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Land use regulations, transit investment, and commuting preferences

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ABSTRACT

In the U.S., various anti-sprawl land use regulations have been implemented for over two decades. Previous studies primarily investigate the impacts of local land use regulations or neighborhood-level built environment attributes on travel behaviors within a narrow time frame. Through a different lens, this paper examines how various local land use regulations and transit investment, both measured at the aggregated metropolitan level, have affected people's long-term travel behaviors over a 15-year period, and how these impacts differ between younger and older age groups. This study combines a set of land use regulation indices measured at the metropolitan level in 2003 with 15 years of travel data (2005–2019) from a pooled representative sample of over 8 million workers in the 50 largest U.S. metropolitan areas. Results show several local anti-sprawl land use regulations (e.g., growth containment, adequate public facilities, and moratoria), when combined at the metropolitan level, effectively reduced driving notwithstanding their marginal effects. Government investment in public transit also significantly increased commuters' likelihood of using public transit and, carpooling, as well as increased carpool group size. Moreover, the commuting mode choices of younger workers are more responsive to transit improvements and land use regulations. Urban planners should commit to regional cooperative planning to promote effective land use regulations at the metropolitan level. Regional collaborative entities, such as metropolitan planning organizations should play a larger role in coordinating local land use planning and regulations. To reduce automobile dependency, planners should commit to improving public transit through enhanced financial assistance, harnessing land use regulations in a more targeted way, and accommodating the needs of different age cohorts.

1. Introduction

Various anti-sprawl land use regulations, also known as growth controls or land use controls, have been implemented in municipalities, counties, and townships in the U.S. since entering the new millennium, aiming to promote more efficient use of land and infrastructure, reduce dependence on automobiles, and facilitate more sustainable and smart growth (Dong and Zhu, 2015). Although several states have passed state-wide growth management legislation, land use controls largely remain a local policy instrument. Typically implemented at the local municipality level. These controls shape local land use attributes, especially the '3Ds'–density, design and diversity, first proposed in R. Cervero and Kockelman (1997), Robert Cervero and Kockelman (1997). Numerous travel behavior studies find that local land use attributes or built environment characteristics affect travel behaviors, which underpins the efficacy of local controls (Chatman, 2003; Levine and Frank, 2006; Levine et al., 2005; Zhu et al., 2013; Wang, 2013; Munshi, 2016; Maharjan et al., 2018). However, individuals' location decisions for home and work often supersede the boundaries of municipalities. Rather, they make these choices across the entire metropolitan area. Individuals can "vote with their feet" and choose to reside in a municipality with their preferred location attributes (e.g., land use patterns) given their income constraints (Banzhaf and Walsh, 2008; Cao and Zhu, 2017; Tiebout, 1956). Moreover, developers may also choose to locate their projects in municipalities that are subject to less restrictive land use regulations. All these suggest that local land use controls may have spillover effects on surrounding jurisdictions, hence indirectly influencing the entire region. A robust evaluation of the behavioral impact of

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land use regulations should therefore take a more holistic view to explore whether the combined effect of *local* land use regulations produce the anticipated travel outcomes at the *regional* scale.

Despite over two decades of experience with land use regulations, there is still a lack of comprehensive understanding of how local regulations combine to influence travel behavior at the regional scale. Specifically, how effective are local land use controls in terms of increasing transit use and reducing reliance on driving at the aggregate metropolitan level? To date, relevant empirical studies have focused on the impact of neighborhood-level land use attributes on travel behaviors, but few considered the spillover effects of local regulations. To fill this research gap, the *first* objective of this study is to empirically examine how local land use regulations, when aggregately measured at metropolitan level, have influenced commuting mode choices over a 15-year period from 2005 to 2019.

Alongside land use regulations, public transit investment is another important policy instrument to influence travel behaviors and urban sustainability. Public transit is a vital component of an efficient transportation system, improving mobility, enhancing regional accessibility, and promoting sustainable travel. However, according to the American Community Survey (ACS), transit commuters constituted only about 5 % of all workers in the U.S. in 2019. In order to address the high dependence on automobiles in the U.S., investments in public transit infrastructure and increased transit services are often advocated by policymakers with expectations of encouraging transit use and reducing congestion. In 2018, total public transportation expenditures were $71.3 billion, up from $42.7 billion in 2005, with $49.5 billion (31 %) spent on operations and $21.8 billion (69 %) on capital investments (American Public Transportation Association, 2020 *Fact Book*). Evaluating of the travel outcomes of public transit investment is essential for guiding the allocation of investment funds as well as for designing targeted policies to increase transit use among urban commuters. Therefore, the *second* objective of this research is to assess empirically how government transit investment has influenced commute mode choice over a 15-year period from 2005 to 2019.

Furthermore, simply pooling data to study the relationship between land use regulations and travel outcomes may mask substantial differences for different age groups, as older and younger workers have different travel priorities and preferences. Young Americans are less likely to own cars, drive less, and are more inclined to use alternative transportation modes (Buchholz and Buchholz, 2012; Davis et al., 2012; Thompson and Weissman, 2012). Due to technological changes and the increasing legal and financial barriers, the trend of less driving among the young is expected to continue (Davis et al., 2012). Young people tend to engage in more transit usage than older age groups, and the proportion of young workers commuting by transit is higher than that of previous generations when they were the same age (Grimsrud and El-Geneidy's, 2013, 2014). Studies have suggested that the commuting patterns of the young are more malleable, and therefore may manifest a more significant behavioral response to policy changes and market innovations. For example, Kuhnimhof et al. (2012) found that the elasticity of older generations' dependence on cars was lower than that of younger generations. Younger generations also seem to show higher willingness to use digital ride-sourcing tools (e.g., Uber, Lyft) for urban commutes (Young and Farber, 2019). Changes in urban transportation system are also subject to the rise of carpooling or ridesharing which can help reducing the number of cars on the street (Wang et al., 2022). Given the distinct commuting patterns of the young, the *third* objective of this research is to examine whether land use regulations and transit investment generate different effects on commute mode choice and carpooling behavior of different age groups.

1.1. Research strategy

This study focuses on the 50 largest metropolitan statistical areas (MSAs) in the U.S. and use a set of indices measuring the prevalence of various land use regulations in each of these MSAs in 2003, as proposed by Pendall et al. (2006). These land use regulation indices are then matched with a dataset for individual-level travel behaviors. We extract data from the 1-year American Community Survey (ACS) and compile a full dataset consisting of over 8 million workers living in the 50 largest U.S. MSAs from 2005 to 2019.[1] Note that each year's ACS sample is independent of the other years.

Three nested dimensions of commuting behavior are examined: 1) the choice between public transit and privately-owned vehicles (POV); 2) the choice between carpooling and driving alone (among POV commuters); and 3) the number of riders (among carpool commuters). While transit commuting yields profound environmental benefits, carpooling is another alternative to ameliorate the problems associated with car commuting, reducing overall traffic volume, vehicle-miles-traveled (VMT), and emissions. Therefore, this paper also investigates POV commuters' carpooling behavior.

Specifically, this paper addresses the following questions:

1) How do aggregate-level land use regulations and transit investment affect commuters' choice between public transit and driving?
2) How do aggregate-level land use regulations affect POV commuters' choice between carpooling and driving alone?
3) How do aggregate-level land use regulations affect carpool group size (i.e., the number of riders) among carpool commuters?
4) How do these impacts differ between younger and older age groups?

2. Literature review

2.1. Effects of land use regulations on travel

Land use regulations impact many aspects of urban life, including travel activities, housing and land prices, urban built environments, and urban growth (Ihlanfeldt, 2007; Huang and Tang, 2012; Feiock et al., 2008; Cervero, 1991; White, 1988). Land use regulations play a central role in shaping the patterns of land use and facilitating changes in the built environments, which consequently influences individual or family's location choices and daily travel needs (Bhat and Guo, 2007). For example, studies have found that automobile usage is negatively associated with density land use, while alternative transportation modes, such as transit, walking, and cycling, are mostly ascribed to compact and mixed land use (Levine and Frank, 2006; Levine et al., 2005; Cervero and Kockelman, 1997). In high-density neighborhoods, a higher proportion of residents use non-automobile transportation modes (Wegener and Fuerst, 2004). Low-density outlying employment centers are associated with a significantly higher rate of driving alone (Robert Cervero and Wu, 1997; R. Cervero and Wu, 1997). These studies for the most part measure land use or built environment features at the neighborhood level; land use mix, density, distance to transit, and destination accessibility are among the features commonly examined (see Wang, 2013; Zhu et al., 2013; Munshi, 2016; Maharjan et al., 2018). This literature provides the conceptual foundation for understanding the impact of micro-level land use or built environment features on commute mode choice.

Although most land use regulations are promulgated and implemented at the local level, it remains unclear whether how the combined effects of local land use regulations influence travel behaviors at the aggregated regional level. Some researchers believe that land use regulations have little impact on travel patterns in car-dependent areas, while the impact is more significant in urban areas that are well-served by public transit (Boarnet and Sarmiento, 1998). A case study in Portland based on an activity-based travel model and stated-preference residential choice model suggested that land use policies had only

[1] For sampling strategy implemented by 1-year ACS, please refer to https://en.wikipedia.org/wiki/American_Community_Survey.

marginal effects on regional travel patterns (Shiftan, 2008).

Overall, the impacts of neighborhood-level land use attributes on travel behaviors have been extensively studied. However, there are few studies holistically evaluating the impact of land use regulations on travel at a larger scale of aggregation. This study adopts a different lens to address this question by using a series of metropolitan-level indices of land use regulations, to supplement existing literature that often uses spatially disaggregated neighborhood-level land use measures. This contributes to a more thorough understanding of how macro-level regional planning and policies can influence commuting patterns, providing important implications for regional cooperative planning practices.

2.2. Effects of transit accessibility on travel behaviors

Transit accessibility has also been widely studied in empirical travel behavior research. Typical measures of transit accessibility include the distance from home to the nearest bus stop or subway station and the number of transit stations within a certain radius from home. Transit accessibility is essential for promoting public transit (bus and train) use and reducing driving (Ewing and Cervero, 2010; Handy et al., 2005; Zhu et al., 2013; Zhu and Mo, 2022). A study in Mexico found less driving in urban areas with better transit supply and less roadway (Guerra et al., 2018). Transit usage can also increase if the public transportation network is able to connect people to various employment and activity opportunities (Lei et al., 2012). Residents living within walking distance of rail stations benefit substantially from the transit system (Lewis and Brod, 1997). Most studies thus far focus on transit accessibility at the neighborhood-level, and thus may be subject to location self-selection bias, where individuals who prefer to use public transit tend to choose to live in neighborhoods with better access to transit systems (Cao, 2009; Cao et al., 2009; Van Wee, 2009; Zhu et al., 2020, 2022). The same bias also applies in other studies on built environment features such as density and land use diversity. Renne et al. (2016) is one of the first studies to examine regional network accessibility by measuring the total share of regional jobs and population within walking distance of transit stations. They found that regional network accessibility was the strongest predictor of the mode share for transit commuting in transit station areas across the U.S. This paper offers a different lens by examining the scale of transit infrastructure at the aggregated metropolitan level, measured by whether the MSA has a transit legacy city. The capacity of the historically built transit system in an MSA is exogenous to any individual travel behavior, thus minimizing residential self-selection bias associated with transit accessibility in our analyzes. The preference for using transit is rarely a significant factor influencing the between-metropolitan residential location choice, because people's decisions to work and live in different metropolitan areas are much more likely to be the result of job opportunities, social relations, and the cost of living in those regions.

Automobile dependency poses a severe challenge to environmental sustainability in the U.S. Policymakers thus have long worked to increase investment in public transit development in order to reduce automobile dependency. An increase in transit supply affects commute mode choice by shifting the relative marginal cost of travel by POV versus public transit (Beaudoin et al., 2015). However, the effectiveness of such investment in influencing commute mode choice is contested in the literature. Investment in transit infrastructure can lead to more spread-out urban form and lower urban density, and subsequentially influence people's travel mode (Tao et al., 2012; Zhu, 2021). Baum-Snow and Kahn (2000) examine new transit projects in five major cities in the U.S. and find that new rail transit projects do impact transit usage, although their benefits are not uniformly distributed across different demographic groups. Other studies question the efficacy of transit investment in influencing commute mode choice. Duranton and Turner's (2011) analysis of 228 MSAs finds that the level of public transit service did not affect the volume of auto travel because of induced demand. Wu and Hong (2017), examining the effects of subway expansion in Beijing, also note it had limited influence on commuting mode choice. Furthermore, a study by Rogalsky (2010) suggests that increased route coverage and bus frequency failed to make transit a preferred travel option for working poor women in a medium-sized American city. Meanwhile, studies of transit-oriented development (TOD) are more consistent in showing positive effects for transport sustainability. TOD has been recognized as a promising strategy in meeting the challenges of urban sprawl, reducing household transportation costs, boosting transit mode shares for commuting through providing real alternatives to traffic congestion (Belzer and Autler, 2002; Lund, 2006; Faghri and Venigalla, 2013a, 2013b; Renne et al., 2016). A study in Brisbane, Australia suggests that TOD reduced car use by 5 % and increased the use of more sustainable modes of transportation by 4 % (Shatu and Kamruzzaman, 2014). Studies in Shanghai, China also concluded that TOD played an important role in placing large, rapidly suburbanizing cities on a more sustainable development path (Cervero and Day, 2008a, 2008b). More recently, a study examined the spatial relationship between fixed-route transit stations and the location of historic buildings across the United States and suggested a complementary effect of TOD on historic preservation (Renne and Listokin, 2021). Using a geospatial network analysis, a study in Wroclaw, Poland found that path networks and the number of entrances to rail stations lead to the spatial variance in citizen's public transport accessibility (Leśniewski et al., 2021). Other recent studies in Malaysia and Thailand suggested walking as a primary mode of transport to access TOD station and transit users' walking attitudes strongly affect their acceptable walking distance and time to TOD station (Sidek et al., 2020; Pongprasert and Kubota, 2019). Between these two bodies of literature, the effects of transport investment on commute mode choice and sustainability remains contested. Furthermore, the majority of studies have concentrated either on particular transit systems/projects or on TOD. There is little research looking at the effect of public transit investment from the perspective of total investment across different systems at the metropolitan level. Therefore, this study adopts this under-examined angle and examines the efficacy of aggregate transit investment on long-term travel behavior changes.

2.3. Lack of understanding for the difference across age groups

Empirical studies on travel behaviors normally consider age as a control variable. Age is consistently found to be an important factor in travel behaviors (Mattson, 2012; Şimşekoğlu et al., 2015; Zhu et al., 2013, 2020). With aging populations becoming a prominent problem in many societies, some studies have specifically investigated the travel behaviors of the elderly. Given declining willingness and ability to drive, the elderly is disadvantaged when it comes to travel (Szeto et al., 2017). Older people tend to travel less and make shorter trips in daily life than the young due to more limited transport options (Hahn et al., 2016). Studies of older people's travel behavior primarily focus on the purpose of their trips (e.g., Horner et al., 2015; Olawole and Aloba, 2014; Feng et al., 2013) and their travel mode choice (e.g., Newbold et al., 2005; Truong and Somenahalli, 2015).

There are also studies that focus on the travel behaviors of young people. They observe that the rapid adoption of innovation and communication technologies (ICT) among young people has been affecting their commute mode choice. Millennials who grew up with ICT may prefer longer commutes riding public transit over shorter commutes driving, as they can make good use of the time spent on public transit (Kuhnimhof et al., 2012; Mokhtarian and Tal, 2013). The popularity of ride-sourcing tools (e.g., Uber, Lyft) among younger generations may also encourage transit usage as ride-sourcing can act as a complement to public transit services (Boisjoly et al., 2018). Moreover, young people's commute mode choice is also influenced by shifts in their attitudes and preferences. Young people are more aware of the negative externalities of driving, better informed about the environmental and health

Table 1
Summary statistics.

Variables	Obs	Mean	Std. Dev.	Min	Max
Commute mode Choices (Public Transit = 1; POV = 0)	8,683,923	0.09	0.28	0	1
Carpool (Carpool = 1; Drive alone = 0)	7,921,685	0.11	0.32	0	1
Rider (how many people, including the driver, usually ride to work in the vehicle)	7,921,685	1.16	0.54	1	6
Land Use Regulation Index					
Zoning: Exclusionary	8,683,923	-0.16	0.90	-2.01	2.12
Containment	8,683,923	-0.08	0.89	-1.05	2.61
Infrastructure: Impact Fee	8,683,923	0.29	0.96	-1.34	2.42
Infrastructure: APFO	8,683,923	-0.21	0.78	-2.67	2.75
Growth Control: Moratoria	8,683,923	0.01	0.71	-2.98	0.58
Growth Control: Permit Cap	8,683,923	0.10	0.96	-1.63	3.96
Affordable Housing	8,683,923	0.55	1.01	-1.25	3
Transit Investment					
Government investment in public transit (millions of current dollar)	8,663,107	1651.91	2321.18	0	10,901.48
Transit Infrastructure					
MSA with transit legacy city	8,683,923	0.32	0.47	0	1
Demographics					
Male	8,683,923	0.52	0.50	0	1
Age	8,683,923	42.73	13.94	16	96
Marital status	8,683,923	0.60	0.49	0	1
Less than high school	8,683,923	0.03	0.18	0	1
High school graduate, some college or Associate's degree	8,683,923	0.58	0.49	0	1
BA degree	8,683,923	0.24	0.43	0	1
Graduate degree	8,683,923	0.15	0.36	0	1
Class of worker (1 = self-employed, 0 = work for wages)	8,683,923	0.08	0.28	0	1
Usual hours worked per week	8,683,923	39.47	11.83	1	99
Ambulatory difficulty	8,683,923	0.02	0.14	0	1
Household Socioeconomic Status					
Total family income (log)	8,622,807	11.22	0.89	0	14.97
Number of families in the household	8,683,923	1.11	0.46	1	20
Number of own children under age 5 in household	8,683,923	0.15	0.44	0	7
Ownership of dwelling (1 = Owned or being bought with loan, 0 = Rented)	8,637,801	0.71	0.46	0	1
Number of rooms	8,637,801	6.29	2.41	1	28
Number of vehicles	8,637,801	2.20	1.13	0	6
Home telephone availability (1 = yes, 0 = no)	8,637,801	0.98	0.14	0	1
Occupation					
Management	8,683,923	0.11	0.31	0	1
Business Operation Specialist	8,683,923	0.03	0.17	0	1
Financial Specialist	8,683,923	0.03	0.17	0	1
Computer and Mathematical occupations	8,683,923	0.03	0.18	0	1
Architecture and Engineering Occupations	8,683,923	0.02	0.15	0	1
Community and Social Service Occupations	8,683,923	0.03	0.18	0	1
Educational, training and Library Occupations	8,683,923	0.06	0.24	0	1
Arts, Design, Entertainment, Sports, and Media Occupations	8,683,923	0.02	0.14	0	1
Healthcare Practitioners and Technical Occupations	8,683,923	0.06	0.24	0	1
Healthcare Support Occupation	8,683,923	0.02	0.15	0	1
Protective Service Occupations	8,683,923	0.02	0.15	0	1
Food Preparation and Serving Occupations	8,683,923	0.05	0.21	0	1
Building and Ground Cleaning and Maintenance Occupations	8,683,923	0.03	0.18	0	1
Personal Care and Service	8,683,923	0.03	0.17	0	1
Sales Occupation	8,683,923	0.11	0.31	0	1
Office and Administrative Occupations	8,683,923	0.14	0.35	0	1
Construction trades	8,683,923	0.04	0.20	0	1
Production	8,683,923	0.05	0.21	0	1
Installation, Maintenance and Repair Workers	8,683,923	0.03	0.17	0	1
Transportation and Material Moving Occupations	8,683,923	0.06	0.23	0	1
MSA- and PUMA-level effects					
PUMA-level Population Density (persons per square mile)	8,683,923	6801	12,124	81	122,271
MSA-level Population (millions of persons)	8,683,923	6.99	5.80	0.11	19.33
MSA-level GDP per capita (thousands of current dollars)	8,683,923	79.25	122.54	3.81	1086.55
MSA with rail transit (dummy)	8,683,923	0.85	0.36	0	1
Region					
Great Plains	8,683,923	0.01	0.09	0	1
Mid-Atlantic	8,683,923	0.22	0.42	0	1
Midwest	8,683,923	0.18	0.38	0	1
New England	8,683,923	0.03	0.16	0	1
Rocky Mountains	8,683,923	0.02	0.12	0	1
South	8,683,923	0.17	0.37	0	1
Southwest	8,683,923	0.14	0.34	0	1
West Coast	8,683,923	0.25	0.43	0	1
Year					
2005	8,683,923	0.06	0.24	0	1
2006	8,683,923	0.06	0.24	0	1
2007	8,683,923	0.06	0.24	0	1
2008	8,683,923	0.06	0.24	0	1

(*continued on next page*)

Table 1 (*continued*)

Variables	Obs	Mean	Std. Dev.	Min	Max
2009	8,683,923	0.06	0.24	0	1
2010	8,683,923	0.06	0.24	0	1
2011	8,683,923	0.06	0.24	0	1
2012	8,683,923	0.07	0.25	0	1
2013	8,683,923	0.07	0.25	0	1
2014	8,683,923	0.07	0.25	0	1
2015	8,683,923	0.07	0.26	0	1
2016	8,683,923	0.07	0.26	0	1
2017	8,683,923	0.07	0.26	0	1
2019	8,683,923	0.07	0.26	0	1

Notes: 1. Transit Infrastructure: MSA with transit legacy city (1 = New York-Newark, NY-NJ-CT-PA; Chicago-Naperville, IL-IN-WI; Philadelphia-Reading-Camden, PA-NJ-DE-MD; Washington-Baltimore-Arlington, DC-MD-VA-WV-PA; Boston-Worcester-Providence; San Jose-San Francisco-Oakland, CA) (0 = Else).
2. The sample excluded three occupations that each accounted for less than 1 % of the national labor force in 2017. They are Life, Physical and Social Science Occupations; Farming Fishing and Forestry Occupations; Extraction Workers.
3. The occupational classification comes from ACS data.

implications, and have a pragmatic attitude towards automobile ownership as they prefer to live closer to vibrant parts of the city (Harris, 2018; Hopkins, 2016; Puhe and Schippl, 2014; Raymond et al., 2018). At the same time, lifecycle changes such as the school-to-work transition may affect their transit use (Grimsrud and El-Geneidy's, 2013).

Overall, the existing literature strong demonstrates that age influences travel behavior and examines how travel behavior differs across age cohorts. However, it does not address whether policies designed to affect transit behaviors, such as land use regulations, have different impacts across different age groups. Zang et al. (2019) and *** (citation deleted for blind review) are among the few studies that investigate the different impacts of neighborhood-level built environment features on travel behavior for different age groups. This paper intends to further address this research gap. The findings help planners and policymakers understand the nuances of different age groups' responses to regulations, thereby enabling them to better plan future transportation infrastructure and improve land use regulations to accommodate the needs of different generations.

3. Data

For the individual-level commuting data that forms the core of the analysis, this study drew on 15 years of American Community Survey (ACS) data, from 2005 to 2019. This large dataset consists of over 24 million individual records, among which over 8 million were regular commuters. The sample used for analysis is limited to workers who commuted by POV or public transit. Our samples were also limited to the largest 50 MSAs to match the measures of a set of land use regulations provided in Pendall et al. (2006).

3.1. Land use regulation indices

For measuring land use regulations, this study utilizes a set of standardized indices characterizing the prevalence of specific land use regulations in each of the largest 50 MSAs in 2003, the time when Pendall et al. (2006) conducted a survey with local planning officials of over 1800 cities, counties, and townships in these MSAs. Based on the survey results, the authors used factor analysis to measure the status of various land use regulations at the metropolitan level using three variables: percentage of jurisdictions covered, percentage of population covered, and percentage of land area covered; these were used to produce a set of land use regulation indices for each MSA. This paper uses these indices to examine four major areas of land use regulations as summarized in their report: exclusionary zoning, containment, infrastructure regulations (including impact fees and adequate public facilities ordinances, APFO), and growth control measures (including building permit caps and building moratoria). Exclusionary zoning is a regulation that facilitates low-density development, while the other regulations promote compact growth. The analysis also takes into account the prevalence of affordable housing programs at the metropolitan level, as housing projects often come with substantial land use changes within and around the project sites.

3.2. Transit investment

Data on public transit investment were retrieved from the Nation Transit Database (NTD) provided by the Federal Transit Administration. The transit investment data collected covers all government investments in nearly 3000 public transportation agencies and includes operation and capital transit funds from federal, state, and local governments. Transit investment received by each MSA in each year is calculated based on the financial data reported by each transit agency to the NTD. Because transit development projects often take time to accomplish, we introduce a one-year lag on transit investment in order to capture the real impact of transit investment on commute duration.

3.3. Control variables

The analyzes take into account individuals' occupation, demographics characteristics, and their household socioeconomic status. We incorporate a variable to indicate whether an MSA has a transit legacy city, to control for the scale of transit infrastructure in the region. Transit legacy cities refer to six historical core municipalities in the U.S. with legacy transit systems (New York, Chicago, Philadelphia, San Francisco, Boston, and Washington) (Cox, 2013). These six legacy cities are also home to the nation's six largest central business districts (CBDs), from which their transit networks radiate. In 2017, over half of public transit commuters had work trip destinations in these cities (Cox, 2018). Therefore, the six MSAs with a transit legacy city have developed a unique urban form where employment and commuting destinations are concentrated in a strong urban core. This variable therefore captures the urban spatial structure and encompasses elements of the comprehensive transit infrastructure in an MSA (e.g., transit coverage, management, and operational efficiency). This measure of transit infrastructure scale offers a different perspective from the more frequently used neighborhood-level variables that concern only single aspects of transit infrastructure (e.g., number of transit/bus stops, distance to the nearest transit/bus stop, and bus/train headways). As discussed in Section 2.2, it is also free from location self-selection bias (Cao et al., 2010; Zhang and Zhang, 2020).

3.4. Classification of younger and older workers

To distinguish between younger and older workers, this study uses a cut-off age of 32. Many reports and articles look at older and younger workers in terms of their generational classification. For example, Bialik and Fry (2020) distinguished between millennials born between 1982 and 1996, Generation X born between 1965 and 1980, and Baby Boomers born between 1946 and 1964. Since our ACS dataset covers a time span of 15 years, for consistency and sample balance purposes, we avoid using these generational categories and simply divide our samples into two age groups: 32 or under and over 32. The selection of this cut-off point is based on the consideration of life stage change and life transition in adulthood. In demographic studies, age of 32 is often considered as the threshold of young adulthood (Hasford et al., 2017; Mackinnon et al., 2016; Fullinwider-Bush and Jacobvitz, 1993; Werner, 1989). This study differentiates commuters by 32 as a crucial watershed to reflect the difference in travel behavior at different life/career stages. The "life course perspective" argues that life course schedules (e.g., getting married, having children, getting employed) could have influence on people's attitude towards different modes of travel (Wang and Wang, 2021; Susilo et al., 2019; Delbosc and Nakanishi, 2017; Scheiner and Holz-Rau, 2013). This classification allows us to compare the differences in the impact on younger workers and older workers. Instead of scrutinizing the generational differences and temporal changes in travel behavior, our research hence puts more emphasis on how land use regulations affect commuting preferences differently for younger and older people in the labor force in respective years. While it is also interesting to track a specific age cohort over time to look for some transitional features of the same group in their different ages (e.g., the temporal changes in commuting preferences for the age cohort of 20 years old in 2005, 21 in 2006, and all the way till 34 in 2019), it is beyond the scope of this research.

3.5. Descriptive statistics

Based on the ACS data on individual commuting behaviors, the sample in our analyzes is limited to workers in the largest 50 MSAs who commuted to work by either POV or public transit between 2005 and 2019. The summary statistics are presented in Table 1. Among all respondents, about 85 % were living in an MSA with rail transit in addition to bus transit, but only 8.54 % commuted by either bus or rail.[2] When we further examined workers who commuted by POV, 11.28 % of them carpooled to work and 88.72 % drove alone. Among the young, 10.90 % commuted by public transit, while 14.06 % of those who commuted by POV chose to carpool. For the older age group, 7.64 % were transit commuters, while 10.25 % of POV commuters chose to carpool. Among those who carpooled to work, the average number of carpool riders (including the driver) was 1.20 for the younger age group and 1.15 for the older age group. A set of land use regulation indices and MSA-level transit investment data were matched with individual-level observations according to the MSA that each surveyed individual was living in. All land use regulation indices were standardized, as indicated in Pendall et al. (2006).

4. Methodology

To study the aggregate impacts of various land use regulations and transit investment on commuting behavior, we present regressions in which the unit of observation is individual commuters. The detailed specifications of our models are explained in the following sections.

4.1. Commute mode choice: transit versus POV

We apply a Probit model to examine how land use regulations and transit investment affect workers' choice between public transit and POV (research question 1). Assume there is a latent variable Y^* such that

$$Y_i^* = \beta_0 + \beta_1 LUR_i + \beta_2 TI_i + \beta_3 TL_i + \beta_4 DE_i + \beta_5 HS_i + \beta_6 OCC_i + \beta_7 REGION_i + \beta_8 MSA_i + \beta_9 PUMA_i + \beta_{10} YEAR_i + \varepsilon_i$$

where $\varepsilon \sim N(0, \sigma^2)$, and

$$Y_i = \begin{cases} 0 & if \quad Y_i^* \le 0 \\ 1 & if \quad Y_i^* > 0 \end{cases}$$

Y_i is the observed outcome variable, representing whether the respondent i commuted to work by public transit or by POV.

Among the explanatory variables, LUR_i is a set of indices measuring land use regulations implemented in the MSA where respondent i lived; TI_i is the log transformed government transit investment received by the MSA in previous year; TL_i is a dummy variable indicating whether respondent i lived in an MSA with a transit legacy city. This research uses a comprehensive set of land use regulation indices proposed and calculated by Pendall et al. (2006), as shown in Table 1. Individual-level factors influencing commuting behaviors are controlled in our models. DE_i is a set of variables measuring demographic characteristics, HS_i is a set of variables measuring household socioeconomic characteristics, while OCC_i is a set of occupation variables. Travel behavior is also subject to regional fixed effects and neighborhood-level characteristics. While an alternative approach to control for MSA fixed effects is to include the full vector of MSA dummies in the models, we chose not to take this approach because of high collinearity with our major variables of interest. This strong collinearity is expected because land use regulations in this research are aggregated at the MSA level. Instead, our models control for regional fixed effects associated with MSA heterogeneity using a vector of dummy variables, $RESION_i$, for the eight U.S. regions as defined by the Bureau of Economic Analysis (New England, the Mid-Atlantic, the South, the Midwest, the Great Plains, the Rocky Mountains, the Southwest, and the West Coast). In addition, our models include MSA population, MSA GDP per capita, and MSA rail availability to further control for MSA-level effects. Our models use population density at the public use microdata area (PUMA) level to control for some neighborhood-level built environment characteristics. Lastly, $YEARi$ is a vector indicating the survey year of each record to control for year-specific effects.

4.2. POV mode: carpool[3] versus drive alone

After limiting our sample to POV commuters, we then estimate another Probit model to examine the impacts of land use regulations on the choice between carpooling and driving alone (research question 2). The variable of transit investment TI_i is removed in this model. We have a latent variable Y^* such that

$$Y_i^* = \beta_0 + \beta_1 TL_i + \beta_2 LUR_i + \beta_3 DE_i + \beta_4 HS_i + \beta_5 OCC_i + \beta_6 REGION_i + \beta_7 MSA_i + \beta_8 PUMA_i + \beta_9 YEAR_i + \varepsilon_i$$

where $\varepsilon \sim N(0, \sigma^2)$, and

$$Y_i = \begin{cases} 0 & if \quad Y_i^* \le 0 \\ 1 & if \quad Y_i^* > 0 \end{cases}$$

Y_i is the observed outcome variable representing whether the POV commuter i carpooled or drove alone.

4.3. Carpool: number of riders

A Poisson regression model is estimated to examine the impact of

[2] Note that this number and all other calculated numbers in this section were the average values for all respondents across 15 years.

[3] According to the definitions in ACS, "carpool" indicates "whether the respondent usually rode to work in a carpool (with at least one other worker) during the previous week. Persons are considered car-poolers only if they rode with other workers.

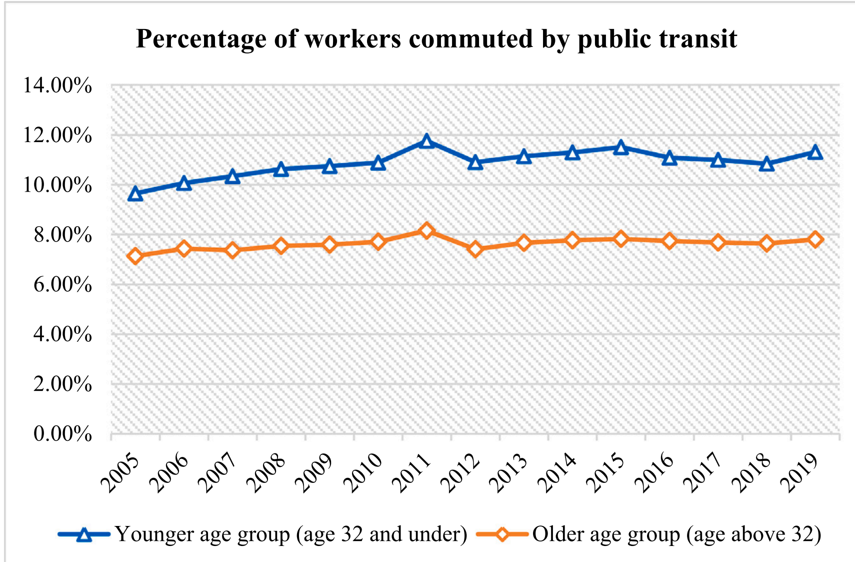

Fig. 1. Percentage of workers commuting by public transit (younger versus older age group). Note: Fig. 1 illustrates the total number of public transit commuters as a percentage of the total number of transit and POV commuters, separately for the 32 or under and over 32 age groups in each year.

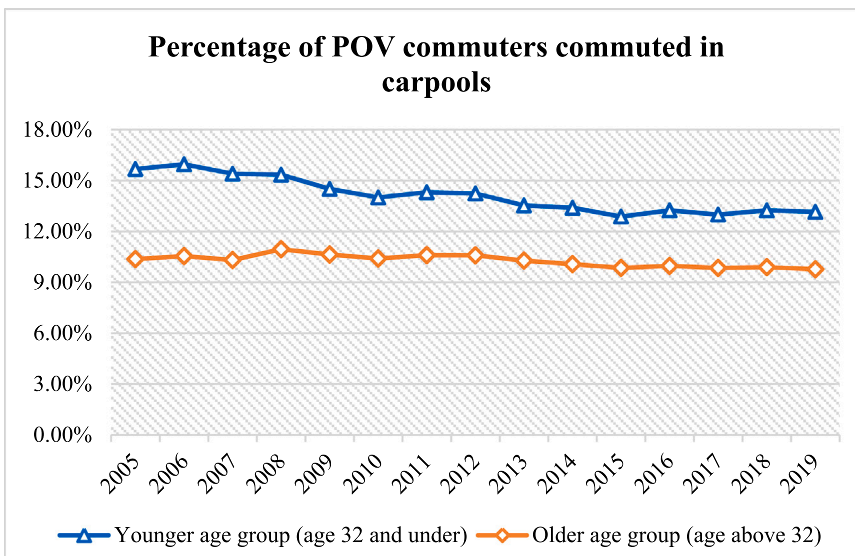

Fig. 2. Percentage of carpoolers among POV commuters (younger age group versus older age group). Note: The sample in this graph was limited to POV commuters. Therefore, the sum of the percentage of carpooling commuters and people driving alone is 100 %.

land use regulations on the number of riders in carpooling situations (research question 3). The sample used in this analysis is restricted to carpool commuters. The Poisson model specifies that

$$Pr(Y_i = k|X_i) = \frac{exp(-\lambda_i)\lambda_i^k}{k!} \quad , \quad k = 0, 1, 2, 3, \ldots$$

$$\ln(\lambda_i) = \beta_0 + \beta_1 TL_i + \beta_2 LUR_i + \beta_3 DE_i + \beta_4 HS_i + \beta_5 OCC_i + \beta_6 REGION_i + \beta_7 MSA_i + \beta_8 PUMA_i + \beta_9 YEAR_i$$

The explanatory variables are the same as the model for choice between carpool and drive alone. In this Poisson model, we directly observe the outcome variable Y_i as the number of riders in the carpool commutes, which only takes on non-negative integer value (k = 0,1,2,3, …) and follows the Poisson distribution with a mean and variance both equal to λ_i.

Note that the setup of the abovementioned three models successfully passed the collinearity check, with the highest variance inflation factor (VIF) of key variables at 5.27, and the mean VIF as low as 3.9. Robust standard error is clustered by MSA to account for the heteroskedasticity across the clusters.

5. Comparing the younger and older age groups

To analyze the historical trends in commuting behavior of younger and older age groups, and the differences in their responsiveness to land use regulations and transit investment, this study divided the ACS dataset into two groups of worker (i.e., the younger and older age groups of workers) in each year, based on the cut-off age of 32. The different trends in their commuting patterns are shown in Fig. 1.

Fig. 1 shows a small increase in the percentage of public transit commuters relative to POV commuters from 2005 to 2019. The share of transit commuters in the younger age group increased from 9.65 % to

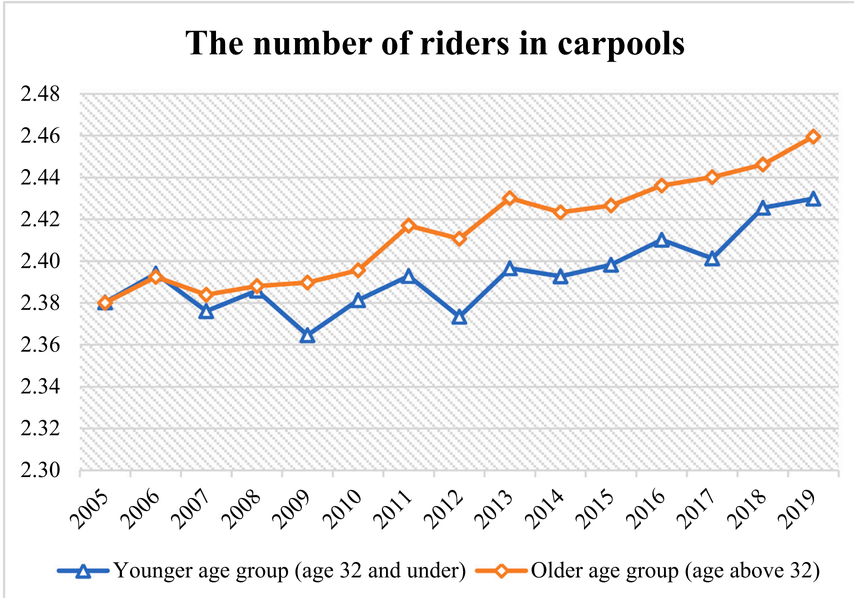

Fig. 3. The number of riders in carpools (younger versus older age group).

11.31 %, while the share among the older age group showed only a slight increase, from 7.13 % to 7.80 %. The younger age group's share of transit commuters was consistently higher than that of the older age group, while there was also a more substantial increase in younger age group's transit share.

Fig. 2 shows that the younger age group's share of carpool commuters was consistently higher that of the older age group. While carpooling declined among POV commuters of both age groups, the decline was faster for the younger age group. The proportion of carpool commuters among young workers decreased from 15.69 % to 13.16 %, while that of the older age group decreased from 10.37 % to 9.77 %.

Fig. 3 shows that the average number of carpool riders (including the driver)[4] has steadily grown for both age groups over the past 15 years. We also observed a widening gap between the two age groups over time, except for a period of indifference between 2005 and 2006. The average number of riders in carpools increased from 2.38 to 2.43 for the youngest generation, while there was a similar increase from 2.38 to 2.46 for prior generations, with some minor fluctuations.

These three figures show different patterns and trends between younger and older groups of workers. Our models will proceed to address whether transit infrastructure quality and land use regulations also exerted different impacts on workers of different age groups.

6. Empirical results: the impacts of aggregate-level land use regulations and transit infrastructure on commuting behavior

Major results are summarized in Fig. 4, which compares the marginal effects of various land use regulations and transit infrastructure quality (i.e., whether the MSA has a transit legacy city) on mode choice (i.e., transit versus POV), POV sub-mode choice (i.e., carpool versus drive alone) and carpool group size for older and younger age groups, respectively. The complete modeling results are presented in Tables 2–4 in the Appendix, separately for the three models.

6.1. Public transit versus POV

The Probit model results suggest that exclusionary zoning, a land use regulation associated with promoting sprawl that maintains a low-density urban landscape, increases the likelihood of people driving to work. If the "exclusionary zoning" index increases by one standard deviation, the likelihood of commuting by public transit for the younger and older age groups decrease by 0.0244 and 0.0179, respectively. Among various anti-sprawl land use regulations, only containment, APFO and moratoria showed significant positive effects in promoting transit commuting for both age groups. Comparison of their marginal effects suggests that building moratoria, a growth control measures controlling the issuance of building permits, was the most effective in terms of increasing individuals' likelihood of commuting by transit. With one standard deviation increase in the "moratoria" index, the likelihood of transit commuting increases by 0.0103 for the younger age group and 0.0063 for the older age group. In other words, people are more likely to commute by public transit in MSAs where building moratoria are utilized to rein in sprawl and control growth. Although marginal in magnitude, people were more inclined to choose transit if infrastructure systems in their MSA were subject to adequate public facilities ordinances or had used growth containment measures that emphasized growth boundaries and density. With one standard deviation increase in the "APFO" index, the likelihood of commuting by public transit for the younger and older age groups increases by 0.0085 and 0.004, respectively. If more growth containment measures such as service areas/boundaries, growth areas/boundaries, and/or greenbelts are implemented, commuters of both age groups are more likely to take public transit. Lastly, some anti-sprawl land use regulations, such as impact fees and permit caps, failed to encourage transit use. This suggests that APFOs and moratoria are more effective than impact fees and permit caps in reducing driving. In general, most anti-sprawl land use regulations that facilitate compact growth encourage people to drive less, but the magnitude of that reduction is generally small. These findings are in line with the argument from the meta-regression analysis in Stevens (2017).

Results also show that affordable housing programs had significant negative effect on transit commuting, especially for people aged over 32. One standard deviation increase in the "affordable housing" index decreases the likelihood of choosing transit by 0.0041 for the younger age group and 0.00106 for the older age group. This suggests that affordable

[4] "Riders" refer to "how many people (including the respondent) usually rode to work in the vehicle that the respondent took to work during the previous week. This excludes persons who drove or rode in the same vehicle to school, or who returned home after dropping off workers, or who rode to any other non-work location. A worker who rode to work with one or more other people, but who was the only worker in the vehicle, was counted as driving alone."

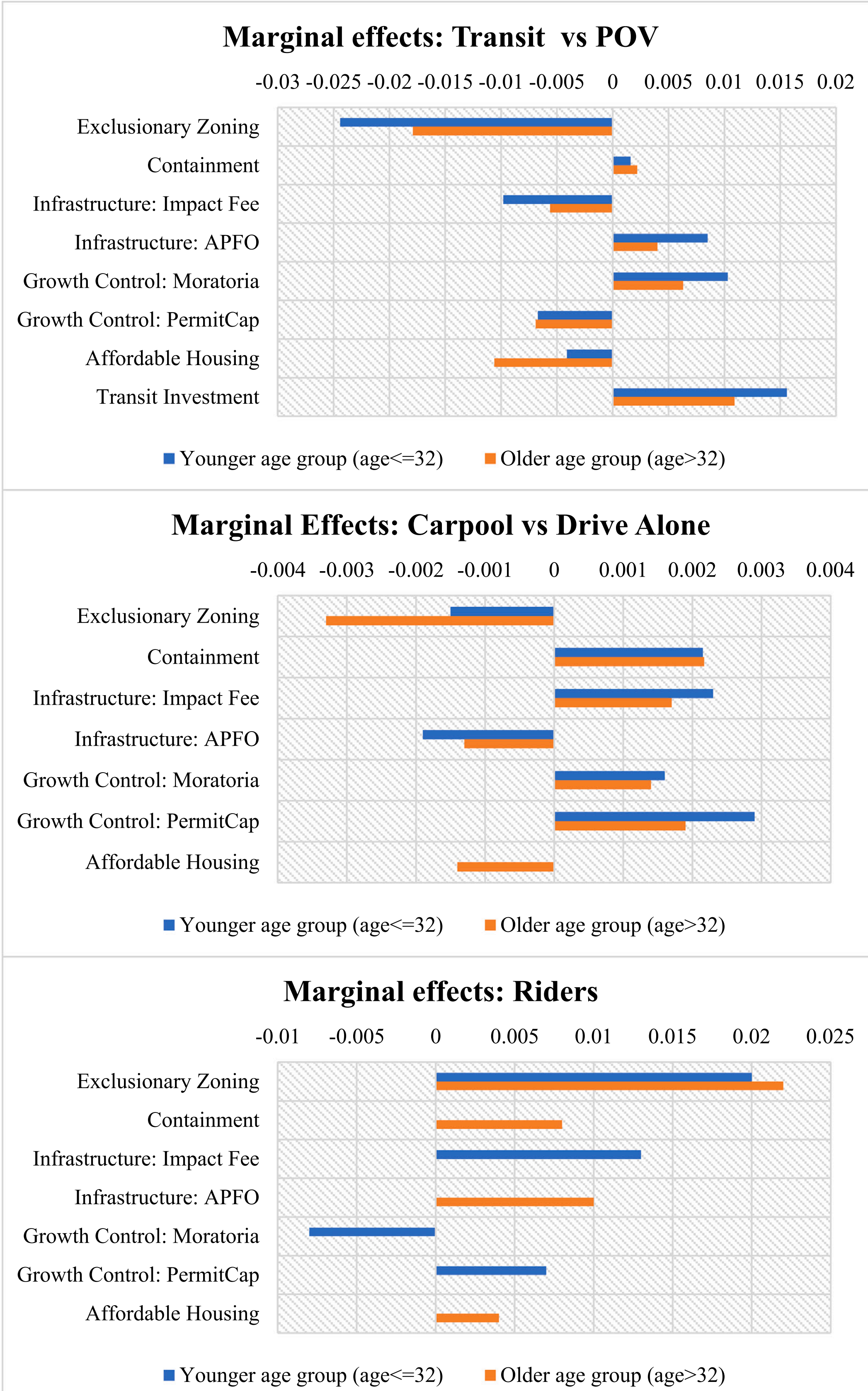

Fig. 4. Marginal effects for the older and younger age groups.

housing programs in many MSAs failed to improve citizens' access to public transit, possibly due to the locations of these housing units. While it is commendable that planners have tried to integrate affordable housing programs with private housing to establish mixed and inclusive communities, we suspect that many low-income, transit-dependent households living in affordable housing may face difficulties accessing public transit because of the location of their housing units.

This study also examined how public transit investment in an MSA affects commute mode choice, while controlling for the influence of the scale of transit infrastructure with a variable indicating whether an MSA contains a transit legacy city. Results show that transit investment had a significant positive impact on the likelihood of choosing public transit, and encouraged transit commuting for both older and younger age groups. With a 10 % increase in transit investment, the probability of commuting by transit increases by 0.16 for the younger age group and 0.11 for the older age group.

Results also indicate that commuters living in MSAs with a transit legacy city were on average more likely to commute by transit (probability increases by 0.058 and 0.055, respectively), for the younger and older age groups, respectively. Legacy transit systems connect the whole metropolitan area with concentrated destinations in core cities, making public transit an appealing choice for commuters.

Next, a set of Chow tests were used to examine whether the marginal effects of land use regulations on commute mode choice differ significantly between younger workers and older workers. In econometrics, Chow test is often used to verify whether the regression coefficient estimates for two subsamples using the same model are significantly different from each other. Test results show that the marginal effects of exclusionary zoning, impact fees, building moratoria, building permit caps, and regulatory affordable housing programs demonstrated significant age differences. The marginal effects of growth containment measures and APFO did not differ significantly between the two groups. In general, younger age groups have been more responsive to exclusionary zoning (which promoted automobile use) and the three anti-sprawl land use regulations (i.e., impact fees, APFOs, and moratoria, which reduced driving). The influence of government transit investment on the likelihood to transit usage was also greater for the younger than for the older age group.

Our results on the impact of demographics and socioeconomic status on commuting behaviors were also consistent with the literature. Higher educational attainment decreased the likelihood of commuting by transit. Men were less like to commute by public transit than women. Among all household socioeconomic factors, the number of vehicles owned had the greatest impact on mode choice. People were less likely to commute by transit if their household owned more vehicles. The likelihood of commuting by transit also decreased if the household had more children under the age of 5. Results on occupational variables suggested that most white-collar workers, especially those in business, finance, or computer related occupations, as well as service providers, were more likely to commute by public transit.

6.2. POV commuting: carpooling versus driving alone

This study further scrutinized how POV commuters' choices between carpooling versus driving alone were influenced by transit infrastructure quality and land use regulations. The sample used in this part of analysis was limited to those who commuted by POV. Table 3 in the Appendix presents the comparison of the marginal effects for the older and younger age groups.

Among land use regulations, growth containment measures, impact fees, building moratoria, and permit caps increased the likelihood of carpooling for POV commuters of both age groups. Their marginal effects are similar in general, and all are of relatively small magnitude. If the "containment" index increased by one standard deviation, POV commuters' likelihood of carpooling increased by around 0.0022 for both age groups. With one standard deviation increase in the "moratoria" index and the "permit cap" index, young POV commuters were 0.002 and 0.003 more likely to carpool, respectively, while older commuters were 0.001 and 0.002 more likely to carpool. This indicates that most anti-sprawl land use regulations, except for APFO, encourage people to carpool, implying less driving but not giving up driving entirely. When residential density and employment density are high in the region, carpooling is convenient as people live close to each other and work at adjacent locations. As expected, pro-sprawl exclusionary zoning increased the likelihood of driving alone as residences were more dispersed. In addition, affordable housing programs had no effect on the younger age group but slightly decreased older age groups' likelihood of carpooling.

Results suggest that transit infrastructure quality had significant positive impact on the choice to carpool for POV commuters. Living in MSAs with a transit legacy city increased the likelihood of carpooling by 0.008 for the younger age group and 0.007 for the older age group. Although the overall share of carpooling declined over the past 15 years (as shown in Fig. 2), POV commuters living in MSAs with a transit legacy city were still more likely to carpool than those living in other MSAs. This may be because the convenience and affordability benefits of carpooling in MSAs with a transit legacy city are high due to the high density and high parking cost in downtowns and surrounding central city areas. Furthermore, people living in MSAs with a transit legacy city might be psychologically more willing to accept carpooling, influenced by the transit culture and norms of space sharing.

Results of the Chow test suggest that there were also significant age group differences in the marginal effects of all land use regulations on the choice between carpooling and driving alone, though the marginal effects were all very small. The older age group was more responsive to exclusionary zoning inclining them to drive alone, while younger workers were more susceptible to impact fees and growth control measures encouraging them to carpool. The marginal effects of affordable housing programs showed no significant difference between the two age groups.

Among demographics and socioeconomic characteristics, educational attainment was a prominent factor influencing the choice to carpool. POV commuters with a higher level of education were more likely to drive alone, and this effect was much more noticeable for the younger age group. Marriage, self-employment, having more children, and number of vehicles in a household, all increased the likelihood of carpooling. POV commuters working in "building and ground cleaning and maintenance occupations" or "construction trades" were much more likely to carpool than those in other occupations.

6.3. Carpooling: number of riders

In terms of the net reduction in total driving, carpool group size may be as important as the choice to carpool. This part of analysis further examined the impact of transit infrastructure quality and land use regulations on the number of riders in carpools (including the driver). In this analysis, our sample was limited to those who commuted in carpools. Results are presented in Table 4 in the Appendix.

The impact of various land use regulations on the number of carpooling riders was complicated. Surprisingly, exclusionary zoning had a significant positive impact on the number of carpool riders for both age groups. With one standard deviation increase in the "exclusionary zoning" index, the expected number of carpool riders increased by 0.02 and 0.022 for the younger and older groups of workers, respectively. Although exclusionary zoning in general made POV commuters more likely to drive alone (see Table 4), those who did choose to carpool were more likely to commute with more riders, perhaps to share the costs associated with long commutes in spread-out regions. The impacts of anti-sprawl land use regulations were mixed. In terms of increasing carpool group size, growth containment and APFO only impacted the older age group, whereas impact fees and permit caps only affected the younger age group. With one standard deviation increase in "containment" and "APFO" indices, older carpoolers' carpool group size increased by 0.008 and 0.01, respectively. If the "impact fee" and "permit cap" indices increased by one standard deviation, the expected number of riders in young workers' carpool commutes increased by 0.013 and 0.007, respectively. In addition, more building moratoria decreased the carpool group size for the younger age group but had no impact on the older age group. Affordable housing programs only increased the carpool group size for the older age group. Note that all these marginal effects were rather weak, and most of them were only statistically significant for one of the age groups. Among all land use regulations, exclusionary zoning has the most prominent effect in terms of increasing riders in carpool commutes for both age groups.

In MSAs with a transit legacy city, young carpoolers were estimated to commute with 0.015 more riders while the older age group would share a carpool with 0.023 more riders. In line with our previous discussions in Section 5, POV commuters who lived in MSAs with a transit legacy city were not only more willing to carpool, but also shared with more riders.

Chow tests were also conducted for key variables of interest to examine whether the marginal effects showed differences for the two age groups. Since the Poisson regression results show that only one land use regulation (i.e., exclusionary zoning) had significant impacts for both age groups, the Chow tests were adjusted to exclude land use regulation variables that only had significant impacts on one age group. Results show that the marginal effects of exclusionary zoning on the number of riders were stronger for the older workers than for younger workers.

Concerning demographics and household socioeconomic characteristics, marriage, educational attainment, and self-employment all had stronger negative impacts on carpool group size for young carpoolers. The number of riders increased if a household had more families and children. People with occupations such as "building and ground cleaning and maintenance occupations" and "construction trades" shared rides with significantly more commuters.

7. Conclusion

Using a large dataset spanning 15 years, this paper sheds light on how a series of land use regulations and transit investment, aggregated at the metropolitan level, have influenced commuting behaviors.

Government transit investment in the MSA is estimated to significantly increase the likelihood of workers commuting by public transit. Therefore, we believe that financial assistance from governments for improvements in transit infrastructure in metropolitan areas have effectively contributed to promoting transit use in a 15-year period. However, our evaluation only covers commute mode choice consequences of transit investment; more in-depth cost-effectiveness analysis needs to be done to assess the overall success of transit investment.

Various land use regulations have also shaped individual commuting behaviors in the 15 years following their implementation. Among anti-sprawl land use regulations, both growth containment and building moratoria demonstrate effectiveness in encouraging commuters to take public transit and carpool. Building permit caps also reduced overall driving by encouraging POV commuters to carpool, especially for younger workers. Overall, moratoria have been the most effective for increasing transit commuting, while permit caps and containment measures were the most effective for encouraging younger and elder workers to carpool, respectively. As metropolitan areas develop in more compact fashion with these anti-sprawl land use regulations and workplaces are established in clusters, both transit and carpooling become convenient and appealing choices. On the contrary, exclusive zoning as a sprawl-inducing land use regulation reduces commuters' likelihood of using transit or carpooling. Although the estimated marginal effects of these regulations on commuting behaviors were numerically small, it should be noted that these estimates indicated the impacts of land use regulations on individual workers. At the metropolitan or national level, the aggregate impact is not trivial. In addition to improving transit infrastructure in metropolitan areas (in an economically efficient way), planners should also be aware that among various land use regulations, containment policies and impact fees are effective measures for reducing automobile dependence. Impact fee programs aim to internalize externalities associated with rapid growth. They can affect urban forms, create open space amenities, and provide better finance for local public infrastructure. Our results show that the implementation of impact fees reduce the demand for commuting by car. This is in line with previous research that suggested the impact fees can help reduce the level of congestion by creating disincentives to residential development at remote locations (Blanco et al., 2012). In sum, to reduce the carbon footprint of urban commuting, planners are suggested to prioritize improving overall transit quality and implementing land use regulations that have proven to be effective in shaping the desired travel behaviors.

Another important finding is that younger workers' commute mode choices (i.e., transit versus POV; carpooling versus driving along) were in general more responsive to improved transit infrastructure and various land use regulations, compared to older workers. This includes both transit investment and various land use regulations including impact fees, APFOs, and moratoria. Future transportation and land use policies aiming to increase transit usage and carpooling should attend to the needs of this age cohort as their travel patterns are more malleable.

Furthermore, we found that affordable housing programs are associated with lower use of public transit and carpooling. This suggests that affordable housing programs may fail to provide good transit accessibility or supportive social networks to facilitate carpooling. Previous evidence in Baltimore, Maryland by Welch (2013) has also suggested the limited influence of the Low Income Housing Tax Credit Program (LIHTC), a low-income affordable housing production subsidy program, in enhancing equitable distribution of transit access. This may be an unintended side-effect of the integration of affordable housing units with private housing development. In the past decades, planners and policymakers in the U.S. have been committed to building affordable housing projects in conjunction with private developers and investors to avoid poverty traps and to pursue more mixed, integrated, and inclusive communities. Although well-intended, affordable housing units were often constructed in scattered sites throughout diverse, middle-class neighborhoods, where public transit networks might be inadequate or difficult to access. As these affordable housing units serve low-income households that are more likely to be transit-dependent, we suggest that these housing programs should be better integrated with transit planning to fulfill the mobility needs of their residents. Local government agencies in charge of housing development and transit planning should communicate and collaborate to prevent working in silos. For example, transit-oriented development (TOD) should continue to be promoted in the design and development of affordable housing projects, so that affordable housing units are strategically located in more compact areas close to public transit stations. Providing monetary incentives such as bus vouchers for low-income families may also be a viable option to encourage transit use. Similar to our findings, a study based on the California Household Travel Survey advocated differentiating affordable housing and market-rate housing in the development review process and suggested the need of establishing development standards that well reflect the characteristics of prospective residents and locations (Howell et al., 2018). Our suggestion is also in line with the recent case study by Smith et al. (2021) which recommends that affordable housing agencies should use more comprehensive transit access metrics to evaluate the transit accessibility of affordable housing sites. Further, the development of affordable housing projects should balance the tradeoff between accessibility and affordable housing dispersion, subject to land acquisition and construction budget. For instance, Zhong et al. (2019) designed a model for locating affordable housing units while maximizing low-income workers' job accessibility by public transit.

7.1. Implications for regional cooperative planning

Although land use regulations are usually implemented in local jurisdictions, our findings suggest that they combine to affect individual travel at the aggregated metropolitan level. Our findings have important implications for regional cooperative land use planning practices: to reduce the carbon footprint of commuting, regional cooperation is crucial in enhancing the efficacy of land use regulations. While deregulation in some cases might be wise due to government failures (see for example, Zhu and Jeffrey, 2013 on the U.S. Federal Highway Program), anti-spawl land use regulations are most likely not on the list, at least when evaluated in terms of their travel outcomes. Rather, stronger regional cooperation is needed in order to ensure their success. Note that we are *not* arguing commuter's travel behaviors are influenced more by metropolitan-level averages of land use configuration and transit provision than by neighborhood-level built environment attributes. The main takeaway of this research is that regional cooperation should be the focal point for sustainable urban land use and transportation planning, because transportation and sustainability challenges are often interconnected and observed at a broader regional scale. Urban planners and policymakers should commit to regional cooperative planning to promote effective land use regulations at the metropolitan level to achieve a low-carbon commute. Regional collaborating entities such as metropolitan planning organizations should play a larger role in coordinating local land use planning and regulations. These entities should be granted higher levels of authority and capacity to fulfill governance and mediation functions, thereby ensuring successful regional cooperation between local planning organizations.

7.2. Potential limitations of the study

It is worth noting that this study has some limitations. In this paper, land use regulations and transit infrastructure quality were both measured at the metropolitan level. Such measurement had clear advantages, such as to avoid residential self-selection bias, but some research has pointed out that individual commute model choice could also be affected by neighborhood-level built environment features, such as density, mixed land use, accessibility to transit. Unfortunately, the ACS dataset does not capture variables appropriate to measure these attributes, nor does it provide the block or block group information of the respondents' residence (for record matching with other data sources). Since the required data was unavailable, our models were only able to include PUMA-level population density to account for a degree of neighborhood-level built environment influences. Future research could consider including both macro-level land use regulations and more detailed local built environment features, to understand commuters' long-term behavioral changes.

Data Availability

The authors do not have permission to share data.

Acknowledgements

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Appendix

See Tables 2–4.

Table 2
Probit estimation results for commute mode choices (public transit versus POV).

Variables	Marginal effects (Public Transit = 1; POV = 0)		Chow test P-value (significant difference)
	Younger age group (age ≤ 32)	Older age group (age > 32)	
Land Use Regulation Index			
Exclusionary Zoning	-0.0244***	-0.0179***	(0.000)***
Containment	0.0016**	0.0022***	(0.550)
Infrastructure: Impact Fee	-0.0098***	-0.0056***	(0.000)***
Infrastructure: APFO	0.0085***	0.004***	(0.190)
Growth Control: Moratoria	0.0103***	0.0063***	(0.058)*
Growth Control: Permit Cap	-0.0067***	-0.0069***	(0.000)***
Affordable Housing	-0.0041***	-0.0106***	(0.001)**
Transit Investment			
Government investment in public transit in previous year (log)	0.016***	0.011***	(0.000)***
Transit Infrastructure			
MSA with transit legacy city	0.058***	0.055***	(0.014)**
Demographics			
Male	-0.002***	-0.001***	
Age	-0.002***	-0.000***	
Marital status	-0.015***	-0.002***	
High school graduate, some college or Associate's degree	-0.022***	-0.024***	
BA degree	-0.011***	-0.014***	
Graduate degree	-0.003***	-0.008***	
Class of worker (1 = self-employed, 0 = work for wages)	-0.030***	-0.029***	
Usual hours worked per week	-0.001***	-0.000***	
Ambulatory difficulty	0.028***	0.008***	
Household Socioeconomic Status			
Total family income (log)	0.003***	0.004***	
Number of families in the household	0.018***	0.016***	
Number of own children under age 5 in household	-0.011***	-0.003***	
Ownership of dwelling (1 = Owned or being bought with loan, 0 = Rented)	-0.008***	-0.017***	
Number of rooms	0.002***	0.001***	
Number of vehicles	-0.048***	-0.036***	
Home telephone availability (1=yes, 0=no)	0.004***	-0.006***	
Occupation			
Management	-0.001	0.005***	
Business Operation Specialist	0.016***	0.020***	
Financial Specialist	0.028***	0.030***	
Computer and Mathematical occupations	0.025***	0.031***	
Architecture and Engineering Occupations	-0.014***	0.003***	
Community and Social Service Occupations	0.008***	0.015***	
Educational, training and Library Occupations	-0.021***	-0.030***	
Arts, Design, Entertainment, Sports, and Media Occupations	0.010***	0.017***	
Healthcare Practitioners and Technical Occupations	-0.044***	-0.031***	
Healthcare Support Occupation	-0.009***	0.015***	
Protective Service Occupations	-0.014***	-0.005***	
Food Preparation and Serving Occupations	0.013***	0.027***	
Building and Ground Cleaning and Maintenance Occupations	0.019***	0.035***	
Personal Care and Service	-0.007***	0.010***	
Sales Occupation	0.005***	-0.003***	
Office and Administrative Occupations	0.005***	0.010***	
Construction trades	-0.030***	-0.013***	
Installation, Maintenance and Repair Workers	-0.036***	-0.025***	
Transportation and Material Moving Occupations	-0.015***	-0.014***	
MSA- and PUMA-level effects			
PUMA-level Population Density	0.000***	0.000***	
MSA-level Population (millions of persons)	-0.002***	-0.001***	
MSA-level GDP per capita (thousands of current dollars)	0.000**	0.000***	
MSA with rail transit (dummy)	-0.002***	-0.000	
Regions (included)			
Years (included)			
Youngest generation: Observations: 2,363,301; Pseudo R-squared: 0.389			
Prior generation: Observations: 6,238,822; Pseudo R-squared: 0.331			

Notes: 1. Transit Infrastructure: MSA with transit legacy city (1 = New York-Newark, NY-NJ-CT-PA; Chicago-Naperville, IL-IN-WI; Philadelphia-Reading-Camden, PA-NJ-DE-MD; Washington-Baltimore-Arlington, DC-MD-VA-WV-PA; Boston-Worcester-Providence; San Jose-San Francisco-Oakland, CA) (0 = Else).
2. The sample excluded three occupations that each accounted for less than 1 % of the national labor force in 2017. They are Life, Physical and Social Science Occupations; Farming Fishing and Forestry Occupations; Extraction Workers.
3. For occupation variables, the reference group is "Production".
4. For region variables, the reference group is "the Great Plains".
5. For year variables, the reference group is "2005".
6. For education variables, the reference group is "less than high school".
*** $p<0.01$.
** $p<0.05$.
* $p<0.1$.

Table 3
Probit estimation results for choice of carpooling versus driving alone.

Variables	Marginal effects (Carpool = 1; Drive alone = 0)		Chow test P-value (significant difference)
	Younger age group (age ≤ 32)	Older age group (age > 32)	
Land Use Regulation Index			
Exclusionary Zoning	-0.001**	-0.003***	(0.001)***
Containment	0.00215***	0.00217***	(0.000)***
Infrastructure: Impact Fee	0.0023***	0.0017***	(0.003)***
Infrastructure: APFO	-0.002***	-0.001***	(0.000)***
Growth Control: Moratoria	0.002***	0.001***	(0.000)***
Growth Control: PermitCap	0.003***	0.002***	(0.002)***
Affordable Housing	0.000	-0.001***	N.A[7]
Transit Infrastructure scale			
MSA with transit legacy city	0.008***	0.007***	(0.000)***
Demographics	-0.012***	-0.021***	
Male	-0.006***	-0.001***	
Age	0.029***	0.041***	
Marital status	-0.087***	-0.061***	
High school graduate, some college or Associate's degree	-0.134***	-0.075***	
BA degree	-0.127***	-0.077***	
Graduate degree	0.027***	0.025***	
Class of worker (1 = self-employed, 0 = work for wages)	-0.001***	-0.000***	
Usual hours worked per week	0.051***	0.028***	
Ambulatory difficulty			
Household Socioeconomic Status	0.002***	-0.004***	
Total family income (log)	0.019***	0.024***	
Number of families in the household	0.008***	0.001***	
Number of own children under age 5 in household	-0.006***	-0.017***	
Ownership of dwelling (1 = Owned or being bought with loan, 0 = Rented)	0.003***	0.000***	
Number of rooms	-0.028***	-0.006***	
Number of vehicles	-0.003**	-0.011***	
Home telephone availability (1 = yes, 0 = no)			
Occupation	-0.058***	-0.036***	
Management	-0.054***	-0.034***	
Business Operation Specialist	-0.058***	-0.038***	
Financial Specialist	-0.026***	-0.020***	
Computer and Mathematical occupations	-0.055***	-0.024***	
Architecture and Engineering Occupations	-0.056***	-0.033***	
Community and Social Service Occupations	-0.031***	0.002***	
Educational, training and Library Occupations	-0.048***	-0.031***	
Arts, Design, Entertainment, Sports, and Media Occupations	-0.092***	-0.049***	
Healthcare Practitioners and Technical Occupations	-0.070***	-0.032***	
Healthcare Support Occupation	-0.080***	-0.050***	
Protective Service Occupations	-0.043***	-0.006***	
Food Preparation and Serving Occupations	0.038***	0.022***	
Building and Ground Cleaning and Maintenance Occupations	-0.057***	-0.029***	
Personal Care and Service	-0.057***	-0.043***	
Sales Occupation	-0.046***	-0.030***	
Office and Administrative Occupations	0.065***	0.026***	
Construction trades	-0.051***	-0.032***	
Installation, Maintenance and Repair Workers	-0.027***	-0.025***	
Transportation and Material Moving Occupations			
MSA- and PUMA-level effects	0.000***	0.000***	
PUMA-level Population Density	0.001***	0.001***	
MSA-level Population (millions of persons)	0.000***	0.000***	
MSA-level GDP per capita (thousands of current dollars)	0.007***	0.006***	
MSA with rail transit (dummy)			
Regions (included)			
Years (included)			
Youngest generation: Observations: 2,108,837; Pseudo R-squared: 0.0503			
Prior generation: Observations: 5,766,542; Pseudo R-squared: 0.0361			

* $p < 0.1$.
Notes: 1. Transit Infrastructure: MSA with transit legacy city (1 = New York-Newark, NY-NJ-CT-PA; Chicago-Naperville, IL-IN-WI; Philadelphia-Reading-Camden, PA-NJ-DE-MD; Washington-Baltimore-Arlington, DC-MD-VA-WV-PA; Boston-Worcester-Providence; San Jose-San Francisco-Oakland, CA) (0 = Else).
2. The sample excluded three occupations that each accounted for less than 1 % of the national labor force in 2017. They are Life, Physical and Social Science Occupations; Farming Fishing and Forestry Occupations; Extraction Workers.
3. For occupation variables, the reference group is "Production".
4. For region variables, the reference group is "the Great Plains".
5. For year variables, the reference group is "2005".
6. For education variables, the reference group is "less than high school".
7. The Chow tests only included key variables of interest which has significant effects for both age groups.
*** $p<0.01$.
** $p<0.05$.

Table 4
Poisson regression results for the number of riders in carpooling.

Variables	Marginal effects		Chow test P-value (significant difference)
	Youngest generation	Prior generations	
Land Use Regulation Index			
Exclusionary Zoning	0.020***	0.022***	(0.000)***
Containment	0.0001	0.008***	N.A.
Infrastructure: Impact Fee	0.013***	0.002	N.A.
Infrastructure: APFO	-0.001	0.010***	N.A.
AGrowth Control: Moratoria	-0.008***	0.002	N.A.
Growth Control: PermitCap	0.007***	-0.001	N.A.
Affordable Housing	-0.001	0.004*	N.A.[7]
Transit Infrastructure scale			
MSA with transit legacy city	0.015**	0.023***	(0.000)***
Demographics			
Male	0.025***	0.026***	
Age	0.005***	-0.002***	
Marital status	-0.040***	-0.024***	
High school graduate, some college or Associate's degree	-0.255***	-0.120***	
BA degree	-0.275***	-0.096***	
Graduate degree	-0.319***	-0.108***	
Class of worker (1 = self-employed, 0 = work for wages)	-0.033***	-0.117***	
Usual hours worked per week	0.001***	-0.000*	
Ambulatory difficulty	0.061***	0.005	
Household Socioeconomic Status			
Total family income (log)	0.017***	-0.013***	
Number of families in the household	0.082***	0.065***	
Number of own children under age 5 in household	0.092***	0.067***	
Ownership of dwelling (1 = Owned or being bought with loan, 0 = Rented)	-0.012***	-0.009***	
Number of rooms	0.000	0.009***	
Number of vehicles	0.031***	0.031***	
Home telephone availability (1 = yes, 0=no)	-0.094***	-0.072***	
Occupation			
Management	-0.096***	-0.048***	
Business Operation Specialist	-0.100***	-0.009	
Financial Specialist	-0.100***	-0.023**	
Computer and Mathematical occupations	-0.086***	-0.007	
Architecture and Engineering Occupations	-0.049***	0.113***	
Community and Social Service Occupations	-0.058***	-0.037***	
Educational, training and Library Occupations	-0.047***	0.011*	
Arts, Design, Entertainment, Sports, and Media Occupations	-0.061***	-0.012	
Healthcare Practitioners and Technical Occupations	-0.063***	-0.061***	
Healthcare Support Occupation	-0.041***	-0.048***	
Protective Service Occupations	-0.036**	0.006	
Food Preparation and Serving Occupations	-0.125***	-0.077***	
Building and Ground Cleaning and Maintenance Occupations	-0.011	-0.037***	
Personal Care and Service	-0.048***	-0.019**	
Sales Occupation	-0.101***	-0.091***	
Office and Administrative Occupations	-0.088***	-0.056***	
Construction trades	0.098***	0.044***	
Installation, Maintenance and Repair Workers	-0.105***	-0.017**	
Transportation and Material Moving Occupations	-0.065***	-0.005	
MSA- and PUMA-level effects			
PUMA-level Population Density	0.000***	0.000***	
MSA-level Population (millions of persons)	0.004***	0.004***	
MSA-level GDP per capita (thousands of current dollars)	0.000***	0.000**	
MSA with rail transit (dummy)	-0.013**	-0.002	
Regions (included)			
Years (included)			
Youngest generation: Observations: 294,175; Pseudo R-squared: 0.0034			
Prior generation: Observations: 587,427; Pseudo R-squared: 0.0019			

Notes: 1. Transit Infrastructure: MSA with transit legacy city (1 = New York-Newark, NY-NJ-CT-PA; Chicago-Naperville, IL-IN-WI; Philadelphia-Reading-Camden, PA-NJ-DE-MD; Washington-Baltimore-Arlington, DC-MD-VA-WV-PA; Boston-Worcester-Providence; San Jose-San Francisco-Oakland, CA) (0 = Else).
2. The sample excluded three occupations that each accounted for less than 1 % of the national labor force in 2017. They are Life, Physical and Social Science Occupations; Farming Fishing and Forestry Occupations; Extraction Workers.
3. For occupation variables, the reference group is "Production".
4. For region variables, the reference group is "the Great Plains".
5. For year variables, the reference group is "2005".
6. For education variables, the reference group is "less than high school".
7. The Chow tests only included key variables of interest which has significant effects for both age groups.
*** $p<0.01$.
** $p<0.05$.
* $p<0.1$.

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