The University of Chicago

Driving to Work: The Chicago Region and its Transport Based Emissions

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A thesis submitted in partial fulfillment
Of the requirements for a Bachelor of Arts Degree in

Public Policy Studies

Paper presented to
Public Policy Studies Preceptor: Rachel Dec

Department of Public Policy Studies

April 2021

Abstract

In 2016, the transportation sector became the single largest emitter of carbon dioxide in the US, emitting almost 2 billion metric tons of carbon dioxide per year. American cities and their metropolitan areas contributed about 63% of total transport emissions and have been responsible for 80% of the increase in transport emissions in the last decade. Less dense urban areas tended to have higher per-capita CO_2 emissions. However, growth in transport related CO_2 emissions has occurred in almost every US city, even those that are relatively dense and have lower car dependence per capita. This thesis investigates the impact of jobs and population on the transportation emissions in the six county Chicago region. The Chicago area has been an outlier among its peer cities in terms of transport based emissions since 1990. Cities with similar densities either lowered their transport emissions or exhibited no change between 1990 and 2010, while Chicago's population density declined and its transport emissions increased. This study attempts to gain insights into the reasons for the higher transportation emissions.

This analysis uses the DARTE, Census and Census' LEHD databases to analyze population, job and transport based emissions in the Chicago region from 2005-17. Data analysis indicates that simultaneous job centralization as well as decentralization is occurring in the region along sustained loss of population in Cook County and a trend toward suburbanization. Two additive models were created to conduct regressions. One used jobs, and population as independent or explanatory variables, and transport-related emissions (TREs) as the dependent or response variable. In the second model, job density and population density were the independent variables and per capita TREs were the dependent variable. Regressions were also conducted for inflow and outflow data of commuting workers and distance traveled to work against transport related emissions data.

Jobs were found to have statistically significant positive correlations with transport related emissions for the overall region while population had negative correlations. Within Cook County, this relationship was only evident after 2010 while for the five other counties there was only a statistically significant positive correlation between jobs and transport based emissions. Inflow and outflow of workers had a positive correlation with transport based emissions especially in the outer suburban counties of Will, Kane and McHenry counties and is a good proxy for transport related emissions in the five outer suburban counties. Policy recommendations include expanding transit service, especially adding inter-suburban connections, encouraging employment and residential transit oriented development, and implementing congestion pricing in Chicago's central business district (CBD).

Acknowledgements

First, I would like to thank Charles Komanoff who helped to grow my interest in environmental and transportation policy. He taught me so much about research and analysis in the field, and I want to thank him for his kindness and generosity.

I would also like to thank Dr. Amir Jina for his advice on thesis research methods and topic selection.

Dr. Conor Gately created the DARTE dataset for transportation-related emissions that I used for my thesis. He was very responsive to my questions about the database and provided helpful tips on how to use it. His work and advice were instrumental in doing this thesis. For this I am very thankful.

Dr. Juan Camilo Osorio connected me to Sofia Hull, who helped me tremendously in troubleshooting the extraction of data from the DARTE GIS model. Without their help, this thesis would not have been possible. I am deeply grateful for their help and generosity.

I am also grateful to Dr. Katherine Baird who was so generous with her time in helping me hone the regression models and analysis that are at the core of my data analysis work. Her advice and class, Quantitative Methods for Public Policy, provided me with the knowledge that was indispensable for my thesis.

This thesis would not have been possible without my two BA thesis preceptors, Charlie Rollason and Rachel Dec. Charlie's guidance provided me with the building blocks for this thesis and set me on the right path. Rachel's advice helped me in the later stages of my thesis. I am deeply grateful to them for their insights, encouragement and readiness to help with issues as they cropped up.

Finally, I would like to thank my family for their support over my time at University of Chicago. Without their guidance and encouragement, I would not be where I am today.

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Introduction

Over the last ten years, US greenhouse gas (GHG) emissions have been declining (Houser et al, 2019) despite population growth. However, this general decline masks an increase in one important area: transportation. In 2016, according to the Environmental Protection Agency (EPA), the transportation sector became the single largest emitter of carbon dioxide in the US, emitting almost 2 billion metric tons of carbon dioxide per year. If such increases continue, the overall decline in US carbon dioxide emissions could be reversed. This could have a profoundly negative impact on the fight against climate change around the world, as the US is among the largest producers of carbon emissions per capita.

American cities and their metropolitan areas contribute about 63% of total transport emissions and are responsible for 80% of the increase in transport emissions in the last decade (Gately et al, 2015). Therefore, analyzing transportation trends in cities and their regions is essential to understanding the national increase in emissions from transport. The literature regarding transportation emissions and trends usually focuses on passenger surface transportation (cars, light duty trucks, and public transportation). Consequently, population density is believed to predict per capita greenhouse gas emissions. Rural counties tend to have the highest per-capita CO_2 emissions, followed by suburban and then urban areas. Between 1990-2010, rural and suburban areas have experienced the largest increases in CO_2 emissions for transport. Less dense urban areas also tend to have higher per-capita CO_2 emissions. (Gately et al, 2015) However, growth in CO_2 emissions from transportation has occurred in almost every US city, including ones that are relatively dense and have lower car use per capita, such as Portland, Oregon and New York City.

Some authors contend that such increases in emissions are tied to employment accessibility and not population density per se. According to Kneebone and Holmes (2016), when jobs increasingly locate in suburbs, the accessibility to these jobs decline. Every US Metropolitan Statistical Area (MSA) excluding the New York MSA has experienced increases in such job decentralization. (Glaeser et al, 2001) This includes high-density cities such as San Francisco, Boston and Chicago. Kneebone and

Holmes (2016) found that job decentralization caused a 7% decrease in job accessibility (number of jobs reachable in a reasonable amount of time by any mode of transportation) across 96 metropolitan areas. In addition, Boarnet et al. (2011) found that job accessibility is a greater determinant of Vehicle Miles Traveled (VMT) than population density. VMT is the metric that is often used to calculate GHG emissions from transportation. Therefore, some authors believe that job decentralization, and the associated decreases in job accessibility, play a greater role in GHG emissions from transportation than population density.

The objective of this thesis is to understand whether job decentralization or population growth impact the increasing per-capita CO_2 *emissions from transport and recommend policies that would help to ameliorate the factors that lead to increases in* CO_2 *emissions.* In order to do so, I will do a longitudinal case study of the transport based emissions from the Chicago metropolitan area. Most literature defines the Chicago metropolitan area as the city itself, Cook County which includes the city of Chicago and its innermost counties, inner suburban DuPage County, and outer suburban Will, Lake, Kane and McHenry Counties. The reason for focusing on the Chicago area is that since 1990 it has been an outlier among its peer cities in terms of transport based emissions. Gately et al (2015) found that while cities with densities similar to Chicago lowered their transport emissions or exhibited no change between 1990 and 2010, Chicago's population density declined while its emissions increased in the same time period. (Magill, 2015)

1990-2017	% Change Total Transport-based Emissions	% Change Per Capita Transport-based Emissions
New York MSA	27%	9%
Los Angeles MSA	16%	2%
Chicago MSA	66%	43%

Source: Popovich and Lu, 2019

In addition, to Chicago's increasing transport based-emissions, recent studies have found that Chicago ranks second in the nation for traffic congestion far outranking New York City and Los Angeles for this measure. (Koziarz, 2020) To add to the conundrums facing the Chicago Metropolitan region regarding automobile driven emissions, it was ranked third in the nation for the highest VMT after Dallas and Houston and yet the third highest bicycle commuting region after Philadelphia and New York City. (Streetlight Data)

Thus, the Chicago metropolitan area presents a unique case where the population density does not seem to ameliorate the VMT or emissions from the transportation sector. An in-depth study of the employment and population growth patterns will help in developing an understanding of the interaction of these variables with transport-based emissions in the Chicago region as well as other cities with similar patterns. One can argue that a case study of Chicago does not lead to a generalized hypothesis about the impact of spatial patterns of job and population growth. However, this case study will increase the body of knowledge by teasing out patterns and trends that may not be possible to investigate in a larger scale comparative or collective case study design.

I will look at several issues in particular that have emerged in recent years as potential causes of increased emissions: locational changes in jobs and population, as well as commuting patterns. Sööt et al. (2006) found that the suburban counties in the Chicago metropolitan area experienced the highest rate of population growth over the past 20 years. In addition, only DuPage, the suburban county closest to the City of Chicago, had a majority of its residents working within its boundaries. The majority of workers in all other suburban counties did not work in the county in which they lived. However, Sööt et al. (2010) only looked at data until 2000. Since then, there has been an economic recession and corresponding burst of the housing bubble. There was also a national decline in VMT spanning from 2005 to 2016, the cause of which is being debated among scholars. To explore the impact of these developments on transport based emissions, I will analyze job, population and emissions data for Chicago from 2005 to 2017.

I will investigate possible patterns in job and population growth in the Chicago metropolitan area and the impact they have had on transport related emissions in the region. To analyze emissions from transport, several databases will be used. DARTE, a database developed by Boston University, will be used for data of road transport emissions in the US from 1990 to 2017. The US Census's Longitudinal Employer Household Dynamics (LEHD) database will be the basis of a longitudinal analysis of job growth and location, places where people are employed, and distance to their workplaces. I will use the US Census to track changes in population growth.

Literature Review

In order to investigate the factors contributing to the increase in transport related per-capita CO_2 emissions in Chicago, it is important to analyze previous works that study the various factors and relationships that impact per-capita CO_2 emissions. What are the causes of increase in transport related per-capita CO_2 emissions, and are these variables related? While large scale metropolitan area studies aim to extract average effects, a smaller scale granular study can uncover smaller trends that are missed by the larger studies.

There are myriad factors that affect transport related per-capita CO_2 emissions. In order to answer the research question, this review focuses on studies that explore the relationship of Vehicle Miles Traveled (VMT), which is often directly related to transport emissions, with population density, population growth, and distance to work or job accessibility. Relevant literature also analyzes the effects of job suburbanization on mode share, i.e., what mode of transportation do people use to commute to work.

American Commutes Distances and Times are Increasing:

Driving alone by car has been the dominant way to commute to work for Americans for decades. Tomer (2018) found that over 76% of Americans commuted alone by car in 2016 with about 115 million cars and trucks on the streets every day. In addition, Schleith et al. (2016) found that commuting distances have been rising over the last two decades. They also found that the commuting distances have increased for higher income workers and had reduced for younger people and low-income workers. The latter is possibly due to fewer job and location choices among young people who may live with their family and low-income workers who do not have much choice in terms of housing or work location due to financial constraints. Transportation costs are the second highest household average expense after housing, leading to difficulties for lower income workers (Tomer, 2018). Thus, commuting distances are connected to income and to some extent with age. Tomer (2018) also found that despite increases in transit options, widening of roads, and the prevalence of ride hailing, no transportation mode saw its share of commuters change by more than 1.5%.

Built Form, Population Density and Emissions:

Car usage is also connected to population density and built environment. Kahn (2000) found that suburban residents drive 31% more than their urban counterparts. In a study of Household Carbon Footprints (HCF) and CO_2 emissions, Jones and Kammen (2014) found that suburban areas of large cities usually had about 25% higher HCF than urban areas. Denser suburbs tend to have higher HCF. Overall, urban cores and rural areas had the lowest HCF, while suburban areas had the highest HCF. In most metropolitan areas, extensive suburban CO_2 emissions outweigh the lower emissions in the city cores leading to high HCFs for the metropolitan areas. The only exceptions are the metropolitan areas of extremely large cities, such as New York City and Los Angeles metropolitan areas, which have lower HCF than one would expect based on other metropolitan areas. Jones and Kammen (2014) found that population density affects the size of homes and vehicle ownership, which in turn impacts HCF. They found a log-linear relationship in which a 10-fold increase in population density leads to a 25% HCF reduction. HCF is influenced by (in order of greatest to least influence) number of vehicles per household, annual household income, carbon intensity of electricity, home size, size of household and population density. The other significant variables are average travel time to work, fuel prices, heating and age of home. Transportation accounted for a significant (26%t to 42%t) of HCF. At densities above 3000 people/mile^2 (or 1158 people/km^2), Jones and Kammen, 2014, find that HCF tends to be lower due to smaller homes, shorter driving distances and somewhat lower incomes. Smaller homes need less energy to heat, cool and provide electricity for than larger homes, resulting in less CO_2 emissions. Shorter driving distances produce less CO_2 emissions than longer ones. People with lower incomes consume far less than people with higher incomes. Lower consumption means lower CO_2 emissions. Thus, CO_2 emissions, and by extension HCF, are lower with lower income, smaller homes, and shorter driving distances to work. However, though population density is correlated with HCF, it is difficult to predict the income of residents that will inhabit the area, making it a sub-optimal policy lever for controlling HCF.

Prior to Jones and Kammen (2014), Cervero and Murakami (2009) found that population density positively impacts Vehicle Miles Traveled (VMT) per capita. However, the connection between VMT and emissions had been postulated but not proven. Gately et al. (2015) extended the prior work on the relationship by population density and VMT by analyzing CO_2 emissions from transportation specifically. In order to do so, the authors created a database of CO_2 emissions per square kilometer (DARTE) using Federal Highway Administration (FHWA)'s Highway Performance Monitoring System (HPMS). Using this model, Gately et al. (2015) found that cities with higher density and higher transit commute shares have lower per-capita CO_2 emissions from transportation and have smaller increases in per-capita CO_2 between 1990-2010 than lower density, more car dependent cities. They found that per-capita emissions increased at densities below the threshold of 1650 people/km^2, which is quite close to the findings of Jones and Kammen (2014). After this, the emissions plateaued until density reached 4000 people/km^2, after which they increased slightly. The authors also found that lower density cities experienced dramatic increases in per capita CO_2 emissions from 1990 to 2010. Denser cities experienced small changes, which were either negative, or neutral in per-capita CO_2 emissions from transportation. However, Chicago was the exception as it experienced larger increases in per-capita CO_2 emissions from transportation than its peer cities in terms of population density, which raises the question of what could be unique about Chicago that bucks the trend among its peers.

The findings of Jones and Kammen (2014) and Gately et al. (2015) regarding the effect of population density on emissions is supported by the work of Mitchell et al (2018) on atmospheric CO_2 produced in the Salt Lake City region over a decade at five locations. They found that urban areas were associated with stable CO_2 emissions, while rural areas that had recently been suburbanized were associated with rapidly increasing CO_2 emissions. This work controlled for seasonal changes in emissions. Thus, household emissions are correlated with built form and population density. Transport emissions play a large part in these emissions.

However, it is not clear whether population density is a valid proxy for transport-based emissions. Landis et al. (2019) found that even if reduced driving was aggressively promoted and development was densified, emissions from transportation would still rise 10% by 2030. However, if these policies are combined with a fuel economy standard of 40 miles per gallon (MPG), decreases in transport CO_2 emissions can be as much as 26% by 2030. This is due to the high degree of sprawl in US cities overall that makes developing alternatives to driving nearly impossible. Choi and Zhang (2017) also confirm some of the results of Landis et al. (2019), namely that dense development on its own does not lead to a decline in vehicular trip frequency and/or emissions. They hypothesized that increased population density could potentially lead to higher CO_2 emissions from transportation as slower cars are generally less efficient and pollute more. While this hypothesis was not confirmed through their study, the authors found that Vehicle Miles Traveled (VMT) in isolation is not a complete proxy for emissions from transport. Rather, analyses should also include trip frequency as well as vehicular speed, as they are critical determinants of vehicular emissions.

In addition, it appears that better balance between jobs and housing at the county level can lead to more households driving (Choi and Zhang, 2017). This counterintuitive result can be explained by the work of Cervero and Murakami (2009) who found that the relationship between population density and VMT is moderated by the traffic-inducing effects of denser road networks in denser urban settings and better local-retail accessibility. Access to basic employment had comparatively modest effects, as did size of urbanized area, and rail-transit supplies and usage.

The increase in emissions at very high density is very peculiar and could be due to gentrification and increasing wealth in these areas, as the wealthy tend to have greater VMT and per-capita GHG emissions (Goldstein et al, 2020). The weaker correlation between population density and VMT could also be due to lack of alternatives to driving to reach the wider metropolitan area in which many jobs and amenities are located, or more specifically, poor regional transit infrastructure despite the density of the area. These findings will help me to understand long term trends in transport emissions and also in evaluating suburban transport emissions within metropolitan areas.

Job Accessibility and Emissions:

Other studies contend that employment accessibility impacts VMT more important population density (Boarnet et al, 2011, Kneebone and Holmes, 2016, Cervero and Landis, 1992, Boarnet and Wang, 2019, Wachs et al, 1993, Glaeser and Kahn, 2001.) The larger scale studies that are more prevalent in the literature focus on the average effect of land use on travel behavior and find that population density is a good proxy for VMT. However, Boarnet et al (2011) find that accessibility to employment is a much greater determinant of VMT than population density in smaller areas as opposed to the findings of the larger metropolitan area studies. Using GIS, the study examines thresholds in population density, employment accessibility, or interactions between the two. After dividing the samples into quintiles for population density and employment accessibility, the authors recommend focusing policies on the 3rd and 4th quintiles of employment accessibility in order to reduce VMT.

Several studies have noted that with the increasing decentralization of jobs, proximity to work has been declining for many workers, leading to increased commuting distances. Using Census data from 2000-2012, Kneebone and Holmes (2016) find that jobs within a typical commute distance[1] declined by 7% across 96 metro areas. Jobs also have been increasingly located in suburban areas, and interestingly, suburbanites saw the number of jobs within a typical commute distance decline by 7% as opposed to a 3% decline for urban residents. Underscoring the growth of suburban jobs, Fee (2020) found that suburban employment grew 5.5% more than urban employment while the share of jobs in "typical commute distance" declined among most cities from 2007-2017. Overall, access to jobs declined by 1.7% across all metro areas in the US. Declines in employment access are associated with increases in suburban employment.

Schleith et al. (2016) found that commuting distances increased from 2003-13 in 26 metropolitan regions. In addition, they found that the commuting distances increased the most for higher income

[1] Median commute distance in the metropolitan area

workers. Young people and low income workers had the lowest commuting distances.

Cervero and Landis (1992) studied the impact of suburbanization of jobs on commute times and transportation mode share in the San Francisco bay area through surveys of 300 employees at several companies whose jobs had moved to suburban locations. The authors found that commute distances remained the same for those who lived in the suburbs, while they increased for those who lived in the city and reverse commuted to the suburbs. However, the travel time for those who lived in the suburbs declined, while the travel time increased for people living in the city. Most notably, the share of people commuting by car increased dramatically when the jobs moved to the suburbs from the city. Driving creates far more CO_2 emissions than public transportation, which means such a shift could increase CO_2 emissions from transportation dramatically. This indicates that shifts of jobs to suburban areas in the Chicago area could contribute to increasing per-capita CO_2 emissions from transportation.

In looking further into the impact of job accessibility on VMT, Boarnet and Wang (2019) analyzed “sub-centers", or localized employment clusters in the Los Angeles Combined Statistical Area (CSA) using household VMT from the 2012 California Household Travel Survey. In their study, they find that greater accessibility to jobs reduces VMT. Focusing again on a smaller area analysis as opposed to larger metropolitan area averages, they find that the reduction in VMT in the outlying counties is only possible when the jobs are located within 5 miles of a person’s home. Accessibility to jobs outside of the employment subcenters has a greater effect on reducing VMT. Thus, encouraging job development between sub-centers and in the center of the region is an effective land-use method to reduce VMT. Placing jobs near residents and residents near jobs is found to be an effective strategy for Los Angeles CSA. I will evaluate the effectiveness of such a policy strategy for reducing VMT in the Chicago area.

However, not everyone agrees that lengthening work trips are the cause of greater traffic congestion and by proxy, emissions. Wachs et al. (1993) studied residential location choices and commuting patterns of 30,000 Kaiser Permanente employees in Southern California over six years. They found that residential location choices were driven by many factors besides accessibility to jobs such as quality of neighborhood and schools and perceived safety. In contradiction to the other studies cited above, they find that local traffic congestion is impacted more by workforce growth than the lengthening of the work trip over time. Many of the studies cited earlier, as well as Wachs et al. (1993), rely on surveys. However, Wachs et al. (1993) only surveyed employees of a certain company, which may not be representative of the broader population. By contrast, Boarnet and Wang (2019) look at the 2012 California Household Travel Survey, which is a much broader survey. Cervero and Landis (1992) have the smallest survey size, but they look at several companies. Schleith et al. (2016) do an aggregate study based on large-scale data across 26 metropolitan regions over a decade, as opposed to surveys. However, the prior studies seem to have focused their questions primarily on travel behavior and measurements, while the survey used by Wachs et al. (1993) may have looked at other factors such as schools and perceived safety as well.

Overall, the established literature finds that access to jobs is often a greater determinant of VMT than population density, and that wealthier individuals tend to have greater VMT. Access to jobs in most US metropolitan areas has also been declining, though some cities have experienced job centralization. However, "job accessibility" varies quite widely depending on transportation mode, and is usually determined in terms of travel time, not distance as most of the literature has done. An outlying suburban area with a fast rail link may be more accessible to jobs than an inner city area served solely by local bus service, even though the suburban area is further away from such jobs. Studies also found that VMT in isolation is not an accurate proxy for per-capita CO_2 emissions from transportation. Rather, other factors such as vehicle trip frequency and vehicle speed are also needed to accurately estimate per-capita CO_2 emissions from transportation. In addition, studies found that job suburbanization (decentralization) has increased in recent decades along with an increase in per-capita emissions from transport in most cities.

In the last three decades, Chicago has experienced an increase in per-capita CO_2 emissions and job decentralization far greater than what one might expect based on its population density. Gately et al. (2015) found that Chicago experienced greater increases in per-capita CO_2 emissions from transportation than expected for a city of its density. According to Glaeser and Kahn (2001) almost all metropolitan areas in the US have experienced job decentralization, with the notable exception of New York City.

Chicago has also experienced a great degree of job decentralization. Indeed, even though Chicago has a population density much closer to that of New York[2], it has similar amounts of job decentralization as Los Angeles, the prototypical low-density, decentralized city. In addition, Chicago has been rated to have the second worst commute in the US by various sources. These findings make Chicago an interesting city to analyze in terms of per-capita CO_2 emissions.

Trends in Job Growth and Commuting in the Chicago region

Sööt et al. (2010) analyzed changes in commuting patterns and population in the six county Chicago metropolitan area from the 1960s to the early 2000's. These six counties include Cook County, inner suburban DuPage County, and outer suburban Lake, McHenry, Kane, and Will Counties. The authors analyzed inter- and intra-county commuting, population growth in each county and household size using Census data from the study period. They found that the outer suburban counties experienced the highest percentage of population growth over this period, but declining shares of people living and working within the county. In fact, in all counties with the exception of DuPage, the percentages of people working in the county in which they lived declined in all counties and commute times increased by about 3.1 minutes. DuPage experienced a decline in commute time and increase in people working within the county. This study provides broader context to the changes in population and commute patterns that have occurred in more recent years. It also provides some explanations behind the population growth in the outer suburban counties, such as lower housing prices.

The analysis by Sööt et al. (2010) provides a great baseline for this thesis. Departing from Sööt et al.'s work, I look at more granular information regarding inter-county commuting patterns. The implications of such information are quite large for per-capita CO_2 emissions from transport. Commuting from outer suburban counties to Chicago, for example, would likely generate less CO_2 emissions than inter-suburban commutes between counties due to many using Chicagoland's extensive Metra commuter

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[2] Chicago population density: 11,943 people/square mile

rail system. Cook County also has many suburban towns in addition to the city of Chicago, many of which have more in common with the suburban counties than Chicago. As such, I use zip code level data to analyze CO_2 emissions, commute patterns, location of job growth and population growth so that intra-county as well as inter-county patterns can be discerned better.

Methods

Data Sources and Time Period for longitudinal analysis

Several factors will be evaluated as potential contributors to the increase in transport-based emissions in the Chicago area. These include job growth and density, population growth and density, distance travelled to work, and inflows and outflows of workers in the Chicago region.

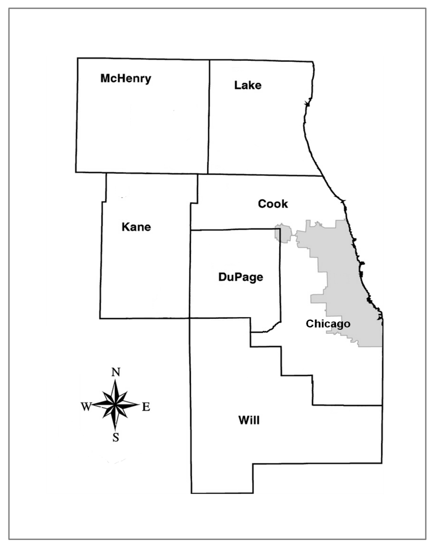
Job growth is a potential primary contributor to increasing transportation-based emissions. According to the Census, the vast majority of commuters in the region drive to work. Thus, work commutes are one of the most important sources of transportation-based CO_2 emissions. Changes in numbers of jobs can contribute to changes in transport-based CO_2 emissions as more workers would be on the road. Job location is also important, as jobs in car-centric, suburban locations may generate more CO_2 emissions than those located in urban ones due to the necessity of driving, which is the most carbon-intensive mode of transportation. Job density, or the number of jobs per square mile, is important as well. Areas that have high job density tend to draw more trips than areas with low job density, which could have an effect on emissions.

Commuters travel from home to work and vice versa. This movement of people will likely impact transport-based emissions, as very few people walk to work. Location of population growth has implications on transport-based emissions. Growth in low-density car dependent suburban settings will likely cause a greater increase in emissions than growth in public transit rich urban centers. Thus, population density could have an impact on emissions. In addition, distance to work could play a role in increases in emissions. Longer commutes tend to produce more CO_2 emissions than shorter ones, especially if they are by car.

Finally, inflows of workers into counties and outflows of residents away from counties to their work destinations could be a proxy for emissions. These inter-county commuters are likely travelling long distances, and the vast majority drive. Therefore, it could be associated with rising emissions.

Travel patterns in the Chicago area are often regional, and longer distance inter-county trips contribute disproportionately to transport-based emissions. Sööt et al. (2010) analyzed changes in commuting patterns and population in the six county Chicago metropolitan area from the 1960s to the early 2000's using inter- and intra-county commuting and population growth data. These six counties include Cook, DuPage, Lake, McHenry, Kane, and Will Counties. They found that the outer suburban counties experienced the highest percentage of population growth over this period, but declining shares of people living and working within the county.

To allow comparison with Sööt et al., 2010, this thesis will focus on a longitudinal study of the six counties that have been used for this study and have traditionally been considered part of the Chicago metropolitan area - Cook, DuPage, Kane, Lake, McHenry and Will counties. Cook County, which includes Chicago, is by far the largest county, and has both larger urban centers and suburban towns. Therefore, an overall analysis of Cook County would not be enough to capture the nuances of transport emissions within it. To remedy this issue, the 10 largest cities in Cook county will be analyzed as well.



Six County Study Region

The analysis will examine data from 2005-17. Starting in 2005 will dovetail into the work of Sööt et al., 2006, while capturing the changes that occurred in the 2008 economic recession. The economic recovery began in 2010, with the national transport emissions overtaking all other sectors in 2015. The end date of the study is 2017 since that is the last date for which DARTE data is available.

This thesis uses three databases. The DARTE database will be used to conduct a longitudinal analysis of transport-based emissions at the county level and for the 10 largest cities in Cook County. DARTE was developed by Boston University, and provides annual data at the square kilometer level for GHG emissions from transportation from 1980-2017. The DARTE database uses traffic data from the Highway Performance Monitoring System (HPMS) as well as data on the types of cars on the road during the sample year. Since the HPMS system takes VMT into account when determining traffic flows, the DARTE database provides a detailed picture of emissions levels across locations. Per-capita emissions can be calculated by dividing a location's transport-based emissions by the number of people who live in it.

Census's Longitudinal Employer Household Dynamics (LEHD) Origin Destination Employment Statistics (LODES) database, which provides data from 2002 onward on jobs and commuting patterns, will be used to conduct a longitudinal analysis of job growth and location, places where people are employed, inflow outflow of workers from and to workplaces, and distance to their workplaces. The Census' American Community Survey (ACS) one year estimates for the years 2005-2017 will be used to track changes in population growth.

Data Analysis:

I performed a longitudinal analysis of the distribution and growth of jobs and population at the county level as well as transport related emissions within the six county study region from 2005 to 2017. Since Cook County is the largest county in the area with the most population, jobs and transport related emissions, I also analyzed data for the ten largest cities in the county in order to understand trends. My overall data analysis focuses on whether the location of population and employment growth, combined with commute patterns, have an impact on transport related emissions (TRE) in the study region. To analyze the impact of changes in job and population location on TRE, I analyzed changes in job clusters and population in the six county study region between 2005-17. Since the outer suburban counties have far lower population and jobs individually as compared to Cook County, I aggregated the data for the five outer suburban counties in order to provide a better comparison to Cook County. Thus, data was analyzed at the level of the entire six county level, at the individual county level, and the aggregated five county level. The number of workers in the metro region, and their travel patterns was analyzed using inflow-outflow data as well as distance and destination data from the LEHD. This helped me understand patterns and trends in job location and population growth and their impact on commuting patterns and by proxy, transport related emissions.

In order to find correlations between the independent variables of localized job and population growth and dependent variable of transport related emissions (TRE), I conducted several regression analyses. I created two additive models based on analysis of the data. For Additive Model 1, I conducted regressions with on-road TRE as the dependent variable and population and jobs as the independent variables. Population and jobs were both used as independent variables, as neither population or jobs impact TRE on their own. It is an interaction between these two factors that likely impact transport-based emissions.

Additive Model 1:

Transport based $CO_2 = \Psi_1[\text{Population}] + \Psi_1[\text{Jobs}] + \alpha$

For Additive Model 2, I conducted regressions with on-road per capita transport based emissions as the dependent variable and population density and job density as the independent variables. Population and job density as independent variables provide better metrics for per capita emissions.

Additive Model 2:

Per Capita Transport based $CO_2 = \Psi_1[\text{Population density}] + \Psi_1[\text{Job density}] + \alpha$

These models were applied at the overall six county level, the combined five outer county level and at the individual county level for the period between 2005-17. The models were also applied to Chicago. Regressions were conducted for the aggregated data from five suburban counties in order to tease out correlation for job centralization as well as decentralization in the six county area.

Since the period of the study included one of the worst recessions in US history, I noticed a lot of variation in the data over the 12 year period. Since job recovery in the region started in 2010 and the emissions data showed increases starting in 2012, I also conducted regression analysis using the above models for the time periods of 2010-17 and 2012-17.

To better understand the impact of commuting generated by work trips on transport based emissions, regressions were also conducted with inflow outflow data and distance traveled to work as the independent variables at all the levels mentioned above and for all time periods mentioned above.

Limitations of Study:

This study is limited by the fact that it focuses on trips to work and does not include personal trips, which are a significant share of the trips a person makes in a week. However, those trips are often shorter in distance than work trips and are considered to have lower impact on transport based emissions.

The study does not account for emissions from commercial vehicles and public transportation. Chicago is the largest land-based port in the US and a large amount of freight travels through the region. VMT from commercial vehicles has increased recently due to the popularity of eCommerce and last mile delivery options. However, passenger cars, trucks and motorcycles account for the majority of the emissions from the On-Road Transportation sector. Recently, there has been significant growth in rideshare services in Chicago. This study does not include the impact of rideshare services on transport emissions.

The study period includes one of the worst recessions in US history. Though officially the economic recovery started in 2009, many parts of the region had not recovered until 2016 or so. These aftershocks from the recession had a significant impact on the population, jobs, and consequently transport-based emissions. Thus, it may not be possible to make clear future predictions from the analysis as there were many other factors beyond the scope of this study that may have influenced patterns.

The study looks at the data at the county level and for some cities in Cook County. This might overlook patterns within the City of Chicago that influence transport related emissions. Finally, the study does not delve into the socioeconomic factors that influence transport based emissions.

Findings:

Population, Jobs and Emissions for Six County Study Area

My thesis project set out to investigate whether population density and/or job density were the underlying causes for the Chicago area's considerable increase in transport related emissions (TREs) as compared to other urban regions with similar demographics. Scholars have been confounded by the fact that TREs continued increasing in the Chicago region despite declining population density.

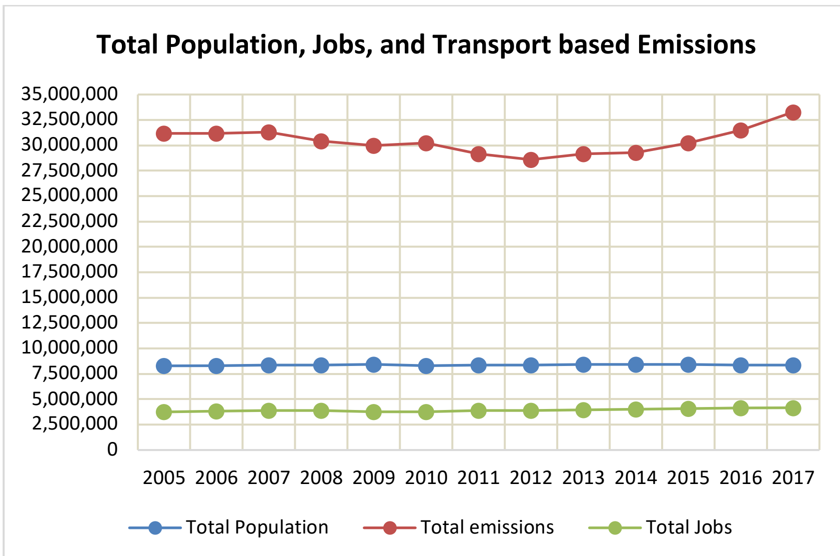


Figure 1

In my findings, I first discuss the trends in population, job growth and transport-related emissions (TREs) in the Chicago region as well as at the individual county level, the aggregated five county level, and the Cook County city level. I then discuss the findings from the regressions I ran for these geographies.

Population:

Between 2005-17, the six county study region experienced a very small 0.91% increase in population. Although the periods between 2005-10 and 2010-17 saw increases in population of less than 0.5%, the region lost population by 0.21% from 2012-17. Thus, the study region population remained relatively stagnant throughout the study period.

	2017 Population	2017 Population Density (per km^2)	% change 2005-17	% change 2010-17	% change 2012-17	% change 2005-10
Study area	8,364,147	879	0.91%	0.47%	-0.21%	0.44%
Cook	5,200,821	2,125	-1.24%	0.03%	-0.74%	-1.27%
5 Counties besides Cook	3,163,306	447	4.66%	1.19%	0.67%	3.43%
DuPage	930,265	1,096	0.66%	1.33%	0.17%	-0.67%
Kane	532,272	395	12.05%	3.12%	2.33%	8.66%
Lake	702,475	611	1.91%	-0.24%	0.06%	2.15%
McHenry	307,815	197	2.87%	-0.4%	-0.13%	3.29%
Will	690,479	319	8.8%	1.72%	1.17%	6.96%

Table 1

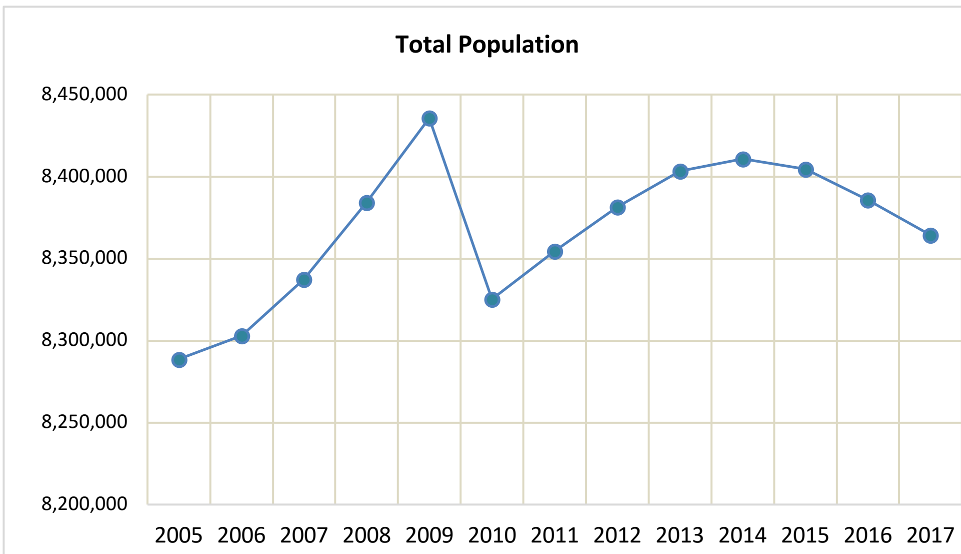


Figure 2

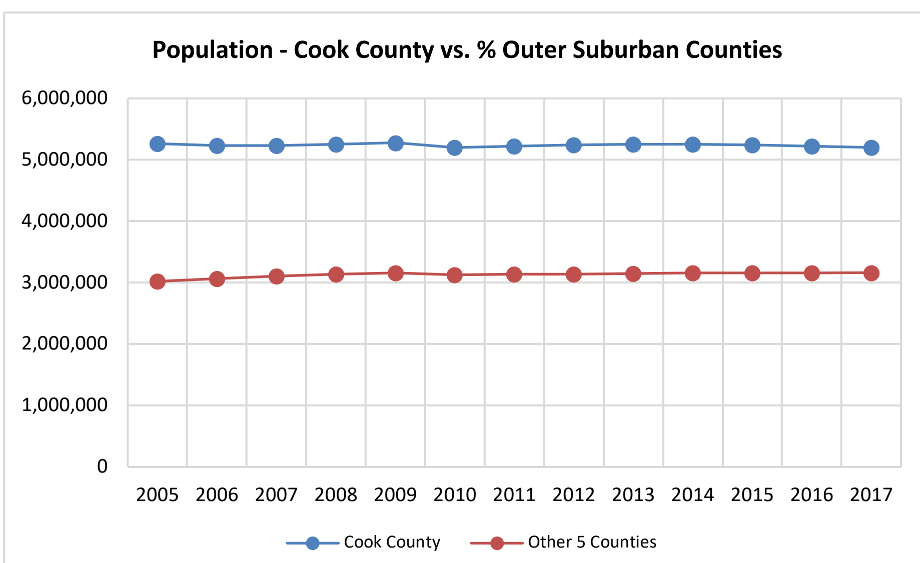


Figure 3

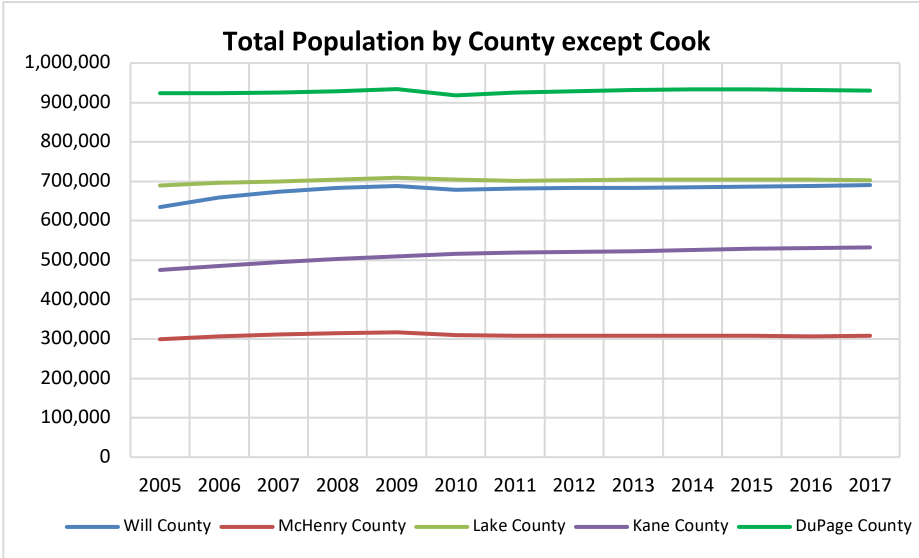


Figure 4

All counties, except Cook County, gained population between 2005-17. During this period the largest population increase occurred in Kane County followed by Will County. All other counties saw lower than 3% increases in population during this period. Overall, the five counties besides Cook saw a 4.66% increase in population over the study period, indicating continuing suburbanization of the region. At the same time, the population of Cook County declined by 1.24%, increasing only marginally during one time period, 2010-17. 2009 was the peak population year during the study period for most counties except Kane and Will County. Between 2005-10, all counties except DuPage County and Cook County saw increases in their population. After 2010, Lake County and McHenry County saw small losses in population. Kane County is an outlier in the region with its population increasing throughout the study period. However, after 2010, its population growth has slowed considerably as compared to the earlier decade. Will County only exceeded its 2009 population peak in 2016. All other counties never reached their 2009 population level again.

Cook County continues to be the largest county in terms of population in the study region. In 2017, Cook County accounted for 62.2% of the population of the study area, while the suburban counties accounted for 27.8% of the population. For Cook County, this constitutes a 2.1% loss in share of population since 2005, while for the suburban counties it constitutes a 3.7% increase in share. While the overall population density of the region is 879 persons/km^2, Cook County is the densest county with 2,125 persons/km^2. This shows the huge variation in terms of population density between the counties in the region.

Cook County Cities - Population

	Population 2017	2017 Population Density (per km^2)	% change 2005-17	% change 2010-17	% change 2012-17	% change 2005-10
Arlington Heights	75,536	1757.57	1.79%	0.37%	-0.53%	1.41%
Chicago	2,713,067	4608.27	-4.10%	0.58%	-0.25%	-4.65%
Cicero	82,448	5397.54	-0.10%	-2.16%	-2.53%	2.10%
Des Plaines	58,120	1580.90	3.64%	-0.58%	-1.48%	4.24%
Elgin	112,181	1155.46	15.11%	3.56%	2.29%	11.15%
Evanston	74,667	3697.45	-1.17%	0.10%	-1.42%	-1.28%
Orland Park	58,658	1029.85	6.81%	3.46%	2.41%	3.23%
Palatine	68,555	1947.01	2.59%	-0.08%	-0.91%	2.68%
Schaumburg	74,089	1482.74	2.61%	-0.27%	-0.94%	2.89%
Skokie	63,898	2443.62	4.04%	-1.53%	-2.09%	5.66%

Table 2

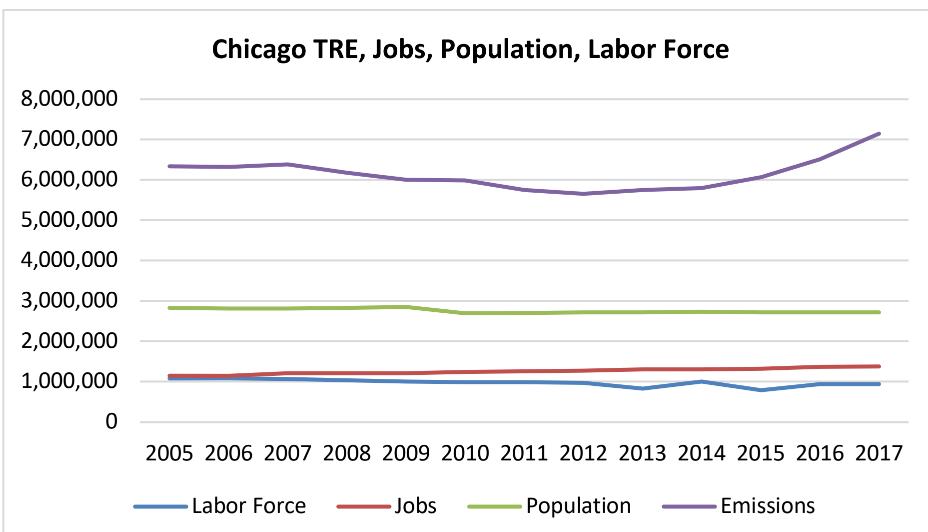
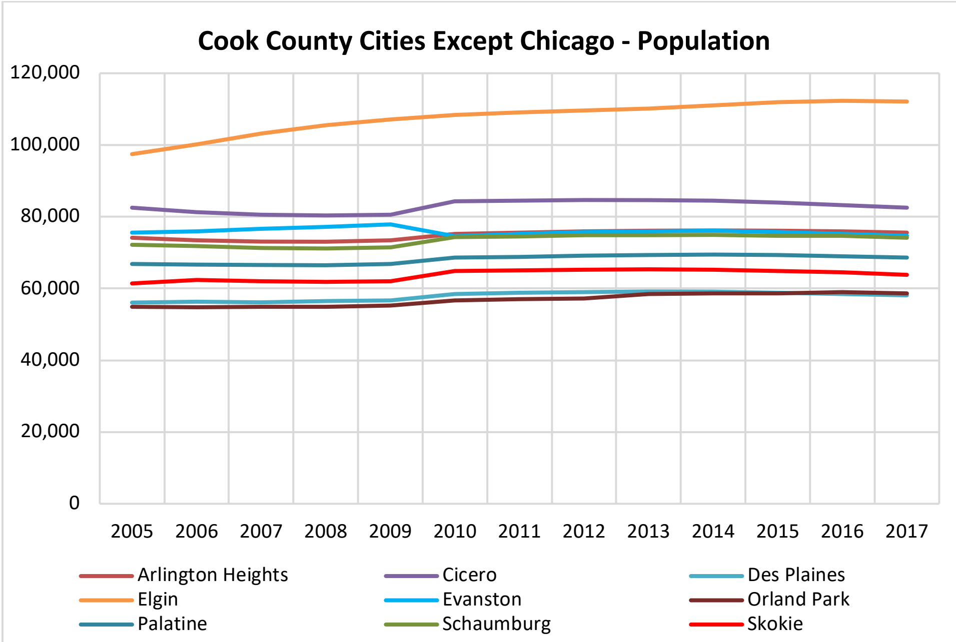


Figure 5



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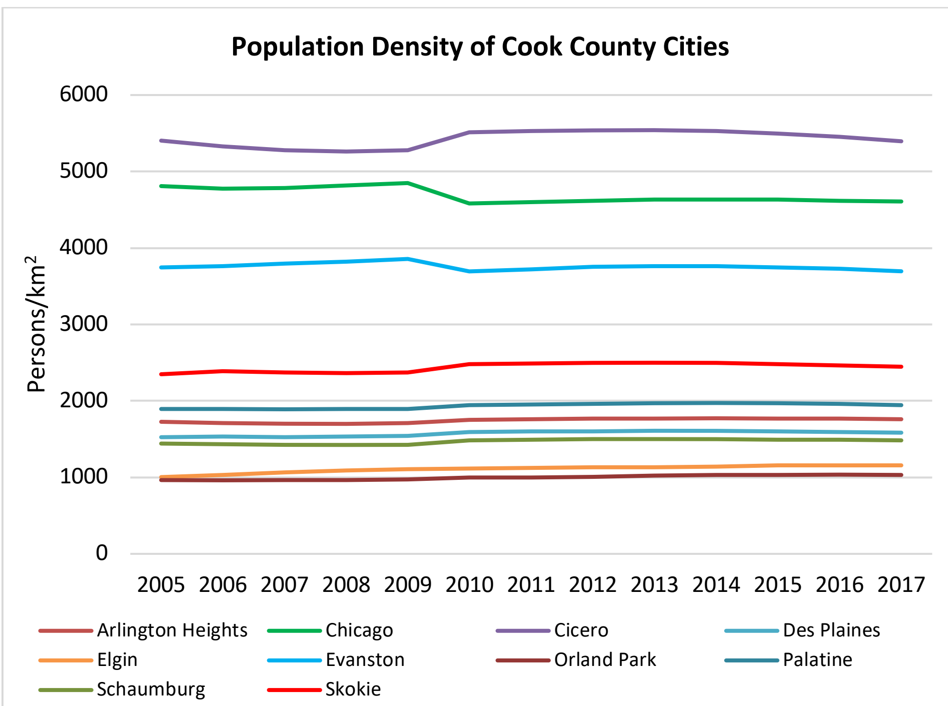

Figure 7

Overall, most cities in Cook County experienced population increases through the study period. However, population losses in Chicago, the largest city, likely explains Cook County's population losses overall. Besides Chicago, Cicero and Evanston also lost population between 2005-17. Chicago's population loss is noteworthy because it experienced the greatest percentage loss in population from 2005-17 of all cities in Cook County. Also of interest is that Elgin experienced tremendous population growth, though most of it occurred between 2005-10.

In the post-recession period after 2010, most Cook County cities either experienced small losses in population. Notable exceptions are Elgin and Orland Park, which have been growing at rates slightly higher than 3%. It is also interesting that Cicero's population density is the highest in the county despite it losing population recently. The population densities of both Chicago and Evanston have been declining.

Jobs:

	2017 Jobs	2017 Job Density (per km^2)	% change 2005-17	% change 2010-17	% change 2012-17	% change 2005-10
Study Area	4,161,724	437.4	11%	10.3%	6.89%	0.63%
Cook	2,624,932	1073.0	9.55%	8.51%	5.45%	0.96%
5 Counties besides Cook	1,536,792	217.4	13.59%	13.54%	9.45%	0.04%
DuPage	635,199	748.5	10.22%	13.3%	9.06%	-2.66%
Kane	212,910	158.3	4.64%	9.39%	5.16%	-4.34%
Lake	329,352	286.6	6.45%	6.47%	4.56%	-0.01%
McHenry	96,262	61.6	1.57%	3.92%	4.76%	-2.27%
Will	263,069	121.6	55.6%	34.2%	23.91%	15.94%

Table 3

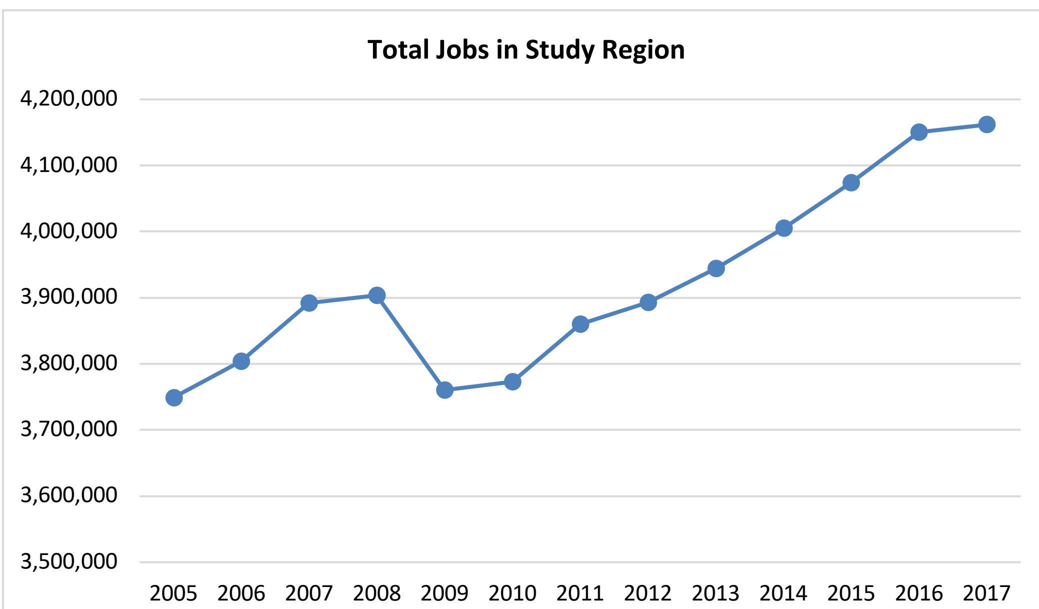

Figure 8

During the study period, the six county region experienced a healthy 11% increase in jobs, despite a 3.66% decline in jobs between 2008-09 due to the economic recession.

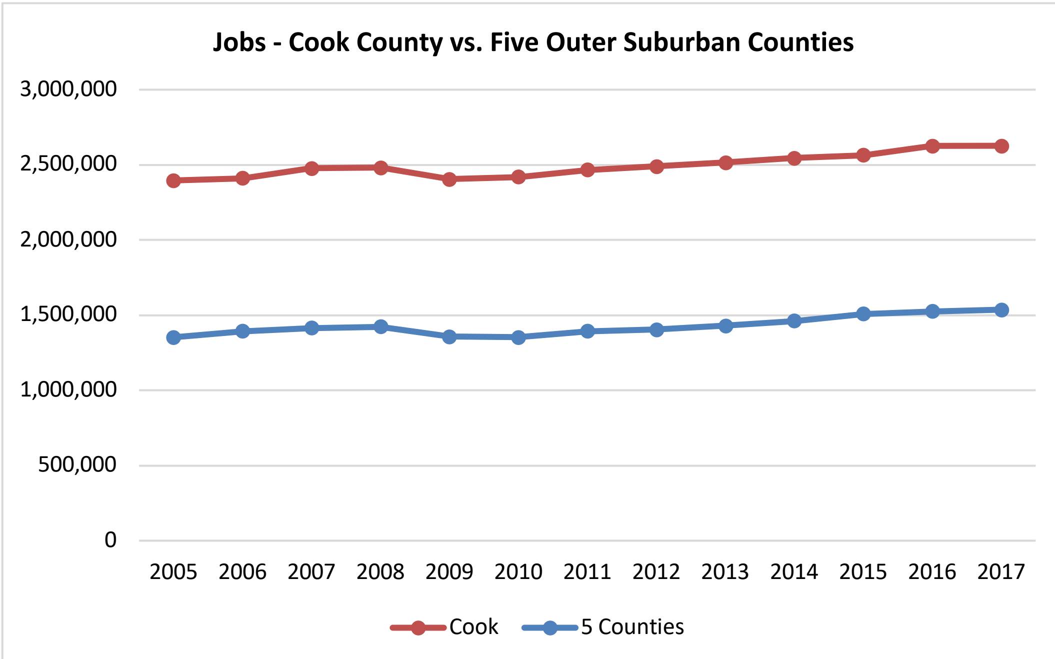

Figure 9

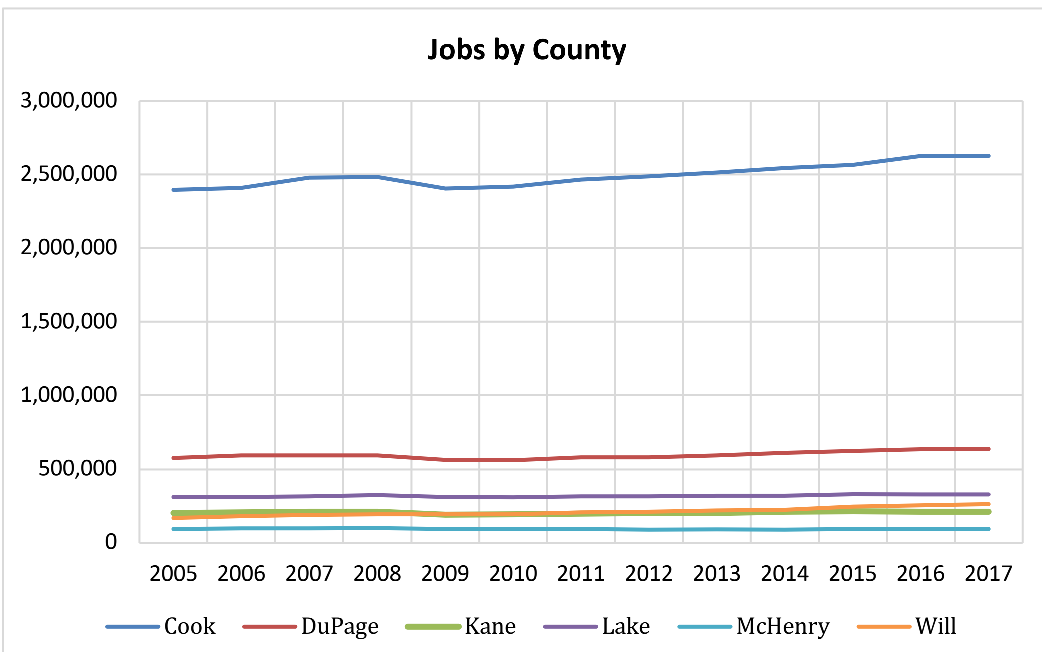

Figure 10

Will County experienced an over 50% increase in jobs over the study period, which is remarkable. DuPage County had the second highest rate of increase in jobs over the study period followed by Cook County. All counties saw losses in jobs between 2005-10, except Cook and Will County. Jobs started recovering from the recession in all counties in 2010 leading to a 10.3% increase between 2010-17. McHenry County, however, continued losing jobs and has not returned to the 2008 peak level of jobs yet.

Cook County is home to the largest number of jobs in the region, despite losing population, followed by DuPage County and Lake County. The study region gained 412,579 new jobs between 2005-17, with Cook County accounting for 55% of these new jobs, while 45% were located in the suburban counties. However, the rate of increase in jobs in the five suburban counties together was higher than Cook County, even though these counties together account for only 27.8% of the population of the region. Most of the increases in jobs in the suburban counties occurred after 2010.

In 2017, Cook County accounted for 63% of the jobs in the study region, a 1.31% loss in its share of jobs since 2005. The suburban counties accounted for the remaining 37% of jobs in the study region, a 2.33% increase in their share of jobs since 2005.

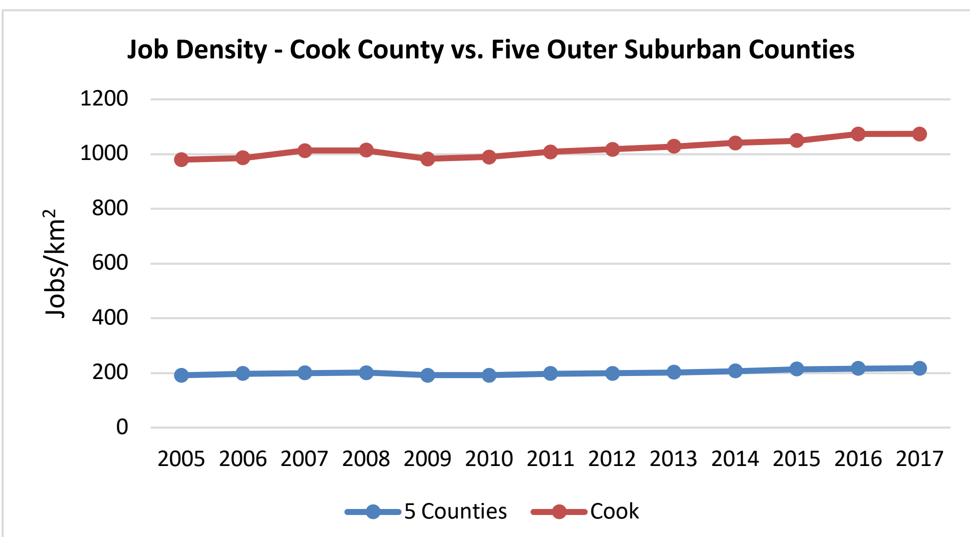

Figure 11

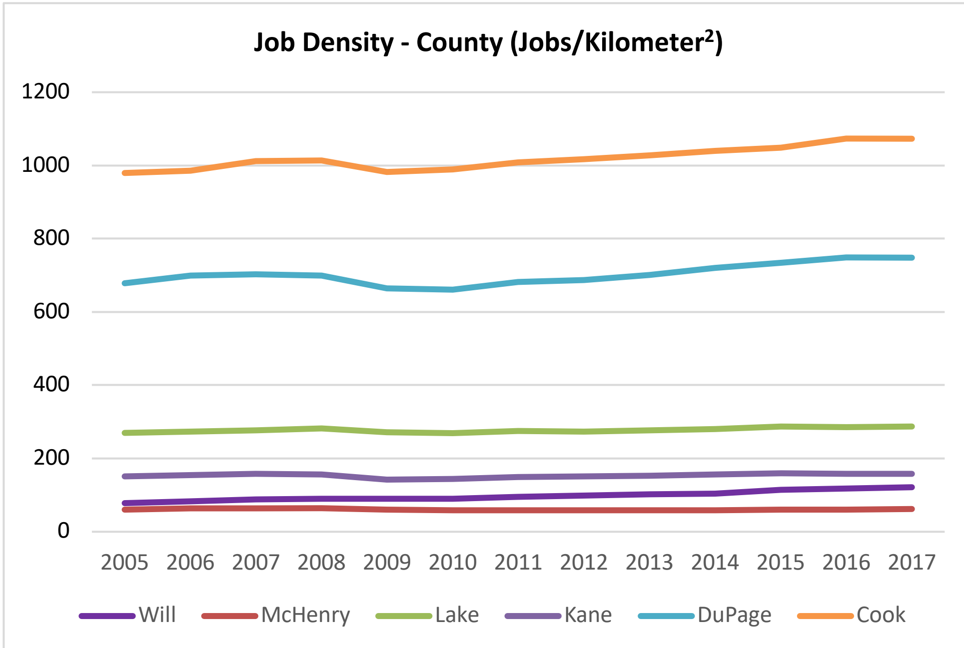

Figure 12

There is a large disparity in terms of job density between Cook County and the suburban counties. Cook County has over 1000 jobs/ km^2. Together, the five suburban counties, on the other hand,have about 200 jobs/km^2. This is not surprising, as most jobs in Cook County are in Chicago, a high-density city, while jobs in suburban counties are spread out across a large area in low-density settings. Job density increased overall in the region after 2009. However, the job density in Cook County is still almost five times higher than the suburban counties.

The data indicates that jobs are both centralizing and decentralizing in the study region. Cook County saw the largest absolute increase in jobs in the region from 2005-17 and accounts for the majority of jobs in the region. This indicates that jobs are centralizing, since Cook County and its largest city, Chicago, saw the greatest absolute increase in jobs during the study period. However, jobs are also decentralizing, since the rate of increase in jobs in the suburban counties is higher than that of Cook County.

Ratio of Jobs/Population	2017	2010	2005	% change (2005-17)
Five Counties	0.49	0.43	0.45	8.5%
Cook County	0.51	0.47	0.46	10.9%

Table 4

The ratio of jobs to population in Cook County and the five suburban counties has been nearly equal, and the difference between them has been nearly constant throughout the study period, with the notable exception of 2010. This indicates that jobs have always been relatively decentralized in the suburbs as well as centralized in Cook county because the ratios are similar even though there is a large disparity in population as well as jobs. However, due to the increase in jobs in both the suburban counties and Cook County, the ratios of jobs to population in both places have increased. Thus, there was continuing job centralization, with accelerating job decentralization occurring concurrently.

Cook County Cities - Jobs

	Jobs 2017	2017 Job Density (per km^2)	% change 2005-17	% change 2010-17	% change 2012-17	% change 2005-10
Arlington Heights	42,779	995.4	-18.97%	-18.60%	-8.15%	-0.46%
Chicago	1,380,600	2345.0	19.89%	11.43%	7.82%	7.60%
Cicero	17,256	1129.7	-10.72%	4.56%	9.81%	-14.62%
Des Plaines	37,934	1031.8	-1.94%	8.51%	2.52%	-9.62%
Elgin	55,036	566.9	-4.08%	0.06%	-5.94%	-4.14%
Evanston	53,286	2638.7	29.56%	16.31%	15.35%	11.40%
Orland Park	26,602	467.0	7.21%	17.08%	1.79%	-8.42%
Palatine	25,602	727.1	6.01%	10.82%	9.00%	-4.34%
Schaumburg	94,895	1899.1	7.01%	16.03%	16.03%	-7.77%
Skokie	36,723	1404.4	1.66%	8.58%	4.36%	-6.38%

Table 5

It is not surprising that Chicago has the largest number of jobs in Cook County. It is, after all, by far the largest city in Cook County and the region. Chicago jobs have been growing at a fast pace throughout the study period and even during the recession, despite the city losing population. Schaumburg has the next highest number of jobs in Cook County, which have been growing at a rate higher than Chicago's after the recession. Evanston, with the third highest number of jobs in Cook County, has experienced tremendous growth in jobs during the study period, undeterred by the recession, even as it loses population. On the other hand, several Cook County cities have lost jobs - Arlington Heights, Cicero, Des Plaines and Elgin. Though much of the losses in jobs in these cities occurred during the recession years, most of them have been adding jobs in the post-recession period. However, Arlington Heights is an outlier as it has been experiencing a decline in jobs at a higher rate in the post-recession period than during the recession. It has experienced a continuous decline in jobs in every time period between 2005-17.

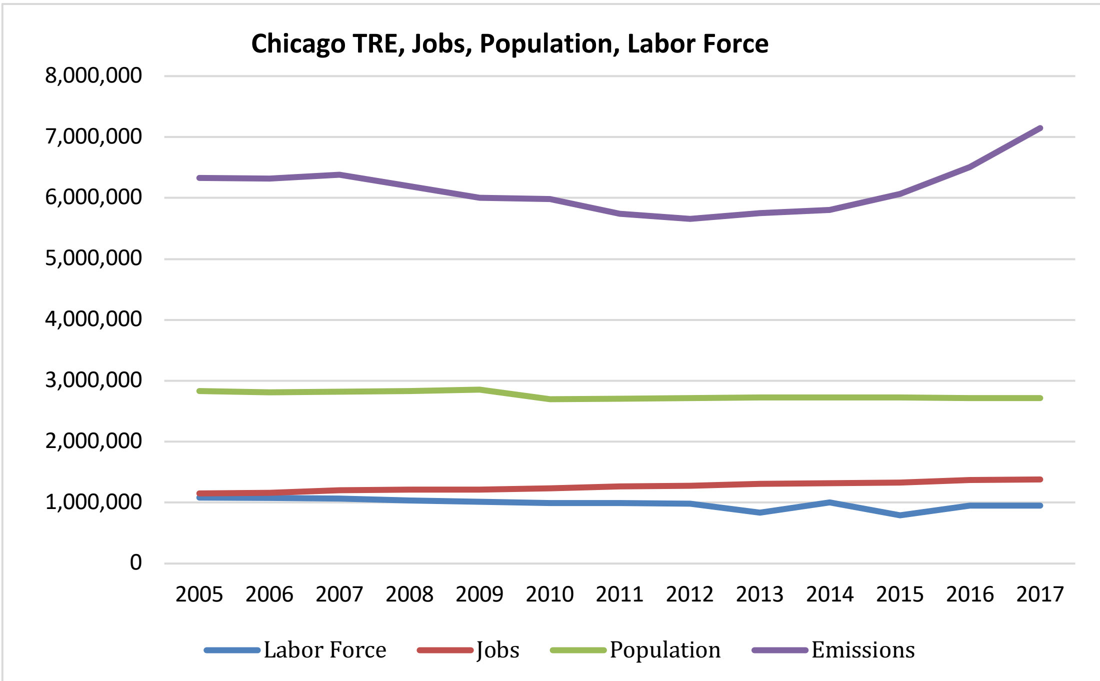

Figure 13

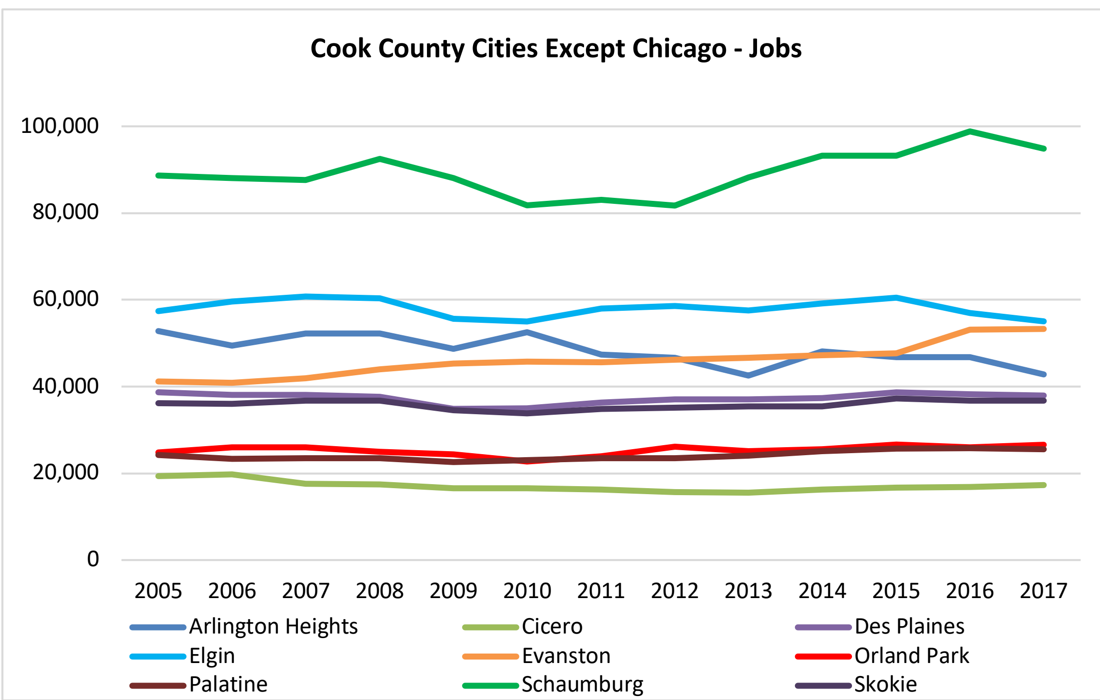

Figure 14

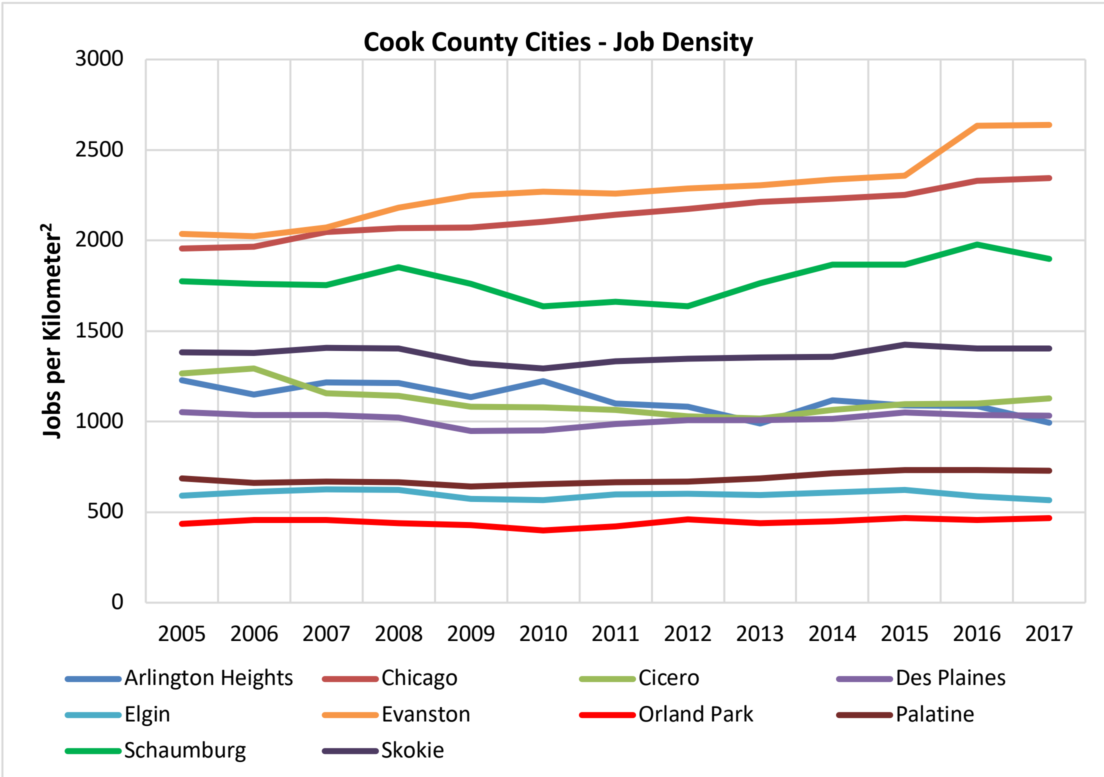

Figure 15

Evanston has the highest job density, followed by Chicago and Schaumburg. Elgin and Arlington Heights have experienced decreases in their job density. Most other cities had either reached their pre-recession job density in 2017 or were experiencing small increases in job density.

Thus, Cook County shows a profound spatial mismatch between population and jobs. More suburban Cook County cities either lost jobs or had slow job growth, though their populations usually increased concurrently. Larger and denser cities, such as Chicago and Evanston, showed the opposite trends. They experienced relatively large declines in population, accompanied by robust increases in jobs. Thus, jobs are centralizing within Cook County while the population is suburbanizing. Distances travelled to work also likely increased due to the spatial mismatch, which may drive increasing emissions if these longer trips are not on public transportation.

Transportation Related Emissions:

Transport-related emissions (TRE) increased by 6.78% between 2005-17. Between 2007-12, there was a 8.7% decline in TRE despite a small peak in 2010. This was likely due to the recession. 2012 marked the lowest TRE between 2005-17 in the six county study region. Only after 2012 did emissions start rising again, increasing by 16.4% from 2012-17. However, due to the reductions between 2007-12, 2007 emissions levels were only reached again in 2016. In the year between 2016-17, transport related emissions increased sharply by 5.64%.

	2017 TRE (Metric tons CO_2)	2017 Per Capita TRE (Metric tons CO_2 /person)	% change 2005-17	% change 2010-17	% change 2012-17	% change 2005-10
Study area TRE	33,275,093.7	3.98	6.8%	10.0%	16.4%	-2.96%
Cook	19,130,371.6	3.68	4.0%	8.7%	16.6%	-4.4%
5 Counties besides Cook	14,144,722.1	4.47	10.8%	11.8%	16.1%	-1.0%
DuPage	5,059,911.7	5.44	10.5%	11.5%	22.0%	-0.9%
Kane	1,818,680.9	3.42	9.4%	9.7%	5.5%	-0.3%
Lake	2,785,978.1	3.97	0.3%	7.6%	4.9%	-6.8%
McHenry	841,662.1	2.73	-11.5%	-16.9%	-14.6%	6.5%
Will	3,638,489.1	5.27	30.0%	27.7%	36.2%	1.8%

Table 6

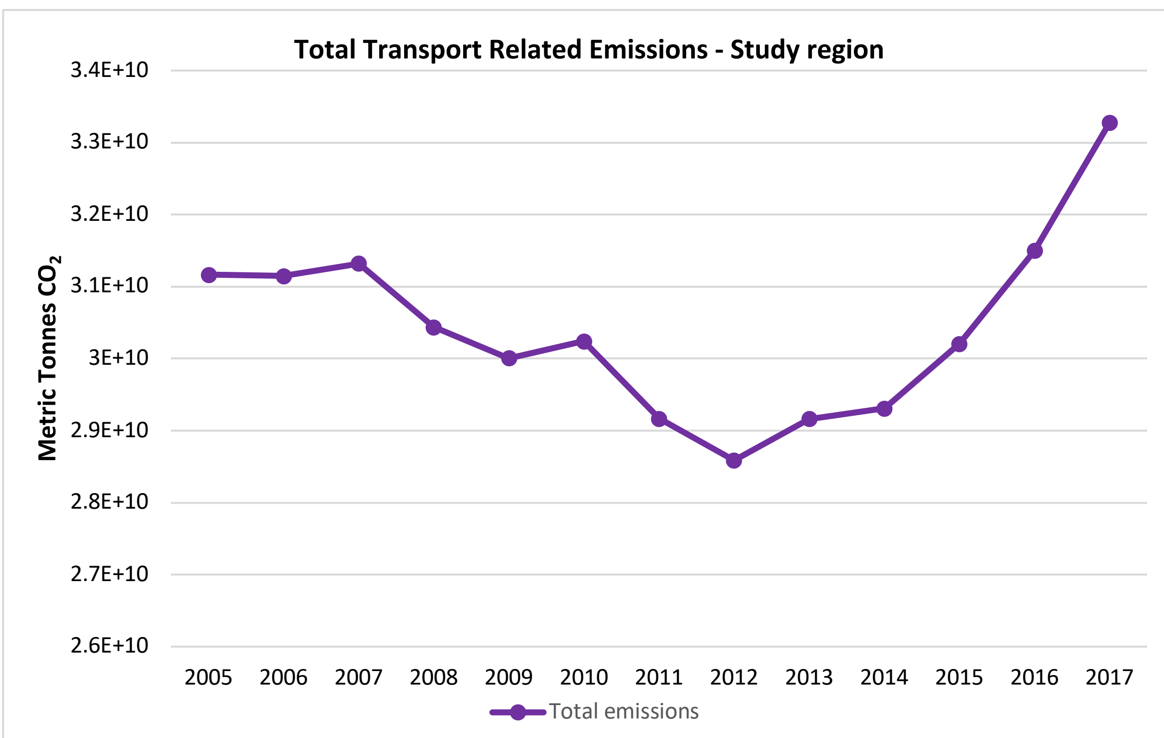

Figure 16

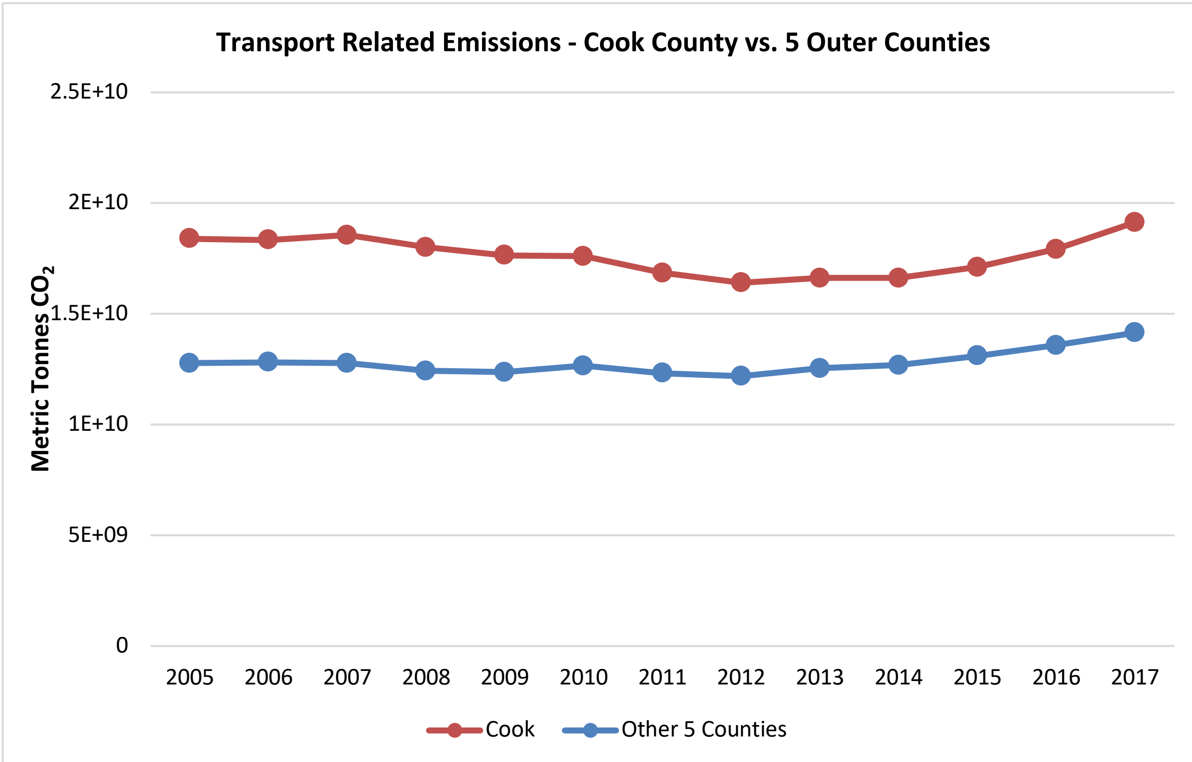

Figure 17

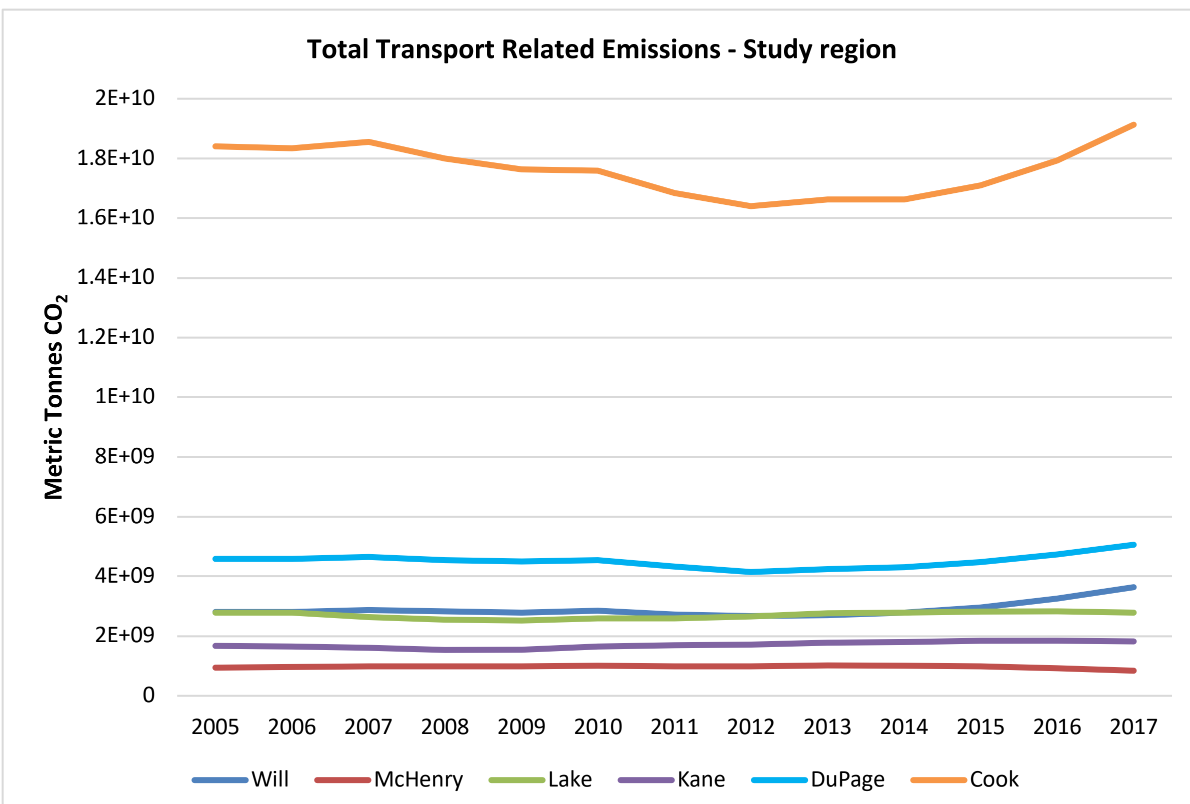

Figure 18

All counties experienced increases in transport related emissions (TRE) between 2005-17, except for McHenry County, which saw a 11.5% decline in emissions. Will County led the region in the rate of increase in TREs with emission peaks in 2007, 2010, and 2017. TREs grew sharply after 2012, with a 9.46% increase in emissions from 2015-16 alone. Despite experiencing a 10.8% decline in TREs from 2005-12, Cook County experienced a 16.63% increase in TREs post-2012, and a 6.7% increase between 2016-17 alone. Despite this sharp increase, 2005 emission levels were only exceeded in 2017. Like Cook County, DuPage County's TREs increased dramatically from 2015-17. There was a 7.6% increase in TRE in 2016-17 alone.

While TREs increased in both Cook and the suburban (non-Cook) Counties, the rate of increase of TREs over the study period was much higher in the suburban counties. From 2012-17 though, the rate of increase in both Cook and the suburban counties was rather similar. It is not surprising that the suburban counties had greater increases in TREs than Cook County. Jobs and population have grown in many suburban counties, especially far-flung ones such as Will County. These areas are usually low-density and car dependent, and distances tend to be longer in the suburbs. Distances are much shorter in Cook County, and it also has better transit service. Thus, it makes sense that TREs increased fastest in the suburban counties rather than Cook County.

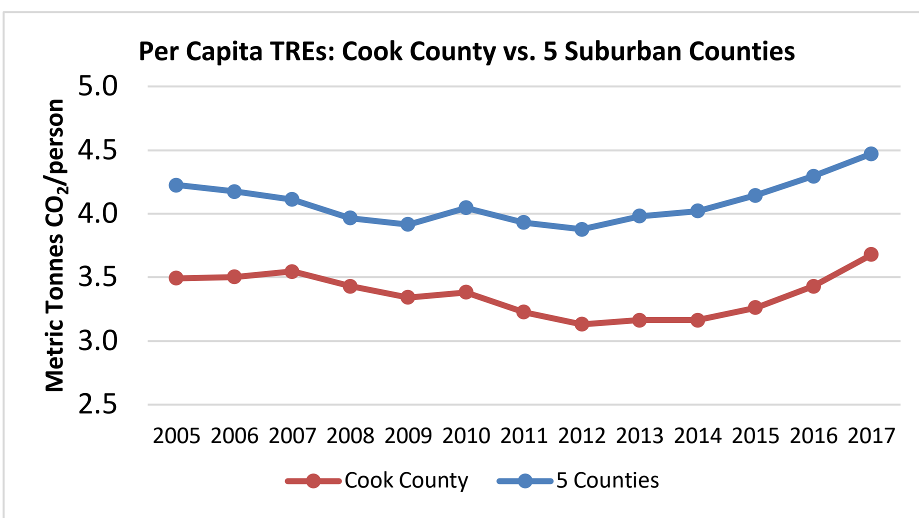

Figure 19

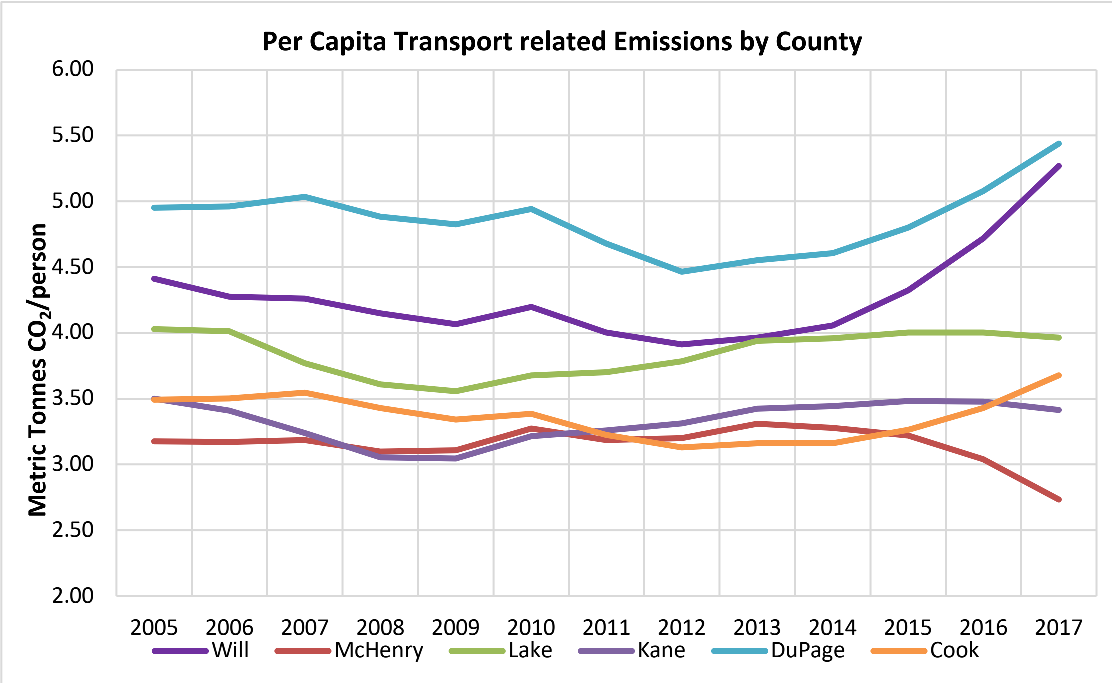

Figure 20

Per capita TRE emphasizes the trends in the overall TRE more dramatically. Even though the total TREs for the five outer suburban counties is lower than Cook County, the per capita TRE for the aggregated five outer suburban counties far exceeds that of Cook County. In 2017, DuPage County led the study region with the highest per capita TRE at 5.4 metric tons/km^2/person followed by Will County at 5.2 metric tons/km^2/person. Cook County was a distant third at 3.65 metric tons/km^2/person. McHenry County has been steadily reducing its per capita TRE and both Lake and Kane Counties exhibit slightly downward trends in their per capita TREs.

Cook County Cities – TREs

	2017 TRE (Metric tons/km^2)	% change 2005-17	% change 2010-17	% change 2012-17	% change 2005-10	2017 Per Capita TRE (Metric tons/km^2/person)	% change 2005-17	% change 2010-17	% change 2012-17	% change 2005-10
Arlington Heights	441,928.22	1.37%	1.04%	3.72%	0.33%	5.85	-0.41%	0.67%	4.27%	-1.07%
Chicago	7,147,498.21	12.86%	19.49%	26.34%	-5.55%	2.63	17.69%	18.80%	26.65%	-0.94%
Cicero	56,502.84	-3.28%	-6.52%	-7.48%	3.47%	0.69	-3.18%	-4.46%	-5.08%	1.34%
Des Plaines	700,907.30	7.56%	10.93%	16.49%	-3.04%	12.06	3.78%	11.57%	18.24%	-6.98%
Elgin	740,413.16	10.36%	0.77%	5.05%	9.51%	6.60	-4.13%	-2.69%	2.69%	-1.47%
Evanston	18,246.59	-6.52%	-12.71%	-19.14%	7.09%	0.24	-5.41%	-12.81%	-17.97%	8.48%
Orland Park	756,490.44	17.56%	0.37%	7.55%	17.12%	12.90	10.06%	-2.99%	5.02%	13.45%
Palatine	222,863.31	-8.44%	-13.21%	-13.10%	5.49%	3.25	-10.76%	-13.13%	-12.30%	2.74%
Schaumburg	854,942.98	5.28%	8.47%	14.53%	-2.95%	11.54	2.60%	8.77%	15.61%	-5.67%
Skokie	338,147.69	12.73%	19.24%	25.93%	-5.47%	5.29	8.34%	21.10%	28.62%	-10.53%

Table 7

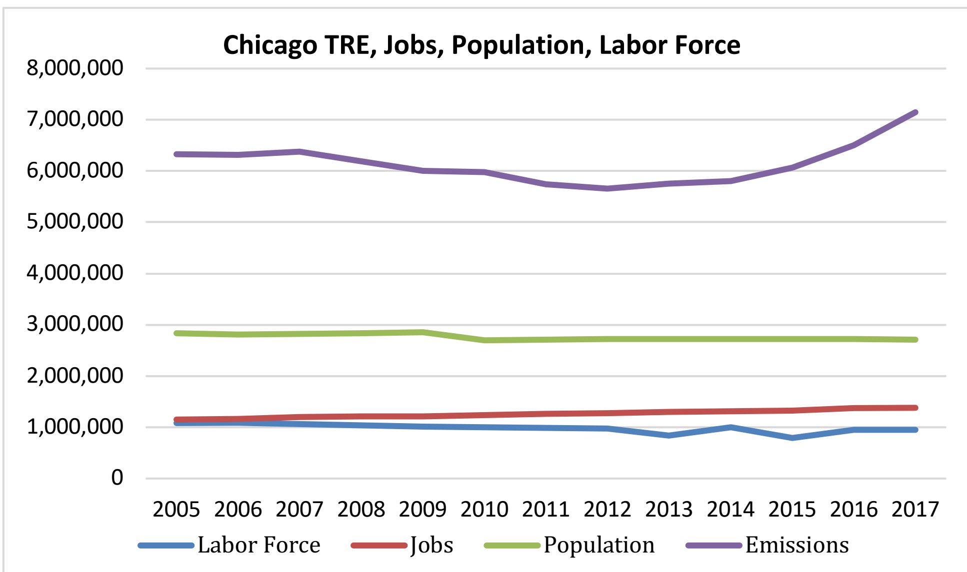

Figure 21

Unsurprisingly, Chicago has the highest quantity of TREs in Cook County, followed by Schaumburg, Orland Park, Elgin and Des Plaines. Between 2005-17, Orland Park experienced the highest percent increase in TREs in Cook County, though most of the increase occurred during the pre-recession and recession period. Chicago, Skokie, and Elgin also experienced large increases in TREs during this period. More recently, between 2012-17, Chicago and Skokie experienced over 25% increases in their TREs. Des Plaines and Schaumburg also experienced double digit increases during this period. Evanston

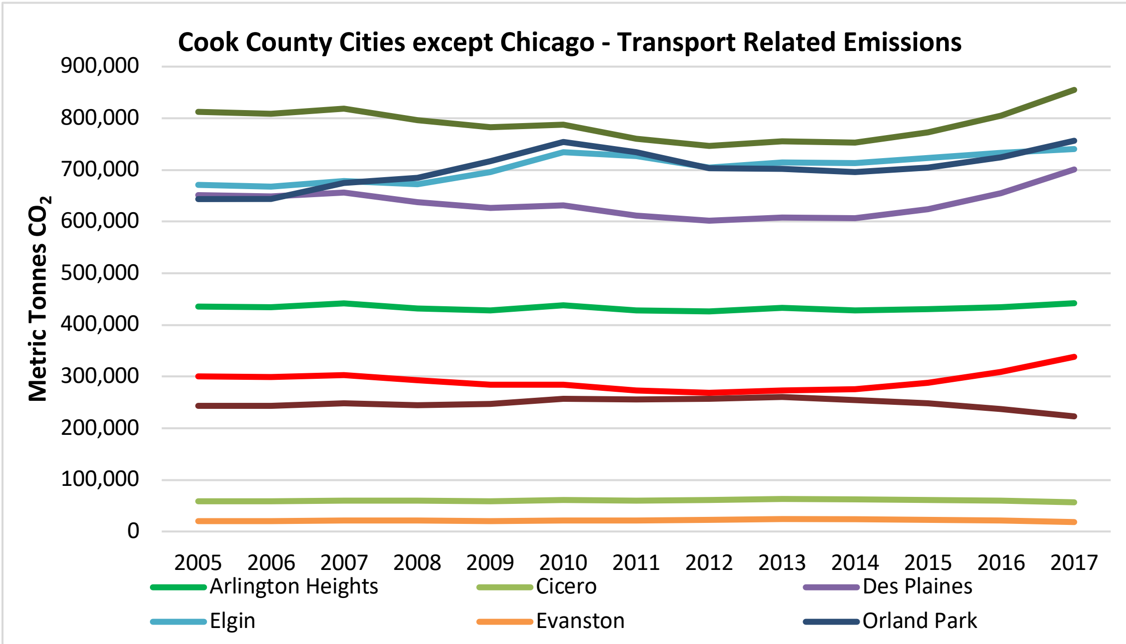

Figure 22

and Palatine are the only cities that experienced declines in TREs between 2005-17, most of which occurred after the recession. These increases in TREs could be due to the spatial mismatch between jobs and population within Cook County, i.e., population declined in Chicago while jobs rose, while the opposite occurred in most of the other municipalities. This mismatch increases distance to work, which

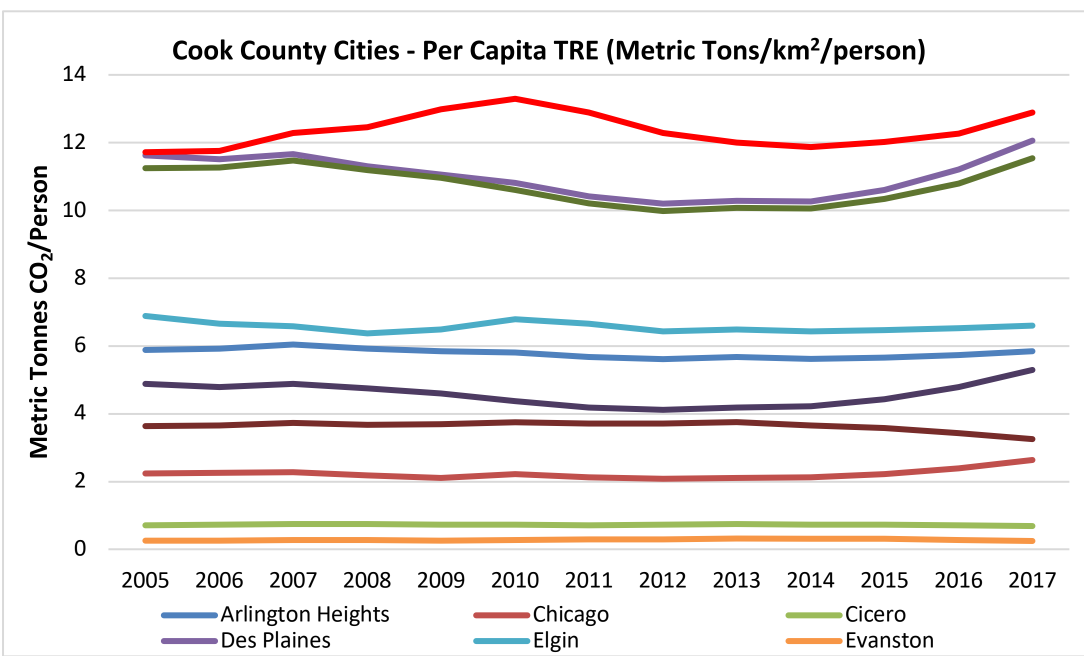

Figure 23

could increase emissions. It could also potentially increase emissions associated with jobs in Cook County.

Orland Park had the highest per capita TREs in Cook County followed by Des Plaines and Schaumburg in 2017. This is not surprising as Orland Park and Schaumburg are regional job centers that are low-density and car dependent. Cicero, Elgin, Evanston and Palatine have experienced declines in their per capita TREs. Evanston had the lowest per capita TRE rate followed by Cicero in 2017. This is not surprising either as both Cicero and Evanston are high-density, inner-ring suburbs. Though Chicago has the third lowest per capita TRE rate in Cook County, it has experienced the largest increases in this category in Cook County over the study period. Thus, per-capita TREs are highest and increased the most in low-density cities in Cook County and are lowest and declined the most in higher-density cities in Cook County.

Other factors:

I also considered a few other factors that might impact the growth in emissions for the region. These include the inflow of workers and outflow of county residents to job destinations, distance traveled to work, and number of workers employed within and outside their home county.

Inflow and Outflow of Workers:

The inflow of workers and outflow of residents to jobs represents the commuters who travel between counties for work. It includes all county residents who leave their home county for work and all people who commute into that same county for work. Thus, it represents the commuters who travel between counties for work. It does not include workers who live and work in the same county, who presumably have shorter commutes.

	Inflow - Outflow of residents and workers	% change 2005-17	% change 2010-17	% change 2012-17	% change 2005-10
Cook	1,305,305	21.79%	14.98%	10.14%	5.92%
Chicago	1,067,704	16.84%	13.29%	9.33%	3.13%
5 Counties besides Cook	1,873,514	21.94%	14.84%	10.5%	6.18%
DuPage	696,828	17.96%	2.56%	10.02%	2.56%
Kane	291,683	20.60%	6.48%	8.79%	6.48%
Lake	345,975	17.02%	6.02%	8.42%	6.02%
McHenry	153,484	14.96%	4.26%	6.01%	4.26%
Will	385,544	40.37%	14.81%	16.77%	14.81%

Table 8

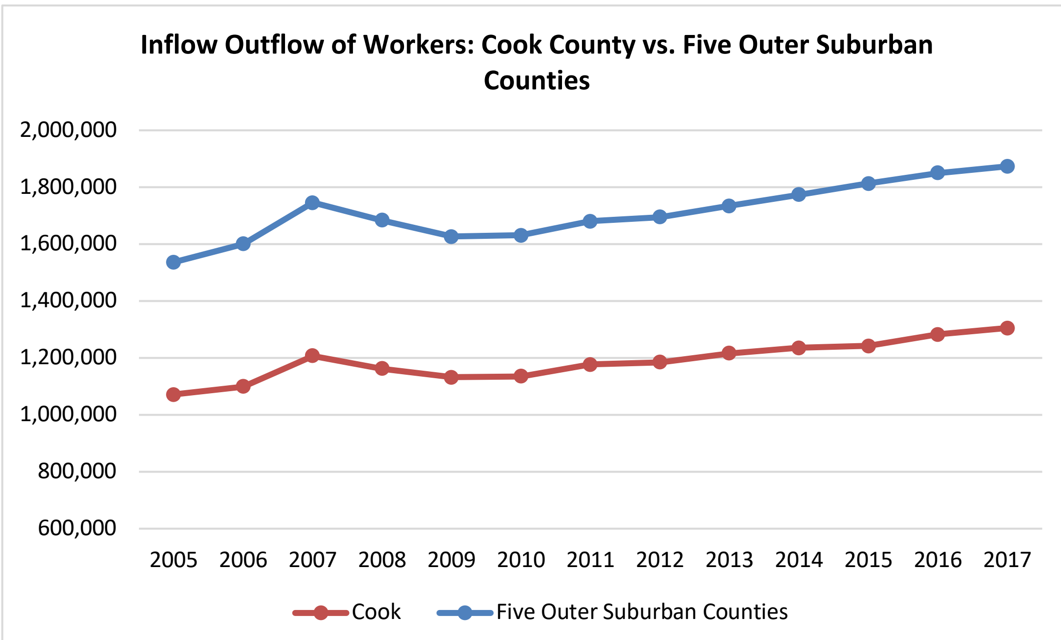

Figure 24

Over the six county region, nearly 3.2 million workers either left their home county to work elsewhere or traveled from another county to work in the region in 2017. This represents a 22% increase since 2005. It is also noteworthy that the five suburban counties together had greater numbers of residents and workers flowing into and out of them as compared to Cook County, though the rate of change for this category was nearly identical.

Cook County had the largest number of commuters leaving and entering the county, followed by DuPage County, Will County and Lake County. All counties had double digits percent increases in this group of commuters between 2005-17. However, Will County has experienced a huge increase of just over 40%. Also notable are Cook County and Kane County, which experienced over 20% increase in those commuting in and out of the county. The period between 2012-17 is significant as this group of commuters has increased in all counties at a faster pace than between 2005-10 and also 2010-17. These trends mirror the simultaneous job centralization and decentralization as well as sharp increases in TREs occurring in the six county region between 2012-17.

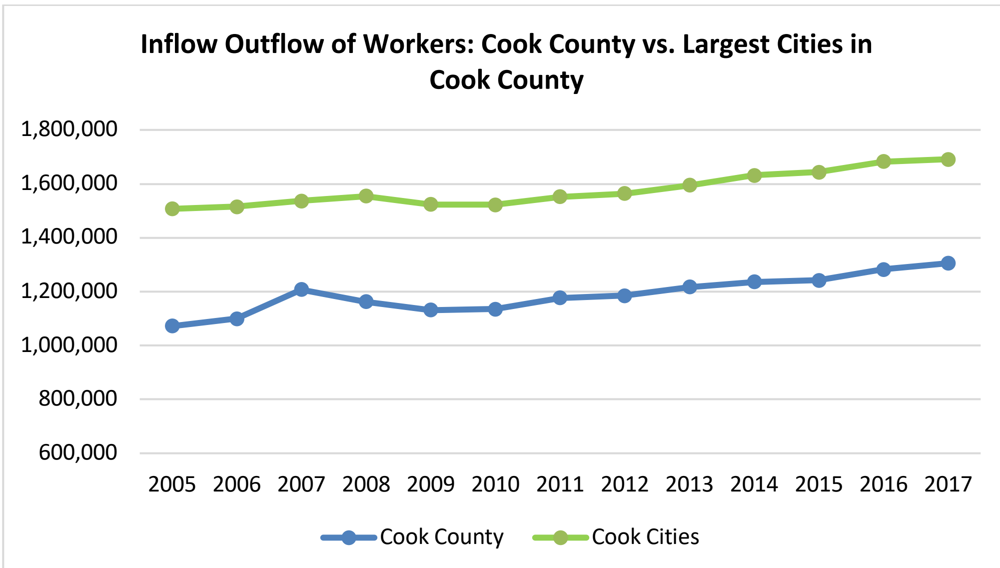

Figure 25

The inflow outflow data for Cook County only captures the people leaving and entering the county for work. However, it is the second largest county in the nation and has several job centers dispersed throughout its geography. Many towns, especially in the northwestern part of Cook County, are further away from Chicago than some towns in suburban counties such as DuPage and even Lake County. As one can see from Figure 26, the inflow and outflow of workers from the ten largest cities in Cook County that were included in this study exceeds that inflow outflow data for Cook County. Thus, this data may not be a good proxy for TREs for Cook County.

Workers who Live and Work in Same County:

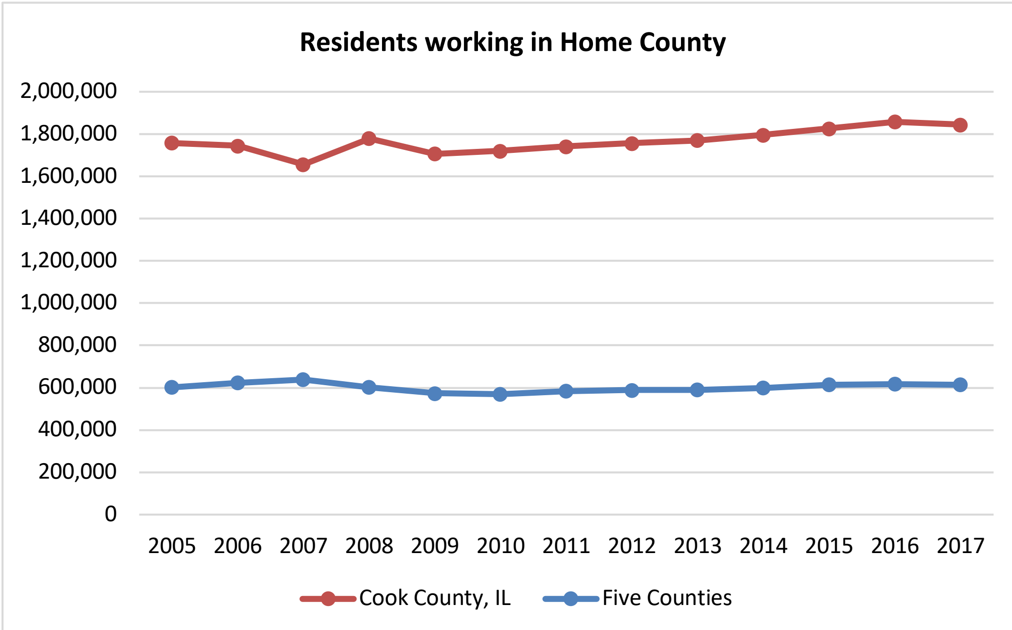

Figure 26

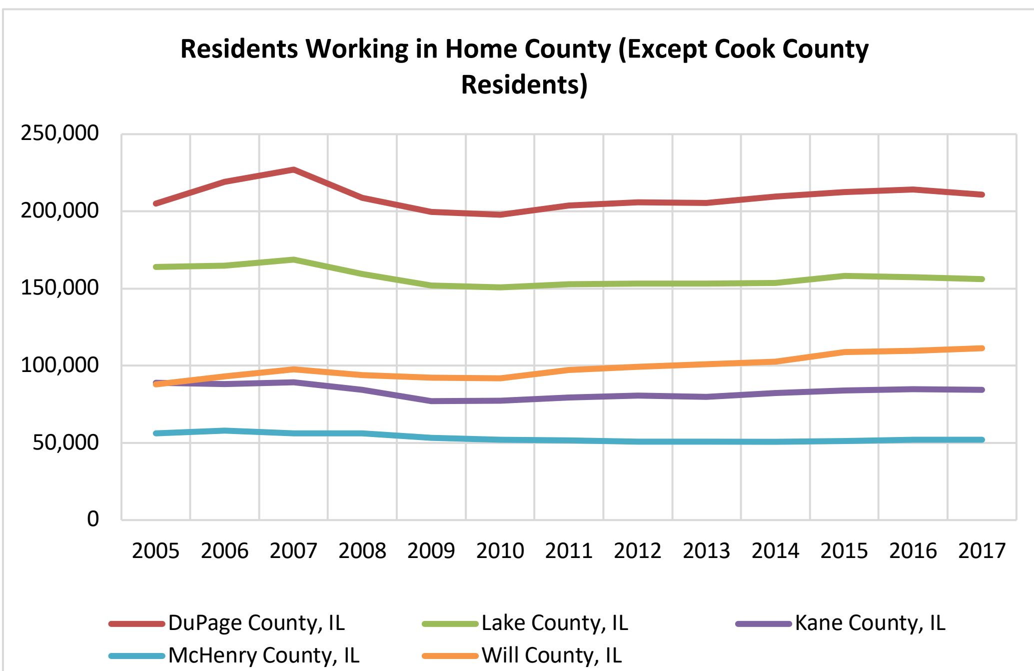

Figure 27

The workers who live and work in their home counties are presumed to have shorter commutes and thus smaller transport-related emissions. However, as mentioned earlier, since Cook County is very large, workers may have longer commutes despite working within their home counties. In 2017, roughly 2.5

million regional residents comprising 59% of the total jobs in the study region worked within their home county representing a 4.2% increase since 2005 and 7.8% increase since 2010. Over the study period, Will County experienced the highest rate of increase in this category. Kane, Lake and McHenry County lost county residents in this category. However, post 2010, both Kane and Lake County have experienced increases in the number of county residents who live and work in the same county, which should lower their TREs.

Home Locations of Cook County Workers:

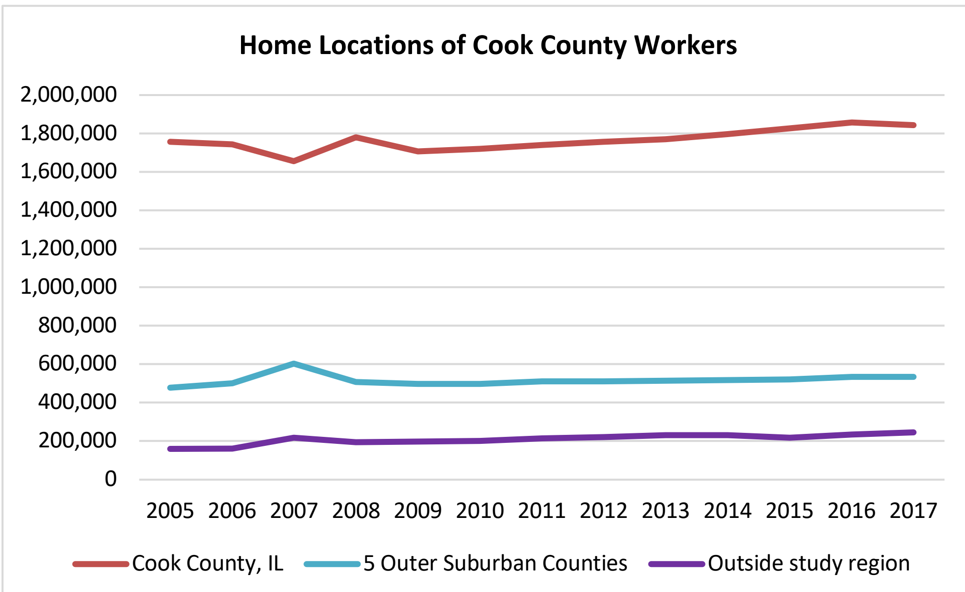

Figure 28

Of the 2.6 million workers in Cook County in 2017, 70% lived in Cook County while 20% lived in the five outer suburban counties in our study region and 9% lived outside the study region. Cook County residents working in Cook County have increased by roughly 5% over the study period, while the five outer county residents working in Cook County increased by 12%. Those living outside the study region but working in Cook County accounted for nearly a quarter million Cook County workers, whose share had increased by 54% over the study period.

Workers from Five Outer Suburban Counties working in Cook County:

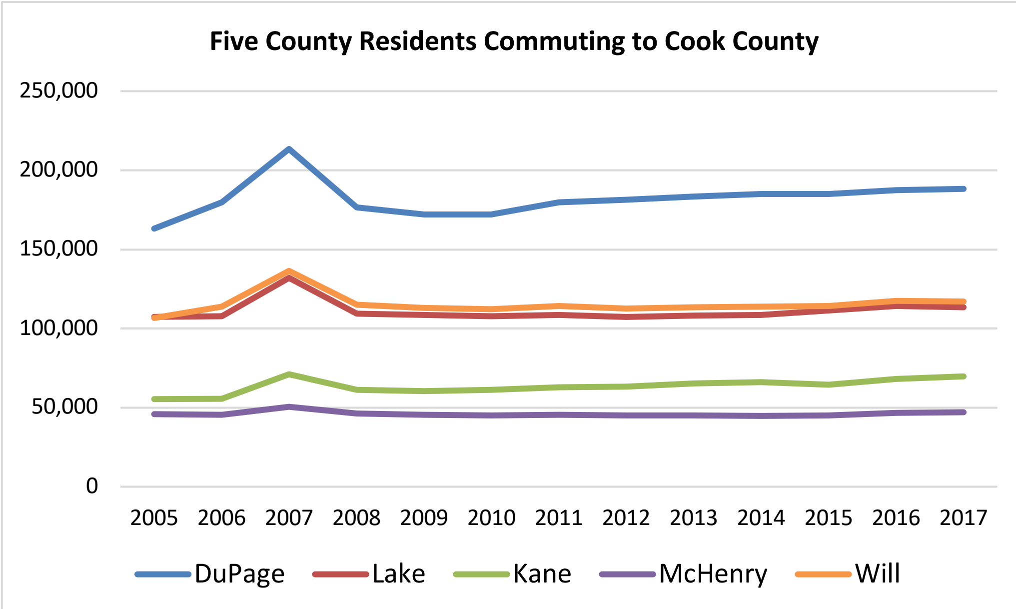

Figure 29

This commute is often the classic suburb-to-city commute. Distances are often long, which could lead to higher TREs. However, it is possible that roughly 30% of these outer suburban county residents working in Cook County have lower TREs than one would expect based on the distance travelled to work as they might use public transit. Roughly half million workers from the five outer counties comprising 13% of the total workers in the study region worked in Cook County in 2017, representing a 12% increase since 2005. Of these workers, 35% lived in DuPage County followed by Will and Lake County, which had over 20% of these commuters each.

Job location of Non-Resident Workers in the Five Outer Suburban Counties:

Within the five outer suburban counties in the study region, workers who did not live in the county where they worked, likely have the most transport related emissions. Distances are often long, and workers commuting between suburban counties likely exclusively drive to work as the public transit connections between suburban counties are either weak or nonexistent. However, Cook County reverse commuters do have public transit options to the outer suburban counties. In 2017, roughly 922,000

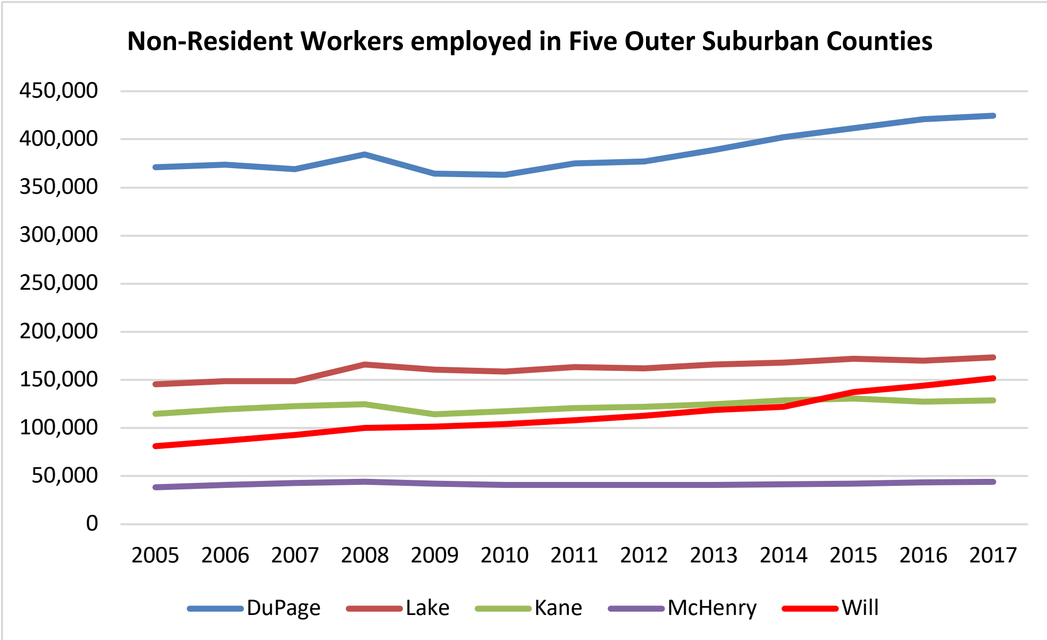

Figure 30

workers in the study region worked in one of the outer suburban counties but did not live there, representing a 23% increase since 2005. These workers represented 22% of the total workers in the region. Of these 2017 commuters, 55% commuted to the five outer suburban counties from other suburban counties either within or outside the study region. These suburban commuters increased by 32% over the study period. Reverse commuters from Cook County comprised 45% of these commuters, a 13% increase over the study period. Will County experienced an 87% increase in these commuters between 2005-17. This trend has accelerated between 2010-17 at the rate of 18% with a sharper increase of 13% between 2012-17. Thus, inter-suburban and reverse commuting increased sharply during the study period, especially to job destinations in Will County.

Distance to Work:

The vast majority of commuters in the six county region travel less than 25 miles to work. In 2017, 1.9 million people traveled 10 miles to work in the study region and 1.3 million people traveled between 10 - 24 miles to work, representing a 3% and a 12% increase since 2005, respectively. In addition, 550,259 people traveled 25-50 miles to work and 284,704 people traveled more than 50 miles in 2017,

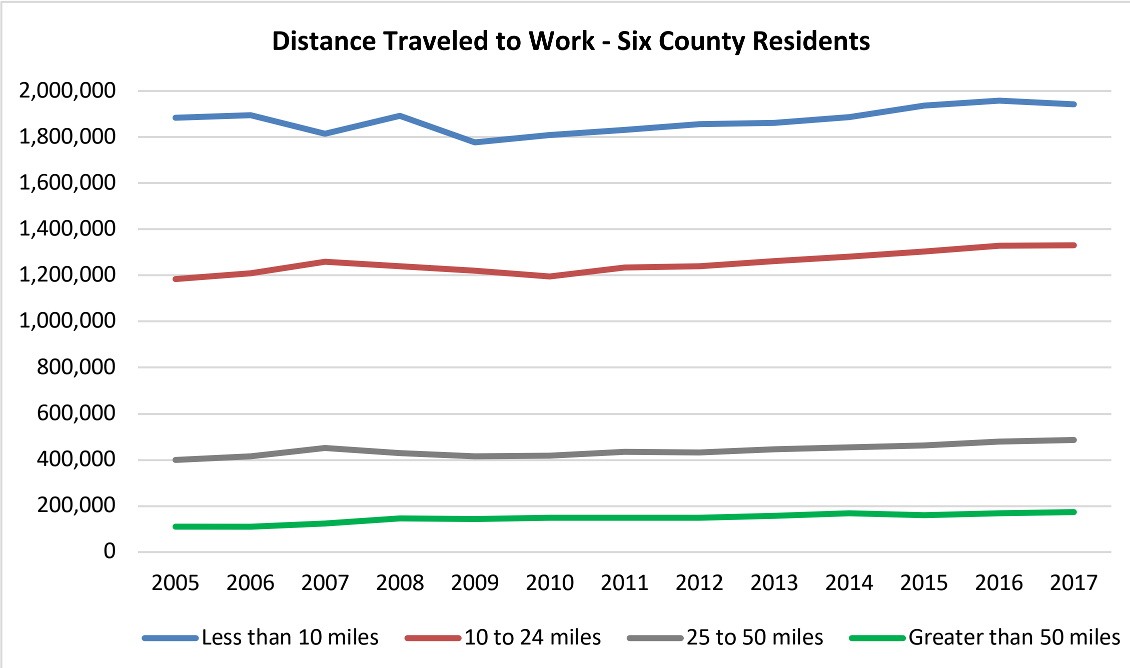

Figure 31

representing a 22% and a 65% increase since 2005, respectively. A large proportion of the increase in those traveling more than 50 miles to work occurred between 2005-10 (35%). However, from 2010 onwards there has been another 23% increase in this category. While these workers only represented 7% of the workforce in the region in 2017, it is a group that is more likely to drive and generate disproportionate quantities of TREs due to the longer distances travelled.

I developed a rough estimate of the numbers of people who drove to work in the six county region using Chicago Metropolitan Agency for Planning's (CMAP) Travel Trends Snapshot report.

2017 Inter-County Analysis	Commuters	Drive to Work Mode Share %	Total Drive to Work
Five Outer County residents working in Cook County	535,378	80%	428,302
Non-resident workers in Outer Suburban Counties	511,713	99%	506,596
Cook County Reverse Commuters	410,526	75%	307,895
Total Inter-County Drivers (longer distances)			1,242,793
2017 Intra-County Analysis			
Five Outer County residents Working in Home County	614,553	80%	491,642
Cook County residents working in Cook County	1,843,528	50%	921,764
Total Intra-County Drivers (shorter distances)			1,413,406

Table 9

Results from Regressions run using Additive Models:

For both additive models, the entire period from 2005-17 was analyzed. However, due to the economic recession between 2008-10, there were many changes in population, jobs and emissions. Jobs started rising again from 2010. Emissions started rising from 2012. Therefore, this study also ran regressions on the annual data from 2012-17 as well as 2010-17.

Results of Regressions from Additive Model 1

Transport based $CO_2 = \Psi_1[\text{Population}] + \Psi_1[\text{Jobs}] + \alpha$

REGION	2005-17		2010-17		2012-17	
	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient
SIX COUNTY REGION						
Population	0.031288001	-18356.27031	0.00210773	-41300.706	0.06473667	-36686.8443
Jobs	0.035026082	5578.623168	0.00045485	12025.707	0.00919588	12429.69841
	R^2: 0.46296791		R^2: 0.933358381		R^2: 0.958223088	
COOK COUNTY						
Population	0.381628892	-10893.93838	0.00059682	-33283.533	0.03740212	-31537.4152
Jobs	0.759251437	-1117.016165	0.00193935	7650.48165	0.08609099	8057.485478
	R^2: 0.077289434		R^2: 0.945999667813125		R^2: 0.96107881	
CHICAGO						
Population	0.170992777	4322.123746	0.00198512	-31360.367	0.11943184	-32526.67193
Jobs	0.15749006	3521.434185	0.00019775	11027.7158	0.01803241	10720.83742
	R^2: 0.206151441		R^2: 0.950919839		R^2: 0.954507096	
FIVE COUNTIES EXCEPT COOK						
Population	0.09382513	-5107.0351	0.07939582	-69417.186	0.59746641	-37958.634
Jobs	0.00081395	8587.98289	0.01881205	21981.6511	0.15671086	18105.8584
	R^2:0.70114893		R^2: 0.85195426		R^2: 0.904401885020773	

Note: Significant correlations are highlighted in yellow

Observations:

__Overall six county region__: Both population and jobs had statistically significant correlations with TREs for all counties during 2005-17 and 2010-17. However, 2010-17 had a far higher R^2 value of 0.93 as compared to 0.46 for 2005-17. For 2012-17, only jobs had a statistically significant correlation with emissions. For all time periods when the correlations were statistically significant, the population had a negative correlation with TREs, while jobs had a positive correlation with TREs. Thus, increase in TREs is correlated with increasing jobs and declining population, especially between 2010-17. However, after 2012, only increasing jobs are correlated with increasing TREs.

Cook County: Cook County did not have statistically significant correlations between population and TREs, and jobs and TREs between 2005-17. However, between 2010-17, both population and jobs were significantly correlated with TREs, with population having a negative correlation. In terms of p-value, the population has a lower p-value than jobs. Between 2012-17, however, only the population has significant negative correlation with TREs. Thus, TREs in Cook County from 2010 onward were correlated with increasing jobs and declining population. From 2012 onward, when there was a spike in TREs in Cook County, declining population was correlated with increasing TREs.

Chicago: As the largest city and job center in the six-county region, Chicago warrants its own analysis. It has no statistically significant correlations between population or jobs and TREs for the years 2005-17. However, like Cook County, it has statistically significant correlations in both these categories from 2010-17, and for jobs and TREs from 2012-17. Similar to Cook County, correlation between population and TREs from 2010-17 is negative. In terms of p-values, jobs have a lower p-value than population. However, unlike Cook County, Chicago exhibits a positive correlation between jobs and TREs from 2012-17.

Five Counties besides Cook County: When evaluating all the five outer suburban counties together, jobs are statistically significantly correlated with TREs between 2005-17 and 2010-17. However, no correlation exists between 2012-17.

Discussion of Findings for AM1:

The Cook County, Chicago, and the five counties except Cook all had statistically significant correlations between jobs and emissions between 2010-17. All correlations were positive, meaning that increases in jobs were correlated with increases in emissions. This time period coincides with the recovery from the

2008 recession, which could indicate that emissions were driven by a growing economy. Cook County and Chicago both had statistically significant negative correlations between population and emissions from 2010-17, meaning that increases in population are correlated with declines in emissions. This similarity makes sense, as Chicago comprises the bulk of Cook County's population. From 2012-17, Cook County had a statistically significant negative correlation between population and emissions, while Chicago had a statistically significant positive correlation between jobs and emissions. During this period, Cook County lost a greater share of its population than Chicago, while Chicago gained jobs at a higher rate than Cook County. Emissions increased in both areas during this period, albeit at a far higher rate in Chicago. Thus, it is not surprising that Cook County has a more significant negative correlation between population and emissions than Chicago, and that Chicago has a more significant positive correlation between jobs and emissions than Cook County.

In the five outer counties, jobs were likely a larger driver of increased CO_2 emissions than population growth. It stands in marked contrast to Cook County, in which population is more likely to be statistically significantly correlated with emissions than jobs. This speaks to the differences in the built environments of these two areas. The suburban counties have a great degree of sprawl, with long distances and jobs often located in car-centric and pedestrian hostile environments. This likely increases emissions. In Chicago, distances are shorter, and jobs are usually located in transit and pedestrian friendly environments. However, only 36.6% of people use transit to commute in Chicago (Active Transportation Alliance), while 58.3% used cars.

Results of Regressions from Additive Model 1 - Individual Counties except Cook County:

Transport based $CO_2 = \Psi_1[Population] + \Psi_1[Jobs] + \alpha$

REGION	2005-17		2010-17		2012-17	
	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient
DUPAGE COUNTY						
Population	0.139177846	-22519.36697	0.00264257	-64373.068	0.11550772	-70570.19922
Jobs	0.036848989	6694.767089	0.0008243	15793.7343	0.0114569	15588.22581
	R^2:0.374278365		R^2: 0.911224416		R^2: 0.912659913	
LAKE COUNTY						
Population	0.029116816	-14160.15758	0.06970986	29549.3109	0.03797603	31303.50185
Jobs	0.021026193	10285.21309	0.00349625	10489.5095	0.02676489	6240.259462
	R^2:0.499344504		R^2: 0.888613793		R^2: 0.936726862	
KANE COUNTY						
Population	0.011246587	3597.692735	0.81692556	1147.39518	0.8009874	1473.351989
Jobs	0.064352855	6024.448538	0.0698807	8685.67133	0.25775818	6920.134655
	R2:0.626126103		R2: 0.931432759		R2: 0.819966739	
MCHENRY COUNTY						
Population	0.271391982	3767.578824	0.8335449	-4083.7693	0.12639955	-61269.70732
Jobs	0.184498813	-6574.494789	0.00575699	-31265.209	0.0084251	-33060.62423
	R^2:0.201975234		R^2: 0.819968417		R^2: 0.9280694	
WILL COUNTY						
Population	0.228931896	-6543.147056	0.95320392	-6065.4463	0.12421614	118751.8688
Jobs	0.008412028	8826.979841	0.45903771	12554.2129	0.92359189	841.3615682
	R^2:0.560381414		R^2: 0.696910194763767		R^2: 0.952545144	

Note: Significant correlations are highlighted in yellow

__Individual county analysis (2005-17)__: When one analyzes the data by county, there are some differences with the trends over the study period. The only statistically significant ($p<0.05$) correlations between population and TREs were those in Lake and Kane Counties. Lake County had a negative correlation, while Kane County had a positive correlation between population and TREs. However, Kane County had a higher R^2 value. Lake County had a very small increase in its population and TREs during this period while Kane County had a large increase in its population and TREs. Thus, declining population was correlated with increasing TREs in Lake County while increasing population was correlated with increasing TREs in Kane County, which had a much higher rate of increase in TREs during this period as compared to Lake County. Will, Lake and DuPage counties had statistically significant positive correlations between jobs and TREs, with Will County having the highest R^2 value among these three counties. Lake County TREs were correlated with both increasing jobs and declining population.

<u>Individual county analysis (2010-17)</u>: Only DuPage, Lake and McHenry Counties had statistically significant correlations during this period. DuPage County had statistically significant correlations between both jobs and population and TREs, with negative correlations between the latter. Lake and McHenry Counties also had correlations between jobs and TREs. While Lake had a positive correlation between jobs and TREs, McHenry County had a negative correlation. Lake County has a higher R^2 (0.88) than McHenry County. Thus, increasing jobs in DuPage and Lake Counties and decreasing jobs in McHenry County were correlated with TREs. This is particularly interesting as McHenry (-16.9%) had a large decline in its TREs during this period while DuPage County had a large increase (11.5%) and Lake County had a moderate increase (7.6%). DuPage County had a large increase in jobs (13.3%) during this period but only a marginal increase (1.33%) in population, which may explain the positive and negative correlations. Of particular interest is the fact that Will County had no statistically significant correlations for jobs and TREs as jobs grew by 34% and TREs increased by 28% during this period. Therefore, there may be a different factor that affects TREs in Will County besides jobs and population.

McHenry County's negative correlation between job density and per-capita TREs could be due to the fact that it is the only suburban county in which the majority of the people employed in the county also live within it. In 2005, 59% of residents of McHenry County workers resided within the county, while in 2017, 54% did so. People working within their county of residence travel shorter distances to work. As a result, increasing job density within McHenry County does not increase TREs as much as in other counties due to the fact that the majority employed within the county usually live there.

<u>Individual county analysis (2012-17)</u>: Lake County had a positive statistically significant correlation between population and TREs. This is interesting as its population only increased marginally (0.06%) during this period. DuPage, Lake, and McHenry Counties have statistically significant correlations between jobs and TREs. DuPage and Lake Counties have positive correlations, while McHenry had a negative correlation. Similar to 2010-17, Will County had no statistically significant correlations for jobs and TREs even as jobs grew by 24%, and TREs increased by 36% during this period. Therefore, after 2010, there may be a different factor that affects TREs in Will County besides jobs and population.

Results of Regressions from Additive Model 2

Per Capita Transport based $CO_2 = \Psi_1$[Population density] + Ψ_1[Job density] + α

REGION	2005-17		2010-17		2012-17	
	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient
SIX COUNTY REGION						
Population density	0.01338936	-25.0124	0.00148624	-50.989297	0.05246819	-45.784995
Jobs density	0.03537736	6.33109335	0.0004661	13.6624794	0.00936025	14.1150354
	R2: 0.516520735		R2: 0.934986816		R2: 0.959740174	
COOK COUNTY						
Population density	0.25809614	-6.6740845	0.00039827	-17.143802	0.02948675	-45.784995
Jobs density	0.76484638	-0.5096943	0.00200216	3.58926563	0.08874577	-16.371949
	R2: 0.126867752		R2: 0.951300359		R2: 0.964742807	
CHICAGO						
Population density	0.473475772	0.000470409	0.00149691	-0.0072723	0.10496161	-0.007534163
Job density	0.151087712	0.0007721	0.00020201	0.00239073	0.0182534	0.002322757
	R2: 0.217549702		R2: 0.951338989		R2: 0.955754363	
FIVE COUNTIES EXCEPT COOK						
Population density	0.00699669	-20.912306	0.06811974	-164.2436877	0.56459547	-92.963197
Jobs density	0.00080987	19.2732494	0.01895568	49.16685509	0.15714543	40.3807897
	R^2:0.69658425		R^2: 0.833102233		R^2: 0.8966503	

Note: Significant correlations are highlighted in yellow

Observations:

There are very few differences in terms of statistically significant correlation between regression Additive Model 2 (AM2) and Additive Model 1 (AM1). There are a few notable differences, however. All places included had at least one statistically significant correlation for job density vs. per capita emissions. In AM1, the “Five Counties except Cook” category had no significant correlation other than job growth. In addition, the Six County region had a statistically significant correlation between job density and per capita emissions from 2012-17 in AM2, while no such significant correlation existed for the same category in AM1.

<u>Cook County</u>: Of note is the negative relationship between job density and per capita TREs in Cook County for 2012-17. This is unlike the correlations between jobs and TREs for Cook County in AM1, which were always positive. The p-value of this correlation is 0.08, or slightly above the significance threshold. Therefore, although this relationship is interesting, it is not very significant.

Chicago: Like many other areas, Chicago has a negative correlation between population density and per-capita TREs. It had positive correlations between job density and per capita TREs in 2010-17 and 2012-17, though the coefficients were quite small.

Five Counties besides Cook County: Besides similar correlations to AM1 between job density and per capita TREs for 2005-17 and 2010-17, the five outer counties together also had a statistically significant negative correlation between population density and per capita TREs between 2005-17 in AM2. The coefficient for the positive correlation between job density and per capita TREs is rather high, suggesting that job clusters foster a large increase in per-capita emissions. This is not surprising, as many job clusters in the suburban counties are located in car-centric locations that people must drive long distances to reach.

Discussion of Findings for AM2:

The six-county Chicago region had negative, statistically significant correlations between both population density and per-capita TREs for all years studied. The region as a whole also had positive, statistically significant correlations between job density and per-capita TREs for all years studied. This indicates that job density and population density could be significant contributing factors to per capita TREs in the region as a whole. This view gets a bit more complicated when looking at the counties, regions, and cities individually. Although Chicago has a positive correlation between job density and per-capita emissions, its coefficient is extremely small (0.002). For the five suburban counties, however, the coefficient of the positive correlation between jobs and emissions is very high, at 49. A small coefficient indicates that increases in job density result in smaller increases in emissions. Larger coefficients, on the other hand, indicate that increases in job density result in larger increases in emissions.

The difference in correlations could potentially be explained by the differing built environments between the suburban counties and Chicago. It is interesting that the six county region had a positive correlation between job density and per-capita TREs, as one might think that high job density would mean lower TREs, as it could indicate a high-density built environment. However, it could also indicate the presence of car-dependent “edge cities" and suburban job centers, which would likely lead to increased per-capita TREs. These assumptions could be part of the explanation behind the difference in coefficients between Chicago and the suburban counties. Chicago’s jobs are mostly in high-density built environments with good public transit access. Thus, one can increase job density without increasing emissions as much, since a large share of workers commuting to these jobs may be commuting via public transportation or walking. High job density in suburban counties, on the other hand, usually means suburban office parks and edge cities, which can only be reached by car.

Results of Regressions from Additive Model 2 - Individual Counties except Cook County:

REGION	2005-17		2010-17		2012-17	
	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient
DUPAGE COUNTY						
Population density	0.07909016	-25.00835	0.00193533	-63.159645	0.10158903	-68.591822
Jobs density	0.03690378	6.10834838	0.00083414	14.4071092	0.01152877	14.2168683
	R2:0.393686658		R2:0.911663325		R2: 0.912839557	
LAKE COUNTY						
Population density	0.00873055	-29.537297	0.10160079	42.0252049	0.0534332	44.7397718
Jobs density	0.02147416	16.7279085	0.00350277	17.1316327	0.02698141	10.2051232
	R2:0.564343028		R2: 0.88304192		R2: 0.929183002	
KANE COUNTY						
Population density	0.88564145	0.4585934	0.64638135	-5.9179093	0.74133152	-4.9761954
Jobs density	0.07270033	15.570659	0.069054	22.5050195	0.25834364	17.7432688
	R2:0.299936808		R2: 0.878837759		R2: 0.662312342	
MCHENRY COUNTY						
Population density	0.85047962	3.17726563	0.7077713	-37.115192	0.11391056	-326.97581
Jobs density	0.18515683	-33.310121	0.00571486	-158.75398	0.00839269	-167.85394
	R2:0.175872805		R2: 0.817793387		R2: 0.928432758	
WILL COUNTY						
Population density	0.05705047	-34.519628	0.91601852	-34.226241	0.13249485	357.99584
Jobs density	0.00830868	27.8172713	0.45516071	39.7691477	0.91391585	2.95367351
	R2:0.519139195		R2: 0.672774539		R2: 0.950232377	

Note: Significant correlations are highlighted in yellow

<u>Individual county analysis (2005-17)</u>: Similar to AM1, Lake County had a statistically significant ($p<0.05$) correlation between population density and per capita TREs. However, unlike AM1, Will County had a statistically significant correlation between population density and per capita TREs. Similar to AM1, Will, Lake and DuPage counties had statistically significant positive correlations between job density and per capita TREs, with Lake County having the highest R^2 value among these three counties. Neither Kane nor McHenry Counties had any statistically significant correlations during this period.

Individual county analysis (2010-17): During this period, the correlation between population density and job density and per capita TREs were the same as in AM1.

Individual county analysis (2012-17): During this period, the correlation between population density and job density and per capita TREs were the same as in AM1.

Kane County has no statistically significant correlations in Additive Model 2, unlike Additive Model 1.

Results from regressions run on Inflow and Outflow of Workers and TREs:

REGION	2005-17		2010-17		2012-17	
	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient
SIX COUNTY REGION	0.37749577	2003.63388	0.04710166	7765.46351	0.00436415	14920.011
	R2: 0.07139342		R2: 0.508391249		R2: 0.894092572	
COOK COUNTY	0.89065266	-527.30034	0.12873206	9442.61118	0.00665836	22387.7061
	R2: 0.001796373		R2: 0.340718996		R2: 0.869768432	
CHICAGO	0.309545771	2431.733054	0.02492704	9307.0336	0.00637612	15974.69847
	R2:0.093528071		R2:0.595319428		R2: 0.872493917	
FIVE COUNTIES EXCEPT COOK	0.01429337	3579.84244	0.00680576	6655.43559	0.00131849	10248.0129
	R2:0.434280859745979		R2:0.73116366		R2: 0.94129548	
DUPAGE COUNTY	0.23609405	2463.13747	0.11021106	5619.2959	0.01048705	12952.1403
	R2:0.124947213		R2:0.368974705		R2: 0.837550554	
LAKE COUNTY	0.40026557	1922.41475	0.00854884	7220.7397	0.08168896	4522.62431
	R^2:0.065075826		R2: 0.710890488904148		R2: 0.572364377	
KANE COUNTY	0.01151084	4482.20852	0.00018558	5429.1092	0.02258717	4405.66289
	R2:0.454438989		R2: 0.916845987		R2: 0.764997603	
MCHENRY COUNTY	0.17497405	-3295.731	0.01740929	-10354.379	0.01161927	-17038.918
	R2:0.160460071		R2: 0.638106573		R2: 0.829277749	
WILL COUNTY	0.00919127	5813.39286	0.00887411	10971.5481	0.00582089	15880.3721
	R2:0.474740689		R2: 0.707436332		R2: 0.878046707	

Note: Significant correlations are highlighted in yellow

Discussion of Regressions with Inflow-Outflow and TREs:

Inflow-outflow is a proxy for people commuting into and out of a county or the region overall. Inflow and outflow of workers within the six county study region had statistically significant correlations with TREs between 2010-17 and 2012-17. Cook County had statistically significant correlations between inflow-outflow and TREs for 2012-17 only, while Chicago had statistically significant correlations for 2010-17 and 2012-17. Chicago's coefficient for 2012-17 is the second largest, after Cook County. This indicates that trips to and from Chicago and Cook County generate large amounts of TREs, possibly due to long distances.

Five counties except Cook had statistically significant correlations between inflow-outflow and emissions for all years studied. This could indicate that people coming to and leaving the suburban counties are a driver of TREs in the region. It is also likely a reflection of the high volume of suburban county residents commuting to Cook County, and vice versa. In both Additive Models 1 and 2, outer suburban counties such as Kane and Will Counties had few statistically significant correlations between jobs or job density, or population or population density, and TREs. Kane County had no statistically significant correlations between job density and per capita TREs, or population density and per-capita TREs. Yet, in the inflow-outflow regressions, both these counties had statistically significant correlations for all time periods analyzed. This is evidence that inflow-outflow is a better proxy for increased emissions in these outer suburban counties than jobs or population.

McHenry County had a negative correlation between inflow-outflow and TREs, which is rather interesting. One possible explanation could be increasing numbers of people taking the Metra commuter train from McHenry County to Cook County. Although these rail commuters travel a long distance, often over 50 miles, rail creates less emissions than cars. Thus, it is possible that people commuting by train from McHenry County to Chicago produce less emissions than those commuting within McHenry county, since the latter group is very likely to use cars.

Results from Regressions run on Distance Traveled to Work:

DISTANCE TRAVELED TO WORK	2010-17		2012-17	
	P-value	Coefficient	P-value	Coefficient
Less than 10 miles 2010	0.07483091	18.4655901	0.04408163	32.5411585
	R2: 0.435769390947505		R2:0.677803005727239	
10-24 miles	0.06625763	22.084105	0.01249514	43.312593
	R2:0.455633983		R2: 0.823169345	
25-50 miles	0.01992913	49.2164244	0.00195046	76.853294
	R2: 0.622497718		R2: 0.928756564	
50+ miles	0.13322967	54.7114829	0.03320071	136.280681
	R2: 0.334367937		R2: 0.717897063	
25+ miles	0.04184393	28.0216021	0.00166155	53.8353005
	R2: 0.525675356		R2: 0.934181437	

Note: Significant correlations are highlighted in yellow

Longer commutes, such as 25-50 miles and 25+ (an aggregate of the 25-50 mile range and the 50+ range) are the only categories that have statistically significant correlations between distance travelled and emissions for both 2010-17 and 2012-17. From 2012-17 though, all distances had statistically significant correlations with TREs. Longer distances also tend to have higher coefficients, which indicates a greater increase in emissions per person commuting such distances. This is not surprising as longer commutes tend to produce more emissions per capita.

Summary of Findings

In all analyses, several key trends emerged. The most significant trend was that transport related emissions increased by 16.4% and per capita transport related emissions increased by 16.6% for the study region between 2012-17 after having dropped considerably from 2007-12. Both Cook County and the aggregated five outer suburban counties had similar increases in TREs during this period. However, Cook County had a 17.5% increase in its per capita TREs while the aggregated five outer suburban counties had a 15.3% increase in this category. In 2017, TREs for the study region were 6.8% higher than in 2005. The increase in TREs between 2012-17 was accompanied by a 6.9% increase in jobs in the study region and a 0.2% decline in population. Cook County experienced a 5.5% increase in jobs during this period while the five outer counties experienced a 9.5% increase in jobs. In terms of population, Cook County lost 0.7% of its population during this period, while the aggregated five outer suburban counties gained 0.7% of their population. The period between 2010-17 was also characterized by a high rate of increase in workers entering and leaving all counties in the study region. These trends points to the need to stem the loss of population in Cook County while at the same time addressing the simultaneous centralization and decentralization of jobs and spatial mismatch between jobs and housing in the study region.

Similar to the period mentioned above, between 2005-17, population decline in Cook County was accompanied by population growth in the five suburban counties, signifying continuing suburbanization of population, with fastest growth occurring in Kane and Will County. Jobs also grew at a slightly faster rate in suburban counties than in Cook County, home of Chicago. However, Cook County still had the largest proportion of jobs in the region. As a result, jobs both centralized in Cook County and decentralized in the outer suburban counties from 2005-17. Within Cook County, Chicago gained jobs, but lost population over the study period, while most other municipalities studied gained population and lost jobs, with the notable exception of Evanston. As a result, there is a spatial mismatch between jobs and population in Cook County.

In absolute numbers, Cook County had the highest amount of TREs. Though the five outer suburban counties had a lower amount of TREs as compared to Cook County, the rate of increase in TREs was far higher for this group. The outer suburban counties had far higher per capita TREs than Cook County. DuPage and Will County had the highest per-capita TREs, and also experienced the most growth in TREs. This is not surprising, as the suburban counties are rather car dependent, and cars generate a lot of pollution.

Chicago had a tremendous increase in TREs, though it has one of the lowest per capita TREs among Cook County cities likely due to its population density and high density of public transit opportunities. Within Cook County, Orland Park had the highest per capita TRE, followed by Des Plaines and Schaumburg. The TREs of these cities far exceeds that of any of the counties in the study. Schaumburg has the second highest job density among Cook County cities and Des Plaines has a high job density as well, though both have had very small increases in their population over the study period. However, Orland Park has a low job density but has experienced a population growth of nearly 7% over the study period. Thus, TREs in Orland Park may be driven by population growth rather than jobs. The high TREs in these Cook County cities as well as their job and population profiles points to considerable spatial mismatch in jobs and housing.

For all time periods in Additive Model 1 and 2, in most cases in which correlations were statistically significant, the population and population density had a negative correlation with TREs and per capita TREs. Jobs and job density, however, had positive correlations with TREs and per capita TREs. Thus, increase in TREs and per capita TREs is correlated with increasing jobs and declining population, especially between 2010-17. Cook County had more statistically significant correlations between population and population density TREs than jobs and TREs, while the opposite was true for the five suburban counties. Chicago, however, had more statistically significant correlations between jobs and job density and TREs. During this period, Cook County lost a greater share of its population than Chicago, while Chicago gained jobs at a higher rate than Cook County. Emissions increased in both areas during this period, albeit at a far higher rate in Chicago. Thus, it is not surprising that Cook County has a more significant negative correlation between population and emissions than Chicago, and that Chicago has a more significant positive correlation between jobs and emissions than Cook County. In the five outer counties, jobs were the primary contributor to increased TREs, rather than population growth even though these counties had experienced population growth.

Deeper analysis reveals a more complicated picture. Although both Chicago and the five suburban counties had positive correlations between job density and per-capita emissions, Chicago's coefficient is extremely small (0.002) while the five suburban counties' coefficient is very high, at 49. A small coefficient indicates that increases in job density result in smaller increases in emissions while a larger coefficient indicates that increases in job density result in larger increases in emissions. This reflects the difference in built environments in the suburban counties and Chicago. Since jobs in the suburban counties are usually located in car centric locations with commuters travelling long distances, increases in job density could lead to large increases in emissions. Since jobs in Chicago are often located in areas with good transit service, increases in job density could lead to smaller increases in emissions, as a smaller share of people drive to work. These factors could explain the difference in coefficients.

McHenry County is an outlier among the other suburban counties as it had a negative correlation between job density and per-capita TREs, unlike the positive correlations for the other counties. The majority of workers in McHenry County also live in the county. Since people working within their county of residence travel shorter distances to work it is possible that increasing job density within McHenry County did not increase TREs.

Cook County had the largest number of commuters leaving and entering the county, followed by DuPage County, Will County and Lake County. It is noteworthy that the five suburban counties together had greater numbers of residents and workers flowing into and out of them as compared to Cook County. Inflow and outflow of workers within the six county study region had statistically significant correlations with TREs between 2010-17 and 2012-17. The five outer suburban counties had statistically significant correlations between inflow-outflow and emissions for all years studied. This could indicate that people coming to and leaving the suburban counties are a driver of TREs in the region. It is also likely a reflection of the high volume of suburban commuters entering and leaving the region. Cook County had statistically significant correlations between inflow-outflow and TREs for 2012-17 only, while Chicago had statistically significant correlations for 2010-17 and 2012-17. Chicago’s coefficient for 2012-17 is the second largest, after Cook County. This indicates that trips to and from Chicago and Cook County generate large amounts of TREs, possibly due to long distances. Thus, inflow and outflow of commuters is a good proxy for TREs. These trends mirror the simultaneous job centralization and decentralization as well as sharp increases in TREs occurring in the six county region between 2012-17.

County residents with the shortest commutes are those who live and work in the same county. Cook County has the largest number of such workers, followed by DuPage, Lake and Will Counties. However, Kane, Lake and McHenry Counties experienced a decline in such workers over the study period. All counties with the exception of Cook County have a larger share of residents working in counties other than home county.

Of the 2.6 million workers in Cook County in 2017, 70% lived in Cook County while 20% lived in the five outer suburban counties in our study region and 9% lived outside the study region. An additional 922,000 study region workers were employed in one of the outer suburban counties but did not live there. These workers represented 22% of the total workers in the region. Of these 2017 commuters, 55% commuted to the five outer suburban counties from other suburban counties either within or outside the study region. These suburban commuters increased by 32% over the study period. Reverse commuters from Cook County comprised 45% of these commuters, a 13% increase over the study period. Will County experienced an 87% increase in these commuters between 2005-17. Large proportions of these workers likely drove to work as suburban transit connections are poor or nonexistent. I estimate that 1.2 million people drive between counties for work while 1.4 million people drive within each of the six counties. These are very conservative estimates based on CMAP's mode share estimates.

The vast majority of commuters in the six county region travel less than 25 miles to work. However, those who traveled 25-50 miles to work and more than 50 miles increased by 22% and 65% respectively over the study period. While these workers represented just 7% of the workforce in the region in 2017, it is a group that is more likely to drive and generate disproportionate quantities of TREs due to the longer distances travelled. Longer commutes, such as 25-50 miles and 25+ miles had statistically significant correlations between distance travelled and emissions for both 2010-17 and 2012-17. These correlations had higher coefficients, indicating greater increase in emissions per person commuting such distances. This is not surprising as longer commutes tend to produce more emissions per capita.

Limitations of the Data Analysis:

One could argue that the analysis was not comprehensive enough. They could argue that many of the findings are not relevant due to the lack of inclusion of trucks and transportation network company vehicles (TNCs). They could also argue that the conclusions are not completely relevant because the analysis does not include non-work trips. While these are real limitations, they are not as substantial issues as they seem. It is true that Chicago is the US's largest inland port and has many multimodal logistics hubs where freight is moved from train to truck and vice versa. According to the Illinois Better Government Association, the overwhelming majority of emissions in the Chicago metropolitan area come from "cars, SUVs and light trucks." (Chase, 2019) Thus, not including trucks will not have a large impact on my data. Use of TNCs has grown exponentially in recent years. One might think that excluding them would create inaccurate results. However, TNCs only account for 3.3% of VMT in Cook County as of 2019. (Irwin, 2019) The share of VMT in other counties is likely lower. The DARTE database from which the emissions data came from, uses VMT to calculate emissions. Thus, due to TNC's relatively small share of VMT, excluding them from the analysis likely would not have too much of a negative impact on emissions.

Excluding non-work trips could be potentially problematic though. About 43% of auto trips in the Chicago area are work-related. (CMAP Transit Trends). Thus, the majority of auto trips were excluded from the analysis. This was due to the fact that the census data used for the regressions only included data based on work trips. There was no data regarding non-work trips. Non-work trips tend to be shorter and thus less polluting than work trips, mitigating the negative impact of this omission a little.

The analysis had a number of limitations. It cannot be used to establish causation, as there is no control group and there are a number of potential confounders, including non-work auto trips, that were omitted. The analysis did not include several possible contributing factors, such as truck traffic, TNC growth and presence and non-work auto trips. Of these limitations, the latter is the most important, as it accounts for the majority of auto trips. The former two are not as important due to their small shares of emissions.

These findings may prove difficult to generalize to other American cities. The recession from 2008-10 drastically impacted emissions, potentially skewing the results. However, it is likely that the recession drastically impacted other American cities as well, as it was a national and international phenomenon. The combination of Chicago's defining characteristics, such as status as a logistic hub, lack of natural barriers to growth, compact city center, and extensive public transportation system, are rare in other American cities. Thus, it is difficult to generalize findings for Chicago unless there are cities with similar underlying characteristics.

Policy Recommendations

Across counties and cities in the study area, several key trends emerged. Jobs, and especially job density, had more significant correlations with TRE than population or population density did. However, this varied considerably based on locale. Cook County usually had more significant negative correlations between population and population density and TREs than jobs and job density. The suburban counties, however, had more significant positive correlations of TREs to jobs and job density than population and population density. The suburban counties also had the most positive correlations between inflow-outflow and TREs. This is especially important, as jobs in outer suburban counties grew at a slightly faster rate than jobs in Cook County. The mode share of commutes to these suburban areas is overwhelmingly car-dominated, with 99% of commuters travelling between suburban counties, 75% of reverse commuters, and 80% of intra-suburban county commuters driving to work alone. This could lead to increases in TREs, as cars produce by far the most TREs of any mode of transportation. Despite growing job decentralization in suburban counties, job centralization occurred within Cook County, as jobs increased the most in Chicago and Evanston, and declined in suburban cities such as Arlington Heights and Palatine. Such differing trends demand a multifaceted regional approach.

Reducing TREs through Improvements in Public Transit for Suburban Commutes:

Addressing the positive correlation between jobs and TREs as well as inflow-outflow and TREs in the suburban areas is of utmost importance. These correlations are likely due to the fact that the vast majority of people drive to suburban jobs, generating an abundance of TREs. Public transit, on the other hand, is far eco-friendlier. Improving public transit to such jobs is an important strategy to reduce TREs in the study region.

Indeed, suburban public transportation in its current form is inadequate and has much room for improvement. There are three transit systems serving the Chicago metropolitan area: Metra (commuter rail), Pace (suburban bus services) and the CTA (local bus and rapid rail service within Chicago). Metra consists of 11 rail lines and serves as the primary public transportation in suburban areas, and it focuses on moving workers from these areas to and from 9-5 jobs in the Chicago city center. The Pace system is designed to provide connections to suburban areas that lack rail service to Metra or CTA stations, as well as regional employment hubs such as shopping malls and office parks. It also provides limited suburb-to-suburb transit service. The CTA provides frequent, all day transit service to Chicago and a few inner-ring suburbs, such as Evanston, Skokie and Oak Park.

The overall public transit system as it is currently structured does not fully serve the travel needs of the Chicago area. Low density areas such as Will County experienced much job and population growth and saw an 88% increase in workers commuting to Will County from counties other than Will and Cook. Overall, jobs increased by over 13% in suburban counties, faster than in Cook County. People commuting to these jobs from other suburban counties increased 23% since 2005. Suburban jobs are poorly served by existing public transportation, especially for the growing share of workers who commute to them from other suburbs. Current transit provides minimal suburb-to-suburb service and infrequent reverse commute (city-to-suburb in the opposite direction of the peak) service. Indeed, only 1% of commuters between suburban counties use public transportation. These suburban jobs are also often located in low-density areas far from older town centers, which serve as transit nodes, causing last mile issues.

Suburban public transit also serves non-work trips quite poorly. According to CMAP's Transit Trends report, 83% of Metra riders use the service for work-related trips. However, in 2008, only 48% of visiting trips to Cook County, and only 24% of trips within Cook County were for work. (Connecting Cook County) Both of these trip categories are primary markets for Metra. Indeed, train service is sparser during times when non-work trips are more popular, such as off-peak and on weekends, often reaching headways of every two hours. Such infrequent service dissuades people from using the system for non-work trips.

These shortcomings are reflected in mode-share data. The transit mode share of commutes in the fastest growing suburban counties is often extremely low; only about 4.3% in Will County and even less in McHenry and Kane Counties (Active Transit Alliance, 2020 Regional Mode Share Report), and an abysmal 1% for suburb-to-suburb transit commutes. (LaBelle and Freve, 2016) Transit has a 28% mode share for trips in Chicago, and a 42% share for traditional commutes, which include trips from suburban areas and outlying city neighborhoods to the Chicago city center. By contrast, public transit accounts for only 12% for reverse commute trips. (Labelle and Freve, 2016).

Mitigating these issues are difficult. Providing fast and high-frequency transit service to and between low-density areas is a challenge due to the fact that transit is most effective at moving people between centralized origins and destinations. Increasing density in low-density areas is physically difficult, and likely to run into considerable political opposition from established residents. Finally, encouraging people who have been accustomed to driving everywhere to use transit can be a challenge as well.

However, there are several improvements that could serve suburban areas better and reduce emissions. One such strategy would be to increase reverse, off-peak, and weekend service on the Metra system. Currently, the system provides frequent service during the morning and evening rush hours in the peak direction. However, off peak, reverse commute and weekend service is usually only every one to two hours. Some lines have minimal or no service during these times at all. Increasing frequency on all lines to one train every 30 minutes in each direction all day could increase the usefulness of the system dramatically. It could help attract more reverse commuters, who likely are accustomed to using transit and are often forced to drive to work currently. Off-peak frequency increases could attract workers who do not work within the traditional 9-5 paradigm. It could also draw more non-work trips to the train system, as most of these occur outside of rush hour and on weekends. Since 60% of trips in the Chicago region were not for work in 2008, modifying train schedules to better serve non-work trips could have a large potential ridership benefit, which in turn, reduces TREs. (Connecting Cook County) Thus, improving the frequency of Metra trains outside of rush hour could reduce emissions in the region.

A way to further increase access to jobs for reverse commuters is to improve schedule coordination between Metra trains and Pace suburban buses, as well as increase service on feeder bus routes. Many suburban employment centers are far from train stations in areas that are hostile to pedestrians. This is known as the "last mile problem". Currently, there are Pace buses that connect some workplaces to rail transit. However, many are plagued by low frequencies, slow travel times, and poor schedule coordination with train services. Improving this situation would require coordination between the RTA (the organization that includes Metra, Pace and CTA), towns, and employers. Pace could work with Metra to coordinate bus departures with the arrival of trains such that little time is wasted waiting for connections. This would improve travel times and make reverse commuting via public transit more appealing.

Finally, improving suburb-to-suburb links could reduce emissions as well. None of the Metra lines serve such commutes. Pace only offers a few bus routes that serve such commutes, and only in suburban Cook and parts of DuPage county. Many of these routes have difficulty competing in terms of driving time because they do not use freeways. Creating bus services that connect larger towns, like Joliet and Elgin, to regional job centers like Schaumburg, could help to reduce emissions. These bus services could increase transit's mode share for commutes between suburban counties. They could use freeways as much as possible to compete more effectively against cars timewise. It would be similar in design to Pace's I-90 express bus services between the Chicago O'hare area and Elgin via Schaumburg, a major suburban job center. Inaugurated in 2016, these services run in dedicated lanes on I-90, and stop at special intermodal and park-and-ride stations. These routes have experienced tremendous ridership gains since inauguration, enjoying the highest rate of ridership growth in the Pace system in 2017. (PACE Bus Comprehensive Annual Financial Report 2017)

Expressway-based suburb-to-suburb bus services could have a great impact in areas as Kane and Will, where there is a high correlation between inflow-outflow and emissions. If some of that inflow and outflow could be captured by buses, emissions could be reduced. In addition, these bus services could increase the abysmal 1% share of public transit for suburb-to-suburb commutes, as well as the 12% share for reverse commutes.

Transit Oriented Development as means of reducing TREs:

Extending a public transit system to smaller or less dense suburban areas is rather difficult, due to a lack of population density. The places linked by the I-90 Pace Express, for example, are local employment, shopping, and transportation hubs, as well as population centers. The suburbs are low-density, dominated by single-family housing. Transit usually needs higher densities to produce cost-effective, quality service, which often cannot be sustained by large areas of single-family housing. The fact that the Chicago area has one of the highest rates of homeownership among metropolitan areas makes this more difficult, especially since most of these homes are single-family. According to Sööt and Dodge-Hayakawa, 2013, the Chicago region had a 67% homeownership rate in 2011, far higher than cities such as New York and Los Angeles, which had rates of 51% and 52%, respectively. This could indicate a higher prevalence of single-family homes, which are harder to serve through public transportation.

It seems that Chicago has been heading in the right direction in recent years, as multi-family homes have been increasing as a percentage of total new construction. They peaked at about 60% of new starts in 2008 and were about 50% of new construction in 2010. (Sööt and Dodge-Hayakawa, 2013). However, more multi-family housing is needed to increase density in order to make public transportation a viable option in suburban areas, and, by extension, reduce emissions from transportation. One way to facilitate this is to give tax credits and incentives to towns and developers who build multi-family housing near transit hubs. This is known as transit-oriented development (TOD). Indeed, many such developments have been built in recent years, including around Orland Park’s train station. Such projects can increase density in suburban towns, which makes provisioning a quality transit service easier. In such developments, things are also more likely to be in walking distance, further reducing emissions.

While increasing population density has the potential to reduce emissions from transport, job location is also an issue. Indeed, there was often a high correlation between jobs and job density in certain areas and TREs. The regressions found that high job centralization, as well as job decentralization, can increase TREs. Chicago, for example, had a strong positive correlation between jobs and job density and TREs. In other words, the higher the job density, the higher the emissions. On the other side of the spectrum was McHenry County. It had a strong negative correlation between job density and TREs. In other words, as job density increased, emissions declined. These findings are not surprising. If jobs are centralized and people drive to work, emissions will likely increase. At the same time, high job decentralization to the suburbs will likely increase emissions, as cars are often the only way to reach them.

One possible strategy to reduce emissions would be to find a middle ground between these two polar extremes. Tax credits can be used to encourage employers to locate in inner suburban towns in TOD areas. This employment pattern would be less centralized than the one present in Chicago, which would reduce distances that suburban residents must commute to work leading to reduced TREs. At the same time, jobs in TOD areas would be easier to service with quality public transportation than classical low-density suburban offices. As a result, they would be easier for reverse commuters and even for suburban commuters to access via public transportation. This could reduce emissions, as public transit produces far fewer GHG emissions than cars. Locating jobs in TOD areas in inner suburbs would also provide them with desperately needed economic boosts, as many of these towns lost jobs from 2005-17. Thus, providing incentives to locate in such areas would reduce TREs and improve economic conditions in these towns.

There are several obstacles to implementing these recommendations. Increasing housing and job density in inner suburban areas could run into fierce resistance from residents. Many such residents resent changes to suburban neighborhoods, fearing they would damage the “character” of the neighborhoods or hurt property values. Such resistance has appeared time and time again when new affordable or multifamily housing is built in affluent, single family suburban neighborhoods. This can stall development, even if the aggrieved are a minority of the population. Tying jobs to the development of denser housing in TODs could address some of these concerns. Increased tax revenue from new businesses and jobs located in TODs could allay some concerns. Thus, providing economic incentives to locate jobs in TODs in inner suburbs can help overcome the fears of suburban residents.

Congestion Pricing to address Chicago's TREs:

TREs could also be reduced through a policy known as congestion pricing. Congestion pricing is a strategy that requires cars to pay to enter the congestion pricing zone, which is usually the central business district (CBD) of a city. This charge is often dynamic, and is usually most expensive when congestion is highest, i.e. rush hour. By making driving into the city center more expensive, the policy disincentivizes driving into Chicago and Cook County, potentially reducing TREs. At the same time, congestion pricing generates revenue that can be used to implement many of the previously described policy recommendations. Dynamic pricing allows for more revenue per vehicle to be collected when traffic volumes are highest, maximizing the effectiveness of the program at raising funds as well as reducing TREs. Revenue can be collected one of two ways: via license plate cameras on the border of the congestion pricing zone, or via radio transponder tags in cars and gantries at the border of the zone. The latter technology is very similar to radio-based tolling systems such as EZ-Pass.

Congestion pricing has been implemented in various cities around the world, including London and Stockholm where it has proven to be successful at reducing traffic in the city center and raising funds. Stockholm's charge reduced air pollution by 10-15% and decreased TREs in the entire metropolitan region by 2-3%. Public transit ridership also increased after congestion pricing was implemented in both cities. (The Civic Federation, 2019) This suggests that the program has great potential to reduce TREs. However, New York is the only American city to have passed a congestion pricing plan in 2019. Its implementation is on hold pending federal approval. In 2020, Chicago implemented a congestion pricing plan that involved surcharges on taxi and rideshare trips into the city center. However, it is not full congestion pricing, as all other vehicles do not have to pay extra to enter the CBD. A full congestion pricing plan was floated by Alderman Matthew Martin in 2020, though the idea did not advance any further. (Greenfield 2020)

There are several potential challenges to implementing congestion pricing. There could be opposition from local retailers who believe that drivers are a large source of business. Suburban elected officials may also oppose congestion pricing as it may make their constituents' commutes more expensive. There could be low initial public support, as people may view the plan as an additional unfair tax. There could also be technical issues with instituting the charging infrastructure, as numerous smaller roads cross into Chicago's CBD, unlike New York, which has a limited number of entry points due to being surrounded by water.

Indeed, both London and Stockholm's congestion pricing plans were quite unpopular at the beginning of their implementation. However, the popularity of congestion pricing in both cities increased over time. The plans' popularities likely improved due including citizens' realizing the policy's benefit of improved air quality and increased travel speeds as time went on. Both cities also had an extensive media campaign that educated the public on the plan, and touted its benefits, which also played a role in the eventual popularity of both policies. Thus, a strong public awareness campaign, as well as a sufficiently long pilot period, could help to solve the potential issue of low initial public support in the Chicago region. Improving and increasing service to suburban public transit in conjunction with congestion pricing could address the concerns of suburban elected officials. This requires less investment than the previous recommendations, as current public transit is optimized to serve suburb-to-city peak commutes, which would be impacted most by the congestion pricing plan. In addition, London faces many similar issues to Chicago in terms of toll collection, as it has many small streets that lead into its CBD. However, London is able to collect the charges effectively, due to using mounted license plate reading cameras at the zone boundaries. (The Civic Federation, 2019) A similar solution could be implemented in Chicago. Thus, the hurdles to implementing congestion pricing in Chicago can be overcome, and the program has the unique benefit of both reducing TREs and raising funds that can be used for other policy recommendations.

Funding Mechanism:

The largest impediment to enacting any of the above policy recommendations, from TOD tax incentives to increased Metra service, is funding. Increasing transit service and encouraging TOD housing and job developments requires large outlays of funds. There are several ways in which to raise funds. One would be increasing the gas tax in Illinois. The gas tax is meant to be used for transportation improvements and raising it would provide funds for service expansion. Increasing the gas tax could also directly reduce TREs, as it provides a monetary disincentive for people to drive and incentivizes purchase of smaller, more efficient cars. Paradoxically, as cars get more fuel efficient, revenues from the gas tax decline due to reduction in gas purchased. The only solution to this issue is raising the tax further to compensate. However, raising the gas tax could run into opposition, especially from the more suburban and rural parts of Illinois.

An alternative tax that charges drivers a fixed rate per mile driven could also potentially provide funds for transit expansion and TOD incentives. This would use a transponder similar to those used for mileage-based car insurance policies. Unlike the gas tax, a vehicle mileage tax does not suffer diminishing returns with increased car fuel efficiency. This could make such a tax a more reliable long-term source of funding. However, it does not provide any incentive for people to drive less polluting cars. It would likely run into similar political opposition from rural and suburban residents, who tend to drive more. A solution to this issue would be to use a gas tax until the average vehicular fuel efficiency in Illinois meets a certain threshold. Once the threshold is met, the gas tax would begin to be phased out in favor of the mileage tax. Such a tax policy would combine the best aspects of both the gas tax and the mileage tax, namely emission-reducing potential as well as long-term fiscal reliability.

Conclusion

The goal of this analysis is to find contributing factors to the increase in transportation-related emissions in the Chicago metropolitan area since 2005. Factors analyzed included population, population density, jobs, job density, distance travelled to work and inflow-outflow into places. Analyses were conducted at the individual county level, the aggregated five suburban county level as well as the city level. Counties analyzed included the five "collar counties" surrounding Cook County and Cook County itself. Cities analyzed include the 10 largest cities in Cook County.

The findings of this study were interesting. Jobs and job density tended to have more significant correlations with emissions than population and population density. Interestingly, jobs tended to have a positive correlation with emissions, while population tended to have negative correlations. Longer distances tended to have more significant, as well as stronger correlations to emissions than shorter distances. This is not surprising, as one would think that longer commutes would indicate higher emissions. Inflow-outflow, or the number of people coming into and out of a place being studied, had the most significant correlations to emissions in outer suburban counties such as Will and Kane counties.

This study is unique as it addresses factors behind the changes in emissions in the Chicago region in a modern context. Sööt et al, 2010, did an analysis of emissions in the Chicago area, but his study only used data up to 2002. The results of this study affirmed the broadly held idea that areas with higher population density have lower emissions. However, it rebuts the idea that high job centralization leads to lower emissions. While other papers have analyzed emissions in metropolitan areas and compared them to density, few did it on as granular a level as this study. Most analyzed it from the broad metropolitan definition. This study goes into greater detail and analyzes emissions at the town and county level. Also, most analyses use older data than the data used in this study. Thus, this study is an update as well as a fresh look at an idea covered by existing literature.

The findings of this study have the power to shape public policy in surprising ways. By finding a negative relationship between population density and emissions, but a positive one between job density and emissions, this study charts an unexpected path for urban policy. It challenges the idea that high job centralization will reduce emissions. At the same time, it affirms the idea that extremely high job decentralization will also increase emissions. However, areas with high population density will have lower emissions. Therefore, the study points to the need for increasing residential and employment development in smaller, dense clusters throughout the metropolitan area. This way, jobs would be relatively decentralized, while population density would still be relatively high.

Such findings are potentially generalizable for other cities in the US and potentially around the world. Many American cities are dealing with increases in emissions. Many of these cities are sprawling and low-density. In some of them, such as Los Angeles, there has been a considerable effort to reduce their carbon emissions. Many believe that densifying and increasing employment centralization in the central business district will reduce transport emissions. This study suggests that an alternate path could yield more reduction in emissions. At the same time, this study highlights the importance of increasing residential density in such cities if one is to reduce emissions from transportation.

There are many ways to expand on this study. One could include analysis of non-work auto trips if data is available, as well as TNCs. Impact of freight and other commercial and delivery trucks could also be included in the analysis to provide a complete picture. One could also conduct a comparative study between emissions in Chicago and a peer city such as Philadelphia.

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