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Captive Nations: Measuring Economic Growth on Native American Reservations in California

Mahsa Ashabi
University of San Francisco, msashabi@dons.usfca.edu

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Mahsa S. Ashabi

Department of Economics
University of San Francisco
2130 Fulton St.
San Francisco, CA 94117

Thesis Submission for the Masters of Science Degree
in International and Development Economics

e-mail: *msashabi@dons.usfca.edu*

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Abstract: A history of institutional oppression and genocide has shaped Native American communities across the United States today, reflected in large disparities of socioeconomic outcomes and infrastructure. Due to a lack of comprehensive data and macroeconomic research, alternative forms of spatial data and theories regarding human settlement are needed to develop an understanding of this stagnation. In our efforts to better understand growth on Native American reservations, we utilize nighttime lights data to proxy for economic output in these geographic areas, measuring the settlement characteristics of reservations themselves and against surrounding U.S. regions. Through a series of log-log regressions that focus on Zipf's scaling law and settlement scaling theory, we measure population and production variables to compare Native and non-Native populations in California. We find that both groups demonstrate scaling coefficients close to 1, consistent with settlement scaling theory. When measured with radiance, there is greater variation, but California demonstrates more increase in brightness as population grows. On reservations in California and throughout the country, increases in population shows no correlation with radiance increase and this measure of infrastructure is stagnated across all cross-sections. With these findings, we conclude our test of this methodology and theory to confirm that societies scale up in productivity with population and other economic growth variables. There are clear indicators of how growth has stagnated on Native American reservations, despite proximity to higher-growth regions, which calls for greater emphasis on improving economic and development outcomes for these communities.

1. Introduction

Past relations with the U.S. government and Native American tribes has often struggled to fully represent tribal sovereignty as Native American communities pursued economic development. This tenuous relationship is marred by a legacy of genocide and discrimination against these communities by settlers in the U.S. and the federal government. As a result, the generational impact of systemic oppression has generating long-term effects on the poverty levels and development outcomes of these communities, shown in the highest levels of poverty across racial groups in the U.S. and lack of resources for communities living on tribal reservations (Huyser et al, 2014; Pember, 2016). Through numerous economic and social disparities, economic measures indicate stagnated growth for these communities, as well as intergenerational effects of poverty that beget cycles of poor development outcomes. One of the most poignant factors that can connected with the slow growth of these groups is through the wiping out of Native American populations across multiple historical periods in the United States.

In California, where the study of this paper focuses on, two of the largest decimations of the indigenous population can be traced to the Spanish Catholic mission system (1769 to 1834; responsible for approximately 37,000 deaths) and the aftermath of the Mexican-American war combined with the influx of settlers to California (1846 to 1873). During the latter period, the Native American population within California decreased by approximately 80% from disease, starvation, and numerous massacres perpetrated by new settlers during the California Gold Rush period (Madley, 2016). Despite the increasing racial tension and violence perpetrated against Native American populations during this period, little was done for retribution or replacement of land lost to settlers and missionaries.

As we address these disparities, it is necessary to acknowledge the historical precedents that resulted in the current economic outcomes of Native American communities and tribal reservations. There has also been varied ideas of development that have been implemented across reservations, frequently against the sovereignty of Native American communities, with incongruent goals of how to help these populations. Some of this implementation can be theorized as a type of institutional failure, where the government uses its resources to develop aims improving livelihoods for Native Americans. However, various social, political, and historical factors have made them unsuccessful, leaving large parts of Indian Country with persisting poverty and high levels of inequality compared to the rest of the United States.

Failures in institutional administration are discussed in Mathers's 2012 paper regarding unsuccessful economic development programs on reservations, indicating that efforts to stimulate growth are impeded by the state's ability to calculate economic measures and resource ownership in these projects. It is argued that resources to foster growth projects have never been the issue, instead being that the current processes in place are not administered effectively (Mathers, 2012). In accordance with this institution, the structure of reservations themselves are the source of much disparity that Native American communities have in comparison to other tribes and to surrounding regions outside of tribal territories. Dippel discusses how the formation of reservations has resulted in a persisting impact after being forced into shared governance that isn't aligned with historical relationships of various tribes. Since the structure that government relations and decision-making occur at fundamentally changed, this paper depicts the negative economic impact on tribal communities that persisted in the long term (Dippel, 2014). As the economic inequality between tribal communities persists, with buffers of growth influenced by some tribes participating in gaming compacts with state-level approval, pushes towards improvement of these institutional failures emphasize maintaining cultural identity in development. Duffy and Stubben looked at the crucial nature of tribal identity in projects taken on by Native American communities and its ability to converge with other impediments that result in delayed and inconsistent economic development on reservations. Reasons are listed as greater issues of US investment and its ability to attract capital, consistent tensions in the relationship between the federal government and tribal leaders, cultural barriers with those representing outside investments, and the lack of inclusion of Native voices in the planning and administration of economic development projects. (Duffy and Stubben, 1998).

In our efforts to better understand economic growth on Native American reservations and how it compares to growth in surrounding regions, we combine demographic census data from the U.S. Census Bureau with nighttime lights data to proxy for economic infrastructure and productivity. With this combined dataset, we utilize the framework of settlement scaling theory to look at a more counterfactual definition of growth to assess Native American reservations. In addition, we will assess the use of our nighttime lights proxy as a measure for both infrastructure and economic output and see how the light measured on reservations represents those measures. Both the dataset that has been compiled and the theory defining growth are novel, particularly in the way it is being used to analyze growth in the cross-section for Native American reservations. Therefore, there are key first-order assessments we want to define and there will be inevitable gaps in our data. Through our research, we aim to see if this remote-sensing data can fill in the gaps of macroeconomic data for Native American communities, as well as allow us to quantify the burden of oppression that exists in current socioeconomic disparities.

2. Literature Review

2.1 Macroeconomic Ideas of Growth and Convergence

Macroeconomic thought has developed many ideas on what drives growth in economies, looking at both endogenous and exogenous perspectives as its key factors. The formalization of endogenous growth was popularized by Romer, who aimed to look beyond neoclassical growth models and form a more representative model for economics (Romer, 1994). By treating previously exogenous factors as endogenous, he more accurately expressed the accessible nature of borders and communities that drove growth within and across boundaries (Romer and Jones, 2009). This improved accuracy at representing what defines growth allows for the transition away from neoclassical growth models. As changes to theoretical framework moved forward, the concept of growth being balanced proved to be less realistic to what economies were actually exhibiting. It was also increasingly more apparent how sociopolitical institutions could be connected to economic imbalances and that reactionary parts of these systems produced dual, unequal economies in proximity of each other (Martin and Sunley, 1998; Ray, 2010). A takeaway from understandings of growth is how linked endogenous growth and slow convergence are, indicating how expansion doesn't filter into surrounding economies, proving that they will not inevitably converge (Martin and Sunley, 1998). These developments in the literature are instrumental into shifting the focus and discussions in macroeconomics to represent what is driving shifts in a population.

2.2 Economics of Marginalized and Oppressed Populations

Key understandings about growth shifting towards better representation are essential in better understanding the economics of marginalized groups, and what historical factors have contributed to that marginalization. Research has been performed looking at how economic theory is entwined with ethnic and racial identity. Alesina and La Ferrara address how economic performance responds to varying levels of diversity and heterogeneity structures, which can be linked to oppression of minority groups. The most significant economic components that diversity influences are preferences, strategies, and production, determined through cross-country comparisons and across local communities (Alesina and Ferrara, 2005). The understanding developed in this paper is essential to our goal of measuring economic performance of reservations, particularly because the structure of these regions is heavily influenced by harmful legacies of historical oppression and imbalanced political relationships. In addition, they conclude how the size of a country emerges through a tradeoff between benefits and costs of diverse preferences, indicating how large racial divisions transformed into existing borders and secessions (Alesina and Ferrara, 2005). This theory is pertinent to our research because it relates to the history of Native American relations with the US government, specifically with how land division and economic outcomes may exist from the discord of these events.

An additional perspective that looks at economic influence of identity norms is in Darity Jr et al's 2005 paper, which utilizes evolutionary game theory to represent the relationship between identity formation and the racial disparities across socioeconomic outcomes. They develop identity equilibriums and classify the types of externalities that are produced through the formation of these identities. They demonstrate how wealth gaps occurred as a cumulative effect of past and present racism, encouraging its own reproduction across time. Also, they discuss how racial identity was intertwined in the introduction of property rights, allowing for environments of exclusion and exploitation to flourish, while also pushing inferior status onto certain minority groups (Darity Jr. et al, 2005). One of the most interesting findings discuss the connection between how racial identity is developed with the productivity of social interactions, resulting in the persistence of racial privilege in market economies that exacerbate economic inequality (Darity Jr. et al, 2005). This theorizing of racial identity into economic outcomes is useful when observing economic growth of Native American populations, because there are crucial legacies of racist policies and historical events that require recognition when measuring current outcomes.

With considerable numbers of individuals and households living in poverty on some reservations, with some notable contrasts compared to wealthier tribes, understanding how certain types of economic activity were forced into these regions through relations with government entities are key in understanding why poverty still endures. An assessment of this is described by Carter and Bennet in their paper about economics linked to persisting poverty traps. A poverty trap is a structure in society that maintains and enables factors that keep a certain group in poverty. This example can be related to the history of economic and social outcomes of Native American populations and how, despite the flow of resources aimed at improving their livelihood, numerous reservations remain impoverished and lacking fundamental resources to improve their well-being. In their paper, Carter and Bennett aim to differentiate transitional trends of poverty that individuals generally move out of to an intergenerational trend of poverty that persists in the long term. They discuss "conditional convergence" as the failure of wealth from richer nations to move into poorer nations because of differing steady state growth rates for nations. In addition, they address a theory of thresholds and multiple equilibria when assessing how poverty traps become possible when returns are locally increasing within a threshold. Therefore, the lack of cohesion with production and market incentive to move out of a poverty threshold, an economy can remain at an equilibrium that provides lower income and produces worse economic outcomes (Carter and Bennet, 2006). A similar expansion on the environment that fosters poverty traps can be seen in Bloom et al, where poor economic performance in Africa is shown to be driven by its disadvantageous geographic location, coupled with certain demographic circumstances that put the region at a disequilibrium. They indicate how location can be a significant indicator in social interactions and shaping of communities, which are represented to demonstrate how growth in Africa relies specifically on demography and public health outcomes (Bloom et al, 1998). Their theoretical framework that focuses on geography makes a call for future policy to resemble geographic reality and correct for a history that has had failure in economic performance for lack of this consideration. Often tied to these socioeconomic and geographic factors influencing poverty traps, the history of institutions that define property rights can be equally as influential in exacerbating this marginalization. The legacy of oppression can be tied to these institutions, impacting economic outcomes and control over the means of productivity in a society (Banerjeee & Iyer, 2005). In more recent research, it is evident that the persistence of certain historical legacies and the impact of those relationships of power are lasting in development and economic outcomes. (Nunn, 2014).

Past literature has also developed a theoretical model linking heterogeneous preferences across ethnic groups and the result on public good shares. Alesina et al focused on the impact of ethnic conflict in various population settings, showing the response of fragmentation towards economic outcomes. Their findings build off a literature that correlates policy preferences and ethnic origins, ultimately concluding that more ethnically diverse areas have higher spending levels but less of that goes towards public goods. As a result, cleavages in ethnic identities can be a strong determinant of the economic well-being of a region (Alesina et al, 1999). With this research, we can look forward with this perspective of ethnic fragmentation and what historical factors have influenced this for Native American populations throughout the US, thus generating a resulting effect on economic growth and development outcomes. Understanding how shares of public good ownerships relate to ethnic fragmentation can also help us look into the overall impact of stratification in growth between Native American communities on reservations, with both between-tribes and in and out of tribal lands.

2.3 Settlement Scaling and Theories Defining Human Agglomeration

When studying the concentration of institutions and people, there are certain trends and relationships that identify how economic growth and changes in output have occurred across time. One of the most crucial ways in understanding these relationships is learning how to define how humans aggregate in space and how it can be influenced by economic geography. A key finding in this realm of understanding was made popular by Paul Krugman in 1991, where evidence of increasing returns to scale in an economy related to concentrations in economic geography. This heterogenous geography is linked with accelerated growth in certain regions, while other areas remain underdeveloped and lacking growth (Krugman, 1991).

With an understanding of this past research, it can improve how to define factors of a settlement and economic growth through models of proportional growth, as well as how it compares across earlier and more modern societies. A crucial paper in understanding these trends is by Bettencourt et al in 2013, where he defines how cities (or even more simply, any concentration of people and institutions) can be determined through a set of basic principles. These principles encompass the relationship between outputs and structures that define the growth of societies, including populations and infrastructure (Bettencourt et al, 2013). The relationships discussed link the growth of societies to elements like infrastructure and institutions, which can be measured through the growth of various socioeconomic outputs (Bettencourt et al, 2013). Much of this framework has helped to define the assumptions of settlement scaling theory and the way it defines growth. Utilized by Ortman in his research, this theory allows for an abstraction away from large sets of accounts data to measure economic growth in a population. In doing so, the main elasticity that is measured is what is increasing in a settlement as the population grows. This moves away from defining a single, central market and defines productivity through socioeconomic rates of interaction (Ortman et al, 2015).

While Bettencourt initially focused on urban systems, the applicability of his methodology has spanned to the measurement of productivity in ancient societies and societies with significant gaps in data. An example of this, which this paper focuses on, was performed by Ortman et al in 2016, where increasing returns to settlement were measured in scale to output for societies in the Peruvian Andes. They use a proxy measurement for productivity to track economic expansion across variables that define the growth of their settlement and economy overall (Ortman et al, 2016). The main theory is defined as "settlement scaling theory," which frames economic change as driven by social connectivity and the expansiveness of networks. This type of growth is measurable against different definitions of aggregate outputs in societies of different structure everywhere. Another key finding is based on how the growth of settlements via population can produce proportional increases in economic outputs, which can be defined as increasing returns to scale (Ortman et al, 2016).

In accordance with this, power laws are another version of scaling that are applied to various economic occurrences and explain measurable parts of society. Gabaix discusses a key type of power law called Zipf's law, which measures frequency of variables with an exponent of 1, allowing it to detect and map distributions that occur. Much of the work discussed in Gabaix's paper looks at the size of cities or firms, as well as for other measures of economic returns or structured measures of a population (Gabaix, 2016). A crucial aspect of this law in measuring a population is the assumption of universality, demonstrating how different types of systems can behave in similar ways. In addition, this type of law is key in defining local growth and forms of regularity in a distribution, displayed through log-log regressions (Gabaix, 1999). Research has also been done to prove that the general assumption that networks are free of any type of scale that guides its distribution and growth are incredibly rare. In particular, when looking at how human settlements have grown with the aid of social networks and interaction, there is a crucial understanding about how that growth scales and is weakly free of that structure (Broido and Clauset, 2019).

As we relate our assessments of growth in Native American populations to the macroeconomic growth literature, Gabaix introduces two key factors that cause power laws to exist: random growth models and the transfer of one power law variable into the explanation of another. Gabaix defends this by defining a variety of economic variables as being structured with a pattern of proportional growth, with occasional small bouts of friction (Gabaix, 2016). Since this is something that can be found through data that contains certain measurable components, in addressing population sizes of reservations, we can use power laws as a way of visualizing the distribution of certain economic factors among the Native American population. The goal with this theory would be to connect it to factors in these communities that may drive this growth. Much of the recent literature about using power law theory in economics has been able to make interesting connections between certain behaviors and how they may connect to the power law distribution of that population. In a more specialized look at power laws in the functioning of cities, Bettencourt et al identify scaling relations through key growth equations to understand how the pace of life in cities was impacted from changes in the population. Key parts of the analysis are based on how the social dynamics of cities are driven by material economies of scale with infrastructure networks, and social interactions as the catalyst for innovation (Bettencourt et al, 2007). While this paper looked more at how power law theory could be applied to growth in urban areas, the factors they regard as crucial catalysts of development are beneficial to understanding growth of any population. In addition, this could apply to comparison of growth between more populous and developing reservation areas and ones that are not.

Furthermore, the literature in both power laws and settlement scaling establishes the framework for how we are measuring growth on Native American reservations. As these areas are not their own macroeconomies and have relationships with the surrounding regions, this set of theories helps us understand how these communities have grown as economic settlements and how the historical impact of Native American genocide had lingering effects on outcomes across time. Methods of measuring this impact draw on the scaling of settlements and how the structure of different types of production are driven by changes in population and city structure. Drawing from the properties of Zipf's law, Rossi-Hanberg and Wright researched how urban settlements favored certain types of productivity over others, define by the evolution of industries and the structure of the settlement itself (Rossi-Hansberg and Wright, 2005). Their findings indicate how the response to a positive shock in production can drive the overall growth of a city, at both the local and regional level.

2.4 Nighttime Lights as a Proxy Measure

To best understand the methodology used in this study to measure economic output, the steps taken in previous papers using nighttime lights establishes the framework and multiple applications that this data can provide. Using proxy measures for economic development were bred out of the need to find objective sources of measurement that were not susceptible to being influenced by political and social institutions. It also allows for transcending across national boundaries without the reliance on country-level data (Henderson et al, 2012). A paper that highlighted necessary assumptions and methods of analysis was by Henderson et al in 2012, which supported the suitability of using nighttime light luminosity as a proxy for economic development or output. Moving forward, additional researchers have made use of the publicly-available luminosity data to derive conclusions about regional development influenced by historical trends or institutions. While looking at pre-colonial institutions in Africa to measure economic outcomes, luminosity data was utilized to show how development was more notable in areas with centralized pre-colonial institutions (Michalopoulos and Papainannou, 2013).

One of the greatest strengths of this data is its potential of filling in gaps that may exist with various kinds of household or survey data, due to its focus on an objective gathering of information. It is also helpful in situations for robustness checks or existing information is viewed as unreliable. In 2018, Martinez used light radiance as a way of measuring economic performance in areas that were characterized by weak or non-democratic governments (Martinez, 2018). The findings from this research were able to be paired alongside official numbers, where it was proved that countries ruled by authoritarian leaders were exaggerating their economic outcomes, which was measured through the elasticity between GDP and radiance numbers (Martinez, 2018). Due to its objectivity, researchers have found useful ways of using nighttime luminosity to observe and measure human activity and how it is expanding across time. Beyond just economic output and proxies for different levels of development, this type of spatial data is useful for understanding distribution of population and other socioeconomic properties (Kumar et al, 2018).

3. Data

The data for this project was gathered from multiple public sources and combined to create a large, cohesive dataset with variables to allow multiple levels of analysis. The following sections detail the sources and how data was retrieved:

3.1 Spatial Data for Luminosity Proxy

In this project, we use nighttime light radiance as a proxy for GDP in our measure for economic development, following the example of Henderson et al's "Measuring Economic Growth from Outer Space" in 2012. The data comes from the Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS), which is gathered by the US Air Force

Weather Agency (NCEI, n.d.b.). The primary purpose of this system is to measure cloud cover and temperature twice a day, but additionally capture images of Earth between the hours of 8:30pm and 10:00pm over the period of a year (Henderson et al, 2012). By doing this nighttime observation, the images are able to capture only manmade lights, due to the removal of sunlight and lunar light on the Earth's surface. The processing of this data is performed by the National Oceanic and Atmospheric Administration's (NOAA) National Geophysical Data Center (NGDC). The datasets are publicly available and have information from 1992 to 2013, available for download from the National Centers of Environmental Information (NCEI). The datasets gathered from these sources were made workable through ArcGIS, so it may be processed through statistical analysis software (ESRI, 2018).

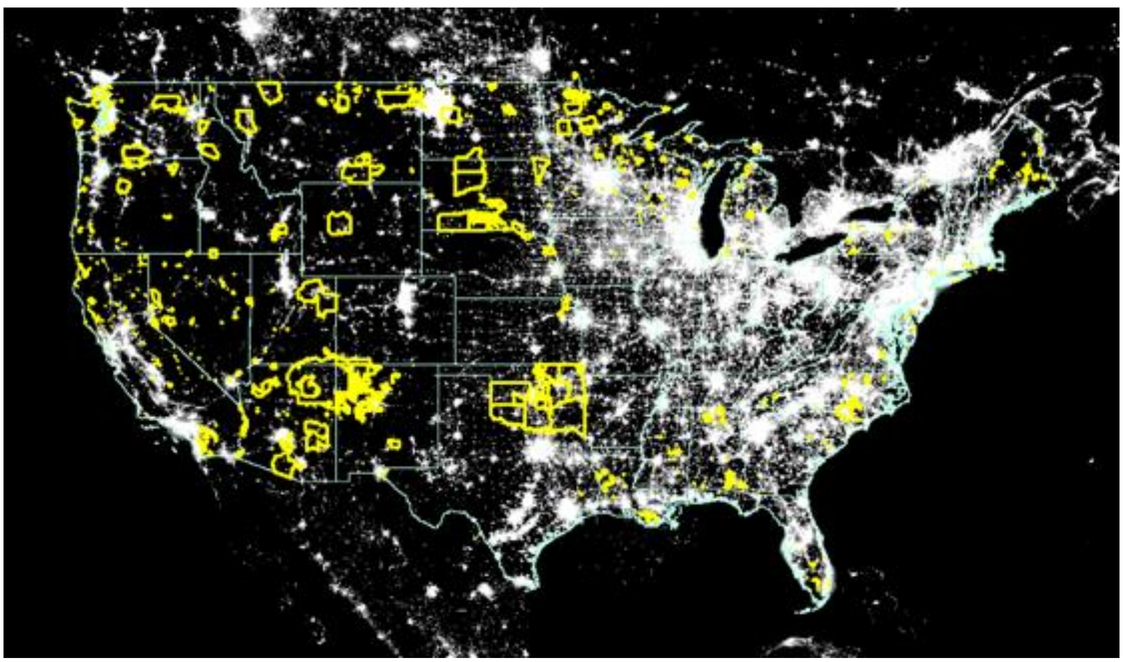
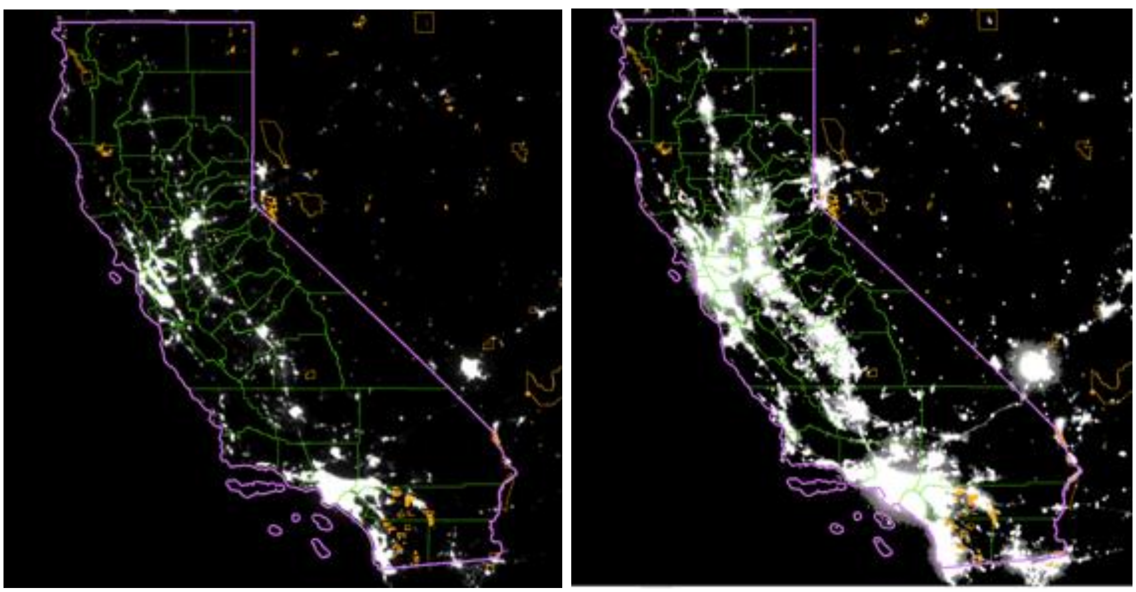


Image of contiguous United States in 2013 with state boundaries (blue) and Native American reservation boundaries (yellow), with nighttime lights imagery. Taken by DMSP Operation Linescan System and processed by the National Geophysical Data Center at NOAA.

We used the TIGER/line shapefiles provided by the US Census to specify the nightlights of tribal reservation lands, marked with specific GeoID codes and used across all years of analysis (US Census, 2014). As discussed in Henderson et al, it is crucial to remember that gas flares are a common source of light that can appear in these satellite images. Fortunately, these sources of light were not reported in the locations we are working with in our analysis. In addition to insight from Henderson et al, the data processing technique was taken from Matt Lowe's 2014 guide for working with nightlights data in ArcGIS. Within the GIS program, the numbers for average radiance across the different reservation lands were isolated with the tool "Extract by Mask." This feature allows for a thorough review of areas that may have difficulty reporting because of cloud cover, which was ultimately not present in the regions of this data set. Following this, we used the "Zonal Statistic" tool to calculate average radiance for every geographic unit in the shapefile for the reservation lands. These numbers are listed as DN, with a range of 0-63 of the radiance in the raw data. These numbers are key to the further analysis in this study, so they are exported into a .dbf that can now be used and converted into a workable format with a statistical programming software.



Images display nighttime lights radiance (averaged) in California in 2000 (left) and 2010 (right) with county boundary lines in green and Native American reservation boundary lines in orange. Taken by DMSP Operation Linescan System and processed by the National Geophysical Data Center at NOAA.

3.2 United States Census Data

US census data was used in a combined format with the spatial data to provide a way of analysis of our proxy for economic development with demographic variables available in the US census. The Census data used for this study was collected and published by Randall K.Q. Akee and Jonathan B. Taylor in 2014, A Databook of the US Censuses and the American Community Survey 1990-2010. This data was used as part of the Harvard Project on American Indian Economic Development, starting in 1987. The collection of information is gathered from public records of decennial census data, from the long-form census form administered in 1990 and 2000 and the American Community Survey that in 2010, with a collection frequency of every five years using sample sizes of a representative population. This data was used in our research to create a more diverse set of demographic variables that can be further linked with our measured of GDP. In their databook, Akee and Taylor address the significant changes that occurred between how information was collected from 2000 to 2010, and how gaps in information for certain variables certainly exists. While being transparent about where gaps occurred, they reassure their audience about the consistency of the majority of the data and its representativeness being adequate for economic analysis.

4. Methodology

4.1 Measuring Nighttime Luminosity

In order to compare Native American reservations to other economic regions in the United States, we use spatial data to compile ways to measure infrastructure and output. This is an especially useful method in situations where we have uneven growth and lower access to data. Since these settlements are not their own macroeconomies and don't have local growth or production, alternative methods that involve spatial data can allow for better objective measures of outcomes. While there are multiple spatial measures used throughout different types of research, our focus remains on nighttime light radiance as a proxy for productivity and infrastructure. This is due to the distribution of communities and how populations can be measured in space as a way of observing growth across time (Kumar et al, 2019).

4.1.1 Calibration of Radiance Variable

Following the correction method utilized by Kumar et al, our radiance numbers were intercalibrated with constant parameters that helped to correct our mean values for radiance. By doing so, the numbers for the nighttime radiance can be fixed for atmospheric conditions and the natural disintegration of satellite imagery, ensuring that the values gathered can be weighted and interpreted properly (Kumar et al, 2019).

4.2 Model Specification

The model specification used in this research is based on the framework laid out by Ortman et al, 2016. The key regression that is used across all variables is a log-log OLS regression, with the explanatory variable representing the representative variable for population and the dependent variable represents our various output variables that define economic productivity or infrastructure on a reservation or county spatial area. Our model is as follows:

$$\mathbf{Y(N) = Y_o N^{\beta}}$$

Y(N) is indicative of our output, which changes throughout the analysis. In the initial regressions that test settlement scaling theory, we use measures of income, occupied housing units, and types of worker residing on reservations as measures of how these settlements are constructed and how it appears in the cross-section as population. The main checks we are confirming is evidence of increasing returns to scale with estimates greater than 1 and evidence of economies of scale with estimates less than 1 (Ortman et al, 2016). In the second part of the analysis, our output variable is measured with the radiance variable, used as a proxy for productivity and infrastructure. To make our radiance variable workable, we took a weighted average of the mean values of the DN that is captured. Then, we used an inverse hyperbolic sine to account for the large number of zeroes that exist for the radiance means. By doing so, the radiance variable is transformed into a form that can be defined at zero. As an alternative of working with the large number of zero values generated by the spatial means, we also try dropping the zero values and creating a log of the weighted average for our robustness check in Section 5.4. The ß value that is generated through our regression is the estimate that we focus on to understand what is occurring throughout our cross-sectional analysis.

The variable for N represents our population-style variable that is the key explanatory factor that is driving settlement growth. In our first order assessments of settlement scaling theory, we use population as the main explanatory variable. As we transition into our regressions using radiance as the dependent variable, N is described with population and other demographic variables from our dataset.

4.3 Caveats to Topic and Data Source

In this paper, the focus of our estimation is on new methods of looking at data on Native American reservations. Our goal is to contribute to a community that has a lack of data and macroeconomic research, in order to provide findings that will detail a greater understanding of outcomes and how they may be improved. With this approach, we combine remote sensing data, generated by satellite-measured nighttime light radiance, and demographic information from the United States Census to create a dataset and perform cross-sectional growth analyses. The combination of these sources will allow us to test multiple measures of economic productivity and develop conclusions for how these communities have grown and stagnated across time. In addition to the novelty of the data being used, the theories on growth that frame our understanding are more recent in the literature and allow us to abstract away from having large amounts of accounts data for our population of interest. By leaning on newer understandings of growth that account for historical shifts and impacts of oppression, we aim to provide a more comprehensive understanding of economic changes on reservations within the timeframe of our study.

5. Results

5.1 Summary of Luminosity Ranges

In lieu of traditional summary statistics, a key understanding about radianc is how it is measured and how that produces the numbers we interpret for analysis. Since the data is gathered through a satellite, it is represented through a number of a pixels that define the image. Therefore, the tribal areas and counties that are the focus of our analysis will have varying numbers based on their spatial area. With this in mind, the minimum and maximum (MIN & MAX) numbers of radiance help to identify the ranges for radiance that are present within each spatial catchment being measured. By observing the ranges, we can look at how large the radiance is for certain regions, how it compares, and how it is concentrated in certain areas.

Tables 1 and 2 are a sampling of how the minimum and maximum values appear for Native American tribes in California overall and California overall. In addition, there are a sample of 5-6 reservations and counties within the state to compare ranges of tribal areas with nearby counties, allowing for a regional comparison of how this measure varies. For the overall measures, California and all reservations within California have the same range for their radiance, with differing means and standard deviations for their minimum and maximum values. When we begin to look at specific Native American reservations and specific California counties in the table, the variation in ranges for radiance are a clear reflection of areas that have low amounts of light, high variation of both light and dark spatial areas, and clear concentrations of radiance that keep their minimum/maximum ranges very high.

For example, when looking at the San Manuel reservation, their minimum/maximum ranges maintain high digital numbers on both the minimum and maximum levels, which indicates a high level of light concentration in this tribal area. This can potentially be tied to the high level of casino activity on this reservation and the output it produces. In comparison, the Yurok reservation shows a significantly low level of light radiance and is reflective of the more rural nature of the region this tribal area exists. In comparison to the Yurok reservation, Humboldt County in California maintains a full range of 0-63 for its maximum values but does not do so for its minimum. This is indicative of the large amount of dark areas (represented as pixels in spatial data) which are impacting the mean values and making them lower for this area. This insight allows us to look how mean values and ranges vary across reservations and between reservations and adjacent counties in California. The amount of light indicated by these statistical measures can help us understand the amount of economic productivity occurring in that region and if any sort of regional influence is causing an impact.

5.2 Scaling Regressions of Population and Economic Variables

Settlement scaling theory and its framework of how socioeconomic outputs are tied to the growth of a society is the basis of where our analysis will be interpreted. Overall, this allows us to focus on aggregate measures and how social interaction influences productivity growth. As stated before, we are observing reservations as economic settlements, but not as their own macroeconomies. With the regressions we perform, we are looking for evidence of increasing returns to scale and constant returns to scale as our population of interest grows across the decadal cross-sections. These estimates are interpreted through the ß variable and if it garners estimates of 7/6 for socioeconomic output (defined as increasing returns to scale) or 5/6 for measures of infrastructure (defined as constant returns to scale). These values can later be interpreted through how it impacts a Zipf's population distribution for the populations we are comparing. (Ortman et al, 2016).

For our first order assessments of settlement scaling theory, we are using the population values for Native American reservations in California for 1990, 2000, and 2010, as our key explanatory variable. We performed log-log OLS regressions to look at the cross-sectional outcomes of the population variable with various measures of settlement growth. These variables include total aggregate income, occupied housing units, government workers, and private sector workers. Since we have fewer demographic data for California counties, we have a greater range of settlement-style variables to use for the Native American reservations in our dataset. Therefore, the main settlement scaling regression that we can analyze comparatively will be for logged total aggregate income vs. logged population.

In our results, we are looking at two main findings. First, we are looking at general changes in our OLS models and what that indicates about the returns of productivity. Second, we are looking at our estimates and if they abide by Zipf's law of regularity, which indicates they would be a value of 1. If they are greater than one or less than one, we are able to check if they fall in the thresholds of settlement growth that are defined by Ortman et al.

5.2.1 Outcomes for Native American Reservations in California

Table 3 and Graph 1 indicate a log-log OLS regression for total aggregate income on population for Native American reservations in California. Our results indicate statistical significance but that is not the key thing to observe, due to the fact that these variables are highly correlated and do not have any controls added to this regression. The trend across the 3 decadal cross-sections do indicate that the growth in population on reservations is correlated with a growth in total aggregate income of these settlements. In addition, for 2000 and 2010, the estimates are 1.115 and 1.044. These estimates indicate evidence of mildly positive returns to scale, though some of the regression points show greater statistical noise in 1990 and 2000, likely influenced by the variability of smaller reservations and rancherias in California. Section 5.2.2 will discuss how these results for reservations in California compare to the way growth has occurred in California counties.

Table 5 and Graph 3 indicate a log-log OLS regression for total occupied housing units and population on California reservations. These variables show a high level of correlation at a statistically significant level, but no controls have been added at this stage of analysis so that will likely be reduced. The trend across the decadal cross-sections indicate that growth in population on Native American reservations corresponds with an increasing growth in occupied housing units. Additionally, for 2000 and 2010, the main estimates 1.029 and 1.024 indicate evidence of increasing returns, though not at the levels of output defined by Ortman et al. These estimates indicate that these reservations scaled at a size distribution that demonstrates the regularity of Zipf's law. However, it is clearly seen on the scatter plots that there is some dispersal of points, particularly near lower end of population size, which could indicate how smaller reservations have greater challenges with growth.

Table 6 & 7 and Graph 4 & 5 allow us to do a comparison of how different types of employment are drivers of growth on reservations. For this paper, we focus on government sector employees versus private sector employees. Table 6 and Graph 4 perform a log-log OLS regression of private sector workers on population for reservations in California. Our resulting estimates indicate that how growth in population across decades corresponds with a growth in the number of private sector workers. In addition, the estimates are close to a value of 1, with

2000 generating an estimate of 1.009. This shows how the growth in that year scaled according to the proprieties of Zipf's law. For comparison, Table 7 and Graph 5 show the results of a log-log OLS regression of government sector workers on population. While all estimates remain sublinear in this context, there is a still a positive correlative relationship between the growth in population across decades and the increase in number of government sector workers. When we compare these two types of employment, we see that a larger amount of settlement growth is gained by private sector workers on reservations than by government sector workers. This comparison is helpful for our analysis because it allows us to tests the returns from government labor and look deeper the role of governments in interacting with people on reservations. In addition, none of the estimates across decades for government workers show evidence of a Zipf's law distribution, which may show the failing in that sector to provide more consistent growth for these economic settlements.

5.2.2 Comparison to Outcomes in California Counties

Comparatively, we perform the same initial regression, where we regress log of total aggregate income on log of population for California counties. As we compare this to our results for reservations in California, we see estimates closer to 1 across all three decadal cross-sections, indicating evidence of growth in this output as the population in California counties grow. This occurs at a more linear rate and a much clearer representation of Zipf's law than we see for reservations in California, displayed in Table 4 and Graph 2. The estimates for 1990, 2000, and 2010 are as follows: 1.057, 1.045, 1.031. The OLS output indicates that as population has grown across these time periods, the impact on total aggregate income has increased at a decreasing rate. While the estimates do not indicate evidence of increasing returns to scale, as defined by Ortman et al, there is evidence of the scaling properties of this variable as the population grows across our timeframe.

5.3 Scaling Regressions with Radiance Proxy Measure

The following regressions will use our radiance proxy for infrastructure and productivity as our dependent variable and utilizes the various demographic census variables we possess to substitute for measures of population or settlement growth. Since the way that radiance is measured is different than the count measurement of census data, our results will have greater variance across the time periods we observe. In addition, since our nighttime light data only begins in 1992, we are using that 1992 measure to perform analysis with our 1990 variables.

5.3.1 Radiance Measures on Reservations in California

Table 8 and Graph 6 show a log-log OLS regression of our radiance proxy measure as the dependent variable and logged population on Native American reservations in California as our explanatory variable. The estimates are very sublinear 1 and don't follow a Zipf's law distribution in the relationship of the variables. In addition, as demonstrated on Graph 6, there appears to be no significant increase in radiance as a population grows, across all 3 decadal cross-sections. While we do garner statistically significant estimates in 2000 and 2010, there is no consistent trend of growth in the level of radiance as population grows across the cross-sections. This demonstrates how there is no consistent growth of the measures used with this proxy as the population is growing on reservations in CA.

Table 9 and Graph 7 shows a log-log OLS regression with radiance and logged total aggregate income on reservations in California. The results here are similar to what we saw in our regression with population and radiance previously. For all three cross-sections, this relationship returns sublinear estimates and there is no indication that growth in income correlates with a growth in radiance on reservations. In addition, we see statistically significant estimates for 2000 and 2010, as we did previously. These results do not indicate any sign of a Zipf's law distribution and indicates how as income grew across time on reservations, the level of radiance stayed relatively stagnant.

Table 10 and Graph 8 perform a log-log OLS with radiance on log of occupied housing units on reservations in CA. Beyond our more traditional population variables, we use occupied housing units as a test of how the number of the housing units could correlate with an increase or infrastructure or productivity in these settlements. Our resulting estimates indicate how growth in occupied housing units on reservations correlates with an increase in radiance at a decreasing rate, with a statistically significant increase occurring only in our 2000 cross-section. However, again we see that all our estimates remain sublinear and not near any of the thresholds defined by Ortman et al. In addition, the graph indicates how growth in the number of occupied housing units on reservations shows no impact on increases in radiance. This is consistent with the relationships observed with radiance and both population and income.

5.3.2 Radiance Measures in California Counties

Since our demographic census data is limited in this study for California counties, we perform regressions with our radiance proxy with population and total aggregate income, which will still allow us to make meaningful comparisons with the results we find from our analysis of Native American reservations. Table 11 and Graph 9 shows a log-log OLS of radiance on logged population in California counties across three decadal cross-sections. First, we do see evidence of zero truncation of this radiance data, which is representative of the fact that the nighttime light data for California contains a much higher amount of zero values. However, despite that, there is still a clear increasing trend that occurs where growth in population is correlated with growth in radiance. Though the estimates are sublinear, they demonstrate growth at a decreasing rate at the 3 cross-sections. Overall, the trend that we see with what is increasing as population in California counties grows is different with the relationships we observed for reservations in California.

Table 12 and Graph 10 perform a log-log OLS of radiance on logged total aggregate income in California counties across our three decadal cross-sections. Similar to the regression just performed with radiance and population, we see evidence of zero truncation in this data that will be corrected for later in the robustness check. While the estimates here are significantly sublinear, they still indicate an increasing trend that shows how growth in income of California counties correlates with growth in that radiance measure of those counties. They also indicate the same general decreasing at an increasing rate trend we saw previously. This general increasing trend is something not indicated in any of the reservation regressions.

5.3.3 Radiance and Population with All U.S. Reservations

For a better understanding of how the growth of our variables indicates greater stagnation on reservations than in surrounding areas in the country, we also wanted to demonstrate the relationship between population and radiance for all Native American reservations in the U.S.. Table 13 and Graph 11 indicate an OLS regression of population and radiance on all reservations in our data set. For the first time in all the regressions, the relationship garners negative estimates. This indicates that as population grows on all reservations, the measure of radiance is actually decreasing, reflective of how infrastructure and productivity do not grow with population on these settlements. Though these estimates may have variance among the population sizes on reservations, we continue to not see any of the growth that correlates with growth of a population.

5.4 Robustness Check

For a check of the robustness of our radiance measure, we utilize a different method of working with the large amount of zero values that exist. Instead of using an inverse hyperbolic sine transformation, we remove the zero values and focus on mean values of the DN that are captured that are non-zero (Pfeifer et al, 2016). These values are dropped prior to creating the logged weighted average version of our radiance measure.

Table 14 and 15 indicate the log-log OLS regressions performed with radiance on population and total aggregate income for Native American reservations in California. In both of these regressions, the estimates for the relationship between growth in population or income on radiance decreased considerably, as well as some loss of statistical significance across some of the cross-sections. In addition, the estimates for the level of income and population in 1990 both have a negative relationship with the measure of radiance in these areas. We can surmise that the zero values that are present in the data captured for reservations isn't something that is downward biasing the estimates we gained. They continue to be sublinear across the measures we test with radiance.

Table 16 and 17 indicate the log-log OLS of radiance on population and total aggregate income for California counties, allowing us to compare the impact of dropping the zero values for radiance. This robustness check for California is crucial due to the large amount of zero values that are representative of dark space that is captured. Overall, the estimates for each decadal cross-section increase and estimates for 1990 and 2000 become more statistically significant. A caveat to this increase is how the number of counties listed in our observations have dropped, due to some counties have such large concentrations of no light, which results in a large number of zero values. Due to this loss in counties that might be useful for our overall comparison of reservations and non-tribal lands, it is a better course of action to use our initial transformation of the radiance measure. However, it is important to take note of what removing the zero values does to our estimates and what it could mean in relation to the structure of land on reservations versus counties.

5.5 Zipf's Population Distribution Graphs Remarks

To further our analysis of Zipf's law in describing how settlements scale with certain factors and its impact on how populations are distributed, we develop two charts to look at the correlation between population and population rank in a Zipf's population distribution. We create this graph for both Native American reservations in California and California counties to allow us to compare between these two economic and geographic populations. Graphs 12 and 13 display this relationship.

As we have discussed prior, if a population distribution abides by Zipf's law, it will produce coefficients of 1 and distribute along a slope line of -1 when measured via rank. Graph

12 shows this relationship for reservations, with adjacent scatterplots for our observation years of 1990, 2000, and 2010. There is clear variation in how populations grow across these tribal areas and that their structure generally doesn't abide by this particular law and has a considerable amount of points straying away from the main distribution. Graph 13 shows this relationship for counties in California, for the same cross-sections across years. The structure of this graph is more congruent with the particular shape of a Zipf's distribution, with small bits of variation at the tail ends that reflect the particularly high and low levels of growth that exist in certain counties in California.

In our previous regressions, we saw evidence of reservations having similar scaling properties with the economic variables that are tested, but far more disparities when using the radiance measure. Due to the similarity in scaling properties of the types of settlements, we would anticipate seeing slightly more similarity in how these population distributions look in comparison. Instead, we see significant variation in how the populations compare, which is also reflective of the fact that Native American populations have experienced large amounts of population decimation that has lingering effects on current outcomes.

6. Discussion & Conclusion

The goal with this research was to fill in gaps of macroeconomic research with Native American reservations, due to lack of data regarding these outcomes and significant socioeconomic disparities that exist in these communities. Across the history of the United States and within California, Native American populations have been severely impacted by genocide and intergenerational effects of trauma, bolstering cycles of discord between the U.S. federal government and impoverished outcomes. In addition, there has been a consistent lack of research that looks at the prevalence of these issues, as well as focusing on the sovereignty of Native American reservations and the destructive legacy that tribes faced at the hands of American settlers. With an understanding of population as a key impetus of economic productivity, based on Ortman et al's derivation of growth from the expansion of human network, we lean on the framework of settlement scaling theory to generate new explanations for slow and stagnated growth on Native American reservations.

Our results can be described in two areas. First, we have our first-order assessments of settlement scaling theory by running log-log OLS regressions of what is increasing in a population as it grows. The framework we use defines estimates of 7/6 for socioeconomic output and 5/6 for infrastructure. Second, we run the same type of regressions using radiance as the proxy measure for infrastructure and productivity to observe what variables drive this growth as they increase. Finally, we make note of what the result of these regressions were and what they indicate about the scaling properties of these populations, and then use a Zipf's population distribution to compare. For both California counties and reservations within California, we see similarities in the scaling properties of economic variables as these populations grow across the 3 decadal cross-sections. Estimates of income and occupied housing units show more evidence of increasing returns to scale for both CA counties and reservations, while estimates for private sector and government workers show greater sub-linearity and evidence of constant returns to scale. With our estimates for income, we see the strongest evidence of Zipf's law for California counties, demonstrated with coefficients of 1 and the linearity shown with its distribution.

Our radiance for proxy indicates something significantly different. This measure has been used in economic literature as a way of indicating economic growth, but it can also be directly used as a measure of infrastructure. In California counties, we see evidence that this measure is increasing as the population in these regions grow. However, when observing this relationship for both California reservations and reservations across the entire U.S., the stagnation of this variable is apparent across all 3 decadal cross-sections. Additionally, when we look at this regression for all U.S. reservations, we see that this measure actually decreases as the population grows. This could be attributed to a number of factors but as we interpret this proxy measure, it is evident that reservations continue to lack the growth and infrastructure to support the population growth that occurs in their region. When looking at this measure as a direct interpretation of infrastructure, it becomes clear that this represents the lack of infrastructure resources to support the populations living on reservations. Statistical evidence about the lack of electricity on reservations further supports this argument. In 2014, it was recorded by the Rocky Mountain Institute that 14% of households on Native American reservations were lacking access to electricity, which is 10 times the national average. Understanding the continued lack of stable resources and infrastructure within reservations is crucial to understand why certain aspects of these communities have stagnated and are not growing with population, similar to what we see in surrounding regions.

With all the information we have gathered, it is crucial to remember that a main purpose of this study was to provide first order assessments of numerous things. We are using remote sensing data that captures nighttime lights and novel theories about economic growth to prepare new understandings about macroeconomics in these stagnated regions. Despite Native American reservations not being independent economic settlements, they have varying levels of productivity and infrastructure that can be measured and viewed comparatively to the growth that is surrounding on non-tribal land regions. By accounting for this variation in how certain tribal areas have grown and produced over time, we can better understand how economic development projects have succeeded or some reservations and have failed for others.

We can ultimately conclude that our results reflect a lot of existing knowledge we have had about Native American reservations. First, their population sizes are extremely low and largely a legacy of the genocide faced by these communities. Second, infrastructure on Native American reservations has significant issues and does not grow in a way to support any population growth that occurs in these regions. With our radiance measure, we see growth in California counties that is not present on reservations, within California or across the whole country. Overall, what we see is that the decimation of the Native American populations does correlate with low development and economic outcomes that currently exist in these communities.

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8. Appendix

Table 1: Radiance Minimum and Maximum Values for Total and Sample of Native American Reservations in California

	Native American Reservations in CA				
	MIN	**MAX**	**MEAN**	**SD**	**OBS.**
All					
MIN	0	63	7.81	12.73	1430
MAX	0	63	18.49	18.94	1430
Pala					
MIN	0	5	1.23	1.65	22
MAX	11	33	19.43	6.98	22
San Manuel					
MIN	38	60	52.22	5.38	22
MAX	51.5	62	59.11	2.46	22
Hoopa Valley					
MIN	0	0	0	0	22
MAX	7	13	9.86	1.63	22
Yurok					
MIN	0	0	0	0	22
MAX	4	6	4.95	0.722	22
Agua Caliente					
MIN	0	5	2.66	1.67	22
MAX	8	63	41.93	25.98	22
Cahuilla					
MIN	0	0	0	0	22
MAX	5.5	10	7.68	1.42	22
Bishop					
MIN	25	45	33.64	6.03	22
MAX	44.5	59.5	53.18	4.38	22

Table 2: Radiance Minimum and Maximum Values for Total and Sample of Counties in California

	California				
	MIN	**MAX**	**MEAN**	**SD**	**OBS.**
All					
MIN	0	63	3.401	9.09	1276
MAX	0	63	14.02	21.103	1276
San Diego					
MIN	0	63	8	13.701	22
MAX	0	63	27.5	25.43	22
San Bernardino					
MIN	0	63	2.91	11.305	22
MAX	0	63	10.41	19.202	22
Kern					
MIN	0	63	1.18	2.02	22
MAX	0	63	19.36	20.91	22
Humboldt					
MIN	0	16	0.135	0.639	22
MAX	0	62	5.27	9.86	22
Fresno					
MIN	0	63	1.45	2.54	22
MAX	0	63	14.27	13.56	22
Inyo					
MIN	0	0	0	0	22
MAX	0	59	2	7.11	22
Riverside					
MIN	0	63	3.77	7.00	22
MAX	0	63	22.32	27.23	22

Table 3: OLS of Logged Total Aggregate Income and Population on Native American Reservations in California w/ Robust Standard Errors (1990, 2000, 2010)

	Log of Total Income, 1990	Log of Total Income, 2000	Log of Total Income, 2010
Population, 1990	0.917***		
	(0.0568)		
Population, 2000		1.115***	
		(0.0428)	
Population, 2010			1.044***
			(0.0788)
Constant	10.30***	8.888***	9.327***
	(0.310)	(0.223)	(0.423)
Observations	54	56	54

Standard errors in parentheses
* p<0.05, ** p<0.01, *** p<0.001

Graph 1: OLS of Logged Total Aggregate Income and Population for CA Reservations

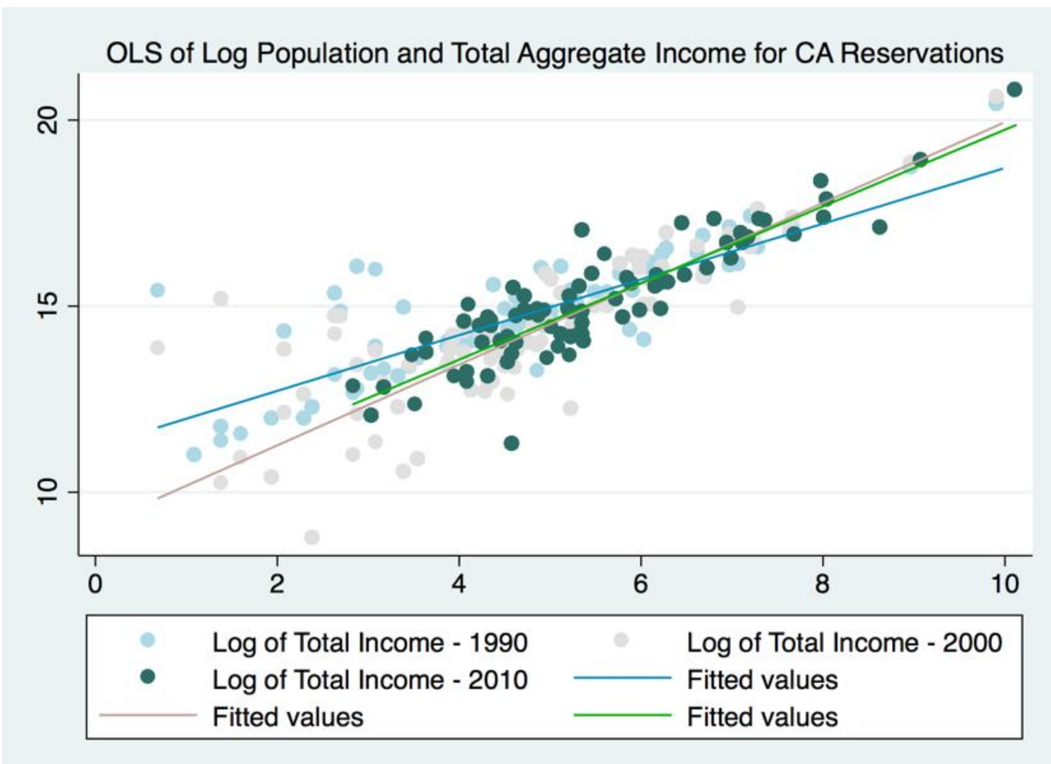


Table 4: OLS of Logged Population and Logged Total Aggregate Income for California Counties w/ Robust Standard Errors (1990, 2000, 2010)

	Log of Total Ag. Income, 1990	Log of Total Ag. Income, 2000	Log of Total Ag. Income, 2010
Population, 1990	1.057***		
	(0.0138)		
Population, 2000		1.045***	
		(0.0183)	
Population, 2010			1.031***
			(0.0172)
Constant	8.872***	9.372***	9.780***
	(0.184)	(0.230)	(0.224)
Observations	58	58	58

Standard errors in parentheses
* p<0.05, ** p<0.01, *** p<0.001

Graph 2: OLS of Logged Total Aggregate Income and Population for CA Reservations

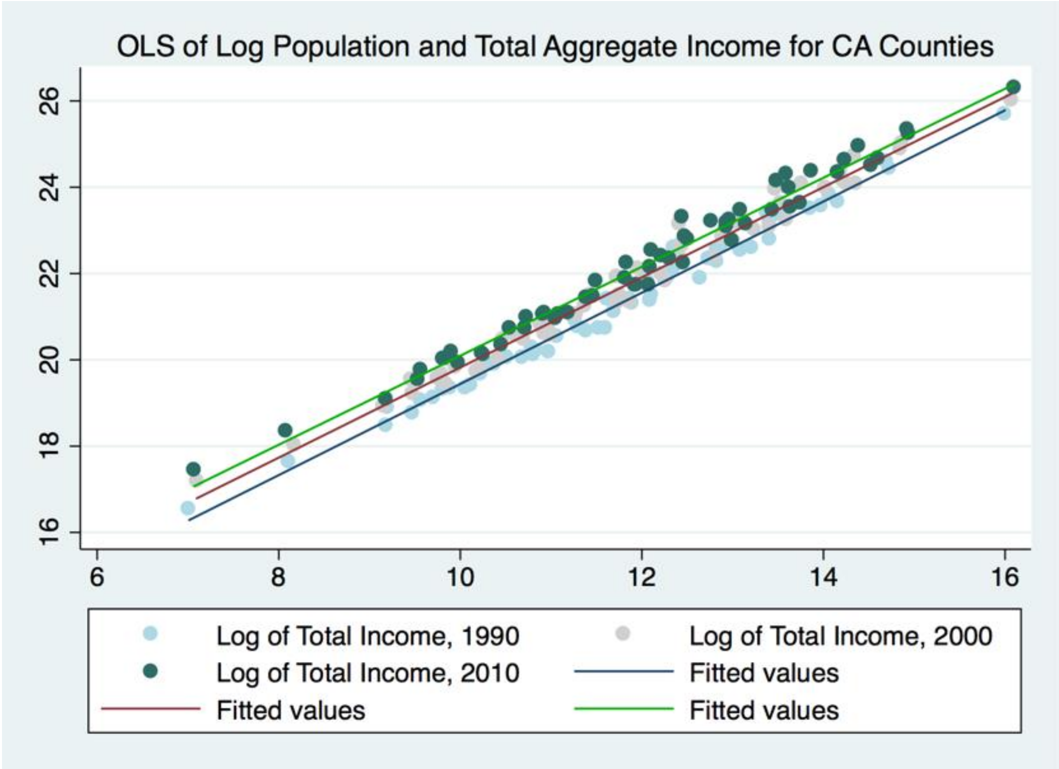


Table 5: OLS of Logged Occupied Housing Units and Population on Native American Reservations in CA w/ Robust Standard Errors (1990, 2000, 2010)

	Log of Occupied Housing Units, 1990	Log of Occupied Housing Units, 2000	Log of Occupied Housing Units, 2010
Population, 1990	0.958***		
	(0.0377)		
Population, 2000		1.029***	
		(0.0315)	
Population, 2010			1.024***
			(0.0550)
Constant	-0.875***	-1.335***	-1.400***
	(0.224)	(0.189)	(0.356)
Observations	54	56	56

Standard errors in parentheses
* p<0.05, ** p<0.01, *** p<0.001

Graph 3: OLS of Logged Occupied Housing Units and Population on CA Reservations

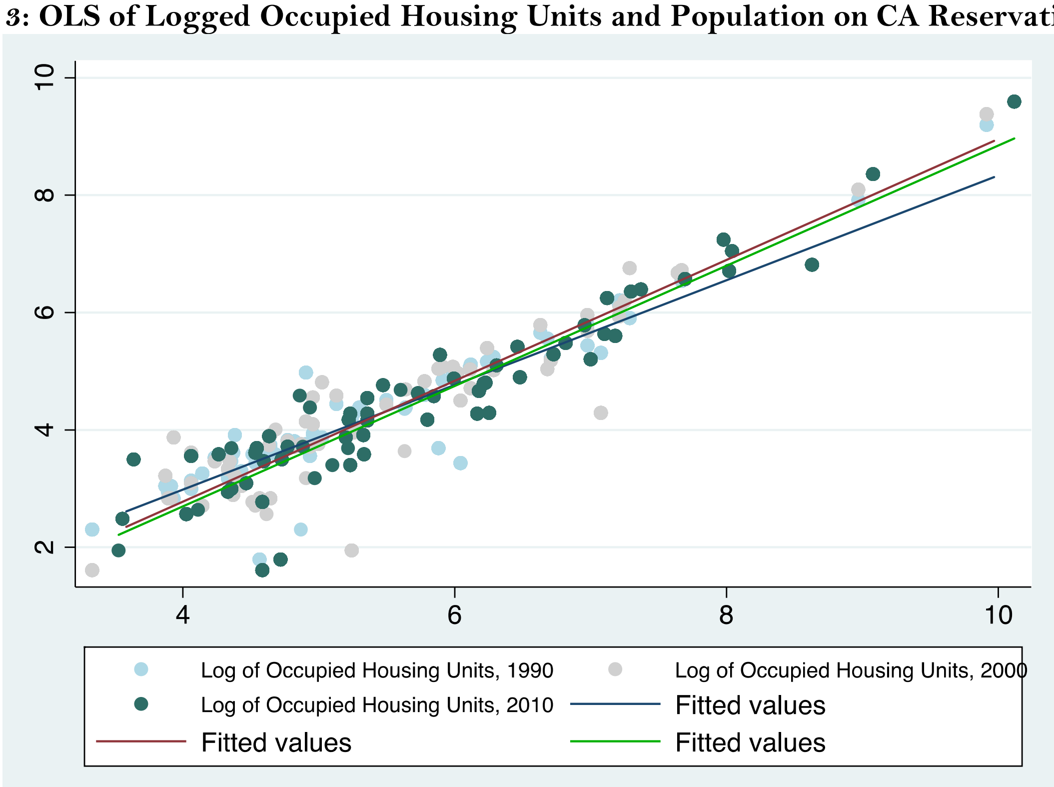


Table 6: OLS of Logged Private Sector Workers and Population on Native American Reservations in CA w/ Robust Standard Errors (1990, 2000, 2010)

	Log of Private Sec. Workers, 1990	Log of Private Sec. Workers, 2000	Log of Private Sec. Workers, 2010
Population on Reservations, 1990	0.830***		
	(0.0665)		
Population on Reservations, 2000		1.009***	
		(0.0606)	
Population on Reservations, 2010			0.931***
			(0.1207)
Constant	-0.539	-1.909***	-1.640***
	(0.384)	(0.363)	(0.738)
Observations	69	65	61

Standard errors in parentheses
* p<0.05, ** p<0.01, *** p<0.001

Graph 4: OLS of Logged Private Sector Workers and Population on CA Reservations

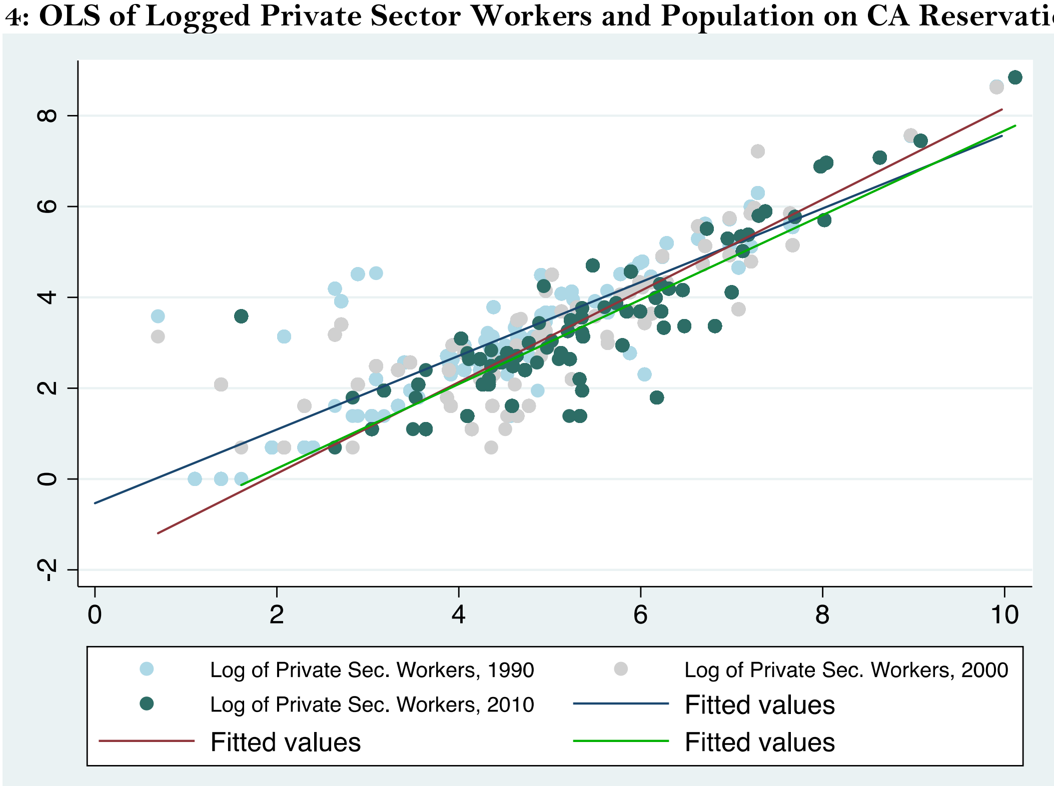


Table 7: OLS of Logged Government Workers and Population on Native American Reservations in CA w/ Robust Standard Errors (1990, 2000, 2010)

	Log of Gov. Workers, 1990	Log of Gov. Workers, 2000	Log of Gov. Workers, 2010
Population, 1990	0.850***		
	(0.0589)		
Population, 2000		0.836***	
		(0.0662)	
Population, 2010			0.906***
			(0.0811)
Constant	-1.813***	-1.552***	-1.878***
	(0.399)	(0.342)	(0.478)
Observations	53	55	51

Standard errors in parentheses
* p<0.05, ** p<0.01, *** p<0.001

Graph 5: OLS of Logged Government Sector Workers and Population on CA Reservations

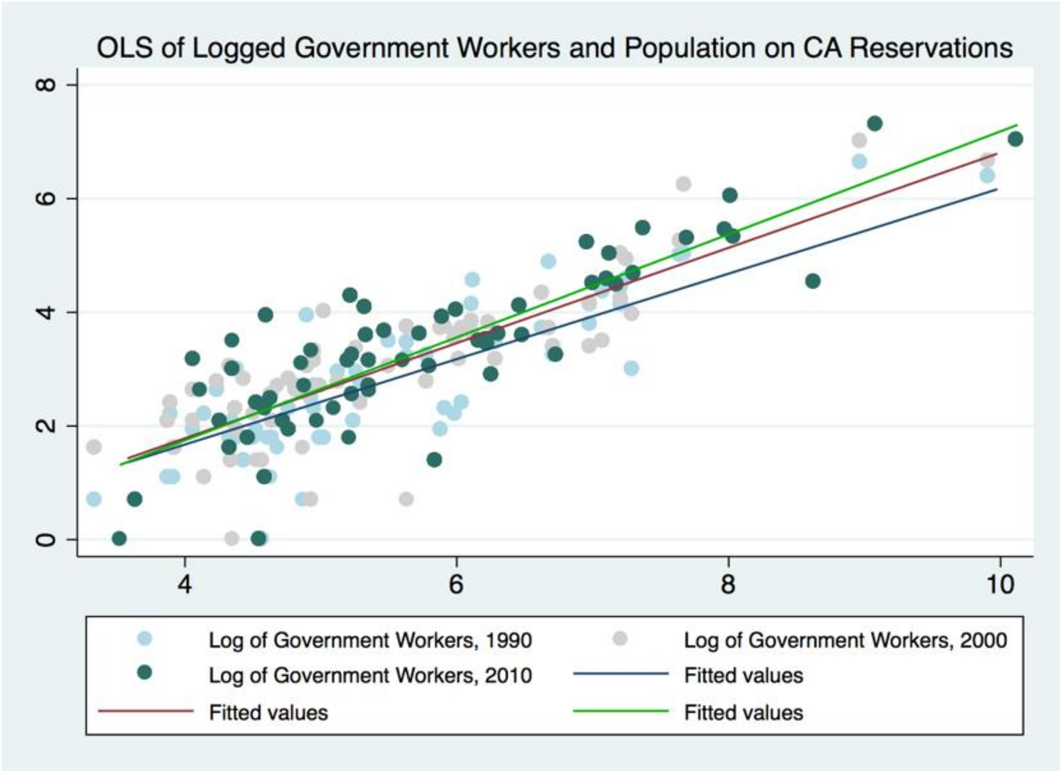


Table 8: OLS of Logged Population and Radiance for Native American Reservations in California w/ Robust Standard Errors

	Radiance, 1992	Radiance, 2000	Radiance, 2010
Population, 1990	0.310		
	(0.207)		
Population, 2000		0.165	
		(0.116)	
Population, 2010			0.204*
			(0.0826)
Constant	0.0519	1.601*	1.603***
	(1.207)	(0.687)	(0.455)
Observations	55	56	57

Standard errors in parentheses
* p<0.05, ** p<0.01, *** p<0.001

Graph 6: OLS of Radiance and Logged Population of CA Reservations

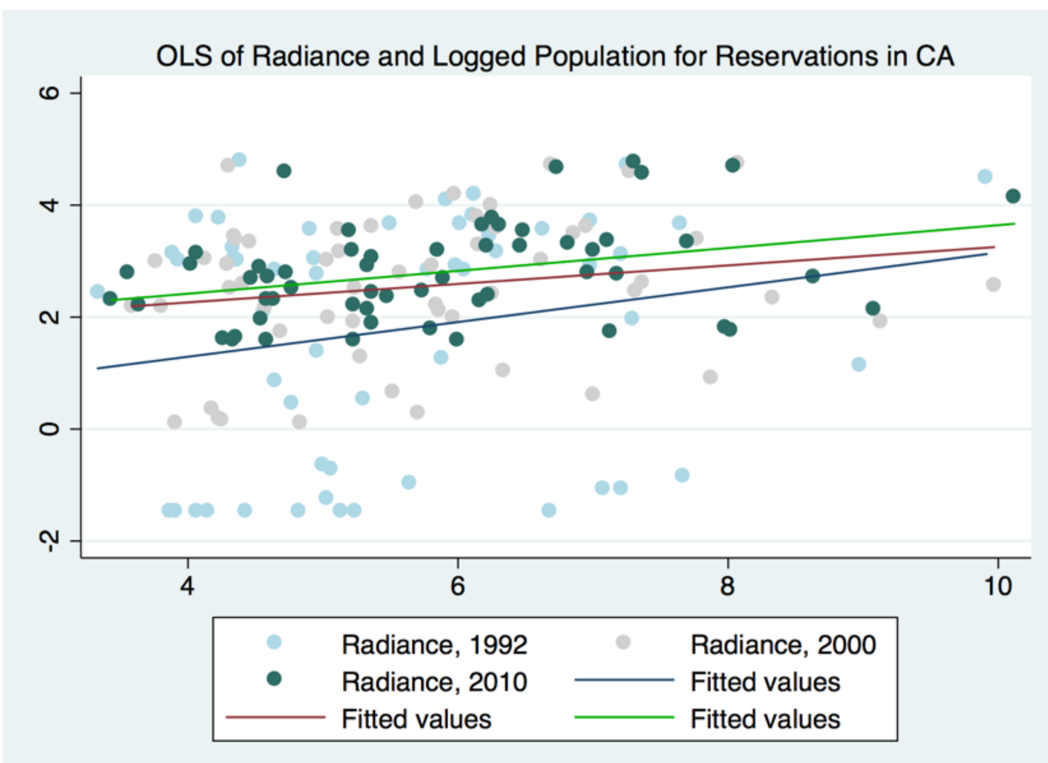


Table 9: OLS of Logged Total Aggregate Income and Radiance for Reservations in California w/ Robust Standard Errors (1990, 2000, 2010)

	Radiance, 1990	Radiance, 2000	Radiance, 2010
Log of Total Aggregate Income, 1990	0.235		
	(0.164)		
Log of Total Aggregate Income, 2000		0.174*	
		(0.0721)	
Log of Total Aggregate Income, 2010			0.242**
			(0.0635)
Constant	-1.739	-0.0364	-0.9988
	(2.501)	(1.070)	(0.932)
Observations	72	70	63

Standard errors in parentheses
* $p<0.05$, ** $p<0.01$, *** $p<0.001$

Graph 7: OLS of Radiance and Logged Total Aggregate Income of Native American Reservations in California

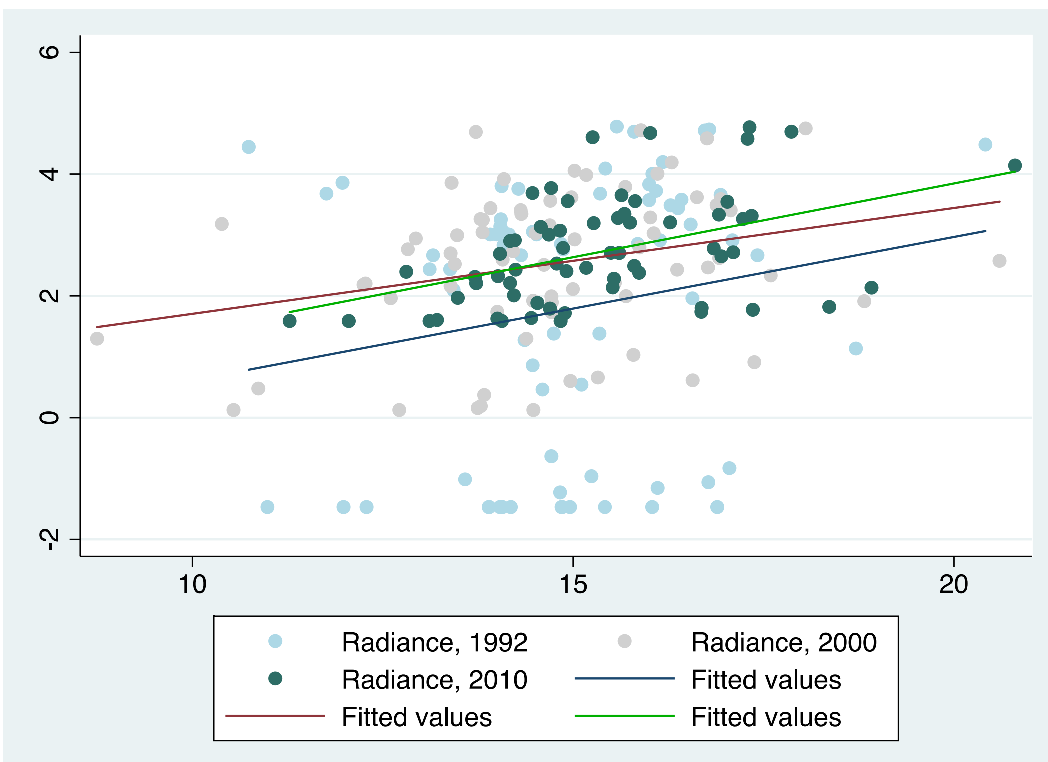


Table 10: OLS of Logged Occupied Housing Units and Radiance for Native American Reservations in California (1990, 2000, 2010)

	Radiance, 1990	Radiance, 2000	Radiance, 2010
Log of Occupied Housing Units, 1990	0.241 (0.160)		
Log of Occupied Housing Units, 2000		0.136 (0.090)	
Log of Occupied Housing Units, 2010			0.157* (0.078)
Constant	0.826 (0.707)	1.977*** (0.401)	2.020*** (0.337)
Observations	72	70	68

Standard errors in parentheses
* p<0.05, ** p<0.01, *** p<0.001

Graph 8: OLS of Radiance (IHS) and Logged Occupied Housing Units on Native American Reservations in California

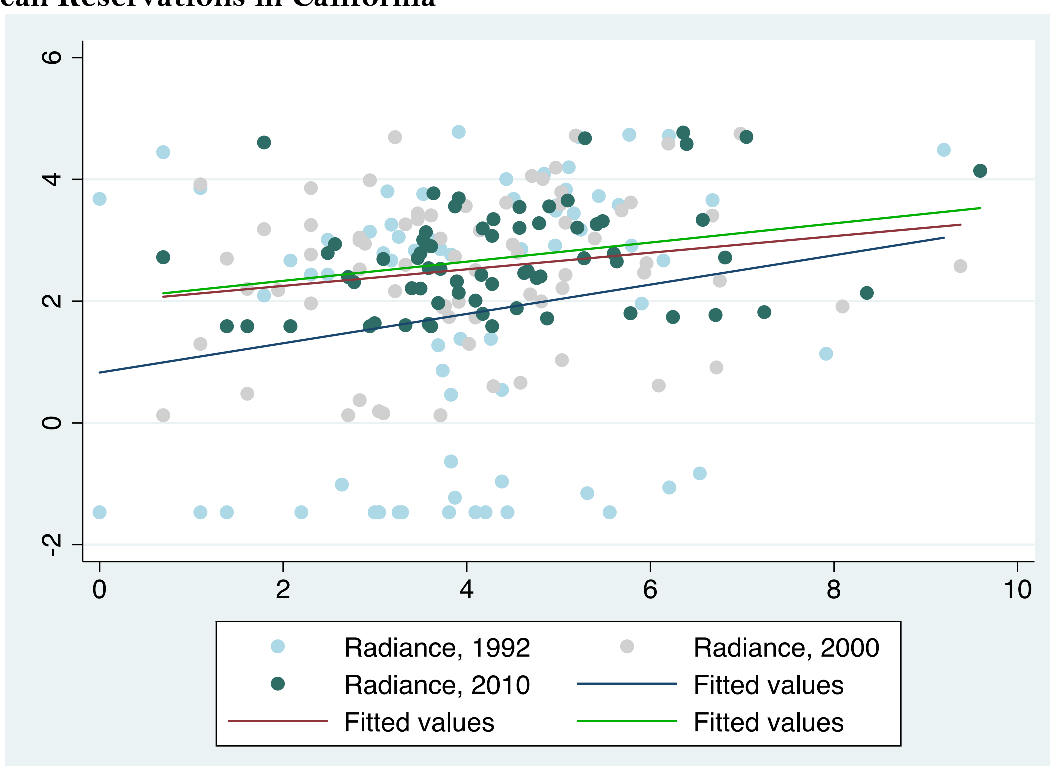


Table 11: OLS of Radiance and Logged Population for California Counties w/ Robust Standard Errors (1992, 2000, 2010)

	Radiance, 1992	Radiance, 2000	Radiance, 2010
Log of Population, 1990	0.0697***		
	(0.0180)		
Log of Population, 2000		0.0579***	
		(0.0162)	
Log of Population, 2010			0.0476***
			(0.0146)
Constant	-0.679***	-0.551**	-0.435**
	(0.192)	(0.175)	(0.159)
Observations	58	58	58

Standard errors in parentheses
* p<0.05, ** p<0.01, *** p<0.001

Graph 9: OLS of Radiance (IHS) and Log of Population in California Counties

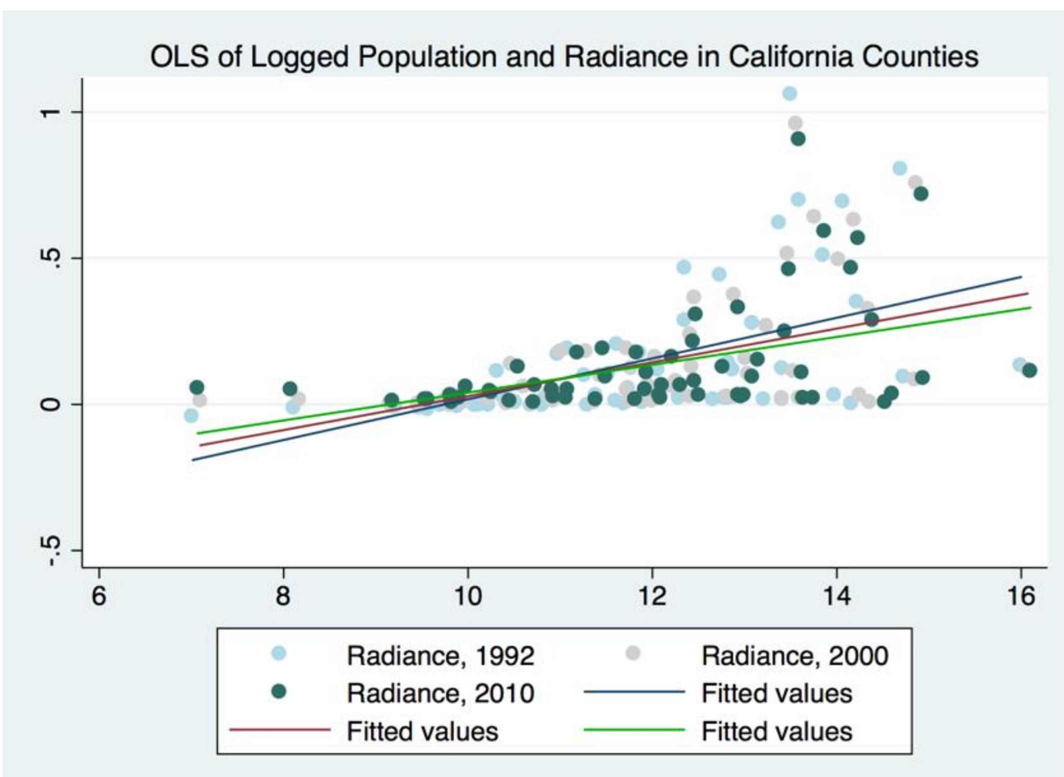


Table 12: Cross-Section of Radiance and Logged Total Aggregate Income for California Counties w/ Robust Standard Errors (1992, 2000, 2010)

	Radiance, 1992	Radiance, 2000	Radiance, 2010
Log of Total Income, 1990	0.0710***		
	(0.0173)		
Log of Total Income, 2000		0.0612***	
		(0.0157)	
Log of Total Income, 2010			0.0516***
			(0.0148)
Constant	-1.372***	-1.198***	-1.007***
	(0.349)	(0.326)	(0.308)
Observations	58	58	58

Standard errors in parentheses
* p<0.05, ** p<0.01, *** p<0.001

Graph 10: OLS of Radiance (IHS) and Logged Total Aggregate Income in California Counties

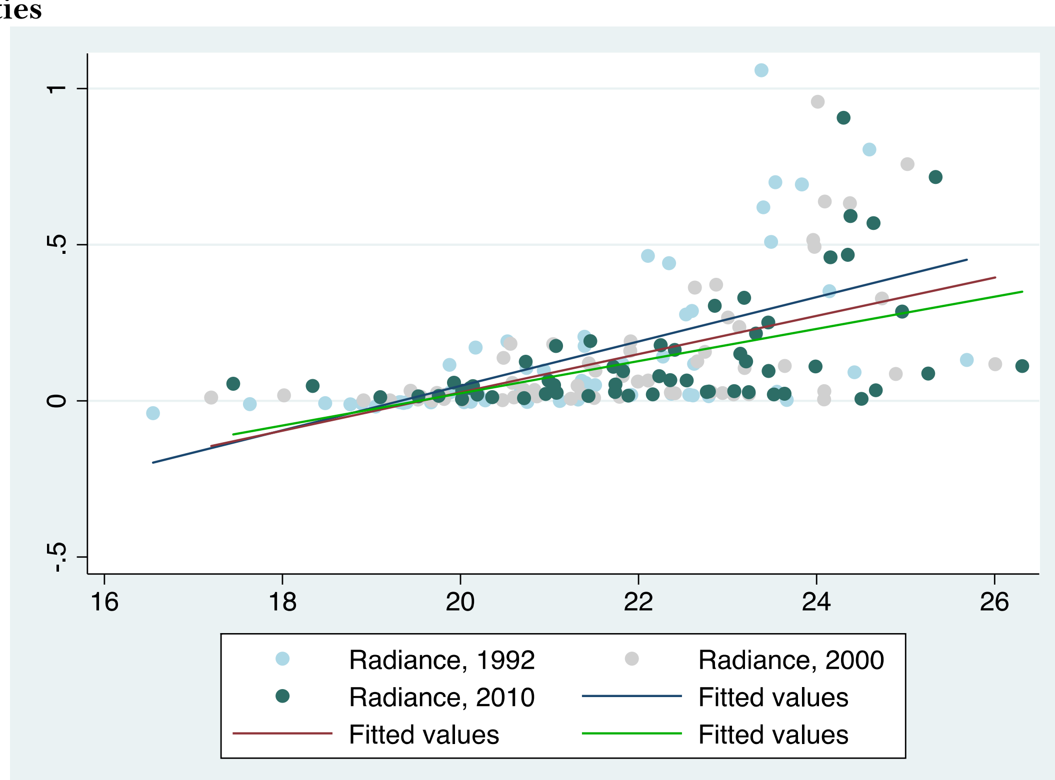


Table 13: OLS of Logged Population and Radiance on all Reservations in the U.S. w/ Robust Standard Errors

	Radiance, 1992	Radiance, 2000	Radiance, 2010
Log of Population, 1990	-0.0465 (0.0564)		
Log of Population, 2000		-0.076* (0.0325)	
Log of Population, 2010			-0.0439* (0.0214)
Constant	1.7004** (0.406)	2.963*** (0.237)	3.017*** (0.159)
Observations	265	294	301

Standard errors in parentheses
* p<0.05, ** p<0.01, *** p<0.001

Graph 11: OLS of Radiance and Logged Population on all Reservations in the U.S.

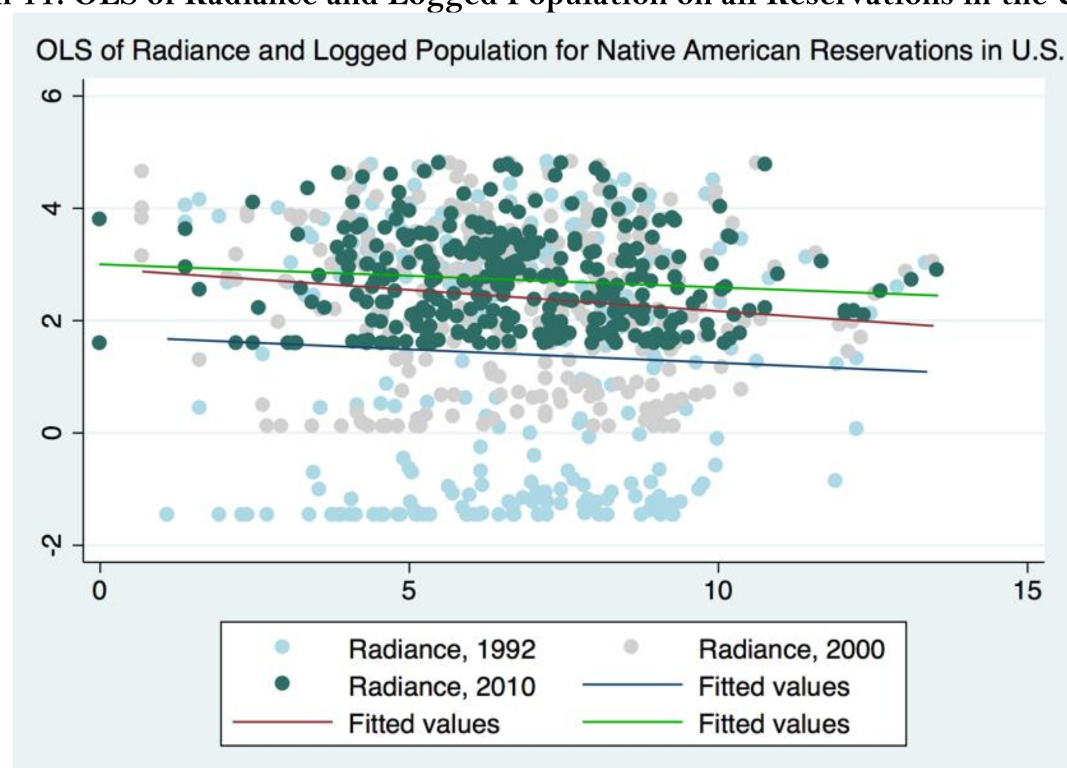


Table 14: OLS of Logged Population and Radiance on Reservations in California (No Zero Values)

	Radiance, 1990	Radiance, 2000	Radiance, 2010
Population, 1990	-0.0566		
	(0.0970)		
Population, 2000		0.0953	
		(0.104)	
Population, 2010			0.113
			(0.0958)
Constant	2.071***	1.324*	1.497**
	(0.536)	(0.569)	(0.546)
Observations	57	67	67

Standard errors in parentheses
* p<0.05, ** p<0.01, *** p<0.001

Table 15: OLS of Logged Total Aggregate Income and Radiance on Reservations in California (No Zero Values)

	Radiance, 1990	Radiance, 2000	Radiance, 2010
Total Aggregate Income, 1990 (log)	-0.0212		
	(0.101)		
Total Aggregate Income, 2000 (log)		0.174	
		(0.0951)	
Total Aggregate Income, 2010 (log)			0.312**
			(0.116)
Constant	2.198	-0.770	-2.792
	(1.537)	(1.423)	(1.816)
Observations	59	66	57

Standard errors in parentheses
* p<0.05, ** p<0.01, *** p<0.001

Table 16: OLS of Logged Population and Radiance in California Counties (No Zero Values)

	Radiance, 1990	Radiance, 2000	Radiance, 2010
Population, 1990	0.437**		
	(0.139)		
Population, 2000		0.566***	
		(0.146)	
Population, 2010			0.342
			(0.218)
Constant	-3.518*	-5.350**	-2.676
	(1.734)	(1.812)	(2.856)
Observations	39	37	30

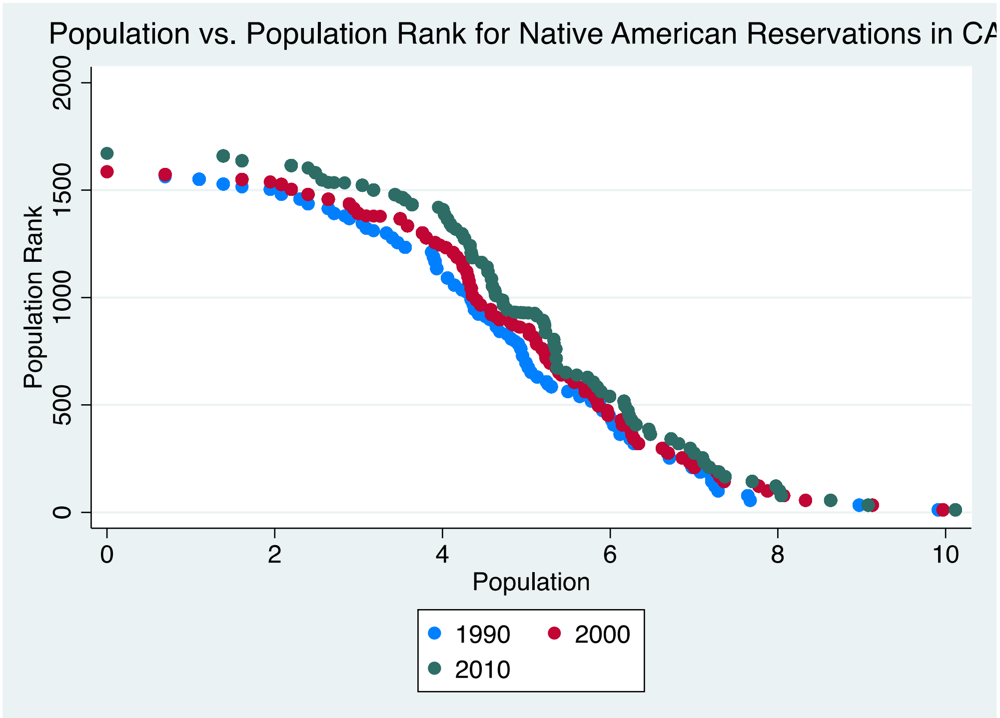
Standard errors in parentheses
* p<0.05, ** p<0.01, *** p<0.001

Table 17: OLS of Logged Total Aggregate Income and Radiance in California Counties (No Zero Values)

	Radiance, 1990	Radiance, 2000	Radiance, 2010
Log of Total Ag. Income, 1990	0.386**		
	(0.127)		
Log of Total Ag. Income, 2000		0.486**	
		(0.142)	
Log of Total Ag. Income, 2010			0.335
			(0.204)
Constant	-6.589*	-9.206**	-6.010
	(2.802)	(3.164)	(4.752)
Observations	39	37	30

Standard errors in parentheses
* p<0.05, ** p<0.01, *** p<0.001

Graph 12: Zipf's power law demonstration with population of Native American reservations in California



Graph 13: Zipf's power law demonstration with population of California counties