# Impact of Urban Sprawl on Greenhouse Gas Emissions

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September 16, 2024

**Abstract**

This study examines the impact of urban sprawl on carbon dioxide emissions. Using county-level panel data, we explore whether low-density urban structures lead to high emissions in the transportation sector. Our findings indicate that a one percentage point increase in the share of single detached housing units results in a 1.5% increase in per-person on-road carbon dioxide emissions. Robust evidence from alternative identification strategies using instrumental variables supports our results. Additionally, we show that the increase in emissions is mainly attributed to private passenger transportation rather than public transport or freight transportation.

**Keywords:** urban sprawl, greenhouse gas, panel data analysis

**JEL:** Q5, R1

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# 1 Introduction

The era of global boiling has arrived.[1] Global temperatures have steadily risen over the past few decades, leading to a series of disasters worldwide. The accumulation of greenhouse gases (GHGs), caused by human activity, is undeniably responsible for climate change. In this regard, international organizations and governments have adopted various methods to mitigate the effects of climate change and reduce atmospheric carbon levels.

This study examines the environmental impact of urban sprawl, often characterized by low-density residential housing, single-use zoning, and increased reliance on private automobiles for transportation. The American preference for single detached housing units is notable; the US is home to 81.8 million single detached units, with the majority of Americans living in them. The widespread adoption of this type of housing has created various urban problems in the US (Nechyba & Walsh, 2002). Low-density residential housing is known to increase private driving on the road (Kahn, 2000; Glaeser, 2011). In the literature, however, few studies have investigated the causal impact of low-density urban structures on on-road GHG emissions.

Estimating the causal impact of urban sprawl on on-road GHG emissions is challenging because of measurement problems (e.g., emissions from other sources) and omitted variables. To address the measurement issue, we utilize data from the National Emissions Inventory (NEI), which provides detailed information on GHG emissions from various sources at the county level. These data enable us to specifically identify on-road GHG emissions by emission source. To address the issue of omitted variable bias, we construct a county-level panel dataset and estimate a two-way fixed effect regression model. We also consider an alternative identification strategy based on an instrumental variable derived from the land's topology (Saiz, 2010).

We find that on-road GHG emissions are positively related to the prevalence of single detached units in each city. Specifically, a one percentage point increase in

[1] The United Nations (UN) Secretary-General, António Guterres, spoke at the UN Headquarters after scientists from the World Meteorological Organization and the European Commission's Copernicus Climate Change Service announced that July 2023 was recorded as the hottest summer month in human history.

single detached housing units in an urban area leads to a 1.5% increase in on-road carbon dioxide emissions per capita. This study also demonstrates that the effects vary across regions, with counties in the Northeast and West regions exhibiting larger effects than those in other regions. Our findings are supported by robust evidence under alternative identification strategies based on instrumental variables. Regarding the underlying mechanism, private passenger transportation mainly drives these effects. We also showed that the increased prevalence of single detached units leads to a high reliance on private cars for commuting; a one percentage point rise in single detached units corresponds to a 0.8% increase in workers commuting by private vehicles.

Based on the predictions of the monocentric model, Bento, Cropper, Mobarak, and Vinha (2005) examined how urban structures influence residents' commuting patterns and travel distances, incorporating public transportation systems into the model. They empirically demonstrated that the likelihood of driving to work decreases with high population centrality, the even distribution of workplaces across the city, and well-supplied public transportation systems. This study expands on the original concept proposed by Bento et al. (2005). If the urban structure affects the use of private automobiles, this influence should ultimately extend to the on-road GHG emissions generated by these vehicles.

Some studies have investigated the environmental effects of suburbanization. Glaeser and Kahn (2004) pointed out that there are two negative driving externalities: GHG emissions and local smog. They pointed out that suburbanization has increased drivers' GHG emissions by 10% on average, whereas the most polluted regions in the US had experienced a dramatic fall in smog levels. Kahn (2000) reported that technological progress in the 1970s contributed to the significant drop in smog levels. Nonetheless, further empirical studies are needed to determine the environmental effects of suburbanization on GHG emissions from driving.

A notable study by Glaeser and Kahn (2010), which is closely related to our work, investigates the relationship between urban characteristics and GHG emissions, focusing on the differences in carbon dioxide emissions across US metropolitan cities. They quantified carbon dioxide emissions by metropolitan area and human activity, such as driving, public transportation, home heating, and electricity consumption. They found that the differences in carbon dioxide emissions between cities are primarily attributed to climate factors, with July temperatures affecting electricity consumption and January temperatures influencing home heating. The present study enhances their approach to comparing carbon dioxide emissions between cities by adopting panel data on GHG emissions, which allows for the identification of emissions by source. This work also verifies the causal effect of urban structures on GHG emissions using these datasets.

The rest of the paper consists of the following sections. Section 2 briefly explains urban sprawl in the US. Section 3 introduces the data sources and descriptive statistics. Section 4 provides the model specifications and related results. Section 5 discusses the policy implications and concludes the study.

# 2 Urban Sprawl and GHG Emissions

Sprawl in the US has a long history. According to Nechyba and Walsh (2002), cities or urban areas emerged and grew in the 19th and 20th centuries. Moreover, the increase in population and broadened land areas are focused on suburban areas. These factors have led to the physical growth of urban areas and to the low population density in urban areas, called *urban sprawl*.

In the early 20th century, a legal and institutional foundation encouraging sprawl was already established. In the case of Euclid v. Ambler in 1926, the US Supreme Court endorsed local governments' zoning ordinances, which could restrict land uses and types of buildings. Accordingly, many local governments and counties have encouraged the construction of single detached units by adopting zoning regulations, such as single-family zoning acts or equivalent measures, in their extensive urban areas.

Several causes of urban sprawl have been mentioned. A primary background is decreased transportation costs and rising income levels (Glaeser & Kahn, 2004). Baum-Snow (2007) showed that accessibility to highways has also encouraged suburbanization, reducing the population in central cities. This implies that ease of accessibility to suburbs has led to urban sprawl. Likewise, other natural characteristics and political reasons contribute to urban sprawl (Burchfield, Overman, Puga, & Turner, 2006).

While people can enjoy commodious and airy spaces, urban sprawl has brought various negative externalities. The indiscriminate expansion of urban areas has caused unnecessary traffic congestion and environmental pollution, has taken away open spaces adjacent to cities, and has discouraged the provision of public goods, such as public transportation. Social segregation may have also increased (Nechyba & Walsh, 2002).

Recently, a few state governments and some cities abolished single-family zoning or banned designating it in populated cities. In 2019, the Oregon State Legislature initially approved Housing Bill 2001, mandating medium to large cities to allow residential buildings to accommodate multiple households in single-family zoning. California and Maine also reduced restrictions on new housing and terminated single-family-only zoning in 2021 and 2022, respectively.

How does urban sprawl affect GHG emissions in the transportation sector? The expanded urban areas covered by single detached housing units increase the distances between housing and business districts. The farther distance increases transportation costs in multiple dimensions; that is, workers have to commute farther, deliveries of commodities have to travel more time, children should go to farther schools, and bus drivers need to cover a wider range of local communities. The increased transportation distance causes high energy consumption in transportation and, consequently, an increase in GHG emissions per capita.

Dispersed housing also obstructs the supply of infrastructure, such as public transportation. A bus stop in front of an apartment can serve all apartment residents. However, a village of single detached units impedes building such an effective public transportation system. Thus, people living in a village of single detached units cannot avoid driving when they move. In short, the predominant housing structure in a city affects residents' transportation patterns and, eventually, the amount of on-road GHG emissions per person.

# 3 Data Overview

## 3.1 Data Sources

The primary dataset used in this study is the NEI, provided by the US Environmental Protection Agency (EPA). The NEI is a panel dataset that estimates the amount of anthropogenic air pollutants observed at the county level every three years. To exclude the confounding effect of sulfur regulation and the gradual replacement of vehicles in the late 2000s, we use data from 2011 to 2020, covering four triennial years.

Appending to the NEI datasets, the US EPA's Source Classification Codes (SCCs) database, which is a codebook systematizing human activities generating GHG emissions, is used. The SCCs categorize the sources of air pollutant emissions into five groups: point, nonpoint, on-road, nonroad, and event sources. [2] Under this broad categorization, the SCCs further separate emission sources by industrial process (or vehicle type), fuel type, and so on. By virtue of the structuralized estimates of air pollutants, we can identify the amount of carbon dioxide emissions by vehicle type separately.

To describe the housing structure composition of each metropolitan city, we adopt the American Community Survey (ACS), conducted by the US Census Bureau. Based on the survey, the Census Bureau has provided the estimated number of housing units by building structure since 2010.[3] Using the estimates, we measure the shares of single detached units by metropolitan statistical areas (MSAs).

We also collect various datasets regarding other covariates related to carbon dioxide emissions in the transportation sector. First, we obtain the historical retail

[2]Point sources include large-sized sources located at certain fixed locations, such as industrial facilities and electric power plants. Nonpoint sources refer to small and individual sources, such as residential heating and cooking. On-road sources include on-road vehicles that use fossil fuels, such as heavy- and light-duty vehicles. Nonroad sources refer to automobile sources that are not on-road vehicles, such as construction hardware and gardening equipment. Event sources refer to nonperiodic events that generate air pollutants, such as wildfires.

[3]The data count the number of housing units in structures by building type, not the number of buildings. The Census Bureau classifies housing units by 10 building structure types: single detached, single attached, apartments (i.e., two units, three or four units, five to nine units, 10–19 units, 20–49 units, or 50 or more units), mobile homes, and other types (e.g., boats, RVs, and vans).

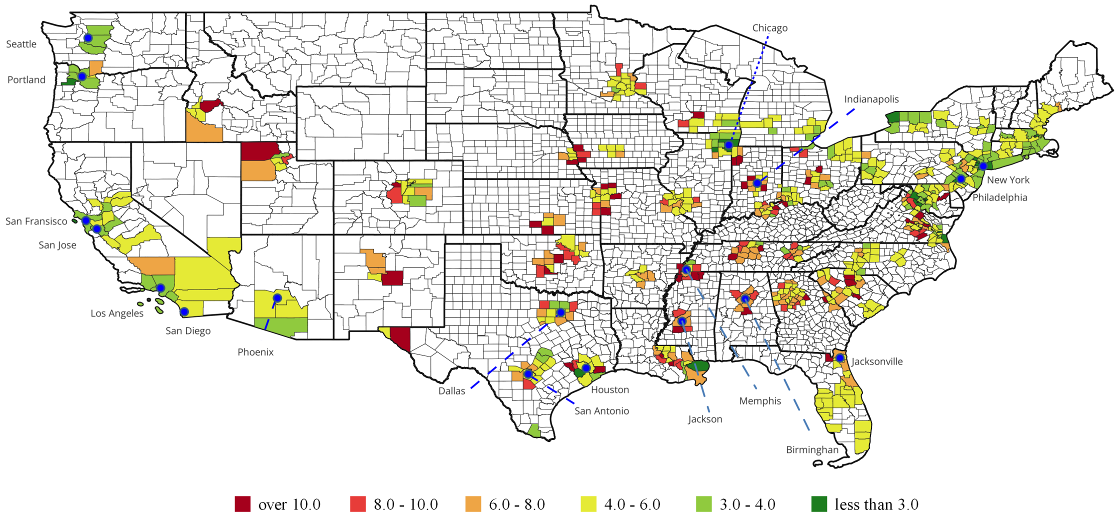


Figure 1: Carbon dioxide emissions in the transportation sector in 2020 (per capita, ton)

prices of fossil fuel energy from weekly retail gasoline and diesel prices provided by the US Energy Information Administration. This agency records the annual prices of gasoline and diesel, including taxes. Lastly, we use the annual population estimates produced by the Census Bureau's Population Estimates Program to compute the per capita carbon dioxide emissions by county.

## 3.2 Data Description

This subsection provides descriptive figures and statistics describing carbon dioxide emissions and housing structure composition across the US. First, we compute the amount of carbon dioxide emissions in the transportation sector per capita by county using the NEI datasets. Because sulfur regulation on diesel fuel has dramatically reduced the nitrogen oxides emitted from automobiles, we focus on carbon dioxide emissions in the transportation sector. This study focuses on the contiguous US, dropping Alaska, Hawaii, and other offshore insular areas. We also restrict counties located in core-based statistical areas with a population of over 500,000 in 2005.

Figure 1 shows the carbon dioxide emissions per capita from on-road transportation by county in 2020. First, we can observe different patterns across regions in the contiguous US. Particularly, counties that generate relatively less per capita carbon

Table 1: Descriptive Statistics of Housing Composition and Other Variables

| | Mean | Census Region | | | |
|---|---|---|---|---|---|
| | | Northeast | Midwest | South | West |
| Single Detached Units (%) | 62.18 | 51.89 | 65.51 | 63.53 | 63.50 |
| | (9.18) | (11.50) | (6.13) | (7.14) | (7.66) |
| | [0.37] | [0.37] | [0.29] | [0.38] | [0.45] |
| Household Income (1,000 $) | 61.89 | 68.16 | 61.71 | 58.90 | 67.06 |
| | (17.10) | (16.91) | 13.18) | (17.91) | (17.85) |
| Family of Married (%) | 75.63 | 75.04 | 78.30 | 74.19 | 77.20 |
| | (7.11) | (7.05) | (6.03) | (7.42) | (5.87) |
| Family with Children (%) | 42.71 | 41.96 | 43.72 | 42.09 | 44.42 |
| | (5.50) | (3.82) | (4.40) | (5.99) | (6.73) |
| Gasoline Prices | 2.91 | 3.03 | 2.87 | 2.83 | 3.14 |
| | (0.62) | (0.60) | (0.62) | (0.62) | (0.53) |
| Diesel Prices | 3.21 | 3.38 | 3.16 | 3.14 | 3.37 |
| | (0.64) | (0.60) | (0.65) | (0.65) | (0.57) |
| Observation | 2,363 | 372 | 573 | 1,172 | 246 |
| Number of MSA | 98 | 17 | 20 | 39 | 22 |

dioxide emissions are located in the states of the Northeast Census Region and the Pacific coastal states of the West Region. An examination of detailed areas on the map reveals that populous cities generate low per capita carbon dioxide emissions in the transportation sector. The blue dots on the map indicate the locations of US metropolitan cities. We can see that people in counties comprising or surrounding such cities emit relatively less carbon dioxide. By contrast, people living in counties within the inland states of the West Census Region and those within the southern states generate higher carbon dioxide emissions, as indicated by red-highlighted counties. As the global average total carbon dioxide emissions in 2020 are around 4.7 metric tons per person, this means that individuals living in the red-highlighted counties emit carbon dioxide (via passenger transportation) that is higher than the global average. These findings are consistent with those of Glaeser and Kahn (2010).

Next, we describe the housing structure composition in metropolitan areas. The first row in Table 1 presents the descriptive statistics for the fraction of single-detached units in MSAs with more than 500,000 population in 2005 across the entire US and other subgroups, classified by city size or region, in this order. The single detached unit structure constitutes the majority of housing unit types in US metropolitan areas, comprising more than 60% of the total housing units. However, heterogeneities in housing structure composition are also evident across regions. Specifically, throughout this study, we classify an MSA with a population of more than one million in 2005 as a large metropolitan city and an MSA with a population from 500,000 to 1 million as a medium-sized city. The remaining four columns show that MSAs in the Northeast region have approximately 10 percentage points fewer single detached units than MSAs in other regions.

Table 1 provides two types of standard deviations for the fraction of single detached units: the total variation in parentheses and within variation in brackets. This implies that most variations come from between variations. This is plausible because the study period is confined to a decade, and the change in housing structure composition cannot be dramatic because of the majority of existing housing units. Nonetheless, comparing the relative magnitude of within variation to total variation is meaningful. The rest of Table 1 presents the statistics of other variables that might affect the carbon dioxide emissions per capita from on-road vehicles in local areas. Using ACS datasets, we compute demographic variables: median household income, the share of families married, and the share of families with children. The median household income is about USD 62,000, and it also shows a considerable difference by city size and region. The fraction of families married and that of families with children make up 75.6% and 42.7% of the total families, respectively. It also differs across census regions.

The next rows report the prices of fossil fuels mainly used in automobiles. The average gasoline price is USD 2.91, and the average diesel price is USD 3.21 per gallon. The higher diesel prices reflect the increased production and distribution costs of diesel fuel as a result of EPA regulations that lower sulfur starting in 2006. Fuel prices rarely vary across city sizes, but they do across regions.

# 4 Estimation and Results

In this section, we present how the urban structure, measured by the share of single detached housing units within a metropolitan area, affects a city's on-road carbon dioxide emissions.

## 4.1 Model Specification

To resolve the potential omitted variable bias, we consider the following fixed effect regression model:

$$Y_{it} = \beta \times SingleDetached_{st} + \delta_t + \zeta_i + X_{it}\gamma + \varepsilon_{it} \tag{1}$$

where the dependent variable $Y_{it}$ is the log-transformed per capita carbon dioxide emissions in the transportation sector. The subscripts $i$, $s$, and $t$ stand for county, the MSA containing the county, and year, respectively. The first term, $SingleDetached_{st}$ on the right side is the main independent variable of the suggested fixed effect model, which is the proportion of single-detached housing units among the total housing units in percentage. The next two terms control for county fixed effects ($\zeta_i$) and time fixed effects ($\delta_t$).

$X_{it}$ represents the control variables, which can affect the carbon dioxide emissions in the locale. They are classified into two groups: covariates related to household characteristics and covariates related to fossil fuel prices.

First, we control for the median household income and other demographic variables. Households with higher incomes are more likely to move farther and drive private vehicles. Marriage and having children fundamentally affect households' lifestyles. Married couples easily share their means of transportation. Furthermore, children under 18 years of age need their parents' assistance, including driving. Thus, household income, the share of married couples, and the fraction of families with children can affect carbon dioxide emissions.

The specification also includes control variables representing the retail prices of fossil fuels used in automobile vehicles in order to control for the indirect effects of costs on moving on-road vehicles. Adding time-variant control variables to fixed effect terms enables the model to resolve possible omitted variable biases. Lastly, $\varepsilon_{it}$ is the error term.

Note that, except for the share of single detached units, all variables are at the county level, which is the most granular level available. By adding county fixed effects, we can control for any unobserved county-level factors that might potentially bias our estimates. The share of single detached units is available at the MSA level. As this variable measures the urban structure of a given city, we believe that it is appropriate to observe the proportion of single detached housing units at the MSA level.

## 4.2 Results

Table 2 presents the estimated results. Column (1) presents the results for the ordinary least squares regression of on-road carbon dioxide emissions on the fraction of single detached units without county and year fixed effects. The coefficient of the single detached units (%) is positive (0.0192). The result in column (2), including county fixed effects, still shows a positive coefficient. However, the adjusted R square jumps when the fixed effects are included, indicating that the county's time-invariant characteristics explain a large amount of the variation in GHG emissions. The most comprehensive model in column (4), which includes control variables, presents a small but still significantly positive coefficient (0.0147); a one percentage point increase in single detached units is associated with about a 1.5% increase in carbon dioxide emissions in the transportation sector.

The following columns present the heterogeneous effects of urban sprawl using subsamples from each census region. Columns (5) to (8) indicate that environmental effects are not observed in the South region, while the Northeast and West regions primarily account for the impact of the fraction of single detached units on GHG emissions.

It might be surprising that the South region does not show a significant positive effect of urban sprawl on GHG emissions in the transportation sector, despite residents in this region generating high levels of carbon dioxide emissions (Figure 1). For a change in housing structure to influence GHG emissions from passenger

Table 2: **Environmental Effects of Sprawl**

| | Full Sample | | | | Census Region | | | |
|---|---|---|---|---|---|---|---|---|
| VARIABLES | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| Single Detached Units (%) | 0.0192*** | 0.0188*** | 0.0231*** | 0.0147*** | 0.0395*** | 0.0086 | 0.0116 | 0.0225 |
| | (0.0019) | (0.0083) | (0.0071) | (0.0070) | (0.0131) | (0.0184) | (0.0106) | (0.0150) |
| Control Variables | | | | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year FE | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| County FE | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Samples | All | All | All | All | Northeast | Midwest | South | West |
| Observations | 2,363 | 2,363 | 2,363 | 2,363 | 372 | 573 | 1,172 | 246 |
| R-squared | 0.1621 | 0.9329 | 0.9480 | 0.9495 | 0.9497 | 0.9327 | 0.9455 | 0.9657 |

Cluster-robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

cars, residents should opt for alternative transportation methods, such as buses or subways. In other words, changes in housing structure do not affect GHG emissions unless supportive infrastructure and transportation systems are in place.

## 4.3 Two-Stage Least Squares (TSLS) Estimates

In this subsection, we supplement the fixed effect model analyses with TSLS models to support the validity of the results of the fixed effect model above. A starting point for our TSLS strategy is the observation that land-constrained cities can lead to a low share of single detached units. We adopt the Saiz (2010) measure, which quantifies geographic constraints. To measure the share of undevelopable land in each MSA, Saiz calculated the fraction of areas covered by water or those with a gradient above 15%. He argued that restrictive geography accounted for housing supply elasticities, so it strongly predicted housing price levels and growth. Taking up Saiz's (2010) assertion, we assume that the scarcity of developable land in a city affects the housing structure composition in it. Concretely, geographic unavailability has driven local housing markets to construct residential buildings that serve many households on a site rather than single detached units because of land shortage. If this is the case, the Saiz (2010) measure, the share of undevelopable areas, is negatively associated with the share of single detached housing units.

The results of the TSLS estimation of the environmental effects of housing structure composition using geographic constraints as instruments are presented in Table 3. As the share of undevelopable land in an MSA has rarely changed over time, we conduct a cross-sectional TSLS regression using four NEI datasets separately for each period. The control variables used in Table 2, Column (4), are included in all TSLS regressions.[4] Each column in Table 3 shows the TSLS estimates for each year. All estimates fluctuate slightly, falling into a range from 2.2% to 2.5%.

The bottom row of Table 3 reports the results of the weak identification test of the instrument variable. All the first-stage F-statistics are larger than 10, indicating that the instrument variable (land) is not a weak instrument. According to the 2020 ACS dataset, a one percentage point increase in the undevelopable land share is associated with a 0.22 percentage point fall in the share of single detached units, on average, as predicted above.

Table 3: **TSLS Estimates of the Environmental Effects of Sprawl**

| | Year | | | |
|---|---|---|---|---|
| VARIABLES | 2011 | 2014 | 2017 | 2020 |
| Single Detached Units (%) | 0.0345*** | 0.0238*** | 0.0277*** | 0.0340*** |
| | (0.0096) | (0.0081) | (0.0091) | (0.0077) |
| Control Variables | | | | |
| Demographics | ✓ | ✓ | ✓ | ✓ |
| Fuel Price | ✓ | ✓ | ✓ | ✓ |
| Observations | 543 | 545 | 545 | 542 |
| R-squared | 0.1262 | 0.2051 | 0.2177 | 0.2069 |
| First-Stage Regression of Single Detached Units (%) | | | | |
| Undevelopable Land (%) | -0.103*** | -0.122*** | -0.121*** | -0.145*** |
| | (0.017) | (0.016) | (0.017) | (0.019) |
| Weak Identification Test (F Statistics) | 37.14 | 58.42 | 50.73 | 61.08 |

Cluster-robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

[4] County and Year fixed effects cannot be included in the cross-sectional analyses.

## 4.4 Mechanism

Up to this point, we have provided empirical results validating the impact of sprawl on on-road carbon dioxide emissions. In this subsection, we suggest empirical evidence that changes in residents' lifestyles are the primary channels of the environmental impact of sprawl. Recall the mechanism by which the predominance of single detached units leads residents to travel farther distances for urban amenities. It can also increase the likelihood of private transportation, restricting the supply of public transportation.

The SCCs classify on-road GHG emissions into 25 subcategories by emission source.[5] To verify the heterogeneous effects of sprawl on on-road GHG emissions, we classify transportation into three categories: private passenger, public passenger, and freight. We estimate the specification (Eq. 1) for each of these three categories. Using ACS datasets, we also estimate the same specification with the dependent variable with the proportion of car commuters to study the impact of sprawl on residents' commuting modes.

Table 4 shows the estimated coefficients. Columns (1) to (4) present the heterogeneous effects of sprawl on on-road GHG emissions across GHG emission sources. All the data in Table 4 present the results of the most comprehensive model, including county and year fixed effects and every control variable. Column (1) shows the significantly positive effects of sprawl on GHG emissions, corresponding to Column (4) in Table 2. However, Columns (2) to (4) show contrasting results across emission sources—the prevalence of single detached units causes high GHG emissions from private passenger transportation, while this is not the case with public transportation and freight trucks. This implies that the environmental effects of sprawl are primarily driven by private transportation, such as passenger cars, passenger trucks, and motorcycles.

Column (5) shows the positive effects of single detached units on the share of workers commuting by car. The coefficient estimate indicates that a one percentage point increase in the proportion of single detached housing units is associated with a

[5]The subcategories consist of transportation types: motorcycle, passenger car, passenger truck, motor home, transit bus, school bus, light commercial truck, refuse truck, and a number of light/heavy duty vehicles by gross vehicle weight rating.

Table 4: **Environmental Effects of Sprawl by Emission Source**

| | National Emission Inventory | | | | ACS |
|---|---|---|---|---|---|
| VARIABLES | (1) | (2) | (3) | (4) | (5) |
| Single Detached Units (%) | 0.0147** | 0.0199*** | 0.0132 | 0.0040 | 0.0080*** |
| | (0.0070) | (0.0072) | (0.0238) | (0.0131) | (0.0023) |
| Emission Source | All | Private Passenger | Public Passenger | Freight | - |
| Observations | 2,363 | 2,363 | 2,363 | 2,363 | 2,363 |
| R-squared | 0.9495 | 0.9194 | 0.7343 | 0.9250 | 0.9701 |

Cluster-robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

0.8% increase in the fraction of car commuters. These results support the possibility that residents living in single detached units need to travel farther distances, and they are more likely to use private transportation rather than public transportation.

# 5 Conclusion

Around the world, people are experiencing a series of heavy rains and floods, wildfires and droughts, typhoons and hurricanes, and extraordinary heat waves. These catastrophic disasters are undeniably attributable to human activities. This study examines how the housing structure composition in cities affects carbon dioxide emissions. A city comprising residential buildings serving few households, such as single detached units, needs to expand its urban area to accommodate a given population, compared to cities with dense residential buildings, such as apartments and multi-unit buildings. Large city areas increase commuting time and costs, and the low population density makes it difficult to build public transportation systems. Therefore, we can expect that residents living in a city filled with residential buildings with low structural densities are likely to generate a large amount of on-road carbon dioxide emissions.

This study confirms that carbon dioxide emissions per capita are positively associated with the prevalence of single detached units in a city. The estimated results suggest that a one percentage point decrease in the fraction of single detached housing units causes 1.5% less carbon dioxide emissions per person. This study also shows the heterogeneous effects across regions. The estimates indicate that the effects are quite significant in the Northeast and West regions. The findings also confirms the mechanism by which widely spread housing units increase the likelihood of residents being car commuters.

These results and heterogeneities suggest potential considerations for environmental policy regarding urban area reorganization. One possible approach could be to explore replacing housing units that serve a few households or residents with residential buildings with high structural densities, such as apartments and multiplexes. For example, in 2019, the Oregon State Legislature allowed multiplex units in areas previously zoned for single-family housing, primarily to address the housing affordability crisis. However, our study suggests that such measures might also help concentrate residents close to city centers and can potentially reduce on-road carbon dioxide emissions, thereby contributing to the alleviation of GHG emissions.

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