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Abstract

This study advocates a multi-dimensional urban planning strategy to help combat climate change under local—and not national—policies. However, the literature does not provide adequate guidance to local governments seeking to enhance urbanization and in turn reduce vehicular carbon dioxide (CO_2) emissions. Therefore, this study sheds light on the effects of the following four urban planning instruments on vehicular CO_2 emissions: *urbanization promoting areas*, *urbanization control areas*, *urban planning taxes* and *property taxes*. Using Japanese city-level data from 1990 to 2010, we find that the two urbanization area planning instruments and the *urban planning taxes* help lower emissions by increasing population density in low-density cities and that *property taxes* help reduce emissions in high-density cities. However, the increased population density associated with these instruments can lead to other negative outcomes, including increased traffic accidents, increased crime and a decrease in the facility condition index. City governments should consider complementary policies to mitigate such negative outcomes when employing planning instruments aiming to increase population density.

Keywords

urbanization, population density, land use taxes, land use regulations, carbon dioxide emissions, multiple outcome

1. Introduction

Greenhouse gas emissions are inextricably linked to economic activities, which are often concentrated in urban areas due to economies of scale and network effects (Fujita and Thisse, 2013); as a result, 80 percent of worldwide greenhouse gas emissions are attributable to cities (United Nations, 2007). It is projected that 66 percent of the world's population will live in urban areas by 2050, compared with 54 percent in 2014 (United Nations, 2014). Due to this urbanization trend, we must make significant efforts to reduce urban greenhouse gas emissions. To tackle this problem, many researchers from a variety of disciplines are theoretically and empirically examining the relationship between urbanization and greenhouse gas emissions (Buxton and Scheuer, 2007). This paper focuses on CO_2 emissions because they constitute the greatest proportion of greenhouse gas emissions. Emissions are generated by various sectors within the city, including the industrial, transportation, household, and services sectors, among others. In this paper, we focus on CO_2 emissions from the transportation sector and specifically from automobiles. Vehicular CO_2 emissions are responsible for approximately 14 percent of global CO_2 emissions (IPCC, 2015).[1]

Researchers and international organizations have advocated for compact-city policies as a means of reducing vehicular CO_2 emissions (OECD, 2012). As an urban planning and urban design concept, the compact city is a place of short distances, high residential density and mixed land uses. Advocates of the compact city argue that there is a negative relationship between urbanization and per capita vehicular CO_2 emissions because residents of a highly urbanized environment might have less need for vehicles than people living in low-density environments, given the availability of well-established public transportation systems. In this study, population density (i.e., population per unit land area) is used to measure the degree of urbanization because of limitations related to data availability and because density is one indicator of a compact city (OECD, 2012).

[1] Similar proportions are reported for Japan (Ministry of the Environment, Japan, 2015).

In a comprehensive study on the impacts of residential density, Buxton and Scheuer (2007) argue that there is no consensus on the effectiveness of the compact city for reducing CO_2 emissions, despite the extensive literature on the subject. This lack of consensus is due to complex interactions among the spatial diversity of city forms and functions, the heterogeneous travel/residential behaviors of individuals and their wealth. For example, high population density/agglomeration generates economic growth (Cuberes, 2012). This growth enriches residents and may then increase their vehicular demands. In addition, residents' increased income may result in changes to the built environment of their homes and workplaces (Ding et al., 2014) and to their attitudes toward the environment (Grossman and Krueger, 1991)[2], transportation systems and infrastructure (Sadorsky, 2014) and green innovation (Qi et al., 2010). All these changes are relevant to vehicular CO_2 emissions. Furthermore, the extent of these changes may differ among cities and countries due to economic, societal, cultural, and geographical differences.

This complexity makes it impossible to draw definitive conclusions regarding the impact of compact cities even from those previous studies that employ country-level aggregate data. Some studies have found a positive relationship between urbanization and CO_2 emissions (Parikh and Shukla, 1995; York et al., 2003; Wang, 2014; Barido and Marshall, 2014; Shahbaz et al., 2015), whereas Sharma (2011) and Martinez-Zarzoso and Muruotti (2011) found different results.[3] This inconsistency among studies suggests that tailored and multi-dimensional urban planning is required for each city and country (Corfee-Morlot et al., 2009; Madlener and Sunak, 2011; Taylor et al., 2012; Kenndy et al., 2012). In other words, city policymakers must choose and introduce urban planning instruments that are appropriate to each situation. In response to this need, municipal urban planning for climate change that is independent of national governments has been undertaken over the years by such established

[2] This is known as the environmental Kuznets curve hypothesis. In developed and developing countries, the relationships between wealth and environmental burden are negative and positive, respectively.

[3] Notably, the lack of detailed inventories of CO_2 emissions by cities also makes it difficult to understand this relationship (Heinonen and Junnila, 2011; United Nations Environment Programme, 2010; Kennedy et al., 2012).

city networks as the C40 Cities Climate Leadership Group, the World Mayors Council on Climate Change and the Local Governments for Sustainability (Bulkeley, 2010).[4] Corfee-Morlot et al. (2009) suggest that national governments should support local governments' decisions to take action to combat climate change.

Even if we assume that increases in population density lead to decreases in vehicular CO_2 emissions, there is little information regarding how city governments can realistically increase population density by means of urban policies (Glaeser, 2012). Although high-density cities may succeed in increasing their density further with a particular urban planning instrument, this instrument may not be similarly effective in low-density cities. The first purpose of this paper is to contribute to understanding which urban planning instruments directly affect population densities and vehicular CO_2 emissions as a result of changes in density , with particular attention to variation in population density among Japanese cities. In other words, we examine the indirect linkage between urban planning instruments and vehicular CO_2 emissions via the level of urbanization. We employ four land-use regulations, including taxes and command-and-control mechanisms (CAC), which will be explained in section 2. The examination of these regulations is consistent with the trend in the literature described above because Japanese city governments can implement/change these regulations independent of national government approval.

City population density potentially influences vehicular CO_2 emissions—in addition to outcomes such as obesity (Skinner, 2006), rent/land prices (OECD, 2012), informal settlements (Jones, 2012), residents' satisfaction/happiness (Rukumnuaykit, 2015), quality of life (Cramer et al., 2004), congestion/traffic accidents (Wang et al., 2009), waste (Hoornweg et al., 2011), and crime (Jargowsky and Park, 2008)—because city functions are inextricably linked to a wide variety of human activities. The second purpose of this paper is thus to examine the effects of population density on traffic

[4] In Japan, several metropolitan cities, including Tokyo, Kyoto and Yokohama, participate in these networks.

accidents, crime, annual cleaning expenditures, and the facility condition index[5] and to argue for complementary policies to address these matters. These external outcomes are also important in evaluating urban policy, as they involve key social issues (Glaeser, 2012). Our study is the first to assess whether, and to what extent, various land use regulations affect CO_2 emissions and other external factors indirectly by encouraging changes in population density.

If city governments succeed in raising population density, traffic congestion may increase (Glaeser and Gottlieb, 2009), and an increase in congestion will likely result in an increase in traffic accidents (Wang et al., 2009). Economic theory suggests that, ceteris paribus, rational potential criminals engage in illegal actions only when the expected benefits from the actions exceed the expected punishment—including the probability of arrest (Cooter and Ulen, 2011)—which implies that the wealth of highly urbanized cities is attractive to such criminals. Thus, a high inner-city crime rate is an incentive for residents to move to outlying areas (Jargowsky and Park, 2008). In addition, informal social interactions among residents are stronger in rural communities than in urban communities, thereby residents in rural areas experience lower crime rates (Bruinsma, 2007). Therefore, the behaviors of both criminals and residents may be associated with population density. Previous empirical studies, including Glaeser and Sacerdote (1999) and Jargowsky and Park (2008), have shown a positive relationship between population/population density and the crime rate. The accident and crime rates negatively impact social welfare and are associated with increased density.

Both positive and negative outcomes may result from increased urban population densities. The size of the areas in which city governments must clean and collect waste may shrink, as development and urban sprawl are reinforced by increased city density and as residential neighborhoods concentrate into city centers. City governments can thus save on expenditures that

[5] The facility condition index is used to assess the financial resources of local governments. It is calculated as the standardized annual revenue divided by the standardized annual demand. Therefore, the larger the index for a given city government, the greater its financial resources.

might have been allocated for cleaning and can use these savings to improve the facility condition index. These effects improve social welfare.

Unlike most previous studies that have focused on specific large cities or countries, the present paper exploits our unique set of panel data covering multiple periods from 1990 to 2007 and all Japanese cities, including small towns and villages. Data from multiple periods allow us to capture the short- and long-term effects of urban planning, the importance of which is discussed in Dulal et al. (2011). Notably, there is significant variation in population density within different regions of Japan (see Appendix, Figure A1). For example, the data include the world's largest super-city, Tokyo-Yokohama, which is larger than New York City, Mexico City, and Delhi (Demographia, 2013). Moreover, the broad cross-section across population densities and time periods enables us to accurately identify the direct and indirect effects of planning instruments.

The remainder of this paper is organized as follows. Section 2 provides background on our research and on Japanese urban planning. Sections 3 and 4 present the empirical models we use to measure the effects of population density and our estimation results, respectively. Finally, Section 5 summarizes our conclusions.

2. Urban Planning Instruments for Urbanization

2.1. Background

Despite the complex effects of population density on vehicular CO_2 emissions, several empirical studies have directly examined this relationship. The first, Newman and Kenworthy (1989), used 1980 data from large cities throughout the world and found that per capita gasoline consumption was lower in high-density cities than in low-density cities. However, this analysis did not account for other socio-economic variables affecting emissions, such as income (Buxton and Scheuer, 2007). Glaeser and Kahn (2010) controlled for income and household size in their detailed analysis based on individual data for 66 large cities in the United States (US) and found a negative relationship between population density and automobile CO_2 emissions. Using data on 370 US regions for 2003, Cervero and Murakami (2010) showed that vehicle miles traveled per capita is negatively correlated with population density. Brownstone and Golob (2009) employed US household survey data to show that people in low-density residential areas tend to use vehicles more than people in high-density residential areas. In addition, in a study based on household surveys in the US, Lee and Lee (2014) found a negative relationship between urban density and transportation CO_2 emissions.[6] However, these studies limited their focus to large cities or drew on data from one-time household surveys in the US. Therefore, it is unclear whether the same relationship will also be found in Japan. In addition, these studies cannot answer our research question, i.e., which urban planning instrument should city governments adopt to reduce vehicular CO_2 emissions?

Figure 1 shows the relationship between population density and per capita CO_2 emissions from automobiles for all cities in Japan. Unlike previous studies, Figure 1 includes small cities and towns. As shown in the figure, even when data from small cities are included, this relationship is found to be negative, which is consistent with previous studies. In addition, the plot shows greater variance in per capita CO_2 emissions from automobiles in areas with lower population density than in areas with higher population density. Therefore, it is important to include data from all cities to gain a more accurate picture of the relationship between population density and CO_2 emissions. We will now explore this relationship in more detail.

Figure 1. Relationship between Population Density and Per Capita CO_2 Emissions from 1990 to 2007

[6] Several studies also indirectly support the position that population density is negatively correlated with vehicular CO_2 emissions. Yamamoto (2009) showed that population density has a negative effect on vehicle ownership in Japan and Malaysia. Additionally, Fang (2008) provided evidence that people in high-density areas tend to own small vehicles, which have better fuel economy than large vehicles. These studies imply that vehicular CO_2 emissions may decrease with increasing population density.

in Japan.

If the negative relationship between population density and CO_2 emissions holds, city governments can decrease CO_2 emissions by increasing population density. We hypothesize that several land use regulations might be used to increase population density, including *property taxes* (Brueckner and Kim, 2003; Song and Zenou, 2006) and *urbanization control areas* (Sorensen et al., 2004). These land use regulations are implemented for purposes of controlling cities' borders and containing urban sprawl. For example, Song and Zenou (2006) have shown theoretically that *property taxes* affect population density, which in turn affects urban sprawl. *Urbanization control areas* influence population density by prohibiting residents from living in designated areas.

2.2. Japanese Urban Planning

In this study, we examined two types of CAC regulations and two taxes stipulated by *Japanese Urban Planning Law*. These CAC instruments, which are known as *urbanization control areas* and *urbanization promoting areas*, have been implemented in certain cities. Instruments that define *urbanization control areas* restrict activities in such areas. As a general rule, particular kinds of development, such as development of home sites through forest removal, are prohibited in such areas.[7] In other words, urban sprawl is restricted, and these areas act as buffer zones to protect the environment. Therefore, city policy planners can use *urbanization control areas* to control urban sprawl and promote urbanization.

Conversely, *urbanization promoting areas* are major urban areas in which governments decide to preferentially and systematically engage in urbanization activities over a ten-year period. To this end, city governments actively build infrastructure, such as water supplies, sewage, roads and

[7] Living in such areas is permitted when certain conditions stipulated in the *Urban Planning Law* are met.

utilities in designated areas. The locations and scale of the infrastructure, including roads, are effectively planned. Well-planned roads might lead to reduced gasoline consumption by reducing congestion. Hence, *urbanization promoting areas* might lead to decreased vehicular CO_2 emissions inside a city.

With respect to taxes, residents face both *urban planning taxes* and *property taxes* imposed by their city governments. Local governments can change these tax rates because they are local policies, like the regulations discussed above. There are significant differences between the two types of taxes. *Urban planning taxes* are used exclusively for constructing infrastructure within *urbanization promoting areas*, and city governments cannot use these taxes for other purposes. Therefore, residents in particular areas, such as the central business district, are subject to both *urban planning taxes* and *property taxes*, whereas residents living in an *urbanization control area* are subject only to *property taxes*. All city governments in Japan impose a *property tax* but not necessarily an *urban planning tax*. Tax rates also vary across city governments.

City governments can use these two types of taxes to create incentives for residents living in outer areas to move to central areas and increase the population density. To increase the population density of cities, it is preferable to increase *property taxes* and reduce *urban planning taxes* (or subsidies) simultaneously. Thus, the cost of living in an *urbanization promoting area* is relatively lower than the cost of living in an *urbanization control area*.

This prediction pertains to the internal movement of residents within a city. In addition, however, residents may move between cities. In other words, people may choose to live in cities in which both *urban planning tax* rates and *property tax* rates are low. In this case, the population densities of cities with low tax rates will exceed those of cities with high tax rates. It is unclear whether the internal movements of city populations will outweigh the external movements of these populations, or vice versa.

Furthermore, these instruments have the important feature that city governments can implement them without input from the national government. The instruments can be implemented by passing/revising city ordinances. Hence, such rate changes are feasible instruments of urban policy that can be used to achieve higher population densities because city governments have the freedom to use them for their own purposes. These features are consistent with the goals of multi-dimensional measures. Using these regulations, we attempt to find useful instruments based on city population density. Figure 2 presents an intuitive example of the four urban policy instruments in a circular city. The outer *urbanization promoting area* is set as the *urbanization control area*.

Figure 2. Imposed Taxes and Regulations in a Hypothetical Circular City.

As of March 2010, there were 1,750 city governments in Japan.[8] Cities can be classified into four types: special ward, city, town and village. Within these classifications, there are 23 special wards (all in the Tokyo prefecture), 786 cities, 757 towns and 184 villages. Of the city governments, 687 levy an *urban planning tax*. Although the standard *property tax* rate is 1.4 percent, 126 city governments have set higher rates.

Urbanization promoting areas and *urbanization control areas* have been established by 649 and 626 city governments, respectively. Histograms of tax rates and regulation area rates (regulation area divided by habitable area) for 2007 are presented in Figure 3. Figure 3 shows that the usage of each of these instruments varies. We can empirically identify the effects of the four instruments on population density by exploiting this variation in tax rates and regulation area rates. Descriptive statistics, such as means and standard deviations, are presented in section 3.

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[8] In Japan, local governments are divided into two types, prefectures and cities. Prefectures are similar to states in the US. There are 47 prefectures in Japan. The other is the city government, defined in this paper.

Figure 3. Distributions of Tax Rates and Regulation Area Rates for 2007.

3. Model and Data

3.1. Empirical Model

This section discusses the empirical model and the data used to examine the relationship among city urbanization/population density, urban planning instruments and CO_2 emissions. The following linear model (1) is used to identify the relationship between population density and CO_2 emissions. The dependent variable, $E_{i,t}$, denotes vehicular CO_2 emissions in city *i* and year *t*. The vector $\mathbf{X}_{i,t}$, on the right-hand side of the equation, is a vector of explanatory variables capturing city characteristics that affect CO_2 emissions, such as per capita income, road length, etc. $POP_{i,t}$ represents population density in city *i* and year *t*. $\boldsymbol{\beta}$ and γ are the parameters to be estimated. η_i and μ_t are city- and time-specific effects, respectively. The city-specific effect captures unobserved socio-economic and geographic factors that are independent of the time effect. An unobserved, idiosyncratic error term is expressed as $\varepsilon_{i,t}$.

$$\ln E_{i,t} = \ln \mathbf{X}_{i,t}\boldsymbol{\beta} + \gamma \cdot \ln POP_{i,t} + \eta_i + \mu_t + \varepsilon_{i,t} \quad (1)$$

If the vehicular CO_2 emissions of a city with a high population density are lower than the vehicular CO_2 emissions of a city with a low population density, the estimated coefficient $\hat{\gamma}$ is negative. Therefore, the sign of $\hat{\gamma}$ is important to our analysis. In addition to CO_2 emissions, we used traffic accidents, crime, annual cleaning expenditures and the facility condition index as dependent variables. As population density increases, we predict that traffic accidents, crime and the facility condition index will increase, and that cleaning expenditures will decrease.

City governments may be able to increase their population densities by means of policy instruments. Four urban planning instruments are considered in this study: *urbanization promoting* *areas*, *urbanization control areas*, *urban planning taxes* and *property taxes*. Hence, population density in equation (1) must be treated as an endogenous variable. We therefore estimate population density using equation (2),

$$\ln POP_{i,t} = \ln \mathbf{X}_{i,t}\boldsymbol{\delta} + \mathbf{UP}_{i,t}\boldsymbol{\theta} + \nu_i + \lambda_t + \varpi_{i,t} \tag{2}$$

where the vector $\mathbf{UP}_{i,t}$ represents the four urban planning instruments affecting population density. The other control variables are contained within vector $\mathbf{X}_{i,t}$. City- and time-specific fixed effects are expressed as ν_i and λ_t, respectively. $\varpi_{i,t}$ is an unobserved, independent and identically distributed error term.

Treating population density as an endogenous variable, as in equation (1), is consistent with previous studies of urbanization (Brownstone and Golob, 2009). Therefore, a two-stage estimation method is used to avoid endogeneity. In this method, we estimate equation (2), and then estimate equation (1) using the predicted values from equation (2). The instrumental variables in equation (2), which only affect population density, are required to ensure the consistency of the estimated coefficients in equation (1). The estimated coefficients are biased in equation (1) if population density is treated as an exogenous variable. In our model, $\mathbf{UP}_{i,t}$ works as an instrumental variable vector because *urban planning taxes* and *regulations* are introduced not to reduce CO_2 emissions but to control land use and implement city design characteristics.

3.2. Data

The study employs data for all 1,750 Japanese cities from 1990 to 2007. Table 1 presents descriptive statistics for the variables used in this paper. Data sources for each variable are indicated in the table. If there are no missing values, the total number of observations is 31,500 (=1,750×18). Due to a lack of available data on vehicular CO_2 emissions, data from four years (1990, 1999, 2003 and 2007) are used in our analysis. There are also many missing values for the number of police stations.

City government data on CO_2 emissions are provided in *Statistics for Local Environments*, published by the Coalition of Local Governments for Environmental Initiatives. The *Basic Resident Register*, which contains population data, is published by the Ministry of Internal Affairs and Communications (MIAC). To convert population into population density, we use habitable area, which is reported by the Geological Information Authority of Japan. The *Annual Report on Fire Defense*, *Taxation Status of Local Governments* and the *Annual Report on Local Public Finance* are also published by MIAC. Both the *Annual Survey on Urban Planning* and the *Annual Report on Road Statistics* were obtained from the Ministry of Land, Infrastructure, Transport and Tourism.

Property tax rates for each city were obtained through telephone surveys conducted in cities with *property tax* rates above 1.4 percent. A list of these cities (126 city governments) was obtained from the MIAC.

Table 1. Descriptive Statistics.

Around the year 2002, Japanese city governments began to be consolidated on a significant basis (see Figure 4). Whereas there were more than 3,000 city governments before 2002, the total number fell dramatically as a result of these consolidations. To account for these consolidations, we created a variable for city-specific government effects. Suppose, for example, that cities *A* and *B* are consolidated and that the new city is named city *A*. In this case, we cannot distinguish between old city *A* and new city *A* because the two cities bear the same name. Therefore, we cannot precisely account for city *A*'s fixed effects in the estimations.

Figure 4. Change in the Number of City Governments in Japan.

Our database is constructed using the following procedure. To avoid incorporating city *A*'s fixed effects, we transform our unbalanced city government data into balanced data by adding the value for city *B* to the value for the old city *A* (before consolidation) and then treating the consolidation of "*B*+old *A*" as a new city *A* in the estimation. Fixed effects without missing values can be obtained by accounting for the decrease in the number of city governments due to consolidation.

4. Results

4.1. Relationship between Outcomes and Population Density

This section discusses the estimation results using the all-city government panel data from 1990 to 2007. Before estimating equations (1) and (2), bivariate regressions are run in which the five outcomes are dependent variables, and the explanatory variable is logged population density. Figure 5 presents a graph of these results. Due to missing values, the number of observations differs for each regression. For CO_2 emissions, the number of observations is smaller than for other variables because the sample period includes only four years.

All relationships between passenger vehicle CO_2 emissions, truck CO_2 emissions, total CO_2 emissions (passengers + trucks) and population density are negative. Hence, population density may lead not only to decreased passenger vehicle usage but also to decreased truck usage. In more densely populated cities, accidents, crime and the facility condition index increase, and cleaning expenditures decrease. These regression results agree with our predictions.

Figure 5. Relationship between Outcomes and Log Population Density from 1990 to 2007.

4.2. Effects of Urban Planning Instruments on Population Density

Population density is associated with income and policy variables. Table 2 shows the results for equation (2). Three of the instruments significantly affect population density in all cases. The *urban planning tax* is the exception, although it is significant in models 1 and 2. Decreases in both the *urban planning tax* rate and the property tax rate are associated with increased population density—a result that does not support the position that the *urban planning tax* and the *property tax* have negative and positive effects on population density, respectively. Instead, these results appear to support our alternative hypothesis involving the external movements of residents between cities. Therefore, city governments can attract people from other cities by reducing property taxes. With respect to the two CACs, the results show that expansion of both *urbanization promoting areas* and *urbanization control areas* leads to increased population density, as expected.

Income is used as a proxy for the economic scale in the city. Because a growing city is attractive to people for a variety of reasons, the effect is positive and strongly significant. Thus, property taxes and regulations can make a city more compact. This empirical finding is important for urban policy planners.

Table 2. Estimated Effects of Urban Planning Instruments on Population Density after controlling for the other variables.

Next, we conduct a quantile regression instead of the usual fixed effects regression (see Koenker (2005) for a review of this method). In the fixed effects model, coefficients are estimated under the condition of variable means. As a result, the model cannot verify the hypothesis that the effects of urban planning instruments on population density in high-density cities are different from the effects in low-density cities. However, quantile regression can address this hypothesis. Estimation results for the four urban planning instruments using a quantile regression are presented in Figure 6. The vertical and horizontal axes in each graph denote the estimated coefficients and quantiles, respectively. Ninety-five percent confidence intervals are added as dashed lines to each figure. To consider computation feasibility, city government- and time-specific fixed effects are omitted from the estimations.

Overall, we find that the two CAC regulations are more effective in low-density cities; the exception is the coefficient for the *urbanization promoting areas* ratio for the quantile 0.1 to 0.2. Conversely, in areas with low population density, the effectiveness of urban planning and property taxes are higher and lower, respectively. In fact, in quantile 0.1 to 0.5, the effect of the *property tax* is statistically insignificant.

These results have two important implications. First, the two regulations are less effective for increasing population density in high-density cities than in low-density cities. However, the two regulations are useful in increasing population density in low-density cities.

Second, the *urban planning tax* is effective for increasing population density in low-density cities. By contrast, *property taxes* are not found to be helpful for increasing density, as the coefficients are insignificant. Although the usefulness of *urban planning taxes* diminishes at higher population densities, *property taxes* are valuable tools for increasing population density in high-density cities. Therefore, appropriate instruments must be chosen to achieve additional increases in population density.

Figure 6. Estimated Effects of Urban Planning Instruments on Population density by Quantile Regression.

4.3. Effects of Population Density on CO_2 Emissions

Population density, on the right-hand side of equation (1), is treated as an endogenous variable, determined by the economic level of the city and the urban planning instruments. We first estimate equation (2) and then calculate the predicted population density using the estimated coefficients. Using the predicted population density, we then estimate equation (1). As a robustness check against previous studies, we also estimate specifications in which population density is treated as an exogenous variable.

Table 3 shows the estimation results. In the first step, population density is estimated using model 3 in Table 2. Here, we apply prefecture-specific fixed effects instead of city government fixed effects (the 1,750 city governments belong to 47 prefectures). The adjusted R^2 in Table 3 is quite high at 0.9.

An evaluation of the effects of population density on CO_2 emissions shows that the coefficients for population density in each model are negative and significant at the 1 percent level. Therefore, increases in population density are associated with decreases in vehicular CO_2 emissions. If governments can increase population density by 1 percent, CO_2 emissions would decrease by approximately 0.21 to 0.24 percent, even without considering the endogeneity of population density (model 2). The population density elasticity per vehicle mile traveled (VMT) reported by Cervero and Murakami (2010) is approximately -0.38, which is not far from our estimates.

The effects of population density might change over time. We therefore add cross-terms for population density and year dummies to model 3. In the base year of 1990, the effect of population density on CO_2 emissions is -0.209. The additional effect had no significant influence on CO_2 emissions in 1999. However, the reduction effect increased by -0.028 and -0.089 in 2003 and 2007, respectively. Therefore, the effect strengthened over time, particularly after 1999. This result sheds light on the long-term effects of urban density relative to the short-term effects and is consistent with Dulal et al. (2011).

Income positively affects CO_2 emissions, suggesting that economic scale is associated with CO_2 emissions. Road length per habitable area is significant and negative only in model 3. Road expansion may thus reduce traffic congestion, resulting in reduced CO_2 emissions. Therefore, governments may be able to use road construction as a policy to mitigate climate change.

Table 3. Estimated Effects of Population Density on CO_2 Emissions by Two-stage Estimation.

4.4. Effects of Population Density on Other Outcomes

In this section, we discuss the effects of population density on the other four outcome variables. As with section 4.3, we treat population density as an endogenous variable and employ a two-stage estimation method (see Table 4 for results).

All coefficients are significant at the 1 percent level. An increase in population density thus yields 1) an increase in traffic accidents, 2) an increase in crime, 3) a decrease in cleaning expenditures and 4) a decrease in the facility condition index. Although governments can reduce cleaning expenditures by increasing their population density, these results imply that such an increase also results in negative externalities, such as increased traffic accidents and crime. Thus, we find that an increase in population density may not always be advisable as an urban planning policy, which implies that city governments should adopt complementary policies to address such negative externalities when increasing population density.

Population density has an adverse effect on the coefficient for the facility condition index. Although city governments can save on cleaning expenditures by increasing population density, the governmental facility condition index decreases. This finding might be related to our findings regarding the effects of population density on traffic accidents and crime because the latter outcomes may require increased expenditures on public safety. As a result, reduced cleaning expenditures may be offset by increased expenditures on public safety and leading to a decrease the facility condition index.

The expected signs are obtained for most of the other variables. As a proxy for policemen, police stations are effective in controlling traffic accidents and crime. Road expansion is also a useful measure for these outcomes. However, traffic signal installation is positively correlated with traffic accidents. Thus, more accidents may occur as more traffic signals are installed; alternatively, this finding may reflect insufficient control for economic scale.[9]

Table 4. Estimated Effects of Population Density on Other Outcomes by Two-stage Estimation.

4.5. Marginal Effects of Population Density on Externalities

We calculate the marginal effects of population density on CO_2 emissions, traffic accidents, and crime because these externalities may negatively impact residents' satisfaction, and the well-being of the entire city. We calculate the marginal effects by using the results of model 1 in Table 2 (for CO_2 emissions) and Table 3 (for the other outcomes). The marginal effect of population density (POP) on CO_2 emissions (E), calculated as the response of the average city, is $\partial E\left[E|_{\mathbf{X},POP}\right]/\,\partial POP|_{\overline{\mathbf{X}},\overline{POP}}$ (see Cameron and Trivedi (2005) for details on the method used).[10] The marginal effects of population density on the other outcome variables are determined by the same formula.

Table 5 presents the estimated marginal effects. The marginal effects on cleaning expenditures and the facility condition index are also indicated as a reference. The sample means for each outcome are shown in the third row. CO_2 emissions decrease by approximately 1,762 tons when population density increases by one person/hectare. The reduction is equivalent to 1.6 percent of CO_2

[9] Allowing for correlation between current unobserved time effects and time-lagged dependent variables (e.g. log crime in the previous year), we estimate the same models by linear dynamic panel estimation by using the 'xtabond' command in STATA software. The results are consistent with those in Table 4.

[10] The subscripts i and t are omitted. For all outcome variables other than the facility condition index, the marginal effects are calculated as $\hat{\gamma}\cdot\overline{POP}^{\hat{\gamma}-1}\cdot\overline{\mathbf{X}}\widehat{\boldsymbol{\beta}}$ because the dependent variables are transformed into log variables. $\overline{POP}$ and $\overline{\mathbf{X}}$ are the sample means for population density and other control variables used in the estimations, respectively. $\hat{\gamma}$ and $\widehat{\boldsymbol{\beta}}$ are estimated coefficients. Because the facility condition index is not in log form, the marginal effect is computed as $\hat{\gamma}\cdot\frac{1}{\overline{POP}}$.

emissions, on average. The reduction generated by increased population density is not negligible because the average population density is 13.8 persons/hectare (see Table 1). If the average urban density were to double, CO_2 emissions would decrease by approximately 22 percent, assuming constant marginal effects.

By contrast, traffic accidents and crime would worsen by an average of 0.7 and 0.2 percent, respectively, when population density increases by one unit. Relative to the reduction in CO_2 emissions, the changes in traffic accidents and crime are small.

Table 5. Marginal Effects of Population Density on Outcomes.

5. Conclusions

Concerns about urbanization have been growing in connection with climate change because cities are responsible for approximately 80 percent of overall greenhouse gas emissions. Based on these concerns, we argued for a multi-dimensional strategy to combat climate change at the local—and not the national—level. However, the literature does not show local governments how to enhance urbanization while reducing greenhouse gas emissions, given the specifics of their local situations. Focusing on vehicular CO_2 emissions, this paper therefore examines 1) what policies are suitable to promote urbanization in high- and low-density cities and 2) what complementary policies are required to mitigate certain negative social issues that are likely to arise from implementing these urbanization policies.

First, we examine the relationship between urbanization (population density) and four separate urban planning instruments—*urbanization promoting areas*, *urbanization control areas*, *urban planning taxes* and *property taxes*—using data for all Japanese cities from 1990 to 2007. Next, we analyze the relationship between population density and five outcomes, including vehicular CO_2

emissions, traffic accidents, crime, and two measures of city governmental expenditures (cleaning expenditures and the facility condition index).

Our results show that city governments can increase residential density by changing/implementing the policy instruments identified in this study. Creating and expanding both types of land use regulation (i.e., *urbanization control areas* and *urbanization promoting areas*) increases population density, whereas lowering both types of taxes also increases density. The effects of these instruments vary across cities. Specifically, their effects differ based on city density. We find that a decrease in the *urban planning tax* rate is more effective for increasing density in low-density cities than in high-density cities. In contrast, a decrease in the *property tax* rate is found to be more effective in high-density cities. City governments can also increase density through two types of CAC regulations, although city governments in high-density cities are advised not to utilize these instruments.

Population density is found to have a negative impact on CO_2 emissions. On the one hand, urban planning policies designed to increase population density can play a role in mitigating climate change. Higher density also leads to savings on public cleaning expenditures. On the other hand, such policies lead to increased traffic accidents, higher crime rates and a lower facility condition index. Therefore, the use of urban planning to increase population density simultaneously generates both positive and negative social welfare outcomes. To assess the effects of urban policies designed to increase population density on the external outcomes considered (CO_2 emissions, traffic accidents and crime), we calculate the marginal effects of increasing population density on these outcomes. We find that increasing population density by 1 person/hectare appears to lead to increases in traffic accidents and crime by 0.7 percent and 0.2 percent, respectively, whereas the same increase reduces CO_2 emissions by 1.6 percent. Therefore, when governments seek to increase population density, they should also consider introducing complementary policies to address traffic accidents and crime.

There are limitations to our analysis. First, we do not evaluate whether these policies affect other important outcomes, such as CO_2 emissions from other sources, air pollution, and inner city temperature (Coutts et al., 2010), among others. Second, our model assumes only inter-city population transfers, whereas intra-city population mobility is not considered. If overall population density in one city is equivalent to that in another city, then both cities are treated the same—even if the density in the center of one city is substantially greater than that of the other city—which implies that our model assumes only inter-city population transfer. Further research is required to consider intra-city population mobility. Third, we cannot explicitly account for many social, economic and geographical factors influencing population density and other outcomes due to lack of data availability. These factors should be incorporated into future analyses to improve the estimation model. Overcoming these limitations would be useful for understanding the complexity of urbanization.

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Appendix

Figure A1: Distribution of City Level Population Density from 1990 to 2007 in Japan

Notes: Obs.=30,923

Table 1. Descriptive Statistics.

Variables	Unit	Obs.	Mean	S.D.	Min	Max	Source
Population Density	person/ha	30923	13.8	23.0	0.12	195.7	Basic Resident Register
CO_2 (Total)	ton-CO_2	6914	110115	226004	0	3758081	Statistics for local environment
CO_2 (Passenger)	ton-CO_2	6921	60746	126105	0	2121385	Statistics for local environment
CO_2 (Truck)	ton-CO_2	6916	49295	103562	0	1675453	Statistics for local environment
Traffic Accident	case	30860	467	1275	0	25712	Annual report on fire defence
Crime	case	29618	1179	4233	0	136454	Annual report on fire defence
Annual Expenditures for Cleaning	1,000 yen	29064	1273080	3674104	0	9.46E+07	Annual report on local public finance
Facility Condition Index	index	28792	0.74	0.64	0	7.34	Annual report on local public finance
Income	1,000 yen	31188	1.06E+08	2.96E+08	239855	7.18E+09	Taxation status of local government
Road Length	kilometer	30553	806	5903	8	550300	Annual report on road statistics
Singuler	place	27961	93.3	233.4	0	4226	Annual report on fire defence
Police Station	place	16823	9.01	15.44	0	259	Annual report on fire defence
Urban Planning Tax Rate	percent	31500	0.10	0.13	0	0.31	Annual survey on urban planning
Property Tax Rate	percent	31500	1.41	0.04	1.4	1.85	Telephone survey
Urbanization Promoting Area Ratio	percent	30720	0.14	0.33	0	37.91	Annual survey on urban planning
Urbanization Control Area Ratio	percent	30720	0.32	0.56	0	7.73	Annual survey on urban planning

Table 2. Estimated Effects of Urban Planning Instruments on Population Density by Fixed Effects Regression.

	Model 1			Model 2			Model 3		
Variables	Coef.	S.E.		Coef.	S.E.		Coef.	S.E.	
ln(income)	0.458	0.045	***	0.460	0.045	***	0.395	0.019	***
Urban Planning Tax Rate	-0.324	0.088	***	-0.336	0.088	***	-0.004	0.011	
Property Tax Rate	-0.587	0.163	***	-0.587	0.161	***	-0.213	0.031	***
Urbanization Control Area Ratio	0.204	0.044	***	0.203	0.044	***	0.009	0.004	**
Urbanization Promoting Area Ratio	1.082	0.574	*	1.080	0.573	*	0.005	0.001	***
Constant	-5.409	0.549	***	-5.341	0.549	***	-4.470	0.408	***
Time Fixed Effects	No			Yes			Yes		
City Government Fixed Effects	No			No			Yes		
Adj. R-squared	0.62			0.62			0.99		
F-value (P-value)	9030.2 (0.00)			2060.8 (0.00)			44985.9 (0.00)		

Notes: Obs.=30,713. ***, ** and * indicate significance levels of 1%, 5% and 10%, respectively. Robust standard errors are used.

Table 3. Estimated Effects of Population Density on CO_2 Emissions by Two-stage Estimation.

	Model 2			Model 2			Model 3		
Variables	Coef.	S.E.					Coef.	S.E.	
ln(population density)	-0.242	0.011	***	-0.240	0.010	***	-0.209	0.011	***
ln(population density)×$Year_{1999}$							-0.015	0.011	
ln(population density)×$Year_{2003}$							-0.028	0.011	**
ln(population density)×$Year_{2007}$							-0.089	0.011	***
ln(income)	0.996	0.006	***	0.996	0.006	***	0.997	0.005	***
road length/habitable area	-0.342	0.210		-0.342	0.210		-0.317	0.128	**
Constant	-6.084	0.103	***	-6.081	0.103	***	-6.160	0.088	***
Endogenous Problem	Yes			No			Yes		
Adj. R-squares	0.92			0.92			0.92		
F-value (P-value)	1471.36 (0.00)			1378.83 (0.00)			1408.04 (0.00)		

Notes: Obs.=6,642. ***, ** and * indicate significance levels at the 1%, 5% and 10% levels, respectively. Prefectural and time fixed effects are included. Robust standard errors are used.

Table 4. Estimated Effects of Population Density on Other Outcomes by Two-stage Estimation.

	ln(traffic accident)			ln(crime)			ln(expenditure for cleaning)			facility condition index		
Variables	Coef.	S.E.		Coef.	S.E.		Coef.	S.E.		Coef.	S.E.	
ln(population density)	0.195	0.051	***	0.041	0.010	***	-0.081	0.006	***	-0.189	0.005	***
ln(income)	1.233	0.024	***	1.067	0.004	***	0.918	0.004	***	0.329	0.004	***
road length/habitable area	-5.252	1.097	***	-1.166	0.126	***	-0.005	0.003	***	0.003	0.002	***
signal/habitable area	8.526	2.679	***	6.448	0.442	***						
police station/habitable area	-341.256	52.892	***	-42.498	6.104	***						
Constant	-16.262	0.402	***	-12.891	0.077	***	-3.091	0.062	***	-4.918	0.071	***
Adj. R-squares	0.56			0.94			0.88			0.53		
F-value (P-value)	338.86 (0.00)			4184.86 (0.00)			3055.08 (0.00)			491.01 (0.00)		
Obs.	15,568			15,499			28,259			28,244		

Notes: ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively. Robust standard errors are used. Time and prefectural fixed effects are included.

Table 5. Marginal Effects of Population Density on Outcomes.

Outcomes	Marginal effects	Sample mean	Change rate from mean
CO2 emissions from vehicles	-1761.69	110115	-1.6%
Traffic accident	3.48	467	0.7%
Crime	1.82	1179	0.2%
Expenditure for cleaning	-5494.41	1273080	-0.4%
Facility condition index	-0.03	0.74	-4.2%

Notes: Units for CO_2 emissions, traffic accidents, crime and cleaning expenditures are CO_2-ton, case, case and 1,000 yen, respectively.

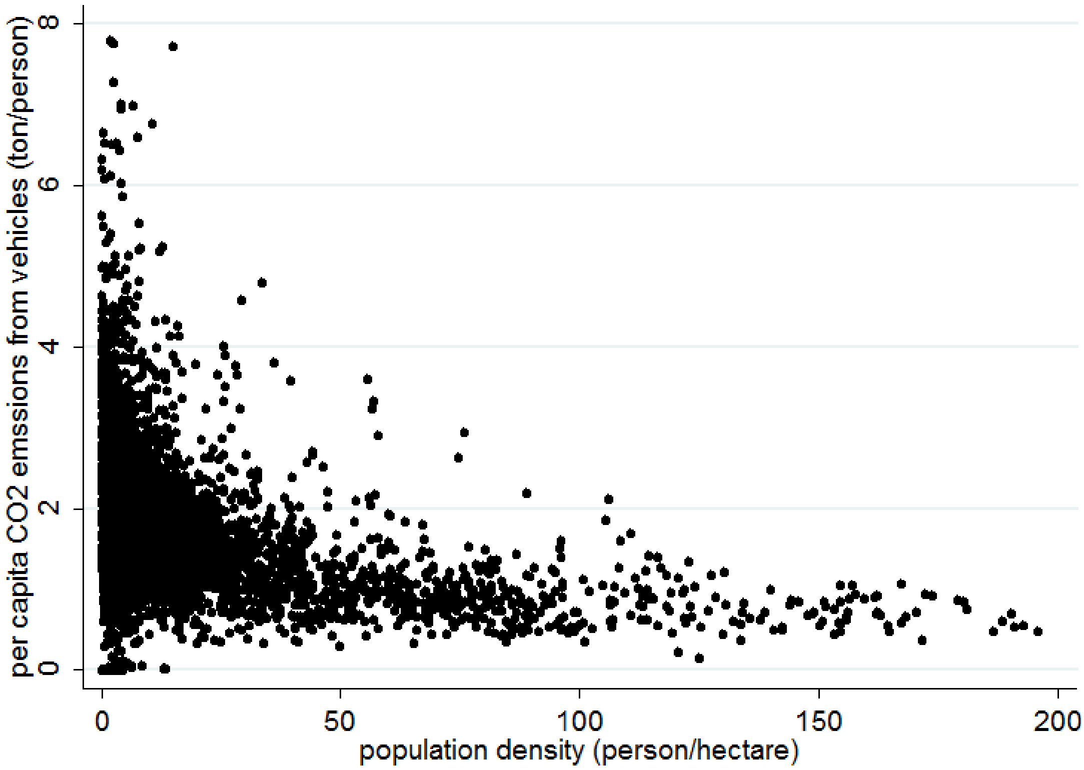

Figure 1. Relationship between Population Density and Per Capita CO2 Emissions from 1990 to 2007 in Japan.

Note: Obs.=6,866. The figure is based on data from 1990, 1999, 2003 and 2007. There are 12 cities in which per capita CO2 emissions are above 8.

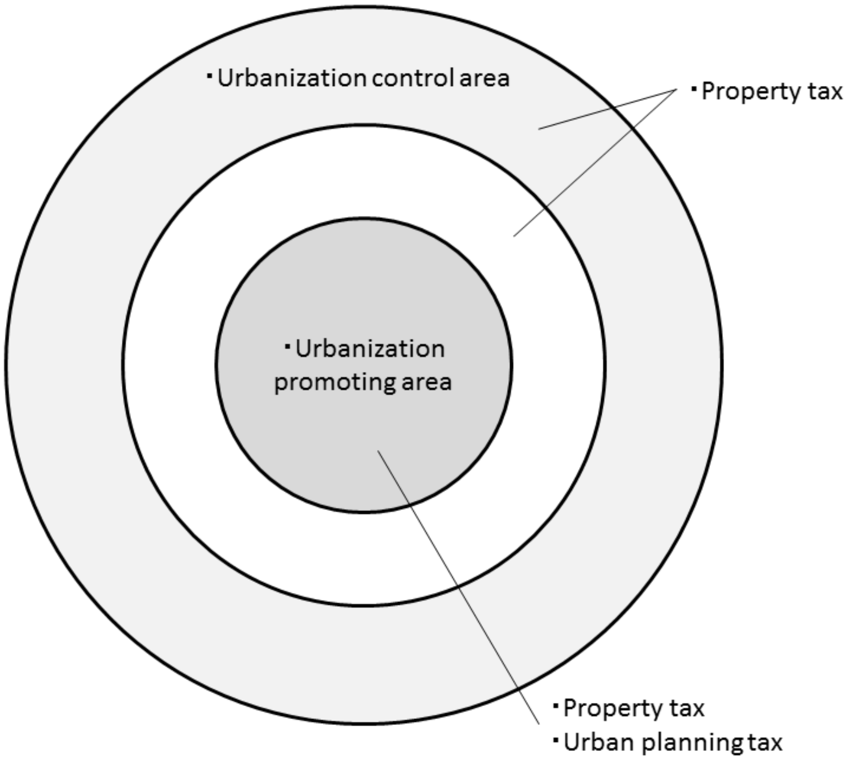

Figure 2. Imposed Taxes and Regulations in a Hypothetical Circular City.

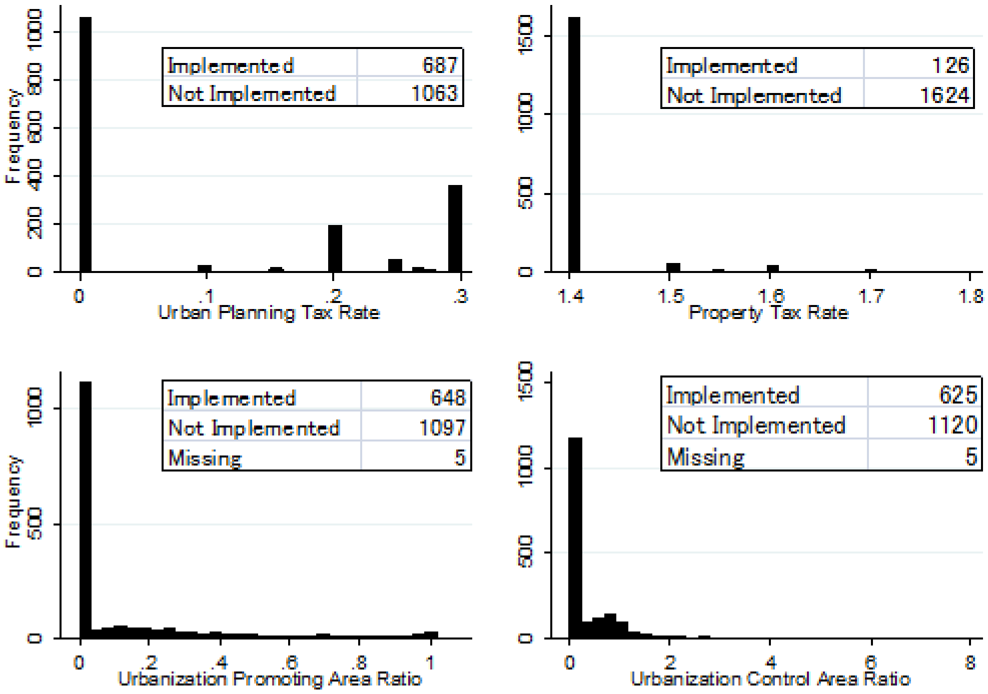

Figure 3. Distributions of Tax Rates and Regulation Area Rates for 2007.

Note: Obs.=1,750. The vertical and horizontal axes denote frequencies and rates, respectively. The urbanization promoting area ratio is measured as the regulation area divided by habitable area. The urbanization control area ratio is calculated by the same procedure.

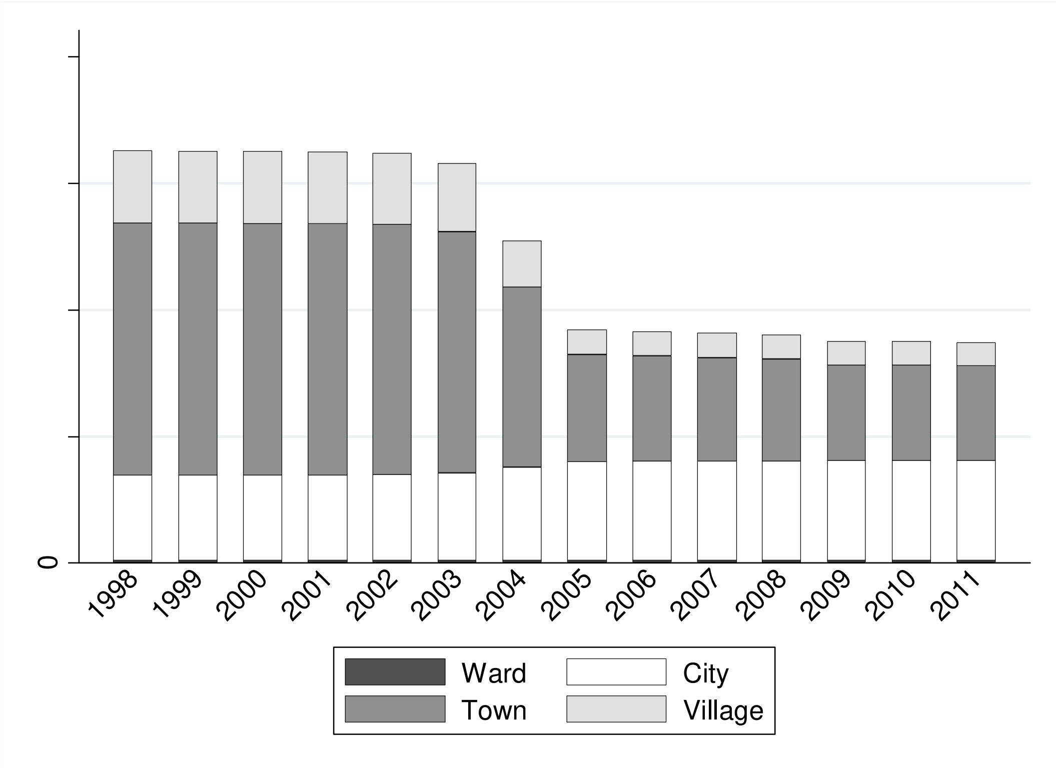

Figure 4. Change in the Number of City Governments in Japan.

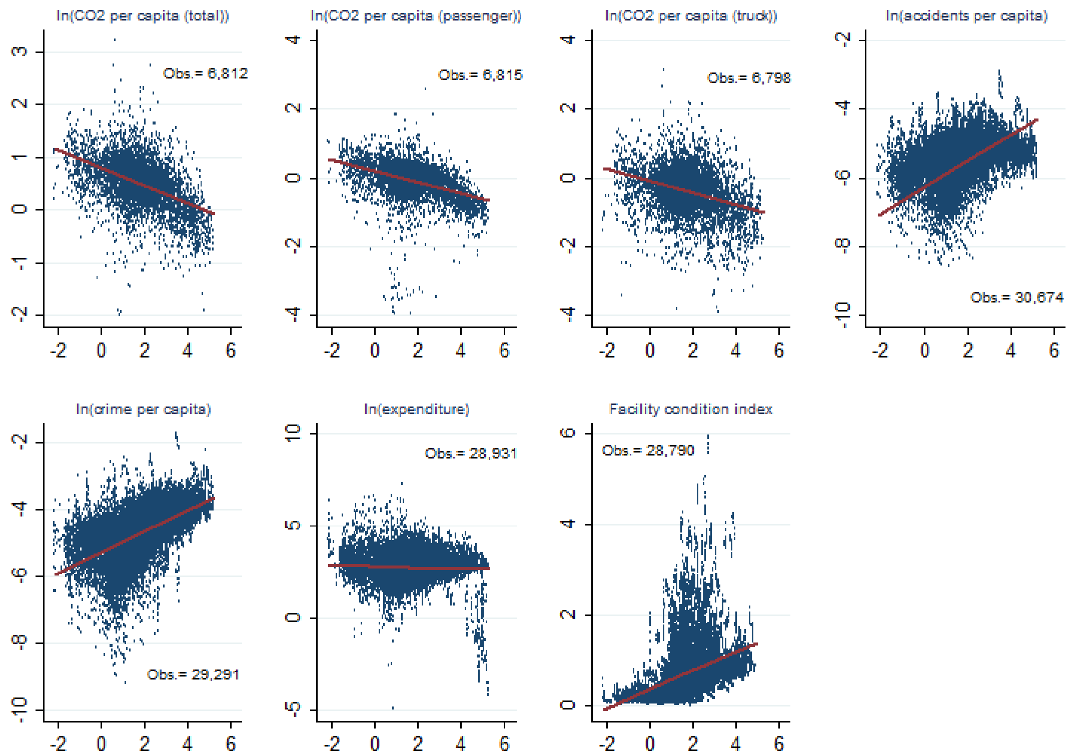

Figure 5. Relationship between Outcomes and Log Population Density from 1990 to 2007.

Note: The vertical axes represent outcomes, and the horizontal axes represent logged population density.

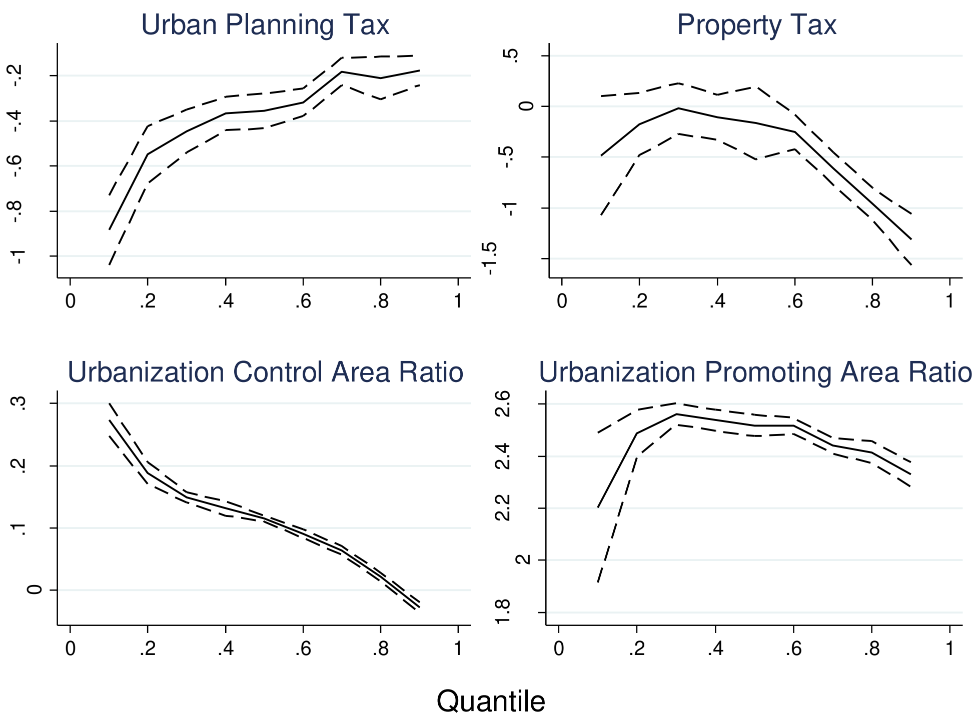

Figure 6. Estimated Effects of Urban Planning Instruments on Population density by Quantile Regression.

Note: Obs.=30,713. The vertical axis denotes the estimated coefficients, and the horizontal axis denotes quantiles of population density. The coefficients for the property tax rate for quantile 0.1 to 05 are insignificant. The other coefficients plotted are significant at the 1 percent level. Standard errors are calculated through bootstrapping, with 20 repetitions.

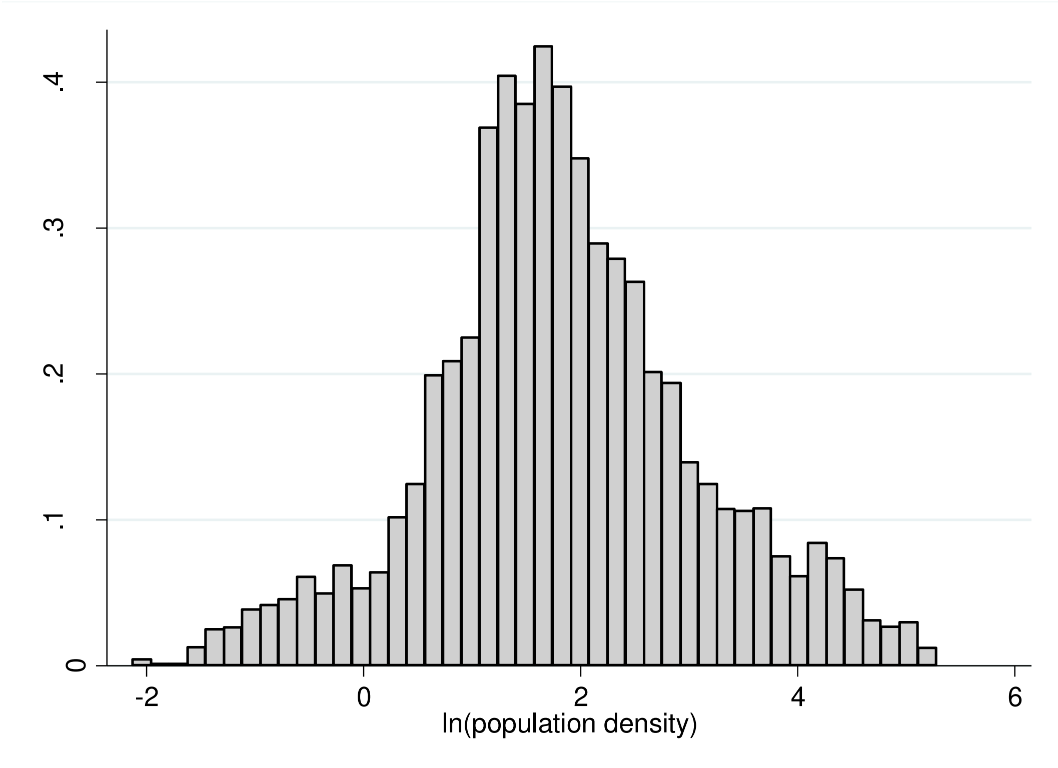

Figure A1: Distribution of City Level Population Density from 1990 to 2007 in Japan.

Notes: Obs.=30,923.