WATCH THEM SEGREGATE

Analyzing patterns of economic segregation and STEM jobs in commuter zones.

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By
Shruti Shubham
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Abstract

STEM workers have been touted as the economic drivers at local and federal level (Langdon, McKittrick, Beede, Khan, & Doms, 2011), and urban planners often engineer policies for growth and economic development around their demand and supply. These individuals make 29 times more than their non-STEM counterparts (Langdon et al., 2011), and are consistently growing in number for the past 40 years (Watson, 2017). Therefore, it is essential to assess their impact on regional patterns. This thesis posits that STEM occupations drive patterns of economic segregation. To ascertain the validity of the phenomenon, the study assesses the relationship between the concentration of individuals involved in STEM occupations and two measures of economic segregation, economic diversity and concentration of poverty. Upon analyzing the statistics at regional and census tract level for the five commuter zones, Seattle (WA), Portland (OR), Denver (CO), Albuquerque (NM) and Fort Worth (TX), the study revealed mixed results. A secondary layer of spatial investigation was done to further explore the variability in the results.

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Chapter 1 - The Diverging Economy

1.1. Introduction

STEM occupations or jobs in Science, Technology, Engineering, and Mathematics primarily employ non-manual skills, innovation, and scientific knowledge. As per U.S. Department of Commerce, STEM workers play a crucial role in the sustained growth of the U.S. economy. The Department's 2011 projections suggest that 1 in 18 workers were employed in STEM occupations in 2010 (Langdon et al., 2011). The U.S. Bureau of Labor Statistics projected in 2001 that during 2010 to 2020, employment in STEM occupations would grow by 18.7%, compared to 14.3% for all occupations (Baccalaureate and Beyond Longitudinal Study (B&B), 2011). As per the latest update from the Department of Commerce, the industry in-fact grew by 24 percent during the time (Langdon, 2017). Individuals employed in such occupations earn considerably more than the median earnings for all occupations. Moreover, the median earnings for STEM occupations were $74,380 in 2009 and $78,270 in 2012, a number that is twice the median earnings for all non-STEM workers during the same time period (Baccalaureate and Beyond Longitudinal Study (B&B), 2011). Upon reviewing the considerable variation among the incomes of STEM and non-STEM workers, it can be asserted that STEM workers and the choices they make based on their socio-economic status, have the potential to propagate patterns of economic segregation.

Research Question

This thesis aims to explore the relationship between economic segregation and STEM jobs by examining the indices that predict segregation patterns. The indices include the Theil index and concentration of poverty. Patterns of concentrated poverty and diversity are analyzed statistically and spatially within select commuter zones across the United States, and are compared to the change in STEM jobs. The results are drawn upon evaluating five case study commuter zones which include Seattle (WA), Portland (OR), Denver (CO), Albuquerque (MN), and Fort Worth (TX). In the conclusion it is determined if the concentration of STEM occupations exacerbated economic segregation within commuter zones during 1980-2010.

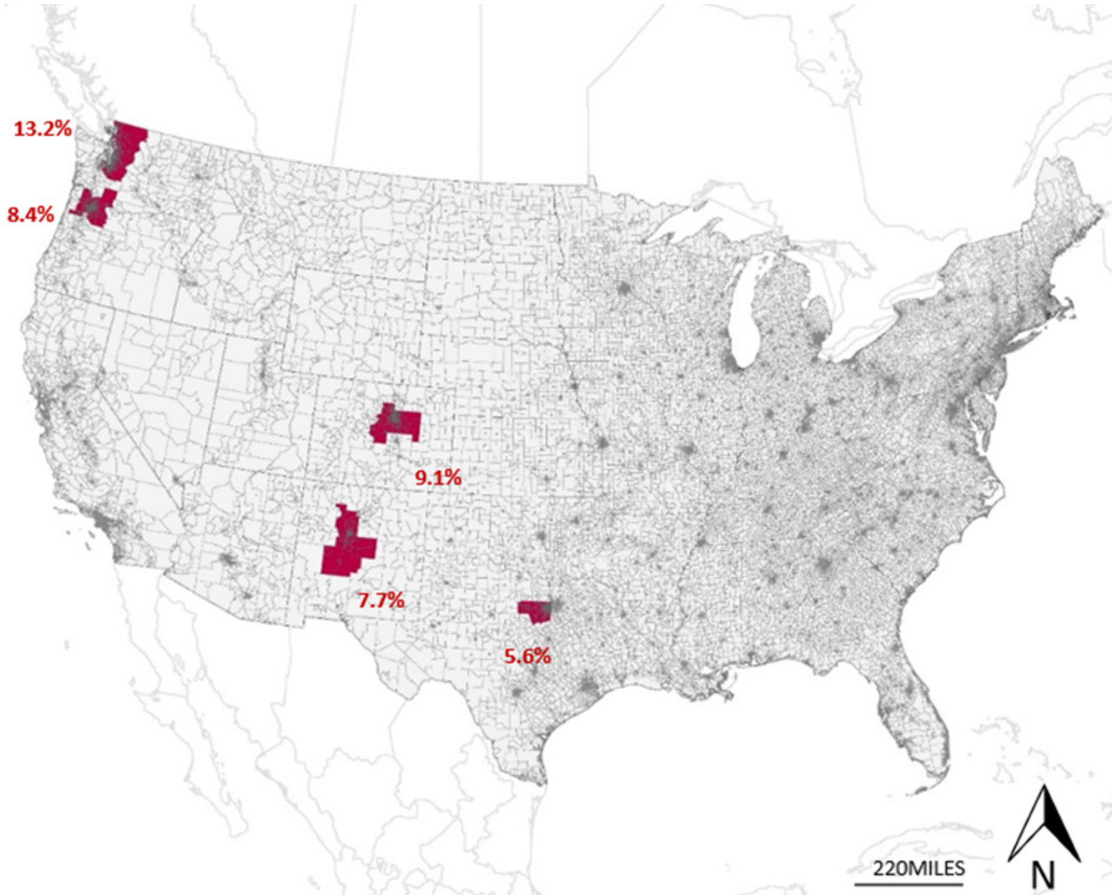


Figure 1| Commuter zones considered for case study, and the percentage of total workforce employed in STEM occupation |Data Source: Bloomberg (2015)

1.2. Background

In order to comprehend the association between STEM jobs and economic segregation, it is essential to develop an understanding of STEM occupations. The acronym STEM refers to Science, Technology, Engineering, and Mathematics (Langdon et al., 2011). Individuals pursuing STEM jobs lead to innovation and have the potential to generate long-term economic growth. Due to their economic viability, the occupations employing STEM workers are widely discussed and analyzed. Moreover, policymakers discuss implications of STEM jobs and employ strategies to derive benefits from them. For example, the economic development plan for Portland outlines establishing a Science and Technology quarter to facilitate and advance the region's biomedical, bioscience, and bioengineering industry (Anderson, 2016).

Previous studies present multiple definitions for STEM. This study uses the Standard Occupational Classification (SOC) system to define it, which is a federal statistical standard used by federal agencies to classify workers (Emmel & Cosca, 2010). STEM occupations include jobs such as engineers, mathematicians, computer scientists and natural scientists. Computer occupations make up nearly 45 percent of STEM employment, and engineers make up an additional 19 percent (Watson, 2017). Mathematical science occupations and architects, surveyors, and cartographers combined make up less than 4 percent of STEM employment (Watson, 2017). Occupations which are listed as STEM-related in the SOC such as dental hygienist and sales occupations are not included in the scope of this research as the subject matter here deals with STEM occupations and not STEM-related occupations.

The United States government has played its part in both creating the demand and supply for STEM occupations. The Congress in the past has acknowledged the vitality of these jobs and has allocated federal funding towards growth and incentives for such occupations (Rothwell, 2013). This funding has been delineated to "promote the progress of science and useful arts"(Vrobart, 2009). Such incentives have been a driving force in growth of STEM jobs.

Witnessing the unmet demand for trained individuals in the STEM fields, in 2006 President George W. Bush launched the American Competitiveness initiative to improve STEM education (Rothwell, 2013). Likewise, President Obama conducted the educate-to-innovate campaign to boost STEM education. He also spearheaded initiatives designed to improve the quality of K-12 STEM education (President Obama, 2009).

With the growth of highly paid STEM workers fostered by growth in the industry (Langdon et al., 2011), local government and jurisdictions tend to develop economic development strategies with a focus on retention of such jobs in their region. These jobs are understood to generate considerable financial benefits to the jurisdictions, which can be redirected further to create better public amenities such as schools, hospitals, infrastructure systems. Thus, the growth of the STEM economy is pursued as a city building strategy.

This competition for attracting businesses employing STEM workers is elucidated by the case wherein Amazon in September 2017 requested for a proposal from local level governments to decide the location for its second headquarters ("How America's cities are competing for Amazon's headquarters," 2017). In response, the company received 238 proposals. This number illustrates the competition. Amazon in their request for proposal had mentioned that the city should have a population of more than one million, and there are only ten cities in the United States that qualify to send a request based on this consideration.

Employment opportunity which may allow them to be placed in the 'middle class,' is one of the top priorities for an American household (Parilla, 2017). As emphasized by Amazon's example, the decisions that policymakers tend to make are taken under intense pressure to deliver more sustained and inclusive economic growth to their communities and fulfilling the demand of the middle class. This vying for tech has brought different levels of development for various towns and cities within a region, causing it to polarize internally (Moretti, 2012). This formation of distinct economies within a given region is also observed in the commuter zones studied in this research. Four out of five commuter zones included here as case studies have comprehensive plans that have outlined explicit strategies to fuel economic growth based on the current STEM economy ("Seattle Economic Development Commission",2014."Economic Development Plan Fort Worth,",2017,"Denver Office of Economic Development," 2017,"Economic Prosperity and Affordable Strategy", 2012).

Redistributing benefits from high-waged STEM workers is not the only motive for understanding the pattern of economic segregation that can be caused by an increase in STEM occupations. Planning professionals need to safeguard these professionals from the vulnerability of an economic downturn as well. Workers in STEM occupation on an average experience a lower unemployment rate than workers in any other field. This consistent low unemployment rate makes these occupations highly desirable. However, they are not completely immune to economic downturns. During the 2001 recession, the rate of unemployment for college-educated STEM workers increased and was higher than the rate of unemployment for non-STEM workers (Watson, 2017). High desirability and high rate of unemployment during a time of economic distress makes it crucial for planners to delve into the relationship between STEM jobs and economic segregation.

As per Moretti (2012), companies employing STEM individuals under thriving market conditions have a potential to generate five times as many indirect jobs as direct jobs. Moretti in his research terms this as the multiplier effect. Given the economic benefits, it is of interest to plan cities and regions in order to support such occupation and redistributing the benefits can be a potential strategy for a sustained economic development of the commuter zone.

To understand the relationship between STEM jobs and economic segregation, it is also essential to understand what the term economic segregation implies, how it is caused and what are its implications for the society. Previous scholarship indicates that many socio-economic constructs can cause economic segregation, most prominent of which is income inequality (Reardon & Bischoff, 2011).

According to a research conducted by Emmanuel Saez (2006), income inequality has been on the rise since 1970. In 2015 households belonging to America's top 10 percent, earned more than nine times as much income as the bottom 90 percent. Moreover, the top 1 percent of America's households have more than doubled their share of the nation's income since the middle of the 20th century. During 1960-2011 the STEM labor force has grown at an average annual rate which is twice as much as the growth rate of the total workforce (Randall, Steele and Zimmer, 2014). It can be understood from the trends, that income generated by the STEM workers have added substantially to the growing economy and has contributed to the rising inequality (Oh & Lewis, 2011).

In their research, Reardon and Bischoff (2011) focus on income inequality from 1970-2000 and observe an increase in segregation with an increase in inequality across all metropolitans in the United States. The growing economic segregation has consequences on social welfare. It determines ones' education level, peers, and social networks (Jargowsky, 1996). In addition to this isolation, the conditions are exacerbated by out-migration of economically well-off African Americans living in economically weaker neighborhoods. This phenomenon takes away economic resources away which catalyzes concentration of poverty, and formation of ghettos (Wilson, 2012).

While the effects of income and occupation on economic segregation have been briefly discussed, there are other factors that augment the negative externalities such as size and density of a metropolitan (Yang & Jargowsky, 2006), level of education attainment (Jargowsky, 1996), concentration of workers in creative class (Florida, Mell, & er, 2015) and number of jurisdictions (Lens & Monkkonen, 2016). For different commuter zones, the geography, economy, school going population and other characteristic attributes vary and therefore the effect of economic segregation on the commuter zones differ.

The parameters listed above contribute to the segregation of the five commuter zones studied with various intensities. In this research, the extent to which the households are distributed based on income is determined by comparing the index of diversity (in this case the Theil index) and concentration of very-low-income households. The analysis is conducted for multiple levels of geographies.

Economic segregation has social and economic consequences for a region. As mentioned before, people choose their neighborhoods based on their personal choice, which is influenced primarily by their level of income (Reardon & Bischoff, 2011). There are secondary considerations in this decision-making such as proximity to schools, amenities, safety, and parks (Baum-Snow & Lutz, 2011; Lens & Monkkonen, 2016; Yang & Jargowsky, 2006), which are often compromised due to lack of affordability. As a result, income determines residential sorting to a large extent.

Well-off individuals seeking a household can afford one in multiple neighborhoods owing to their high incomes. They are able to make a choice depending on the desirability of a specific neighborhood. On the other hand, individuals with low incomes are left with limited options. As a result, low-income level households are never provided an opportunity to be selective about the socio-economic group they reside with. Determinations made by individuals with high incomes determine to a large extent the choices of low-income households. This geographic sorting of households gives rise to patterns of segregation.

These patterns accentuate the economic advantages of a high-income household and exacerbate the economic disadvantage of a low-income household. The mechanisms by which the economic disadvantages are caused can be broken down into two categories, the neighborhood composition effect which determines the composition of a neighborhood based on attributes such as poverty rates, level of education and single-parent household and the spatial resource distribution, which leads to unequal distribution of resources among the affluent and the poor (Reardon & Bischoff, 2011).

Coupled with inequitable distributions of public amenities, there is also inequity in sharing of public resources. Thus, economic segregation also leads to a difference in the level of service based in the income class. A considerable body of scholarship corroborates this theory. Segregation demonstrates first-order impact on several neighborhoods characteristic outcomes such as schooling (Baum-Snow & Lutz, 2011), health (Acevedo-Garcia, Lochner, Osypuk, & Subramanian, 2003) and inter-generational mobility (Chetty, Hendren, & Katz, 2016). Economic segregation also has consequences on political participation of low-income neighborhoods. Residential segregation along economic lines, created by the housing, transportation, and urban redevelopment policies, may set in motion large-scale developments. Such developments can potentially harm the public environment in poor neighborhoods while nurturing the public environment in rich ones (Widestrom, 2015, p. 166).

To uncover the connection between the two phenomena this thesis employs a systematic approach to assess the measures of segregation at the macro and micro level and determine their relationships with the concentration of STEM occupations. It will also understand the extent to which STEM jobs exacerbate economic segregation. The comparative analysis is iterated over five commuter zones enabling conclusions based on similar trends observed. Previous scholarship in this area of research is discussed in the next chapter following which the methodology adopted is detailed.

Chapter 2- Methods of Exploration

2.1. Previous Scholarship

There has been amount of research on the impacts of economic segregation and its implications. Moreover, the increase in STEM occupations is periodically documented by the Department of Commerce. Despite this, the effect of the distribution of STEM workers on the sorting of households has yielded little research. The research method used in this study is rooted in previous scholarships that evaluate causes of economic segregation and understand the implications of the knowledge-based industries.

This study contributes to the literature on the causes of economic segregation within commuter zones in the United States. The earliest research exploring patterns of economic segregation and its implication was done by Park (1926), who stated in his research that “physical distances are indexes of social distance” (p.18). Wilson (1987) concluded in his study that out-migration of the Black middle class has isolated poor Blacks in the inner city, with disturbing "concentration effects”(p.58).

Jargowsky (1996) in his research observed a steady increase in economic inequality in U.S. metropolitan areas since the 1980s despite the slow decline in racial segregation, highlighting the distinction between the two phenomena and how they cannot be used interchangeably. More recently, Reardon and Bischoff (2016) found that economic segregation grew sharply in the 1980s, changed insignificantly in the 1990s, and then grew again in the early 2000s. The researchers attributed this to the rise in income inequality in the past four decades.

The role of factors other than income inequality that contributes to economic segregation has been intensively analyzed by researchers such as Baum-Snow and Pavan (2013, 2016). The authors document a positive relationship between city size and an increase in the dispersion of earnings. They interpret this relation as evidence of a skill-based change in agglomeration economies. In 2016, Diamond studied the economic segregation of college graduates across U.S. cities between 1980 and 2010. The criteria for segregation in Diamond's study was education, whereas the current study focuses on the sorting of households based on economic characteristics.

Income segregation has been widely studied with respect to its neighborhood effects, and the role it plays in social and economic outcomes, such as education, health, and intergenerational mobility. This is essential to understand in order to provide suitable recommendations for commuter zones that evaluated as economically segregated. Education and segregation have a strong two-way link in the United States as public spending in schooling is very localized in the country. For example, Baum-Snow and Lutz (2011) have analyzed the patterns of desegregation in local schools and found that school desegregation in large urban districts led to public enrollment decline for the whites and an increase for blacks. Chetty and Hendren (2016) used tax records in a quasi-experimental setting to measure the strength of neighborhood effects on children and their ability to explain differences in inter-generational mobility across areas.

Although the effects of an increase in STEM workers on the society have not been specifically investigated, the expansion of the STEM economy, innovation economy or knowledge-based economy has been of interest to many researchers. Richard Florida in his book *Rise of Creative Class* (2002) posits that the creative class has the ability to be the economic drivers of the 21st century. He makes a persuasive case to planners that creating spaces for the creative class and providing them an opportunity thrive can help bring financial aid to the city centers and contribute to its economy. Thus, the book stressed on the potential and implication of choices of one-third of the national workforce constituting the creative class – a group believed to bring economic growth to a region. Fifteen years hence, the author reflected on the route to urban revival he prescribed in his previous book and wrote *The New Urban Crisis* (2017). In this book, he writes about the divergence in urban cities between the creative class and the service class. In the literature, the author states that grouping of industry, economic activity, and talented and ambitious people in cities is the primary engine of innovation and economic growth. However, even as urban clustering drives growth, it carves deep divides in cities and the society. As the wealthy and advantaged return to cities, they "colonize the best locations"(Wainwright, 2017). Everyone else is then crammed into the remaining disadvantaged areas of the urban core or pushed farther out into the suburbs.

Another book that creatively dissects the impact of tech-industries on the economy is Enrico Moretti's book, ***The New Geography of Jobs*** (2012). Moretti discusses how regions across the U.S have witnessed economic growth and prosperity and how the growth is representative of the diversity of jobs that the region offers. He states that innovation workers and companies create prosperity and the gains are mostly metropolitan in scale. These gains are crucial in determining the vitality of a region such as a commuter zone. He also states based on his research that innovators create demand for other occupations creating a multiplier effect and in a thriving economy, a single STEM worker can create as many as five jobs.

Empirical research on this topic also includes a recent study conducted by Florida and Mellander in 2015 wherein the authors perform a comprehensive study on urban segregation in U.S. metro areas. The study found a correlation between economic segregation and the emergence of creative class and the expansion of jobs in the high-technology industry. A more recent study published by the Northwestern University and funded by the Ewing Marion Kauffman Foundation (Berkes, 2018) explores this nexus by basing their research on patent citations which stand as a proxy for local innovation. The study determines the pattern of segregation in relation to the the knowledge-based economy.

Building knowledge about the existing studies that drive the knowledge-based industry and economic segregation is important. It is also essential to understand ways in which the relationship can be measured. To do so, the following text explores research on the metrics of economic segregation.

While there is a rich literature discussing measures of segregation among unordered categorial groups such as race and gender (Massey, 1978; Massey & Denton, 1988; Reardon & O'Sullivan, 2004), in comparison methods of measuring economic segregation are much less developed. Massey and Denton (1988) conceived residential segregation as a multidimensional phenomenon and use cluster analysis to identify 20 different indices of segregation, classifying them into five key dimensions of segregation. These dimensions describe evenness, exposure, concentration, centralization and the clustering of the demographic groups. The measures were developed to evaluate residential segregation by race. However, they can be applied to understand representation of economic groups within the area. The research is built on the premise that a diverse geography tends to be less segregated.

Within this research, the measure of evenness is explored and the research evaluates the entropy of an area to measure it. The measure was proposed originally by Theil (Theil 1972; Theil and Finizza, 1971). The entropy index (also referred in this research as Theil score, Theil index and diversity index) measures the (weighted) average deviation of each areal unit from the metropolitan area's entropy or racial and ethnic diversity, which is greatest when each group is equally represented in the metropolitan area. A large entropy index indicates greater economic segregation. A score of 0 determines a perfect distribution of socio-economic groups, whereas 1 implies complete segregation.

P <- Population belonging to the concerned income group

The city’s entropy is given by,

$$E = (P)\log[l/P] + (1-P)\log[1/(1-P)]$$

and a unit's entropy,

$$Ei = (pi)\log[l/ pi] + (1- pi)\log[1/1- pi)]$$

Cumulative of weighted average deviation of each unit's entropy from the city-wide entropy, The Theil index is a measure of the redundancy of income (or another measure of wealth) in a given income group, which implies scarcity in others. This method is able to satisfy the Pigou-Dalton property (inequality increases as a result of a regressive transfer). It is basic, easy to understand and can be calculated based on a matrix of household distribution with the help of an R package. Thus, it is used in this research as a metric.

Another measure of economic segregation explored in the research is the concentration of poverty, or the ratio between the lowest income class in the area to the total number of households in the area. This metric when calculated at a regional level enables the understanding of the health of the economy by indicating how many households are poor, however upon performing a cluster analysis on the metric, and based on the spatial location and pattern of the low-income households, this metric has the potential to reveal the degree of segregation within a commuter zone.

The concentration of poverty within the city is given by,

$$C= Pvery\text{-}low / P$$

The concentration of poverty within the unit is given by,

$$C = Pi\_very\text{-}low / Pi$$

Thus, this research examines economic segregation based on two metrics, by determining the entropy, and the concentration of poverty based on census tract level information. The metric does not provide inferences related to spatial patterns. Therefore a secondary layer of analysis is done to explore the relationship spatially. The approach to analysis is described in the following paragraphs.

A commuter zone is essentially a network of communities, geographies, and economies which impact the long-term growth and stability of one another. Thus, cooperation between municipalities within the same commuter zone is vital for sustained regional growth. To understand the opportunities and weaknesses of a regional entity, five cases were picked. Three of the five case studies picked in this research have a strong history of regional planning. Seattle adopted its first regional plan in 1994 (Hauger, 1994), and has revised it twice since. On the other hand, Denver adopted the Comprehensive plan-Blueprint Denver in 2002 (Helicopter Planning, 2000). These plans have been given five-star ratings by the American Planning Association ("Comprehensive Plan Standards for Sustaining Places Recognition Program Pilot," 2016). The regional planning of Portland is unique as well. Portland and its surrounding towns and cities comprise the first regional planning entity called the Metro, whose executives are elected representatives of the community (Anderson, 2016). This entity determines plans and policies that the region of Portland is mandated to follow. Portland is also a unique case study as it is the first region in the United States to adopt the urban growth boundary in the year 1967, and the commuter zone spans over two states, Oregon and Washington.

In contrast, Fort Worth and Albuquerque do not have such strong regional planning devices enforced. The regional planning efforts for these regions have been enacted only recently (in the past ten years). Across the commuter zones, there is an emphasis on economic development derived from STEM industries and its workers ("Economic Development Plan," 2017).

These commuter zones were also analyzed based on their Cost of Segregation as outlined by Rolf Pendall, Gregory Acs, Mark Treskon, and Amy Khare in their study published in March 2017. The study analyses hundred most populous commuting zones and documented its Generalized Neighborhood Sorting Index (GNSI) and spatial proximity between black and white neighborhoods. Based on the analysis, Fort Worth was placed at 43rd, Seattle at 46th, Denver at 49th, Portland at 78th, and Albuquerque at 94th position, thus representing various degrees of economic segregation. All the regions have higher than the national average of STEM workers contributing to their economy and therefore provide an opportunity to test this relationship in various socio-political climates.

The data used to test these geographies is publicly available, anonymized and aggregated data, made available by the Bureau of Labor Statistics and Census Bureau. The data tables include occupation of civilians of ages 16 and over, distribution of household income and median household income. The data belong to datasets that were extracted from decennial census summary files of 1980, 1990, 2000 and 2010. The 1980 and 1990 data tables are called STF1 Summary Tape File and STF3 Summary Tape File. For the years 2000 and 2010, they are called the SF1 Summary File 1 and SF3 Summary File 1.

While measuring the concentration of poverty, generally reasearchers employ federal poverty standard (Bureau). This method has some flaws, primary of which is that it ignores the differences in cost of living across commuter zones, thus overlooking the regional context. To initiate the process, the 2000 commuter zone boundary was imposed on the census tract cartographic boundaries of 1980, 1990, 2000 and 2010. Census tracts which were completely contained in the commuter zones were included in the scope of the study. The median household income data collected from Census Bureau was joined to the cartographic boundaries. The quintiles based on median income of each commuter zone was recorded, and the range of each quintile was used to categorize the household by income dataset.

The categories of income are determined by the household income dataset provided by the Census Bureau for the years 1980, 1990, 2000, and 2010. These data tables contain 17 income groups for 1980 and 1990 and 16 for 2000 and 2010. The income groups are absolute in their dollar value, therefore polynomial curves were used to interpolate the breakdowns. Once the breakdown points were identified, the income groups were split into income classes based on quintiles of distribution of median household data. Households belonging to the first quintile of the range of median household income were classified as 'very-low' income household, the second quintile as 'low,' the third quintile as the middle,' the fourth as 'high' and the last quintile as 'very-high' income classes. These income classes were then used to calculate the two measures as described in the earlier section. The Theil index was determined using an open source software using R as a programming language, whereas the concentration of poverty was calculated by using excel.

To obtain the occupation data Standard Occupation Classification (SOC) is used. This classification is used by federal agencies to classify workers of occupation to collect, calculate or disseminate data(Emmel & Cosca, 2010). All workers are classified into one of the 867 detailed occupations. The Standard Occupation Classification list for 2010, 2000, 1990 and 1980 is provided by the Bureau of Labor Statistics (BLS). BLS has also provided crosswalks between the multiple lists, which establishes horizontal consistency among the lists. Using the above lists, occupations were classified as STEM occupations. It was found that majority of the occupations were listed as Professional Specialty Occupation. For the purpose of this study, the Professional Specialty

Category in the civilians by occupation dataset is used to calculate the number of STEM workers in a census tract.

To begin the commuter zone level analysis, the Theil index and concentration of poverty were calculated for the entire region. The percentage of STEM workers was also determined. Thereafter the change in the percentage of the three indices across the region and timeline were calculated. The calculated result is plotted as a bar chart. To test for the relationship at the census tract level, multiple regression analyses were conducted with the concentration of STEM jobs as the independent variable and concentration of poverty and Theil index as the dependent variable. This was done to understand the nuances of the relationship as opposed to relying on one metric for an entire region. The regression analysis was done to understand the extent to which STEM jobs predict these two measures.

The STEM occupation data and the median income data is thereafter divided into quintiles. For the STEM data, census tracts were identified which have the maximum number of STEM workers (top twenty percent). The distribution of these census tracts is tabulated. This distribution is reviewed thereafter.

Together, the comparison of these statistics across the five commuter zones is used to analyze and develop an understanding of the spatial pattern of very-low-income households as influenced by STEM workers from 1980 to 2010 and across the five case study regions. The findings and conclusions are based on the patterns observed as a result of statistical and spatial analysis.

2.2. Limitations

The data used for the analysis is aggregated based on census tracts, and the hot-spots for the concentration of income clusters were created based on the adjacent edges. This leads to misrepresentation of data as tracts with larger boundaries will reveal clusters with large areas. These large clusters might not be more significant than other smaller clusters represented with the same intensity. This inherent limitation of spatial exploration based on aggregated data over a surface area can be termed as the Modifiable Areal Unit Problem.

The modifiable areal unit problem is a source of statistical bias that affects results when point based measures of spatial phenomena are aggregated into districts (Fotheringham & Rogerson, 1993)., for example, the datasets used in this study, median income, households income, and occupation distribution calculate average statistics for a census tracts which is used to perform further calculations. A daysymmetric mapping of clusters of poor and diversity index might help resolve this issue and might help understand nuances in the relationships being explored.

The household income is accounted for by Census Bureau in specific income buckets, and thus breaking off households based on quantiles of median income and calculating the number of households with the help of these categories can depend on the device of interpolation. In this study, the polynomial curve is used to interpolate the breakdowns.

Chapter 3- Findings

3.1. Regional level analysis

Commuter zones are large geographies and have been developed by USDA to delineate the economy better. The largest commuter zone discussed in this research is Seattle, which measures close to 100 miles if measured along the north-south axis. It includes parts of Mt. Baker Snoqualmie National Forest, Wenatchee National Forest and Mt. Rainer National Park. Given the geographic predicament, the clusters of households organically form at places which have feasible access to resources necessary for survival. While talking about a region, the focus here is specifically on towns and cities with a large concentration of households (> 10,000).

The first result being discussed is the regional level statistics of the Theil index, the concentration of poverty concerning the total observed population of STEM workers in the region. The statistics observed are summarized in Figure 02.

The figure above is explained with the help of charts bar charts in figure 3 that illustrates the percentage change in the indices across the three-time period.

Commuter Zone	1980			1990			2000			2010		
	Theil diversity index	Concentration of poverty	The ratio of STEM workers	Theil diversity index	Concentration of poverty	The ratio of STEM workers	Theil diversity index	Concentration of poverty	The ratio of STEM workers	Theil diversity index	Concentration of poverty	The ratio of STEM workers
Seattle	0.3739	0.3264	0.18	0.4054	0.358	0.2	0.346	0.3873	0.23	0.31	0.35	0.25
Portland	0.3283	0.3412	0.15	0.2793	0.358	0.18	0.4585	0.4163	0.21	0.42	0.4	0.23
Denver	0.3421	0.3107	0.17	0.2938	0.2163	0.21	0.3072	0.3152	0.23	0.26	0.33	0.23
Fort Worth	0.3415	0.0811	0.14	0.3751	0.3241	0.18	0.3679	0.3051	0.19	0.35	0.31	0.19
Albuquerque	0.3081	0.121	0.21	0.3756	0.3163	0.23	0.4005	0.3102	0.23	0.34	0.37	0.24

Figure 2 | Table indicating overall Theil index, concentration of poverty and the ratio of STEM workers for commuter zones.

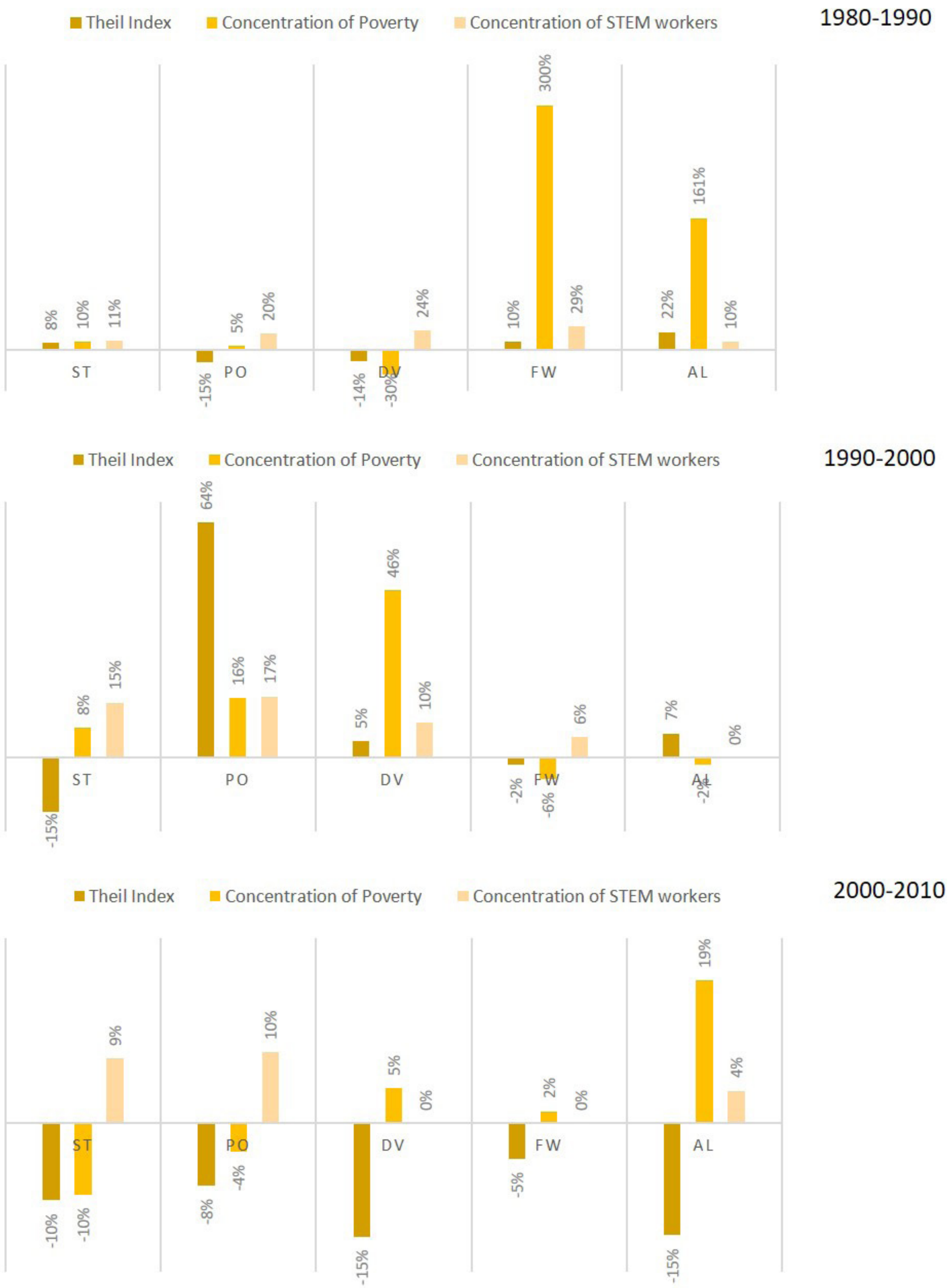


Figure 3 | Percentage change in the parameters, Theil index, concentration of poverty and concentration of STEM workers

The first chart shows the changes occurring in the time period 1980-1990. In this decade the first two years were defined by the recession, wherein more than 12 million Americans faced joblessness (NW, Washington, & Inquiries, 2010). Steel and other heavy industries, particularly in the Midwestern Rust Belt struggled with competition faced from Japan and Germany, and the nation was experiencing large-scale deindustrialization (NW et al., 2010).

Given the economic flux in the country, Denver shows positive statistics. The diversity index decreased by 14 percent and concentration of poverty decreased by 30 percent. During this time, many individuals left the city of Denver to find jobs elsewhere, however considering the overall region of Denver and the commuter zone around it, the chart depicts growth in the number of stem workers of about 24 percent. Seattle saw an increase in the diversity index, whereas Portland witnessed a decrease, however, both the regions seem to control the growth in concentration of poverty. The number of STEM workers also increased in both the regions. Lastly, during this time in Fort Worth and Albuquerque (comparatively smaller commuter zones), the number of STEM workers decreased 30 and 10 percent, and the diversity index also increased by 10 and 22 percent respectively. The fluctuation in diversity index and STEM workers are comparable to other commuter zones. However, the concentration of poverty is six to ten times higher. Fort Worth is also a part of a larger economy which is comprised of the cities, Dallas and Arlington. To gain a more holistic view of the Fort Worth sub-region, census tracts from these cities can be included. Based on the 1980-1990 observations the area was disproportionately inhabited by very-low-income households and saw a huge increase in such households as compared to other commuter zones.

The commuter zone of Albuquerque also shows a rapid increase in very-low-income households in the period 1980-1990. Herein, the concentration of poverty increased with increase in STEM occupations. Thus, it can be interpreted that technology market was growing at the time. However, the disbursement of the financial benefits was inequitable in smaller commuter zones. The larger commuter zones were able to hold well against the economic challenges of this time period.

The 90s were the age of the internet marked by the World Wide Web (NW, Washington, & Inquiries, 2014) and rapid growth in STEM occupations across the United States (Langdon et al., 2011). Internet became the new frontier for conducting business, and there were dramatic shifts witnessed in the existing economic landscape. This growth in STEM jobs impacted regional patterns, especially the larger commuter zones. The time period 1990-2000 saw a reversal in trends as compared to 1980-1990. Herein, the concentration of poverty increased for larger commuter zones.

The Theil index does not show any consistent pattern. There was an increase in the diversity index for Portland and Denver implying they were more segregated. Seattle saw a 15 percent decrease in Theil index indicating that the region has become more diverse. The concentration of poverty however increased by 8 percent. These trends suggest that Seattle during this period suffered from a checkerboard problem, whereby a landscape with alternating exclusively low-income and high-income is not evaluated by traditional segregation measures as less segregated that the case where the same areas are rearranged into larger exclusively low-income and high-income regions (O'Sullivan & Wong, 2007). Concurrently, the number of STEM workers grew by 10-20 percent in the three larger regions.

1990-2000 also witnessed a marginal decrease in concentration of poverty for smaller economies such as Fort Worth and Albuquerque. The diversity index decreased for the former by 2 percent and increased for the latter by 7 percent. Moreover, they saw a 6 percent increase and 0 percent increase in STEM jobs. The percentage change is substantially less than those observed in the previous decade and when compared to the larger commuter zones.

The last figure (Figure 3c) describes the changes that occurred in 2000-2010. The economic boom continued until the first few years in the 21st century (Mishel, Schmitt, & Bernstein, 2000), and so did the number of STEM occupations for three of the five regions. Denver and Fort Worth did not see an increase in the number of STEM workers. Despite a downturn between 2006 and 2009 (Amadeo, 2018), the concentration of poverty was -10 percent to 2 percent for all the commuter zones except Albuquerque, which saw a 19 percent increase in very-low-income households.

The Theil index statistics for 2000-2010 ranged from -5 to -15 percent for all the five commuter zones. This indicates that the regions at the time became more diverse economically. The trends also suggest that the wages earned by STEM workers, which are comparatively higher than non-STEM workers (Langdon et al., 2011) were distributed equitably. The percentage change in both, the small commuter zones and the large commuter zones represent this trend. Out of the fifteen cases observed, for five commuter zones across the three time periods, six cases represent an inverse relationship between the Theil index and concentration of poverty and five cases represent an inverse relationship between Theil index and STEM workers. This indicates that as number of STEM workers increased, the diversity of the region increased. Eight of the fifteen cases studied observe an inverse relationship between the concentration of poverty and STEM workers, indicating that as the number of STEM workers increased, the number of very-low-income households increased in the region. A low diversity index and high concentration of poverty as observed in eight of the fifteen cases indicate towards the 'checkerboard problem'(O'Sullivan & Wong, 2007) and is a mark of diverging economy wherein there are high concentrations of households with median incomes that are very-low or very-high.

Observing the parameters and their relationship with one another, it can be concluded that there are no apparent trendlines. The percentage change in STEM jobs does not relate to the percentage change in Theil index or concentration of poverty at a regional level.

		Theil index		Concentration of poverty	
		R squared	Intercept	R squared	Intercept
Seattle	1980	2%	0.3%	9%	-0.7%
	1990	0%	-0.1%	11%	-0.7%
	2000	0%	0.0%	18%	-0.8%
	2010	3%	0.2%	12%	-0.5%
Portland	1980	7%	0.6%	5%	-0.5%
	1990	0%	-0.1%	14%	-0.7%
	2000	5%	0.3%	12%	-0.6%
	2010	0%	0.0%	10%	-0.5%
Denver	1980	21%	1.0%	33%	-0.6%
	1990	4%	-4.0%	44%	-2.0%
	2000	2%	0.3%	36%	-0.9%
	2010	5%	0.5%	27%	-1.0%
Fort Worth	1980	21%	1.0%	33%	-0.6%
	1990	4%	-0.4%	44%	-1.6%
	2000	2%	0.3%	37%	-1.4%
	2010	5%	0.5%	27%	-1.0%
Albuquerque	1980	20%	1.0%	12%	-4.0%
	1990	12%	0.7%	28%	-1.0%
	2000	23%	1.0%	26%	-1.0%
	2010	2%	0.2%	12%	-0.5%

(blue)	***
(grey)	*

Figure 4 | R squared statistics and intercepts for equations determining Theil index and concentration of poverty based on independent variable, concentrations of STEM workers at the census tract level

3.2. Census tract level analysis

The regional level analysis outlined in the previous section provided a comprehensive overview and understanding of the economic conditions and regional trends vis-à-vis parameters of segregation. The percentage change of the three metrics across the timeline did not reveal any consistent patterns. To confirm the findings of the first set of analyses, and confidently state whether the concentration of STEM workers exacerbates economic segregation or not, the study delves deeper into the relationship between the STEM occupations and the selected measures by conducting series of regression analyses. The results of these analyses are discussed in this section.

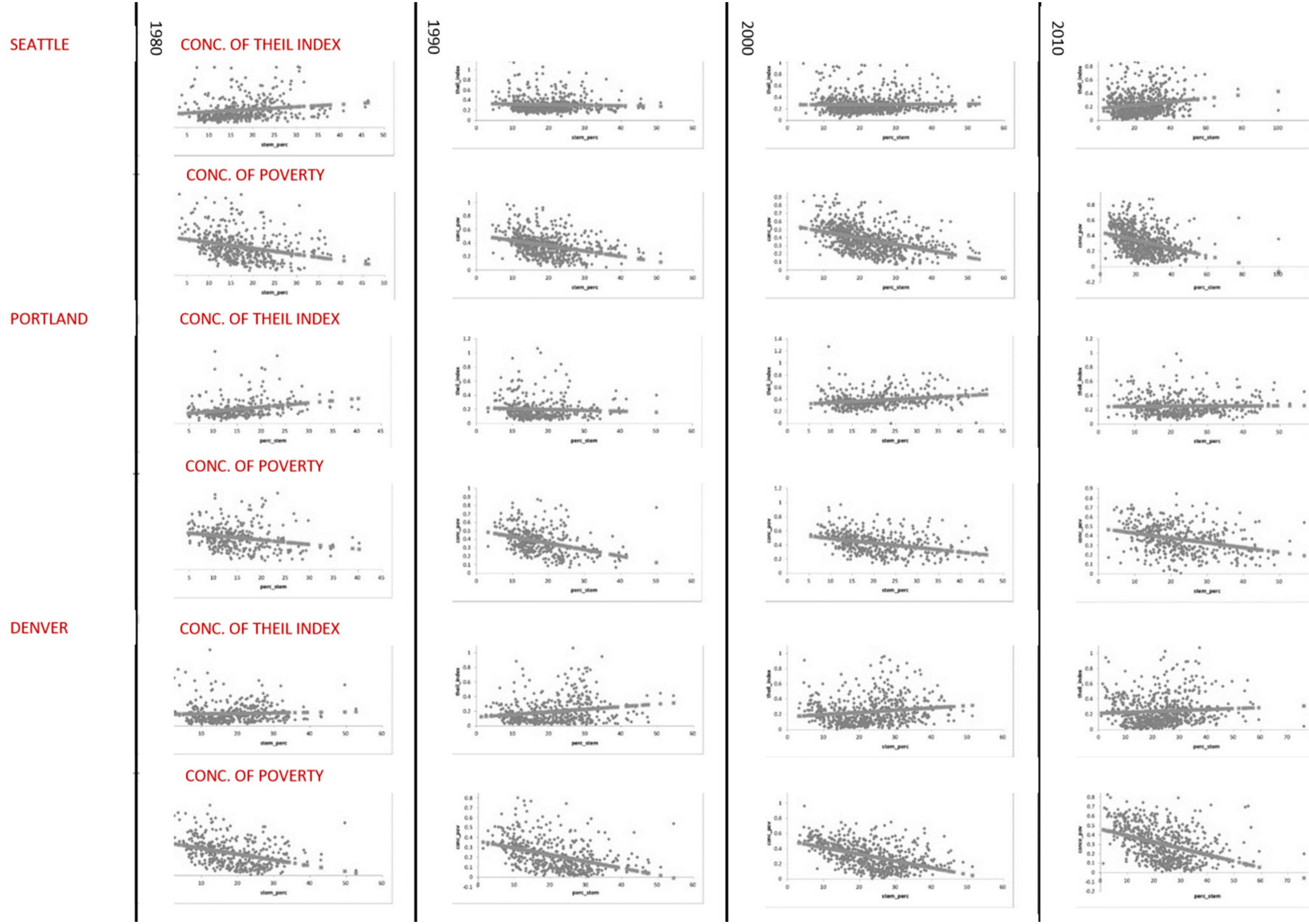
The regression analysis is used as an instrument here to quantify the relationship between the parameters of economic segregation in consideration. The two indices are designated in the analysis as the dependent variable, and the number of STEM jobs are designated as the independent variable or the covariate. The analysis was conducted using observations associated with each census tracts for the four years, 1980, 1990, 2000 and 2010. The need of quantifying the relationship between a dependent variable and a set of independent variables is to calculate the contribution of each independent variable to the value of the dependent variable. The models described in this study predict the relationship between each of the indices of economic segregation and the concentration of STEM workers. The results are statistically significant. A statistically significant regression model of the parameters concerning the STEM occupations indicates that concentration of STEM workers in census tracts do exacerbate economic segregation. However, the value of the intercept and the robustness of the model (figure 4) indicates that there is a small change in the measure of the indices with a large increase of the concentration of STEM workers.

The table in figure 4 summarizes R squared statistics and intercept for both Theil index and concentration of poverty. It is observed that the values for Theil index have low R squared statistics. This indicates that the variability of Theil index around the data line is high and the measure is not well explained by the independent variable (ratio of STEM workers to the total employed individuals). The linear regression plots for this data are visualized in Figure 5.

In the observed regression models, Theil index generally demonstrates a slightly positive or no correlation with the concentration of STEM jobs in a census tract. This indicates that the diversity of households belonging to various socio-economic background within census tracts decrease with an increase in the concentration of STEM workers. Based on the trends it can also be concluded that the chosen parameters perform better in the cases of Fort Worth and Albuquerque which have smaller economies and high concentration of workers involved in knowledge-based industries. For larger economies such as Seattle, Denver, and Portland, more information is required to generate a model that can predict economic segregation at a commuter zone level. Although the trends are consistent with the initial assumption, the results cannot be considered due to extremely low values of R squares.

On the other hand, STEM occupations provide better estimates of variability in concentration of poverty, than the Theil index. The results for concentration of poverty have higher significance and are inversely related to an increase in STEM occupations. One can interpret a census tract within which many individuals are employed in STEM occupations, the level of concentration of 'very-low' income household belonging to the bottom 20 percentile of households based on the median income decrease. Based on the statistics observed for every 10 percent increase in STEM occupations, one can observe 0.07 – 0.4 percent increase in the concentration of poverty. The numbers for the intercept are low, representing only a marginal change in concentration of poverty based on STEM occupations. Nevertheless, it can be stated that the concentration of STEM jobs impact concentration of poverty more than the diversity of a commuter zone.

In the literature reviewed studies stated multiple factors of economic segregation at a regional level including education, income, and employment. Individuals belonging to the STEM sector is a measure of employment, and therefore only partially explain the patterns of segregation. The literature also confirms that STEM occupations have higher incomes and high level of education. An increase in a number of STEM workers must mean an increase of educated individuals and increase in high-income households, however as witnessed in the research, this is not the case, especially at a regional level.


SEATTLE
PORTLAND
DENVER
1980
1990
2000
2010
CONC. OF THEIL INDEX
CONC. OF POVERTY

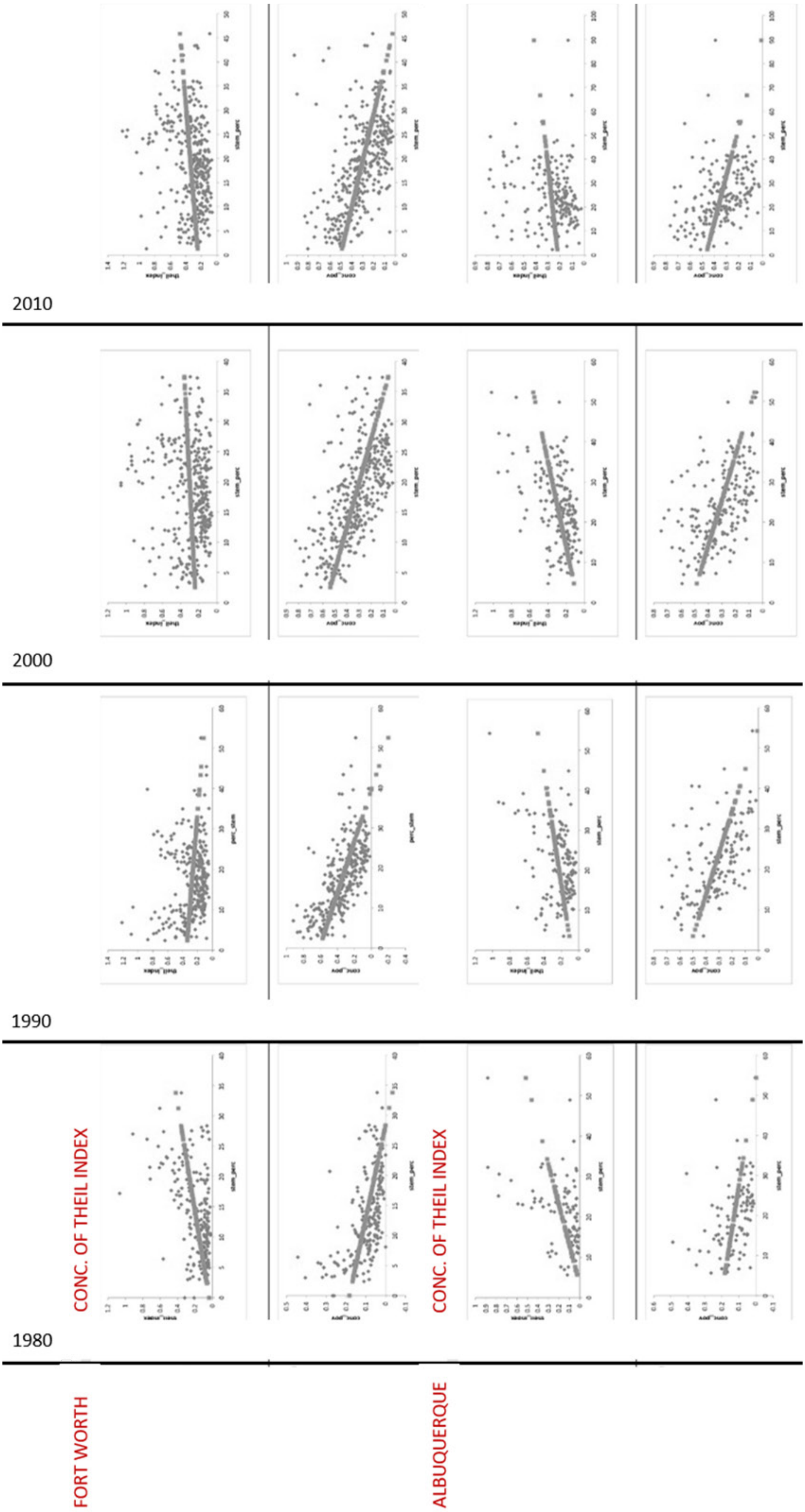


Figure 5 | Regression plots for Theil index and concentration of poverty based on independent variable, concentrations of STEM workers at the census tract level

3.3. Exploring spatial relationships between case study commuter zones

The last section discussed the robustness of the relationship between concentration of STEM workers and measures of economic segregation. It was observed that concentration of poverty is explained better by the concentration of STEM workers, as compared to the Theil index. To investigate the relationship further a secondary layer of analyses was conducted which spatially observed the clusters of low-income census tracts and high-income census tracts. Moreover, the distribution of census tracts with a high concentration of STEM workers (top twenty percent), was understood across very-low, low, middle, high and very-high-income census tracts. The percentage change in number of census tracts with high concentration of STEM workers within in each group was also tabulated and compared.

Figure 6| Location map- Seattle commuter zone and important commercial centers.

3.3.1. Seattle (Tacoma-Bellevue)

The geography of the Seattle commuter zone is illustrated in Figure 6. Figure 7 depicts the clusters of high and low concentration of poverty in the region observed from 1980 to 2010. The areas with high concentration of STEM occupations include city centers of Everett, the county seat for Snohomish County, situated north of Seattle, North Bend (King's County) situated in the east and Tacoma (Pierce County) in the South. The western edge of the city is lined with Elliot Bay.

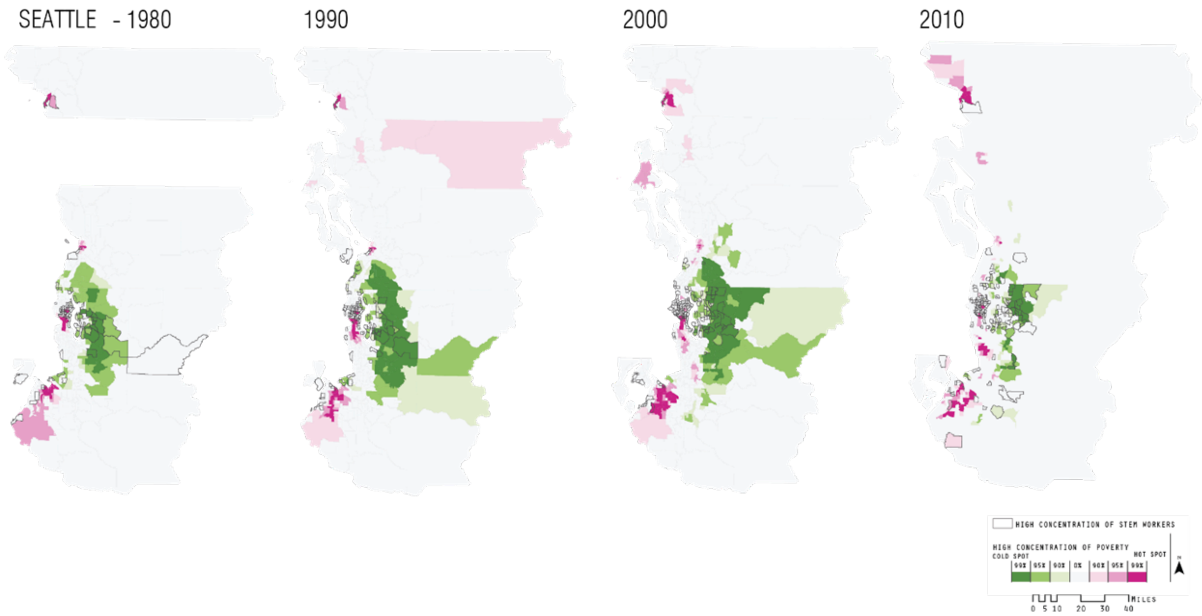


Figure 7 | Spatial relationship between census tracts with high concentration of STEM workers and clusters of 'very-low' income households (poorest 20 % households), Seattle 1980-2010.

The Seattle commuter zone has been heavily industrialized (Warren, 1999). It has served as the headquarters of Boeing, a leading manufacturer of airplanes, from 1916 until the 1970s (Kershner, 2015). With the decline in demand for industrial goods post-Vietnam war, the city saw a decline in the economy (Levi & Olson, 2000). Seattle had an intense economy before the 1980s and was subjected to a series of boom and busts. It is not surprising that the commuter zone demonstrated clustered low-income and high-income census tracts in 1980.

During 1980 to 1990, Seattle commuter zone's fortune was closely associated with the growth of Microsoft (Levi & Olson, 2000). Its first product BASIC came out in 1976, and the company was incorporated in Albuquerque. In 1978, Microsoft sales exceeded one million. Soon after, the company shifted based to Seattle Commuter zone (in Bellevue) in 1979. By 1985, the sales were recorded over $140 million (Campbell-Kelly, 2001). Unlike Boeing which contributed to the economy only by employing individuals, Microsoft cultivated a thick labor market in Seattle, which supported the technology created by Microsoft (Moretti, 2012). This transformed the city. However, the locations of concentrated poverty did not change.

In 1980, the clusters of high-income census tracts were concentrated in and around Bellevue, which has been historically an affluent suburb of Seattle, whereas the poverty was concentrated in the city centers of Seattle, Everett, and Tacoma. It is evident from the figure 7, map of 1980 that individuals with STEM occupations did not choose to locate in areas with high concentration of poverty.

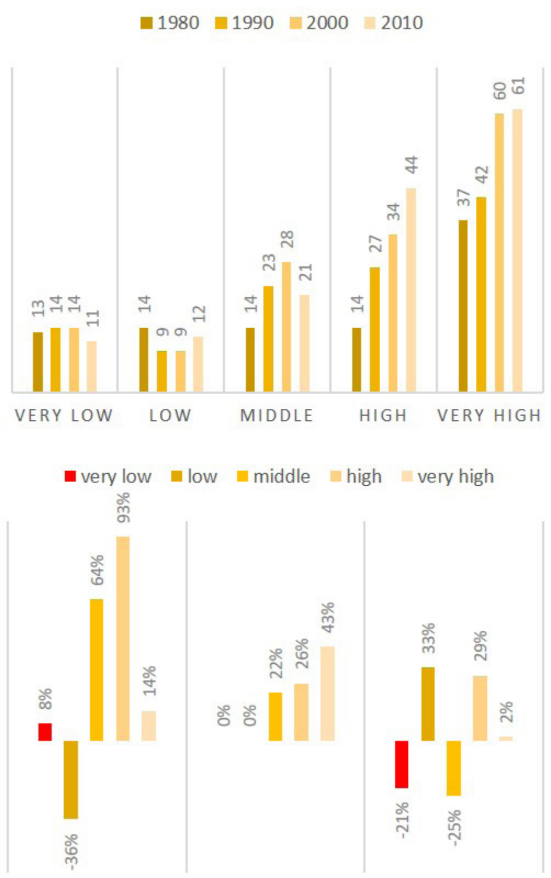


Figure 8 | a. Distribution of census tracts with high concentration of STEM workers across the five economic classes in Seattle. b. percentage change across the three time periods 1980-90, 1990-00, and 2000-10.

Although the census tracts with concentrated poverty are spread out across the region, only few of them have high concentration of STEM workers. From the year 1980-1990, the number of census tracts having a high concentration of STEM workers increased, however, the percentage change was higher in the middle, high and very-high-income groups. The very-low income group saw an increase of 8 percent, whereas the low-income group witnessed a decrease in percentage of census tracts with a high concentration of STEM workers.

Tacoma and Everett wherein clusters of low-income households were located in the 1980s, saw a decrease in the number of low-income census tracts in 1990-2000. This pattern continued in 2000-2010. Areas with a concentration of poor households saw an increase in the number of STEM workers, benefitting from the regional economy. The trend witnessed in the Seattle region indicates that movement of STEM workers in clusters of very-low-income census tract dissipates poverty.

Figure 8 indicates the distribution of census tracts with a high concentration of STEM workers across the five income groups being studied. In the year 1980, 13 census tracts with a high concentration of STEM workers also had large concentrations of very-low-income households. Low, middle and high-income households also consisted of 14 census tracts each. A large proportion of census tracts with high concentration of workers, 37 census tracts, also had high incomes.

In the year 1990, the number of census tracts with low-income saw a decline in the concentration of STEM workers and the very-low-income census tracts saw a slight increase. In the next decade, the number of census tracts with high concentration of STEM workers in low and very low-income groups did not increase. In the time period 2000-2010, a negative growth of 21 percent is observed for very-low-income census tracts and an increase in the concentration of STEM workers in high-income census tracts. Overall the number of census tracts with high-income groups and high concentration of STEM workers have increased substantially over the years, with STEM workers choosing to locate themselves in high and very high-income groups.

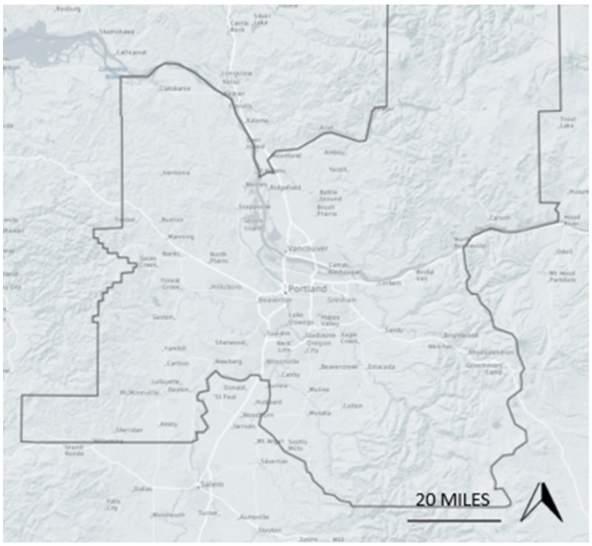
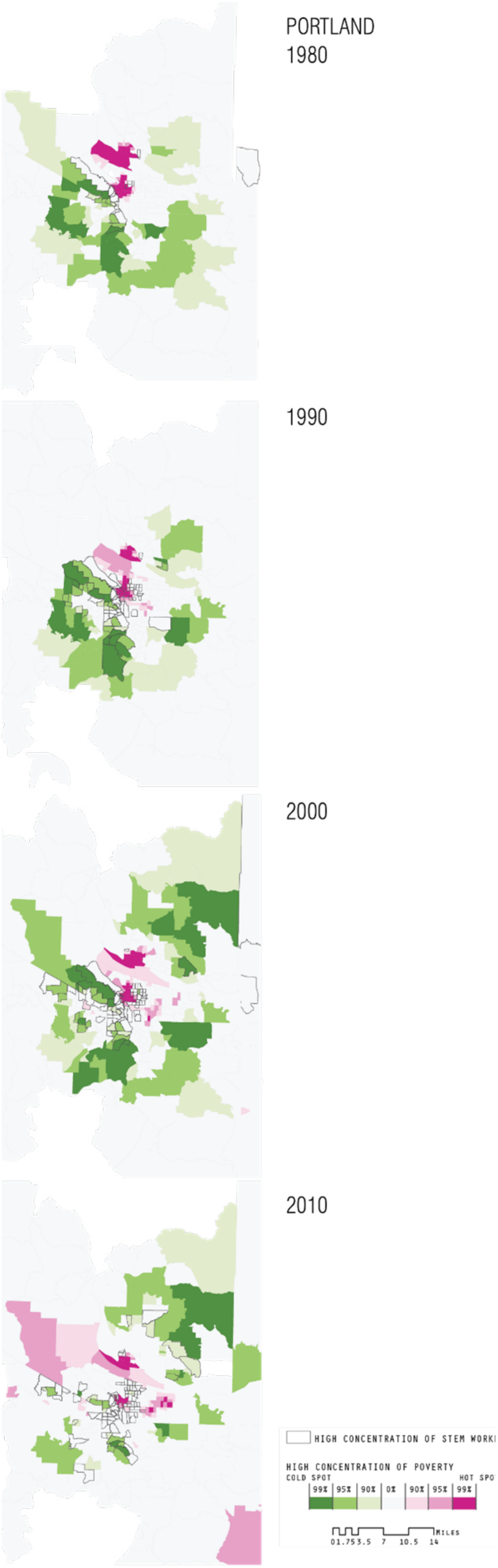


Figure 9 | Location map- Portland commuter zone and important commercial centers.

3.2.2. Portland (Vancouver-Hillsboro)

While Seattle's STEM workers seem to occupy census tracts with a high concentration of poverty and transformed them into areas with comparatively lower concentration of poverty, in Portland an increase in the number of such census tracts was observed in areas with a concentration of very-low and low-income census tracts. This pattern was witnessed south and southwest of the border of the states, Portland and Washington. Areas in the commuter zones which belong to the state of Washington consistently did not witness any clustering of low-income households, or census tracts with a high concentration of STEM workers, across the timeline.

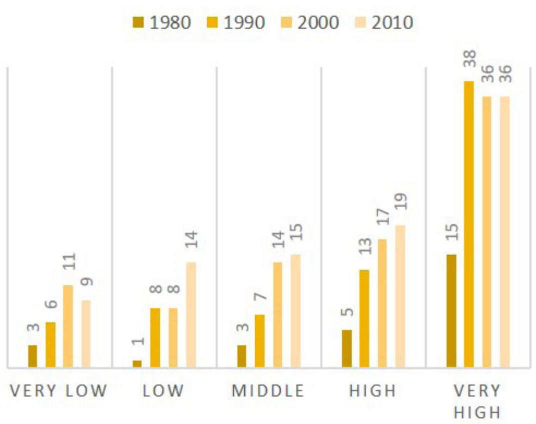
Portland has long been Oregon's dominant economic center. The city's importance stems largely from its location. Situated on the confluence of Columbia and Willamette River, Portland is a major port in the Pacific North-West (Gibson & Abbott, 2002). During the post-war years (World Wars), Portland maintained a strong commercial base and diversified its economy considerably (Price et al., 1987). This diversity allowed Portland to remain unfazed during economic downturn experienced by the rest of America in the 1970s and 1980s (Bianchi, 2012). In figure 11b it is observed that despite country-wide depression in economy during 1980-1990, the region of Portland continued to add STEM workers, especially in low and very-low income census tracts. In 1986, the major STEM employers situated in Portland were Tektronix, Intel, Boeing of Portland, Floating Point System, and Electro-Scientific Industries(Price et al., 1987).



In 1980, STEM workers situated themselves in Beaverton, extending up to Hillsboro as indicated in figure 10. Apart from these select census tracts where the number of STEM workers were high, concentrated poverty was observed. In 1990, the number of census tracts with a high concentration of STEM workers increased, in and around the city centers, in the region south-west of the river. The number of census tracts with low-income increased during this time, specifically along the Hillsboro- Beaverton corridor. This growth in census tracts with low-income households located adjacent to census tracts with high STEM workers is unlike the growth witnessed in Seattle commuter zone.

In 2000 the number of census tracts with a high number of STEM employees increased yet again. The pattern of growth of such census tracts is observed moving westwards towards Hillsboro which houses the Ronler Acres campus, Intel's largest campus opened in 1994 (Siemers, 2012). This movement can also be explained by the MAX light rail which

Figure 10 | Spatial relationship between census tracts with high concentration of STEM workers and clusters of 'very-low' income households (poorest 20 % households), Portland 1980-2010.



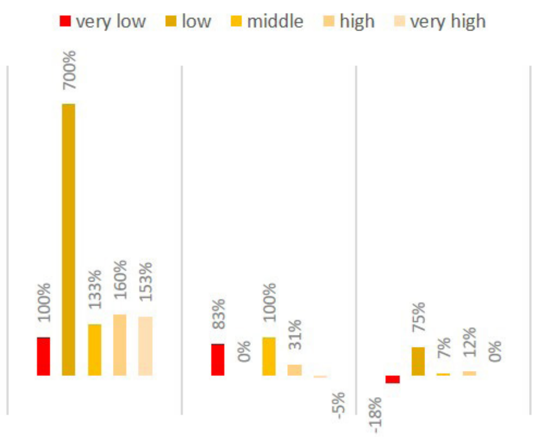


Figure 11 | a. Distribution of census tracts with high concentration of STEM workers across the five economic classes in Portland. b. percentage change across the three time periods 1980-90, 1990-00, and 2000-10.

connects Portland, Beaverton, and Hillsboro (Ozawa, 2004). Despite building proximity to the clusters of low-income census tracts, census tracts with high number of STEM workers do not change in location or in number. In the year 2010, the cluster of low-income census tracts expanded along the axis of the light rail, and the number of census tracts with STEM workers decreased.

Looking at the figures 11a and 11b, it can be inferred that across the three time periods analyzed, concentration of STEM workers increased in low income and very-low income census tracts. Despite an increase in number of STEM workers choosing to reside in low-income census tracts, the number of STEM workers residing in high and very-high-income census tracts far exceeded them.

The trends suggest that the commuter zone of Portland encouraged individuals from a lower-income census tract to pursue STEM jobs, an opportunity other census tract failed to provide. Majority of low-income census tracts were observed along transport infrastructure. This might have played a role in delineating mobility to the individuals residing in them and increasing their economic opportunity.

Moreover, Portland as a region is bounded by the Urban growth boundary as discussed in Chapter 2, the adoption of which limits the expansion of the 27 towns and cities in the Portland commuter zone area (Fulton, 2001). Adopted in 1977, this Boundary created an increased value of real estate in and around the city centers which can be afforded only by high-income households. As a result, STEM workers might have chosen to live in a more affordable location, given they cannot sprawl (Gibson & Abbott, 2002).

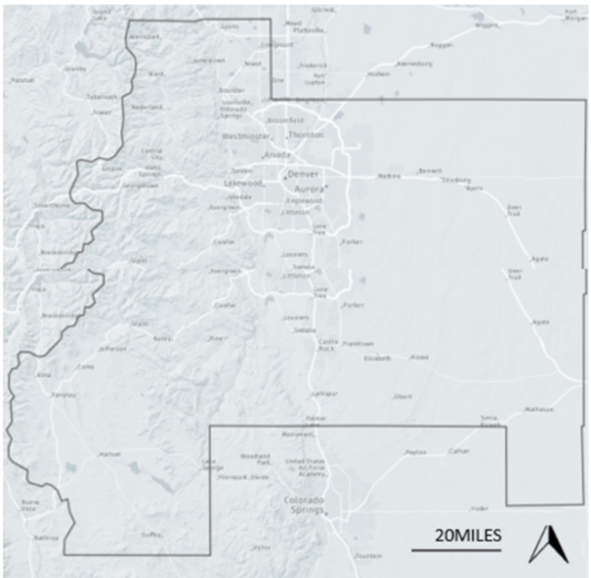
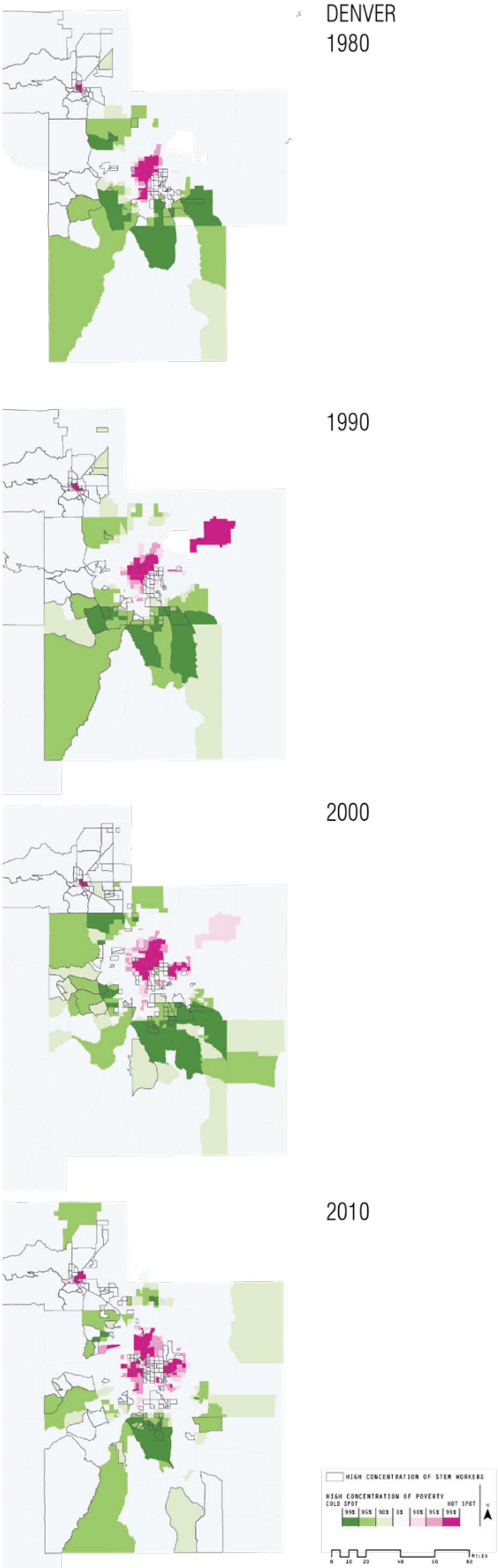


Figure 12 | Location map- Denver commuter zone and important commercial centers.

3.3.3. Denver (Aurora-Lakewood)

In the 1860s, the plans for transcontinental railroad bypassed Denver for cities like Cheyenne and Wyoming. Efforts of business and civic leaders such as John Evans helped to pass a bond to connect the 106-mile railroad from to Denver (Ambrose, 2001). This investment which was risky at the time has paid off tremendously in the long run. It served as the key factor in the transformation of the city into one of the most thriving economies of the USA (Ambrose, 2001). Due to its strategic location, Denver has facilitated the movement across the breadth of the country for over 150 years, and as a center of confluence, the region saw a growing manufacturing industry and became a telecom hub during the early 20th century.

Denver had a thriving tech-industry before the other case study commuter zones considered in this study (“Denver’s Changing Economy,” 2016). In 1962, George M. Wallace envisioned the first suburban office park in the south-east of Denver. Throughout the 1970s more offices, residential, hotel and infrastructure was added to the area (Malecki, 2002). Around the suburban tech-center, a cluster of tech industries came to thrive soliciting expertise in data, telecom, and aviation. This made Denver extremely an attractive destination for migrants and also contribute to a massive over speculation of the success of the city, which inflated real



estate rates (Chris & Stephen, 2001).

Due to the inflated real estate rates, Denver's economy fell precipitously during the economic distress experienced by the country in the 1980s. A large population was rendered below poverty level (Malecki, 2002). This distribution of low-income households is evident from the concentration of poor income households mapped during 1980 (Figure 13). During the time workers involved in STEM occupations clustered around the south of Denver, where George Wallace had established the Denver Technology Center decades before. On the other hand, census tracts with low income were mainly observed in and around the city center.

In the 1990s, there were strategic attempts made by the administration to revive the city, such as low rentals for office space, to make the rates competitive and attracting more businesses (Chris & Stephen, 2001). These exercises in economic planning paid off as

Figure 13| Spatial relationship between census tracts with high concentration of STEM workers and clusters of 'very-low' income households (poorest 20 % households), Denver 1980-2010.

Denver thrives as a region today. Denver's economy has strong industries across sectors such as aerospace, aviation, bioscience, telecom, energy, health and IT employing a large number of STEM workers ("Denver's Changing Economy," 2016).

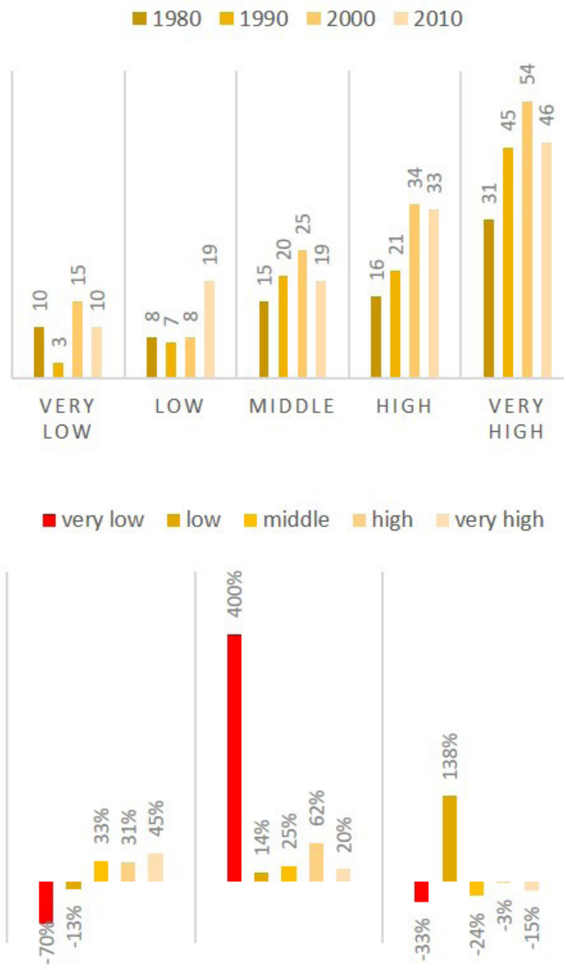


Figure 14| a. Distribution of census tracts with high concentration of STEM workers across the five economic classes in Denver. b. percentage change across the three time periods 1980-90, 1990-00, and 2000-10.

Figure 13, the map of 1990, depicts an increase in area of cluster of low-income census tracts. The number of census tracts where STEM workers are observed in high concentration increase marginally and continue to thrive in locations similar to the ones observed in 1980. In the map of 2000, it is observed that the number of individuals in STEM jobs increased in LoDo (Lower Downtown), which was once a thriving tech hub under George Wallace before he moved to the suburban office park (Malecki, 2002). Having witnessed extreme economic woes in the past four decades, Denver at this time had adopted a comprehensive plan- DenverBlueprint, for the region in the year 2000 (Helicopter Planning, 2000), in a commitment to grow the economy equitably and control the urban growth pattern. In 2010, with clustering of STEM occupation around the city center, the concentration of poverty gripping the city center seemed to be alleviated.

Observing statistics in figure 15a and 15b, it is evident that the high number of STEM workers consistently chose to live in high and very-high-income census tracts. However, there is an observed increase in the number of very-low-income census tracts during the time-period 1990-2000.

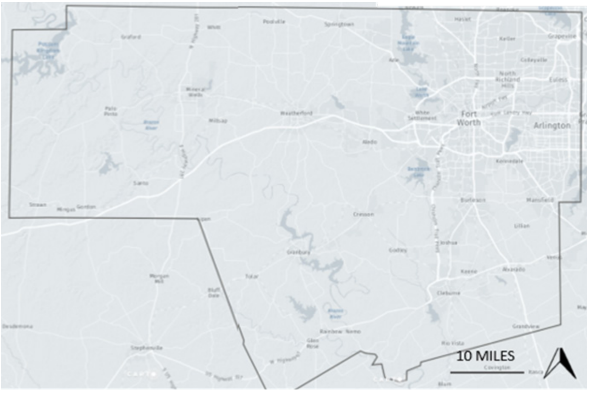


Figure 15| Location map- Fort-Worth commuter zone and important commercial centers.

3.3.4. Fort Worth (Dallas-Arlington)

Fort Worth as a city is an outcome of the war. With the discovery of oil in Texas in 1917, refineries and pipeline companies such as Sinclair Refining Company, Texaco, and Humble Oil and Refining (Exxon Company) converged on Fort Worth, which also developed into a center for oil stock exchanges. The region thrived as an economy during the first half of the nineteenth century (Paddock, 1922).

With the outbreak of World War II, the aviation industry came to Fort Worth. The opening of Dallas/Fort Worth International Airport in 1974 ushered in a new era of aviation history. At the time it was built, the airport was the largest in the world. The aviation/aerospace industry remains an important factor in Fort Worth's economy today (Montgomery et al., 2005).

Fort Worth enjoys the benefits of being a center in the aviation industry and its proximity to Dallas, the largest inland metropolis in the USA. It also profits from the thick labor force contributed by several reputed university communities primary of which are Texas Christian University, Texas Wesleyan, University of North Texas Health Science Center and Texas A & M University School of Law. The primary employers for STEM workers in the area are Bell Helicopter,

Figure 16| Spatial relationship between census tracts with high concentration of STEM workers and clusters of 'very-low' income households (poorest 20 % households), Fort Worth 1980-2010.

Lockheed Martin, American Airlines, and XTO Energy ("Economic Development Plan," 2017). Fort Worth has been dependent on Dallas for its growth, but it is growing fast as an independent economy. The effects of this change are captured in the maps, in figure 16. The northeast part of the region consistently has a low concentration of poor households over the timeline observed. This area is also closest to the city of Dallas. As one moves towards the southwest, the concentration of poverty increases.

In Fort Worth, the low-income census tracts are clustered in the city centers for all the years observed, and census tracts with a high concentration of STEM workers are located in the suburbs.

During 1980-1990 the middle, high and very-high-income census tracts observe a percentage increase in STEM workers, whereas the low and very-low census tracts saw a negative growth and no growth respectively. During this time period it was observed in the first set of findings that the concentration of poor reduces in the commuter zone. Therefore, it can be stated that because the total number of poor households are decreasing Fort Worth, there appears to be a decrease in STEM workers in low-income census tracts.

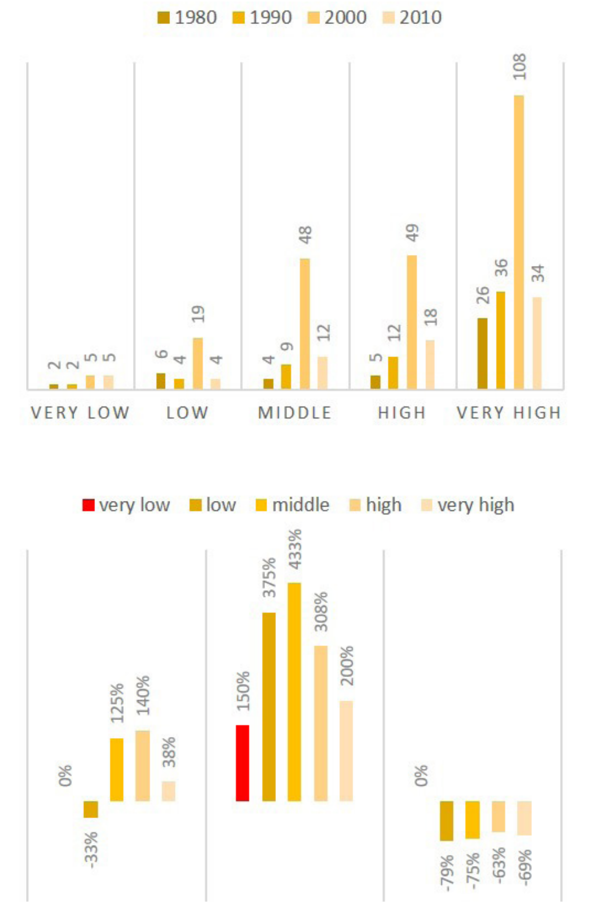


Figure 17 | a. Distribution of census tracts with high concentration of STEM workers across the five economic classes in Fort Worth. b. percentage change across the three time periods 1980-90, 1990-00, and 2000-10.

In the next time period, substantial growth is observed in all economic classes, middle-income group attracting the most number of STEM workers. Lastly, In the decade of 2000-2010, all the census tracts show a negative percentage growth of concentration of STEM workers. It is clear that the regional economic factors affect all types of economic groups somewhat equally in the city.

With dramatic change in population of individuals working in STEM fields and the observed leapfrogging of nodes with high concentration of poor and simultaneous suburbanization of STEM workers indicate that there is a tendency of sprawl in the region of Fort Worth, the sprawl in the region is expected to continue, if the growth is not directed by careful policy-making. This can result in substantial disinvestment over a large area.

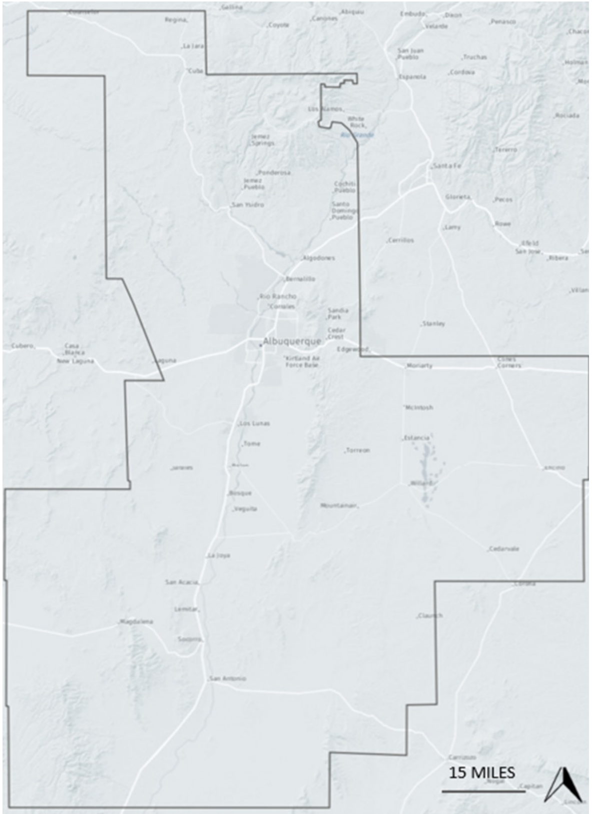


Figure 18| Location map- Albuquerque commuter zone and important commercial centers

3.3.5. Albuquerque (Santa Fe- Las Vegas)

The city of Albuquerque was founded in 1706 as the Spanish colonial outpost. The city had been a region of political tension until 1912 when it incorporated in the US (Reps, 1965). The establishments critical for economic development of the region are US military-based organizations. The thick labor of STEM workers is maintained by the University of New Mexico, Kirtland Air Force Base, Sandia National Laboratories the National Museum of Nuclear Science & History and Lovelace Respiratory Research Institute. The city also has played a key role in the atomic age (Simmons, c1982, p. 2016). Sandia National Laboratories (later named as Honeywell) developed non-nuclear components for nuclear weapons (Forma, 2017). During the cold war, this area witnessed increased investment. The boom of Albuquerque's economy was short lived. Its downtown entered a phase of urban decline in the 1980s (Forma, 2017).

The trends witnessed in Albuquerque are quite erratic. Constrained by development in west and east the region grew southwest and southeast along the Rio Grande River. The concentration of poor income households remained at the periphery of the zone, with the commercial center of the commuter zone, the city of Albuquerque remaining affluent throughout. The poverty levels are alleviated only in the time period 2000- 2010, after three decades of sustained growth of STEM occupations.

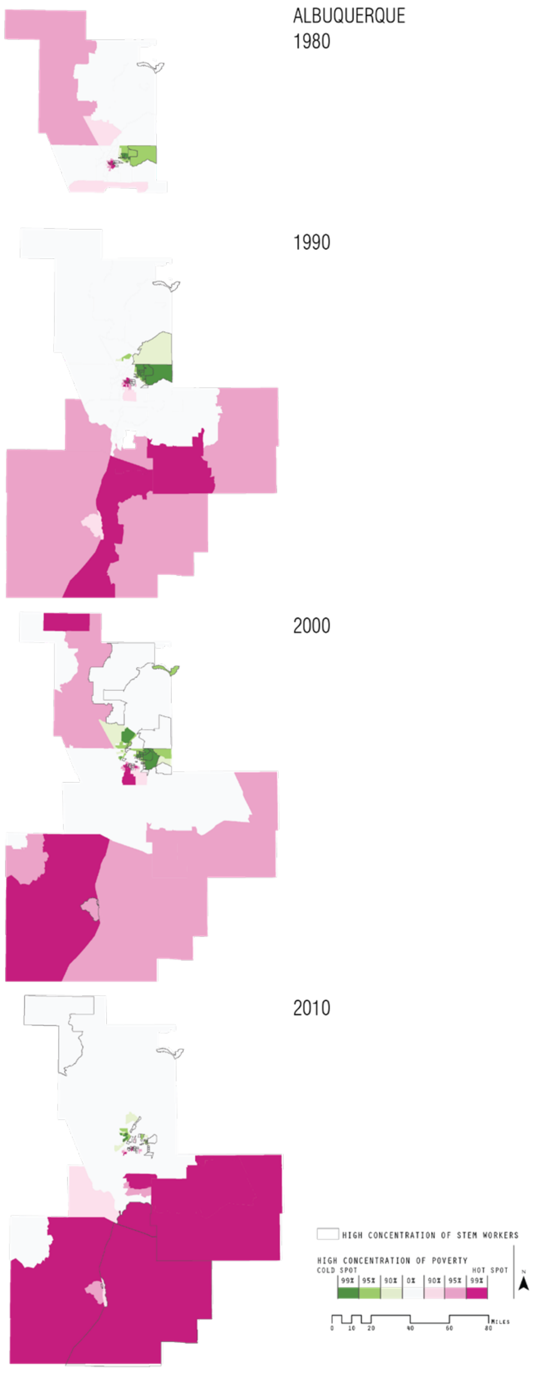


Figure 19 | Spatial relationship between census tracts with high concentration of STEM workers and clusters of 'very-low' income households (poorest 20 % households), Albuquerque, 1980-2010.

Figure 20a and 20b indicate that although the number of STEM workers is constantly high in the very-high-income census tracts, the very-low, and low-income census tracts witness a substantial increase in STEM workers as well. The middle-income group saw 500 percent increase in the number of census tracts having a high concentration of STEM workers in the years 2000-2010. The spatial distribution of clusters of concentration of poverty is observed leapfrogging from northeast of the city in 1980 to the south of the city in 2000. The south valley or the large census tract with high number of poor households saw an increase in STEM workers. Following the transition of the particular census tract further into the timeline will allow a deeper understanding of the effect of STEM jobs on economic segregation in Albuquerque and in particular for low-income census tracts.

Paul Allen, the co-founder of Microsoft worked at Honeywell, and Bill Gates joined him in Albuquerque to create Microsoft, in 1975. It

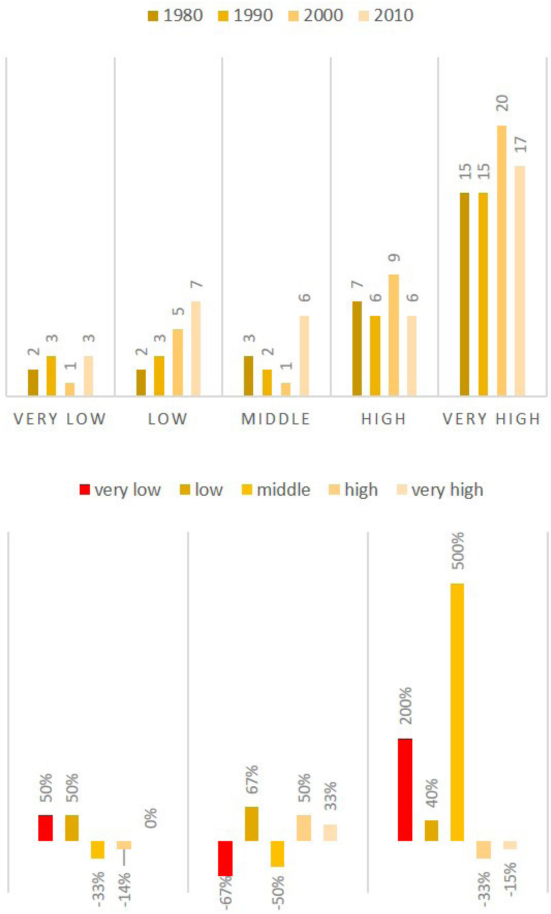


Figure 20 | a. Distribution of census tracts with high concentration of STEM workers across the five economic classes, Albuquerque. b. percentage change in across the three time periods 1980-90, 1990-00, and 2000-10.

was evaluated at $3 Million when it moved to Bellevue in Seattle. This move singlehandedly changed the fate of two commuter zones studied here. While Seattle during the same time period coped with dramatic changes, in Albuquerque the cluster of low-income census tracts increased dramatically over the years (Campbell-Kelly, 2001). This brings into light the long-term effects of STEM jobs and the lack of it, which has resulted in the formation of distinct economies over the 30 years observed.

3.3.6. Summary of findings

Regional Level
The percentage of STEM jobs increased/ stayed the same for all regions across all time periods.
The positive trend in STEM jobs did not simultaneously occur with a positive trend in Theil index or concentration of poverty.
It can be interpreted that increase in STEM jobs does not necessarily imply a decrease in diversity or increase in the concentration of poverty
Census Tract Level
A regression model with STEM jobs as the explanatory variable and Theil index as the dependent variable is statistically significant but not robust.
A regression model with STEM jobs as the explanatory variable and concentration of poverty as the dependent variable is statistically significant and more robust as compared to that of diversity index.
Theil index is directly proportionate to the concentration of STEM workers whereas the concentration of poverty is inversely proportionate.
Spatial Exploration
STEM workers live in wealthy neighborhoods across the five cities and timelines observed. This is despite sharp increases observed from time to time in concentrations of STEM workers in very-low, low and middle-income census tracts.
The percentage change is not constant and seems to be driven by larger political and economic constructs rather than occupation of local individuals.
There is clear suburbanization of STEM workers. They do not tend to reside in city centers, however, in cases such as Seattle and Denver, it is attempted to break this pattern.

At the regional level, the relationship is not apparent between STEM jobs and the selected measures of economic segregation. However, at the census tract level, all the readings indicate a specific relationship. This speaks to the robustness of the model, in addition to the R squared statistics. It also suggests that at a regional level statistics might not reflect the conditions of individual census tracts. For example, if Tacoma consistently represents a high concentration of poverty with a low concentration of STEM workers and Seattle consistently represents a low concentration of poverty with a high concentration of STEM workers, the overall statistics would not be able to represent the ground level conditions of the region. Thus, it can be concluded that the relationship between STEM jobs and the measures of economic segregation are more local in nature and to observe regional patterns, the research needs to consider specific census tracts to understand the picture.

Moreover, upon visualizing spatial patterns, it is consistently observed that high concentration of STEM workers places themselves in high and very-high-income level census tracts. The maps also indicate clusters of low-income census tracts and high concentration of STEM workers in them. This spatial relationship is not captured in the statistics calculated and the regression model. Theil index is non-spatial in nature. Therefore it fails to reveal how spatially occurrence of STEM jobs segregate clusters of low-income households.

Chapter 4- Conclusions and Recommendations

It is clear from the findings that the relationship at a regional level between the occurrence of STEM workers and the indicators chosen do not reveal a consistent relationship. Also, the census tracts wherein the concentration of STEM workers is high, are located primarily in high-income census tracts across the five commuter zones. This confirms that the individuals in STEM workforce tend to be wealthy. Given there was a consistent increase in STEM workers across the five commuter zones and timelines, there was little done to redistribute the wealth and maintain equity across the economic groups.

In the commuter zones Seattle and Denver, patterns are observed wherein high concentration of poverty in the years 1980-2000 is broken during the years 2000-2010. Both the commuter zones were able to move STEM workers from their suburban dwellings to populate the city center. This could be a resultant of the comprehensive plans adopted by the region in the late 1990s and early 2000s which targeted growth of the city centers by delineating growth potential to them. Growth can be allocated in multiple ways, increasing access through infrastructure, increasing permitted building bulk or rezoning building blocks. In addition to breaking patterns of poverty and redistributing STEM jobs, such strategies can also increase the risk of an increase in real estate prices (as observed in Portland) and gentrification of neighborhoods. On the other hand, Fort Worth and Albuquerque both witness sprawling of STEM workers and growth of clusters of low-income census tracts in and around the city centers. This indicates a lack of a common mission for the region. This demand-driven approach which allows for a sprawled development will be costly over a long term, as a large area would demand services to that scale.

In all the maps depicting clusters for the five commuter zones from 1980 to 2010, it is observed that clusters of low-income households continue to develop at the same locations across the timeline and increases in size over time. Thus, a pattern of poverty is being propagated and is apparent. For the regional economy to thrive, interconnectivity and accessibility to opportunities, such as job centers need to be maintained from these census tracts. As clusters grow, providing connectivity becomes increasingly difficult. Maintenance of infrastructure over a large span becomes cost intensive as the service area increases. Therefore, it is important to break the patterns such as these clusters with a high concentration of poverty to distribute resources equitably and sustain economic development in the area.

Another observation that seems consistent across the observed commuter zones is that the STEM workers locate themselves in census tracts that are suburban, rather than within the city. The affluent middle-class image of a suburb continues to exist, a trend dwindling in Denver and Seattle. This pattern is still prevalent in the other three regions discussed and are indicative of lack of mixed-use development. An exception here is Portland, wherein the zoning outlined in comprehensive plan and the level of service (Anderson, 2016) ensures mixed-use of land resources across the region. This lack of mixed-use development poses increased risk as the contingencies are not distributed over various land use types. The regions must allow for various uses to exist nearby which is the basis of walkable and livable cities.

The sprawl pattern observed also adds to the cost of amenities. This system also creates a framework that favors individuals who are employed in the STEM and works towards betterment for their children's education, is mindful of access to employment based on their location and increases the quality of life that they enjoy. This fosters livability in the towns and cities where the STEM workers reside, away from the city centers. On the other hand, it makes the living conditions worse for the rest of the population, living either in the city centers or in other pockets of the region. In economies such as Denver and Seattle, once the city centers became more viable, the low-income clusters were pushed out to the suburbs. In such cases, it is increasingly difficult to sustain the urban poor in the areas. While pushing these individuals away from the centers, the system increases the travel cost and travel time of low-income households. This in turn provides more unpredictability in the choices of urban amenities and infrastructure they can access.

While this phenomenon can be considered similar to the suburban flight, there is a stark contrast. While in suburbanization the typically wealthy live far away from the city. The wealthy have adequate finances to maintain infrastructure for themselves through private investments, even when the government was unable to provide for them. They are able to maintain their access to employment opportunities and enjoyed living by choice in socio-economic groups that mirror their choices in the neighborhood and make the same income.

In some of the commuter zones (Albuquerque and Fort Worth), it is observed that the poor are located further away from the city center. This is not a choice for the low-income group but merely a result of economic woes. It thereby would result in complete segregation of the low-income households resulting in their isolation. It reduces access to amenities and infrastructure, facilities which are essential for survival. It reduces access to employment which might increase the levels of unemployment, and consequently increase crime (Yang & Jargowsky, 2006). It also isolates the individuals living in lower-income groups from the network of innovation. It reduces their probability of collaboration with like-minded individuals and reduces the opportunity for the people living in these census tracts to create economically viable products (T. Watson, 2009).

Another event to highlight is that in 2000-2010, data for all the five commuter zones reveal that the percentage change in census tracts with a high concentration of STEM workers in affluent areas were smaller than that in 1990-2000. This indicates that in the last decade, STEM workers were not able to locate themselves in high-income neighborhoods. After several years of strong growth, wages across STEM industries might be declining (Vincent, Kehrig, 2017). Therefore, it might be risky to assume STEM jobs as economic drivers without planning for contingencies.

Moreover, the lack of strong correlation between economic segregation and STEM workers reveal that the proximity of high-waged and high-skilled STEM workers to low-skill and low-wage workers is not being capitalized. In the ever-changing economic realities, there is a need to bridge the gap between the skills that jobs demand and the skill that the individuals have. This also leads to massive untapped energy, on which the region can capitalize. The region upon building diversity in the workforce will be able to supply labor for all types of skill and for various levels of expertise. While creating a pool of economically diverse talent, the region will be able to prepare themselves for unforseen economic distress.

The conclusion section highlights the positives and pain points delineated by the spatial location of STEM workers vis-à-vis clusters of low-income census tracts. Planners and policymakers for decades have been approaching strategies of urban growth to manipulate the choices of individuals involved in knowledge-based communities banking on their tolerance, flexibility, and eccentricity. They hope to resolve the rigid patterns of economic divide created by industrialization and to bounce back from the financial impacts of the economic downturn caused during in 1980s. Thus, building on the observations, the following section outlines specific recommendations for planning at the regional level which can enable equitable distribution of resources.

Recommendations

Based on previous knowledge, results and the conclusions this study provides a few recommendations which will allow policymakers and urban planners to plan for growth while accounting for the negative externalities observed.

Robust Workforce Development-Areas affected with a concentration of poor in a region must focus on retaining local talent while drawing new leaders from outside to serve as a creative catalyst. Efforts should be delineated to cultivate a pool of talented younger individuals who can step into leadership roles as they arise. This will also render possibilities to increase mentors and innovators in low-income census tracts which can benefit from such positive reinforcements. A healthy population of young professionals can ensure replenishing civic leadership essential for creating consensus on policies determining economic growth and representation of the city within the region.

Moreover, there is already existing pool of professionals from STEM industries. This provides an opportunity to develop robust workforce development program wherein students, and disconnected youth (Fernandes-Alcantara, 2015) can be connected to mentors working in the industry. Due to proximity to the industry, there is an opportunity to build skills on the field and bridge any gaps between the skills sought out by the job market and the skills individuals have. This will increase the human capital within the region and allow the commuter zone to have a competitive advantage for other commuter zones.

Diversifying the economy- As listed in the conclusions, STEM workers are no longer locating themselves in census tracts with high-incomes. It was also discussed as a part of background research, that during the economic depression, STEM workers also witnessed phases of unemployment. Thus, we can conclude that STEM jobs are vulnerable to economic downturns and it is recommended that planners should set up instruments for economic development in preparation for such an event. One such strategy is to plan for diversity. The commuter zone must be able to adapt and delineate space for required use. Therefore, mixed-use development with reprogrammable spaces could be a potential tool. Diversity could also be delineated by incentivizing spaces for jobs ranging from low-skilled to high-skilled and across multiple industries, for example, STEM in manufacturing and STEM in telecommunications.

Lastly, Fujita (et al. 1999) use the 'love of variety' in preferences and technology as the building block of their theory of spatial development. They state that the production of a larger variety of goods and services in a given location increases the productivity and utility of people living in that location. This will sustain the innovation engine, and in turn the economic engine set up by the STEM workforce.

Share a regional vision for infrastructure and conservation- For commuter zones, long-term success hinges on aligning economic growth of all the economic centers within a city. In this research, the location of residence of STEM workers is captured. It is recommended that the locations be mapped with centers of employment and transportation network.

During peak timings, traffic is observed in a particular direction, for example in Portland, a large cohort travels from Vancouver to Portland for employment (Ozawa, 2004), moving from residential communities to the commercial center. If the places of residence, places of employment and travel infrastructure is mapped, planners can identify alternate centers of employment in the reverse direction of usual daily traffic, thus redistributing and alleviating the pressure on infrastructure. For example, alternate centers of employment can be set up in Vancouver which can enable reverse commuting. This will increase the number of job centers in the region, thereby increasing the potential of land value capture.

It has been observed that in cases of sprawl, census tracts with a high concentration of STEM workers tend to locate away from city centers. A regional vision for infrastructure can create a possibility of including such census tracts while planning for mobility. This will ensure desired critical mass to the infrastructure being created and allow for opportunities of tradeoffs wherein infrastructure for low-income census tracts can be paid in return for increasing diversity in labor market.

A holistic vision for conservation can be also pursued by reorganizing the places of residence of the STEM workers. As they are the reason in many cases observed for sprawling of city and inturn pushing the boundaries of growth, rethinking land use for them in essential. In Portland, the balance between growth and conservation is maintained by imposing an urban growth boundary. Such instruments do not allow the urban fabric to sprawl thereby preserving farmlands and local landscapes for every individual living in Portland region.

A competing vision among cities within a region might instigate the phenomenon of the race to the bottom (Stiglitz, 2012). This race limits the potential and eliminates possibilities of the region to prosper based on their strength as an entity. Finally, it compromises the quality of amenities, the safety of neighborhoods and most of all the conservation of the environment.

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