimated place effects. This specification not only provides insight into the mechanisms driving place effects, as in the event study analysis, but also allows for more precise counterfactual analysis within the KSS framework. When considering interventions that impact household carbon emissions through changes to local amenities and the built environment, isolating the place effect component not driven by climate or electricity-generating sources may be more relevant, though the appropriate specification remains context dependent. For instance, a city-wide initiative to install solar panels on parking lots, potentially coupled with EV charging stations, could decrease the average emissions intensity of electricity while promoting EV adoption. Moreover, while regional climate is, to first order, exogenous to local actions, there are many interventions cities and neighborhoods could enact to decrease heat island effects and in turn reduce local heating degree days (Druckenmiller 2023).

I find that controlling for climate and electric grid intensity together decreases the CBSA share of spatial heterogeneity by roughly 10 percentage points, or by more than half, to 4–7 percent of overall heterogeneity. At the neighborhood level, controlling for climate and electric grid intensity decreases the place share of heterogeneity by roughly 6–7 percentage points (column 6), by less than half, leaving the remaining neighborhood attributes explaining approximately 15 percent. In columns 3 and 7, I additionally partial out variation driven by prices, using a price index constructed from interacting local lagged fuel shares with national retail prices. This does not further change the results at either the CBSA or tract level.

In the Supplemental Appendix, I control separately for electricity emissions factors and climate, and I find that the majority of the decline in place share observed in columns 2 and 6 comes from controlling for electricity emissions factors. It is well understood that climate has a robust effect on energy demand (e.g., Goldstein, Gounaridis, and Newell 2020; Levinson 2016), so why the disparity? Many places that are otherwise low-emissions are in regions that have made efforts to decarbonize their electricity (Murray and Maniloff 2015; Petek 2020), so there is a positive correlation between electricity emissions factors and high other emissions attributes. In contrast to this, I estimate a negative correlation between having above-average heating degree days and low other carbon emissions attributes; many colder cities are in the Northeast, a region that disproportionately contains older, denser cities and neighborhoods (Tomer et al. 2021). These correlation terms enter the place effect variance component, amplifying it when electricity emissions factors are included in the place effect and diminishing it when heating and cooling degree days are included.

Across all three specifications discussed so far, estimates of the place share of heterogeneity are quite comparable between the panel and mover sample. This is not true of the estimates of the household components; a comparison between the panel sample and the mover sample reveals that the contribution of unobserved household characteristics to overall heterogeneity is highly sensitive to which sample the model is estimated on. In the panel sample, unobserved household heterogeneity accounts for 50 percent of overall heterogeneity when defining place at the CBSA level, and 36 percent when measuring place at the neighborhood level. Using the mover-only sample substantially decreases the unobserved household contribution across specifications, to 14–17 percent in the CBSA specification and 10 percent

in the tract specification. The correlation estimates between unobserved place and household characteristics are also sensitive to sample choice, increasing across all specifications by up to 8 percentage points when switching from the panel to the mover sample. This suggests some assortative matching of household types to place types (especially neighborhoods), but in the specification where the correlation coefficient is largest, it remains relatively low, at under 20 percent. The share of overall heterogeneity attributable to matching implied by the covariance term (which is not shown in Table 4 but can be computed from the correlation coefficient and variance components) is less than 5 percent across all specifications.

The panel and mover samples may yield different estimates due to inherent differences between stayers and movers, or KSS's inability to correct for serial correlation in stayers' error terms. To distinguish between these causes, I compare the KSS decomposition estimates with an uncorrected Abowd, Kramarz, and Margolis (1999)—henceforth, AKM—decomposition, presented in the Supplemental Appendix. If differences between stayers and movers drive the discrepancy, both KSS and AKM estimates should reflect this pattern. Conversely, if serial correlation in stayers' error terms is the main factor, AKM should show similar relative contributions of unobserved household heterogeneity across samples (both inflated due to limited mobility bias), with significant differences emerging only after the KSS correction. The AKM estimates reveal relatively stable place and household shares across panel and mover samples, with only minor reductions in the household component's relative size in some specifications. This contrasts with the more dramatic shifts observed in the KSS analysis, suggesting that KSS estimates of household variance components are likely more reliable in the mover sample. Panel sample estimates likely represent an upper bound, with upward bias primarily driven by serial correlation in stayer error terms. The Supplemental Appendix discusses potential sources of this serial correlation, many arising from the survey nature of the data, and their implications for result interpretation. Additionally, the Supplemental Appendix evaluates the sensitivity of results to alternative outcome definitions in the KSS decomposition.

Up until now, I have been estimating place effects pooling over the entire sample time frame; however, place effects may evolve over time in ways that differ from national average trends in carbon emissions. Local or state governments particularly concerned about climate change may enact regulatory changes or make place-based investments aimed at reducing emissions for their residents. Changes to place effects could also arise from local or regional planning initiatives motivated by factors completely unrelated to decision-makers' climate objectives. For instance, the Phoenix metropolitan area—one of the fastest growing metropolitan areas in the United States—grew by nearly 1.6 million residents between 2000 and 2020. This period of growth has been accompanied by a mix of suburban expansion, urban development, the opening of a new light rail system, and several highway expansions (Maricopa Association of Governments 2020). To allow for such place-specific changes, I follow Lachowska et al. (2023) and estimate time-varying fixed effects ψ_{jt} at the CBSA level, using stayers to identify variation across time within place.[17]

[17] Because tracts by definition consist of many fewer observations than CBSAs, including a time-varying component introduces either substantial noise, or a substantial geographic restriction to only the most populated tracts, so I do not estimate time-varying tract effects. Studying neighborhood-level changes is an important direction for future study.

To maintain connectivity in my set of places, and because for the most part places evolve slowly, I define the time-varying place effects using five-year intervals. Thus, there's a different time-varying place effect for each period: 2000–2004, 2005–2009, 2010–2014, and 2015–2019. Results are shown in column 4 of Table 4; allowing CBSA effects to evolve increases their variance share by only 1 percentage point relative to the baseline specification. This implies that changes in places over my sample period are either mostly captured by national secular trends or are unrelated to household carbon emissions. In the Supplemental Appendix, I provide some descriptive results on the nature of changing time-varying place effects in my sample. I also discuss some of the ways in which place effects may have evolved following the COVID-19 pandemic and the ensuing transition to remote work, which was accompanied by a steep decline in commuting and a shift toward larger homes to accommodate home offices (Van Nieuwerburgh 2023; D'Lima, Lopez, and Pradhan 2022).

As a final specification test, in the Supplemental Appendix, I show binned scatterplots similar to those presented in Section IVA, but now with deciles of changes in estimated place effects rather than observational means, on the x-axis. I plot these against two sets of changes in household mean outcomes: changes for the full mover sample and changes in the sample restricted to only households with no big life events. In a correctly specified model, changes in place effects should lead to one-for-one changes in household carbon emissions, though attenuation bias from noisily estimated place effects is expected to decrease the slope by some. This is roughly what I observe. Moreover, I find no discernible difference between the primary sample and the subsample of households experiencing no big life events, which provides additional reassurance that selection on heterogeneous preference shocks isn't a first-order threat to identification in my analysis.

C. *Interpreting Decomposition Results*

How do the event study and KSS results inform one another? First, recall that event study estimates are unbiased only if heterogeneity in the share parameter is uncorrelated with observed and unobserved household characteristics. I have shown evidence that the event study estimates are fairly stable across several observable dimensions of heterogeneity in the data. I also showed in the KSS decomposition that the covariance between unobserved components of heterogeneity is relatively small; the largest correlation coefficient across the four baseline estimates corresponding to the specifications examined in the event study is 0.08. Together, this evidence suggests that bias from this assumption on selection should be minimal.

Second, even when unbiased, the event study yields estimates of shares of mean differences *between* places attributable to place effects, while the KSS estimates yield a variance decomposition of *overall* variation, and this can lead to meaningful discrepancies in magnitudes. To help illustrate this, consider a simplified version of the two-way fixed effects model, where $y_{it} = \alpha_i + \psi_j + \varepsilon_{it}$. Song et al. (2019) show that unobserved heterogeneity can be decomposed further into a between-place component $\text{var}_j\left[\bar{y}_j\right]$, which captures the variation in mean household carbon emissions across places, and a within-place component

$\text{var}_i\left[y_{it} - \bar{y}_j \,|\, i \in j\right]$, which captures the heterogeneity in carbon emissions of households living in the same place:

$$(9) \quad \text{var}\left[y_{it}\right] = \text{var}_j\left[\bar{y}_j\right] + \text{var}_i\left[y_{it} - \bar{y}_j \,|\, i \in j\right]$$

$$= \underbrace{\text{var}\left[\psi_j\right] + 2 \cdot \text{cov}\left[\bar{\alpha}_j, \psi_j\right] + \text{var}\left[\bar{\alpha}_j\right]}_{\text{Between}} + \underbrace{\text{var}\left[\alpha_i - \bar{\alpha}_j\right] + \text{var}\left[\varepsilon_{ij}\right]}_{\text{Within}}.$$

Equation (9) highlights that heterogeneity between places reflects variation in place effects, sorting of certain types of households to certain types of places (the covariance term), and "segregation" of households—the extent to which households of different types segregate across places, whether or not this pattern reflects systematic sorting on place types.[18] In addition to the between-place heterogeneity, overall heterogeneity reflects heterogeneity in household carbon emissions within places, as well as heterogeneity that cannot be explained by the two-way fixed effects model.

For intuition, imagine two places, one ψ_{low} and one with ψ_{high}, with identical populations. If there is high variation in carbon emissions within populations and a small difference between ψ_{low} and ψ_{high}, the event study would yield a share coefficient of one (since populations are identical across places, all between differences are driven by place effects), but the KSS decomposition would yield a place variance component of close to zero (because of a large within component to the variance). In practice, this is very close to what happens at the CBSA level; the vast majority (85 percent) of differences between CBSAs can be attributable to variation in place effects and not household attributes, but there is much more variation in household carbon emissions within CBSAs than there is across, leading to a variance component of approximately 15 percent in the KSS estimation (more than half of which is attributable to climate and electric grid intensity). At the neighborhood level, household sorting contributes more to variation between places, dropping event study estimates of the place share to roughly 55–60 percent. Accounting for variation within neighborhoods in the denominator decreases the neighborhood share to 22–23 percent of overall heterogeneity, or about 15 percent when excluding climate and electric grid intensity from place effects.

V. The Characteristics of Low- and High-Emissions Places

With estimates of place effects in hand, I proceed to characterizing high- and low-emissions places. As highlighted in the conceptual model, place effects reflect a mix of differences in demand for energy services, energy prices, energy demand elasticities, fuel mixes, and emissions factors. The urban planning literature has identified many local amenities that could contribute to differences in average household energy demand and energy demand elasticities. In the residential energy sector, larger homes tend to use more energy, as do single-family homes; there is a strong relationship between carbon emissions and density, though it is potentially

[18] $\bar{\alpha}_j \equiv E\left[\alpha_i | i \in j\right]$.

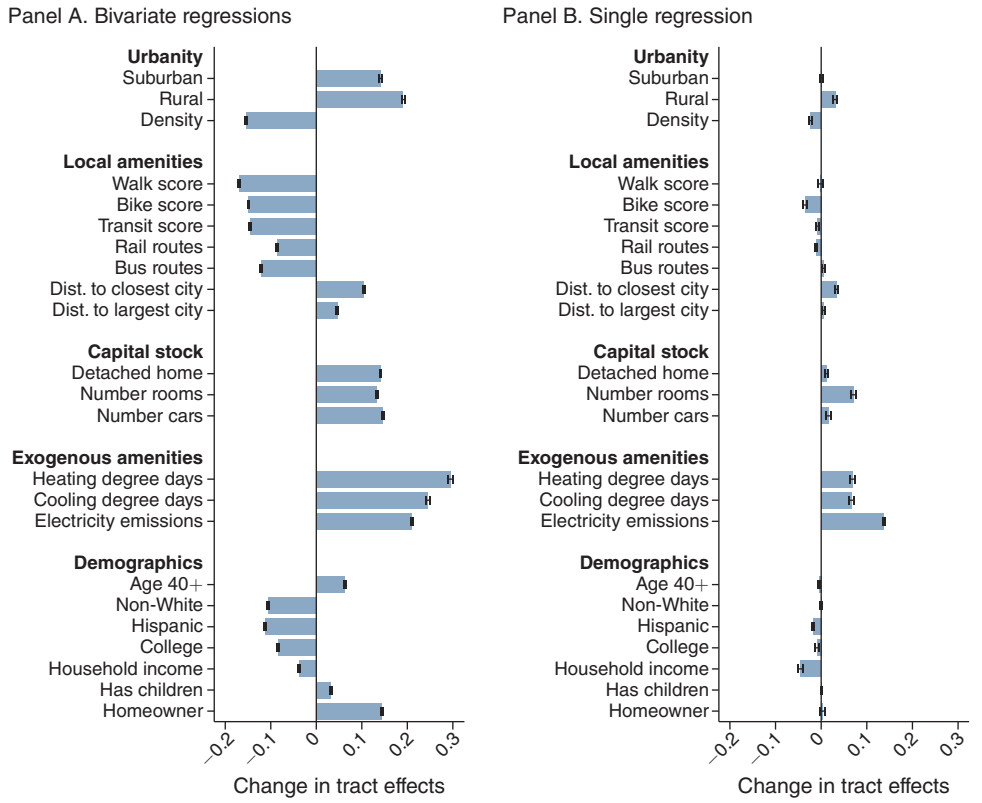

FIGURE 6. CORRELATES OF TRACT EFFECTS

Notes: This figure presents estimates from OLS regressions of estimated tract effects on a set of observable place-based and household characteristics. Panel A shows results from separate bivariate regressions, while panel B shows results from a single regression on all covariates. All amenity variables are tract-level means, normalized to have mean 0 and standard deviation 1, except the rural and suburban indicators, which are retained as indicators. Regressions are weighted using ACS sample weights. Thus, estimated coefficients reflect the average change in place effect—and in turn the percent change in carbon emissions, given the log specification of the model—associated with a 1 standard deviation change in observable characteristics.

nonmonotonic due to the effect of density on microclimates; and parks, plants, and green surface coverage are all negatively correlated with energy use (see, e.g., Ko 2013 for a review). In the transportation sector, car use is lower in places with better public transportation, less parking, and more direct road connectivity (e.g., Transportation Research Board 2009; Barrington-Leigh and Millard-Ball 2017), and mechanically, people drive fewer miles when they live closer to where they work, shop, and spend their leisure time. Many of these amenities are intertwined and simultaneously relate to residential and transportation emissions, underscoring the value of studying these sectors together. For instance, higher density not only implies smaller homes but also enables more efficient public transportation networks by reducing distances between transit stops and destinations.

In Figure 6, I show the results from regressions of estimated tract effects onto a set of observational tract-level characteristics. In panel A, I show coefficients from bivariate regressions of tract effects onto each of the shown tract-level characteristics

independently (except for suburban and rural, which are estimated in a single regression), while in panel B, I show coefficients from a single regression onto all of the characteristics.[19] Observable characteristics are all measured at the tract level and are normalized across tracts to have mean 0 and a standard deviation of 1 (except for suburban and rural, which are retained as indicators). Thus, coefficients should be interpreted as showing approximately the average percent change in carbon emissions associated with a 1 standard deviation change in neighborhood-level observable characteristics.

Observable characteristics fall into five categories. Both "urbanity" and "local amenities" cover aspects of urban form that households effectively taken as given but that vary neighborhood to neighborhood. These include whether a tract is urban, suburban, or rural, its density, measures of local public transportation amenities (walk scores, bike scores, transit scores, number of nearby rail routes and bus routes), and measures of sprawl (captured by geodesic distance between tract centroids and the centroid of the closest city and the largest city within the CBSA). "Capital stock" characteristics reflect household choices among the set of options available in a place, which are determined at least in part by local zoning regulations or other policies. These include the share of single-family detached homes, average house sizes, and the number of cars in a household. "Exogenous amenities" are predominantly shaped by factors beyond local control, and households also take these as given. These include annual heating degree days, annual cooling degree days, and electric grid intensity.[20] Finally, the "demographics" category captures tract-level variation in household observable characteristics.

The results of the bivariate regressions (panel A) are consistent with observational data and conclusions in the urban planning literature. Higher-emissions neighborhoods tend to be less urban and dense, with poorer walkability, bikability, and public transit options, and are typically situated farther from city centers within their CBSA. Higher-emissions neighborhoods feature a higher proportion of detached and larger homes, with households owning more cars on average. They experience less mild climates and have higher electricity emissions factors. Finally, looking at the projection of tract effects onto demographics, I find that non-White, Hispanic, college-educated, and higher-income households are more likely to live in low-emissions tracts, while older households, households with children, and homeowners are more likely to live in high-emissions tracts.

When including all of these characteristics in a single regression (panel B), directionally, the relationships remain the same, but many of the coefficient magnitudes decrease substantially. Electricity emissions factors, heating degree days, and cooling degree days emerge as three of the four strongest correlates of place effects. The second-largest correlational coefficient is on the number of rooms in a house; a standard deviation change in tract mean number of rooms is associated

[19] I used a LASSO regression with 10x crossfold validation to select characteristics, and it retained all of the variables.

[20] As mentioned earlier, neither climate nor electricity emissions factors are impervious to local influence. Urban form can quite meaningfully impact local microclimates through urban heat island effects, but in this paper my measure of climate is at the NOAA climate division level, a geographically coarser definition. And municipal utilities can shape local electricity emissions factors through energy procurement choices but currently make up a small share of overall electricity supply.

with a roughly 7 percent change in tract-level carbon emissions. The remainder of tract effects appear to load primarily onto measures of sprawl, the quality of local bike infrastructure, rurality, density, and household income, with standard deviation changes in these characteristics being associated with a 2–4 percent change in carbon emissions each. It is notable that measures of walkability, transit quality, share of detached homes, and number of cars appear to become less important after conditioning on density, sprawl, and home size. It is possible that this is because these characteristics are very colinear in the observational data; as highlighted earlier, many of these relationships are interconnected.

The Supplemental Appendix shows analogous projections of household fixed effects onto observable neighborhood-level characteristics. I find that correlations between household effects and observable characteristics are about an order of magnitude weaker than those between tract effects and observable characteristics in both the bivariate regressions and the full regression. This is consistent with minimal sorting on unobserved household characteristics that I estimate in KSS. The largest coefficients imply that households with high unobservable potential for carbon emissions sort to tracts where people are on average higher income and have more children, where it is warmer, where electricity is higher-emissions, and where houses are bigger. The Supplemental Appendix presents additional results on the correlates between observable household characteristics and observable place characteristics.

These regressions do not elucidate causal relationships. As is the case with inference about place effects as a bundle, inference about the role of specific amenities from observational data alone is likely to be biased by household sorting. Nevertheless, the observational data suggest features of urban form whose effect on household carbon emissions should be studied further with credible exogenous variation in the amenity itself. Previously, one might worry about whether a setting for such a case study is selected. Can we learn about the effect of lifting zoning restrictions and allowing for smaller lot sizes if people who live in denser cities have significantly different preferences than those who don't? Are improvements to bike infrastructure only effective in cities where a lot of people already bike? The core results of my paper suggest that a meaningful share of variation between places is driven by variation in place effects, with evidence that place effects are constant across heterogeneous populations, mitigating some of these concerns about external validity.

VI. Implications for Aggregate Carbon Emissions

The wide distribution of place effects suggests that there may be an opportunity to substantially reduce household carbon emissions from residential and transportation energy through what I refer to as place-based climate policies. Place-based climate policies—distinct from regional energy sector regulations or market-based mechanisms designed to encourage decarbonization—aim to reduce household carbon emissions by altering local characteristics that shape household energy choices.[21] They could be implemented at federal or local levels and, building on insights

[21] As transportation and residential sectors electrify and the power grid decarbonizes, the impact of place-based drivers of household emissions will diminish. However, given current challenges in clean electrification, particularly

from labor and urban economics, could be designed to simultaneously reduce carbon emissions and address economic development goals, housing shortages, or local externalities like pollution and congestion.

Infrastructure and local public goods investments make up one category of potential place-based climate policies. The federal government has a history of investing into transportation infrastructure, with the Interstate Highway System being its most notable example (US Department of Transportation 1977). More recently, the Bipartisan Infrastructure Law provided a significant increase to transit funds across the country; the Federal Transit Administration announced in early 2024 that it would be investing $9.9 billion to support local transit systems in urban areas across the United States (US Department of Transportation 2024). While adding and expanding public transit networks is perhaps the most obvious example of an intervention that might decrease place effects, many cities are implementing less costly initiatives that repurpose existing urban space for community use. Paris's Plan Velo has converted over 200 miles of roads into (often protected) bike lanes as of 2024, with further expansions planned through 2026 (Ville de Paris 2021). Barcelona's Superillas program aims to transform more than half of its car-dominated streets into mixed-use public spaces (Roberts 2019), while New York City's High Line project has repurposed an abandoned elevated railway into a popular pedestrian walkway and park. The COVID-19 pandemic accelerated this trend, sparking "slow" or "open" streets programs that temporarily restricted car traffic to benefit pedestrians and cyclists in many cities of the United States, with some cities now working to make these changes permanent (New York City Department of Transportation 2023; Combs 2020). Expanding the network of electric vehicle chargers is another example of a lower-cost place-based infrastructure investment that can reduce carbon emissions.

A second category of potential place-based policies includes regulatory changes intended to encourage—or remove barriers previously preventing—sustainable urban development. Zoning deregulation, land use reform, and transit-oriented development have all gained traction in the United States in recent years. In 2018, Minneapolis became the first city in the United States to enact a city-wide ban on exclusionary zoning, a common practice across the United States that restricts land to be used for single-family homes only (Mervosh 2018). In 2021, the California State Assembly passed Bills 9 and 10, which streamlined the process of "upzoning" residential land, allowing for the development of up to four units on land previously zoned for single-family homes only and facilitating higher-density construction near transit corridors. This was followed by AB 2097 in 2022, which eliminated most parking minimum requirements for new development (Fulton et al. 2023). At the federal level, President Biden's original infrastructure bill proposal in March 2021 included grants to cities that eliminated exclusionary zoning. While this portion of the bill did not get passed, and many states and municipalities are still debating but not implementing zoning reforms, these examples illustrate the relevance of such approaches in the current policy debate. At the same time, some states and

transmission capacity constraints and aging infrastructure (e.g., US Department of Energy 2015), place-based policies that reduce energy demand and alleviate pressure on the electricity grid could be complementary to more traditional decarbonization instruments.

municipalities are making regulatory efforts to make building codes more stringent by, for example, enacting energy efficiency minimum requirements (Levinson 2016) or mandating electrification through natural gas hookup bans (Payne 2021).

This paper does not identify a causal relationship between any specific amenity and place effects, or any specific intervention and place effects, but it shows evidence that low-emissions places are low-emissions not simply due to sorting of low-emissions people to those places, and that low emissions places tend to have amenities that are characteristic of more urban, less sprawling neighborhoods. Using this as motivation, I examine how carbon emissions would change if the national distribution of place effects was more urban than it currently is. Specifically, to approximate a scenario in which the United States limits suburban sprawl and increases the share of households within a region that live in an urban neighborhood, I estimate the effect on emissions if households currently living within a suburban or rural area lived instead in a place with the average place effect of the nearest principal city. A naïve comparison of household emissions shows that, on average, households living in principal cities emit 20 percent less than households living in surrounding areas. After accounting for sorting of households between suburban and urban neighborhoods, my estimates suggest that if every tract had the place effect of the nearest principal city, the emissions of suburban and rural households would decrease by approximately 15 percent.

The majority of principal cities in the United States would not be considered particularly urban on a global scale. To consider the potential effect of deeper urbanization, I examine how household carbon emissions would change if more people lived in places like Manhattan, which is uniquely dense, walkable, and transit oriented within the US context. Specifically, I examine how the emissions of households in the principal cities of the nine largest CBSAs after the New York Metropolitan Area in the United States (US Census Bureau 2024) would change if those cities developed into a place with the average place effect of Manhattan. The observational gap is enormous: Even using large cities as a comparison group, households in Manhattan emit about 73 percent less than observably comparable households in the other 9 large cities. Accounting for unobserved fixed differences between households reduces the gap to 60 percent; people who choose to live in Manhattan are a selected subsample, but their emissions are nevertheless much lower as a result of living in Manhattan than they would be if they lived elsewhere.

These exercises lend insight into how development that shifts population shares across place types by "expanding" places with lower place effects—either by making their neighbors look more like them or by allowing more people to live in such places without changing their fundamentals—could affect emissions in the future. My estimates yield only a first-order, partial equilibrium approximation to the effect of such interventions, as in practice, there would be some re-sorting of populations in response to place-based changes, which would change the distribution of household types living in each place and thereby change aggregate carbon emissions. More importantly, my estimates don't lend insight into the specific interventions that would result in the largest changes to place effects; this is a critical direction for future research. My results highlight that the potential for urbanization-induced reductions to carbon emissions is overstated when inferred from observational means across places because people choose where to live based in part on their

potential carbon emissions. Nevertheless, because there is substantial variation in household carbon emissions and neighborhood effects explain 15–23 percent of this variation—depending on whether climate and electricity emissions are included in the place effects—my results also imply that even relatively small shifts in the distribution of place effects that households are exposed to could meaningfully decrease aggregate carbon emissions.

VII. Discussion

This paper is the first to estimate the causal effects of places on household carbon emissions and decompose spatial heterogeneity in carbon emissions into a component driven by these place effects and a component driven by household characteristics and sorting. I find that up to 23 percent of overall heterogeneity in household carbon emissions from residential energy use and commuting across the United States can be explained by neighborhood effects, or roughly 15 percent can be explained by neighborhood effects after accounting for variation driven by climate and electric grid intensity. Paired with high overall heterogeneity, these estimates imply that interventions that change the population-weighted distribution of place effects across the United States, either through direct changes to places or through regulatory changes that make it possible for more people to live in low-emissions places, could result in meaningful reductions in household carbon emissions.

There are several limitations of my empirical analysis that should be taken into consideration while interpreting my results. The first is that due to the survey nature of my data, carbon emissions are noisily measured. This leads to lower explanatory power of the model than is standard in papers using these methods with administrative data to estimate firm wage premia. The relatively low explanatory power of the model could also reflect model misspecification, but with only two observations per household for the majority of my sample, the number of specification tests I can do is limited. Second, there is relatively little variation in urban form and transportation options across the United States; 75 percent of residential land in the United States is zoned for single-family homes only (Badger and Bui 2019), 95 percent of commuters in my sample commute by car, and there is only 1 high-speed rail line in the entire country, which operates at high speed over only roughly 50 miles of track. This is in stark contrast with other parts of the world, where many cities are denser and substantially less car oriented. Moreover, place effects are identified from movers, who differ from the general US population in meaningful ways. Thus, the external validity of my results relies upon estimates being stable to widening the distributions of place and household types.

Establishing that place matters—and how much it matters—for household carbon emissions takes a critical first step toward investigating the welfare impacts of specific place-based climate policies. The welfare effects of a given intervention depend on several parameters whose estimation is outside of the scope of this paper. First, they depend on the causal relationships between local amenities and place effects, and on household preferences for local amenities. While Tiebout (1956) posits that residential sorting allows for efficient provision of local public goods, his framework only applies to amenities without scale economies. Moreover, there is reason to believe that residential sorting is not efficient due to frictions and

exclusionary policies (e.g., Rothstein 2017; Hausman and Stolper 2021; Christensen and Timmins 2023; Avenancio-León and Howard 2022). Estimating causal relationships between local public amenities and household carbon emissions and quantifying whether emissions-relevant local public amenities are at an efficient level are important directions for future work. Second, the welfare impacts of place-based interventions would depend on the costs of implementing them relative to the cost of business as usual or other contender climate policies. Costs can vary dramatically for the same intervention in different settings (Goldwyn et al. 2022), making this estimation difficult, but incorporating cost estimates for a marginal value of public funds analysis (Hendren and Sprung-Keyser 2020) is another important avenue for future research. It is worth emphasizing that because built environment is sticky, infrastructure investments and regulatory choices made in the present day have the potential to increase or decrease the costs of carbon mitigation efforts in the future. Finally, welfare impacts would depend on other externalities or agglomeration benefits of the intervention. For example, the types of interventions highlighted in this paper could also impact local air pollution, congestion, traffic fatalities, and labor market productivity. These co-benefits and harms have been extensively studied in the environmental and urban economics literatures, and estimates could be incorporated into an aggregate welfare effect.

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