Are Compact Cities Greener? Evidence from China, 2000-2010

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Abstract
Whether a city develops toward a more compact or sprawling one may affect many aspects of urban environment, such as public and ecosystem health, greenhouse gas emissions, and quality of life. Using longitudinal data of Chinese cities during 2000-2010, we investigate the relationship between the compactness of urban growth, measured by average population density and several important indicators of urban greenness. Panel fixed-effects estimates support the widely held belief that compact urban growth can improve air quality and reduce per capita carbon footprint. Results also suggest that compact development reduces the growth in road capital and vehicle ownership, while its effect on travel behavior seems more significant in terms of promoting walking instead of reducing driving. On the other hand, increasing density reduces cities’ per capita urban park and green space, although denser cities may compensate for the reduction with better access to park and green space. Our study strengthens the urban policy and planning literature with the much needed longitudinal evidence and fills the gap of empirics in the Chinese context. The overall finding provides Chinese cities supportive evidence for higher density as opposed to lower density development.

Key words
Compact city, air quality, carbon emissions, transportation, park and green space, China

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1 Introduction

Urban growth can be achieved by densification or green-field development. Whether a city develops toward a more compact or sprawling one may affect many aspects of urban environment, such as public and ecosystem health, greenhouse gas emissions, and quality of life (Downs, 2004; Frumkin et al., 2004; Kahn, 2006; Ewing et al., 2008; and TRB, 2009). By examining mostly the transportation sector, existing literature emphasizes the relationship between urban compactness and carbon emissions and air pollution. However, a full consensus has not been achieved as to the environmental impacts of compact vs. sprawling urban development. Taking the United States as an example, some support compact development by evaluating the costs of urban sprawl (Real Estate Research Corporation, 1974; Burchell et al., 2005), while among others, Gordon and Richardson (1989 and 1997) argue that the problems are wrongly diagnosed because of faulty assumptions, data, and statistical inference. Still, the effects of the compactness of urban growth on other aspects of urban environment, such as urban parks and green spaces (instead of open and agricultural spaces outside of cities), have not received much attention. There is also much less robust evidence from developing countries, where urbanization has been occurring at a much faster rate.

In China, the grandest wave of urbanization in human history began more than three decades ago. For example, China’s urban population grew from 458.4 million in 2000 to 656.6 million in 2010, a 45% increase in just ten years. Such a dramatic growth in population, however, is dwarfed by the average growth in land occupied by cities. According to official statistics, the total built-up area (BUA) of cities increased by 78.5% between 2000 and 2010, and recent evidence based on satellite images showed an even larger growth of 85.5% in the largest 147 cities (Wang et al. 2012).

This study conducts an indicator-based evaluation of the relationship between compactness of urban growth and greenness, focusing on air quality, carbon emissions, transportation, and park and green space. Using panel data of China’s mid-sized and large cities during 2000-2010, we explore the significant longitudinal variation in density change across cities1 for the identification of urban compactness’ impacts on urban greenness. Our results provide support to some previous findings in the developed world, despite some potentially alternative ways to interpret our results in the specific context of China. This study provides much needed longitudinal evidence to the existing literature and helps further our knowledge on the environmental implications of the compactness of urban development. As one of the earliest quantitative studies on this topic in China, it has important policy implications for the rapidly urbanizing cities in China and other developing countries.

The rest of the paper is organized as follows. Section 2 reviews the existing literature on the environmental, resource, and livability consequences of the compactness of urban growth. Section 3 explains our method to quantify urban compactness’ effects on the greenness of cities. Section 4 describes the data. Section 5 presents the key results, followed by a conclusion in Section 6.

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1 China’s significant inter-regional heterogeneity in the compactness of urban growth provides excellent power of identification that may not be available elsewhere. Among the 147 largest cities, the ratio between population growth and spatial growth ranges from 0.18 to 2.89 during 2000-2010.
Urban Compactness and Greenness: the State of Knowledge

The concept of urban compactness does not have a widely agreed definition. “Compact” literally means “dense”, “packed together”, and “closely united”. Intuitively, urban compactness means the density of people and activities in an urban area. In the urban studies and planning literature, compact development relates closely to sprawl. These concepts refer to the two opposite ends of urban form (i.e., spatial pattern of land use or the built environment), which is considered one of the determinants of urban environmental, economic, and social sustainability (U.S. EPA, 2013). However, consensus has not formed around the concepts’ exact definition and the question of how the extent of compactness or sprawl impacts everything from open space preservation, air quality, traffic congestion, housing affordability, and quality of life (Banister et al., 1997; Neuman, 2005; Hamidi and Ewing, 2014). The measures of compact development or sprawl have been evolving. Many studies rely solely on average density (Pendall, 1999; Fulton et al., 2001; Lang, 2003; Lopez and Hynes, 2003; Mindali et al., 2004; Boussauw and Witlox, 2009), while others assign additional dimensions, such as land use mix, block size, and intersection density, to the concept of compact development (Galster et al., 2001; Ewing et al., 2002; Cutsinger et al., 2005; Frenkel and Ashkenazi, 2008; Mubareka et al., 2011). Nevertheless, it seems density remains the most important single component of urban compactness (U.S. EPA, 2013). After measuring four dimensions (density, land use mix, clustering, and street design) of 162 largest urbanized areas in the U.S., Hamidi and Ewing (2014) find that density has the highest eigenvalue and accounts for more of the total variance than the variables of the other dimensions combined. In fact, they find that only density is statistically related to all three commuting statistics: the share of walking, the share of transit, and drive time.

The broad literature on the environmental, resource, and livability consequences of urban compactness (or sprawl) is large and continues to grow. A notable feature of this primarily empirical literature is the dominance of urban transportation from perspectives such as travel mode, trip frequency, automobile ownership, and associated energy use and carbon emissions. Many scholars claim that a higher degree in urban compactness is associated with increased transit use, more walking, less driving, and reduced energy use and carbon emissions, although some argue that the effect of density is more complicated (e.g., Gordon and Richardson, 1989; Gomez-Ibanez, 1991). For instance, using a global sample of cities, Newman and Kenworthy (1989) find that households consume less fuel in denser cities. Such a correlation has been confirmed by other studies, especially in the U.S. and Europe (Cervero and Murakami, 2010; Brownstone and Golob, 2009; Chattopadhyay and Taylor 2012; Gim, 2012). However, the vast majority of empirical findings are merely correlations of cross-sectional households or communities, which suggests that more compact development patterns are only likely to reduce vehicle miles driven and produce reductions in energy consumption and carbon emissions (TRB, 2009).

In a similar fashion, studies have linked urban compactness to air quality, which is affected by toxic vehicular emissions such as carbon monoxide, volatile organic compounds, nitrogen oxides, ozone and particulates. Frank et al. (2000) find an inverse relationship between household and employment densities and vehicle emissions in Seattle. Stone et al. (2007) confirm that denser neighborhoods have lower concentrations of pollutants emitted by vehicles in the Chicago area,
with the effect more significant in urban zones. Still, some have pointed out that the public health consequences of increased density may be complicated. For example, while increased compactness may promote physical activity and reduce regional air pollution levels, it can exacerbate traffic congestion and increase exposure to harmful emissions within central areas (Marshall et al., 2005; Frank and Engelke, 2005; Schweitzer and Zhou, 2010; Clark et al., 2011).

Besides transportation, urban compactness may be related to other aspects of urban greenness. For example, Ewing and Rong (2008) show that multi-family housing consumes much less energy on both heating and cooling than single family housing, and that the tendency of citizens in sprawling counties to live in big single family houses rather than compact multi-family houses lead to higher residential energy use. On the other hand, there is growing evidence supporting that landscapes impact local climate and human health and well-being (Sullivan et al., 2014). Urban parks, especially the well-vegetated ones, through their shades, evapotranspiration, park breeze, and sequestration of carbon and other pollutants, mitigate the impact of the urban heat island and minimize local climate change (MacDonald, 2007). The impacts of urban compactness on parks and green space deserve attention because the preservation and allocation of parks and green space has become more challenging with compact development (Jim, 2004).

In general, the majority of the existing literature on urban compactness’ impacts on urban greenness concerns the role played by transportation, especially in the context of highly motorized or auto-dependent societies. There are much fewer studies on other aspects of urban greenness such as parks and green space. There are also few studies in the context of developing countries, especially those facing the increasing pressure of motorization. A couple of studies have associated urban compactness with carbon emissions in China (Anas and Timilsina, 2009; Zheng et al., 2011), but not other aspects of urban greenness. More importantly, most empirical evidence should be considered as correlations instead of causality, to a significant extent due to the prevailing use of cross-sectional data (Mokhtarian and Cao, 2008; TRB, 2009). There is an urgent need for studies using longitudinal data, which are more robust to spurious correlations.

3 Method

To reliably inform policy makers and planners about the effects of urban compactness on urban greenness, a crucial task is to identify the associations between the two factors that represent real causal effects. Assuming that the urban greenness measure $Y$ of city $i$ is determined by a vector of observable explanatory variables $X$, which includes urban compactness, a vector of unobservable explanatory variables $Z$, and a random error $\mu$, as shown in

$$Y_i = \beta X_i + \gamma Z_i + \mu, \quad (1)$$

Because $Z$ is unobservable, the estimate of $\beta$ is unbiased only when $X$ and $Z$ are uncorrelated. If, however, urban compactness is correlated with unobservable urban greenness-related city characteristics, such as certain topographic characteristics, the estimated compactness-greenness relationship would be biased. This explains the weakness of many previous studies.
But we know both the compactness and greenness of a city can vary over time, which could be exploited to reduce the confounding effects of certain variables in vector $Z$. That is, when we have a panel of $N$ cities and $T$ time periods of observed $Y$ and $X$, we know that

$$Y_{it} = \beta X_{it} + \gamma Z_{it} + \mu_{it}, \text{ for } i = 1, 2, \ldots, N \text{ and } t = 1, 2, \ldots, T.$$  \hfill (2)

Now suppose that $X$ and $Z$ are each composed of two vectors of variables: the time-varying $X^1$ (including compactness) and $Z^1$ and the time-invariant $X^2$ and $Z^2$. Under the assumption that only variables (such as topography) in $Z^2$ correlate with $X^1$, for any given city $i$,

$$Y_{it} = \beta_1 X^1_{it} + \alpha_i + \epsilon_{it}, \text{ for } i = 1, 2, \ldots, N \text{ and } t = 1, 2, \ldots, T,$$  \hfill (3)

where $\alpha_i = \beta_2 X^2_{it} + \gamma_2 Z^2_{it}$, representing all factors that are constant over time for city $i$, and $\epsilon_{it} = \gamma_1 Z^1_{it} + \mu_{it}$, representing all unobserved factors that vary across time for city $i$. In Eq. (3), confounding variables in vector $Z^2$ are combined into the city-specific constant $\alpha_i$, which makes the estimate of $\beta_1$ unbiased. Such a city fixed effects design avoids the endogeneity bias resulting from time-invariant unobservable variables $Z^2$. Eq. (3) could be estimated easily using longitudinal data through adding city dummy variables to the classical linear regression.

4 Data

To estimate urban compactness’ impacts on greenness using Eq. (3), we first identify appropriate measures of the two concepts. Following the literature and given data available to us, we measure urban compactness using average urban population density. As the most relevant and measure for urban compactness, population density is defined as the number of urban residents per unit built-up area (BUA), which is dynamic due to urban growth, instead of area within jurisdictional boundary, which is often fixed. For urban greenness, there is no widely agreed single or set of measures. This study includes some basic aspects of urban greenness such as air quality and carbon emissions. We also give specific attention to urban transportation and urban park and green space, both important for urban regions’ ecosystem health, human health, and quality of life.

Using multiple sources, this study collects data from Chinese cities with at least 500,000 urban residents in 2010.2 Observations from years 2000, 2005, and 2010 are collected because of the aforementioned impressive growth of cities during the period of 2000-2010 in China and the better availability and quality of official statistics compared to earlier years. For example, the Fifth National Population Census, conducted in 2000, was the first time when residents not registered locally were accounted for.

The dependent variables include four groups of indicators of urban greenness: air quality, carbon emissions, urban transportation capitals (given the importance that the literature put on urban transportation), and park and green spaces within the urban area. Urban air quality is measured

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2 Among all 286 prefecture-level cities in China, 242 had a population of at least 500,000 in 2010. The four provincial-level cities, Beijing, Shanghai, Tianjin and Chongqing, are excluded from our study since they are distinctly different from prefecture cities in terms of administrative autonomy and political and financial resources at dispose.
by the median score of the daily Air Pollution Index (API), and the number of days per year with API greater than 100. The API is based on the daily average concentrations of criteria pollutants including nitrogen oxides, sulfur dioxide and particulates recorded by monitors in cities (MEP, 2006). A daily API greater than 100 indicates unhealthy to more severe levels of air pollution. Annual per capita CO2 emissions of each city are calculated based on the estimated city carbon emissions in the China Environmental Economics Database, in which carbon emissions are aggregated across the secondary and tertiary industries, the construction industry, the transportation industry, and private consumptions using official energy and urban statistics and methods specified by the IPCC. The transportation variables include per-capita urban road space and per-capita number of private motor vehicles from official city-level statistics. Finally, we measure the sum of green and park space at the per-capita basis and as percentage of BUA.

The key explanatory variable of interest is urban compactness, measured by the average population density in urban BUA. Both urban resident population and the BUA of each city are available from the official statistics. However, it is likely that local governments have been motivated to manipulate the amount of land consumed by urban growth in official statistics. Since the urban land and housing reforms in the 1990s, Chinese local governments have increasingly relied on leasing land to developers and firms for short-term revenue and economic growth (Lichtenberg and Ding, 2009). Concerned about the loss of agricultural land, an overheated housing market, and local fiscal sustainability, the central government has tried to maintain control over urban expansion (Tao et al., 2010). It is thus understandable that cities may “miscalculate” land used for urban development. As a robustness check of the official statistics, urban built-up area is measured alternatively using satellite image-based data in years 2000 and 2010 for 147 most populous cities obtained from Wang et al. (2012). While the two BUA measures are correlated (correlation coefficient 0.852, p-value 0.000), we find that on average the satellite image-based BUAs differ from the official statistics by about 12-13% among the common cities in both samples.

Three other time-varying factors are important as they may influence urban greenness via various mechanisms such as economies of scale in resource use (e.g., in municipal services and energy consumption), government capacity, demand for quality of life, and the environmental footprint of industrial activities. These control variables include city size measured by resident population (POP), economic development and income levels measured by per capita urban gross domestic product (GDP), and urban economic structure measured by the percentage of secondary industry output in total economic output (IND). Table 1 presents the summary of variables and their sources. We convert all variables to their natural logarithms in regression analyses except variables indicating percentages or indexes.

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3 This database is developed based on the research of the Institute of Environmental Policy and Planning, Renmin University of China. Detailed sources of official statistics include the China Energy Statistical Yearbook, China Urban Construction Statistics Yearbook, and the provincial and regional urban statistical yearbooks, all for the year 2000 and later.
### TABLE 1 Summary of Data

<table>
<thead>
<tr>
<th>Variable</th>
<th>Definition (source)</th>
<th>2000</th>
<th></th>
<th></th>
<th>2005</th>
<th></th>
<th></th>
<th>2010</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Obs.</td>
<td>Mean</td>
<td>S.D.</td>
<td>Obs.</td>
<td>Mean</td>
<td>S.D.</td>
<td>Obs.</td>
<td>Mean</td>
<td>S.D.</td>
</tr>
<tr>
<td>POP</td>
<td>Urban population in 10,000 persons (China Urban Construction Statistical Yearbook, multiple years)</td>
<td>241</td>
<td>109.77</td>
<td>114.74</td>
<td>236</td>
<td>125.95</td>
<td>122.77</td>
<td>239</td>
<td>143.3</td>
<td>145.21</td>
</tr>
<tr>
<td>GDP</td>
<td>GDP per capita in municipal districts in 10,000 yuan (China City Statistical Yearbook, multiple years)</td>
<td>223</td>
<td>12696.83</td>
<td>8569.34</td>
<td>236</td>
<td>24049.56</td>
<td>16523.09</td>
<td>239</td>
<td>46995.76</td>
<td>28757.17</td>
</tr>
<tr>
<td>DENyb</td>
<td>Population density in built-up area in persons/km² from official statistics (calculated using POP and BUA data from China Urban Construction Statistical Yearbook, multiple years)</td>
<td>228</td>
<td>23235.33</td>
<td>18616.25</td>
<td>238</td>
<td>20460.6</td>
<td>16888.67</td>
<td>241</td>
<td>14734.14</td>
<td>8062.203</td>
</tr>
<tr>
<td>DENrs</td>
<td>Population density in built-up area in persons/km² from satellite image (calculated using POP and data from Wang et al., 2012)</td>
<td>133</td>
<td>25066.58</td>
<td>19328.32</td>
<td>133</td>
<td>21186.87</td>
<td>15851.58</td>
<td>133</td>
<td>18712.63</td>
<td>13248.09</td>
</tr>
<tr>
<td>IND</td>
<td>Proportion of the industrial sector in GDP in % (Provincial Statistical Yearbooks, multiple years)</td>
<td>223</td>
<td>50.44</td>
<td>12.62</td>
<td>241</td>
<td>50.39</td>
<td>13.28</td>
<td>240</td>
<td>52.49</td>
<td>11.92</td>
</tr>
<tr>
<td>APImed</td>
<td>Median score of Air Pollution Index or API (Ministry of Environmental Protection)</td>
<td>72</td>
<td>68.94</td>
<td>12.52</td>
<td>102</td>
<td>64.35</td>
<td>7.74</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>API100+</td>
<td>Number of days with API above 100 (Ministry of Environmental Protection)</td>
<td>72</td>
<td>44.41</td>
<td>35.6</td>
<td>102</td>
<td>27.94</td>
<td>20.15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ROAD</td>
<td>Urban road space per capita in m² (China City Statistical Yearbook, multiple years)</td>
<td>226</td>
<td>5.48</td>
<td>2.97</td>
<td>239</td>
<td>7.76</td>
<td>4.01</td>
<td>240</td>
<td>9.48</td>
<td>5.6</td>
</tr>
<tr>
<td>PVEH</td>
<td>Number of private motor vehicles per capita (Provincial Statistical Yearbooks, multiple years)</td>
<td>209</td>
<td>0.087</td>
<td>0.096</td>
<td>236</td>
<td>0.15</td>
<td>0.14</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GRN%</td>
<td>Parks and green space as % of built-up area (China City Statistical Yearbook, multiple years)</td>
<td>233</td>
<td>25.82</td>
<td>9.83</td>
<td>240</td>
<td>30.13</td>
<td>7.98</td>
<td>236</td>
<td>34.79</td>
<td>6.63</td>
</tr>
<tr>
<td>GRNpc</td>
<td>Parks and green space per capita (China City Statistical Yearbook, multiple years)</td>
<td>222</td>
<td>22.98</td>
<td>29.98</td>
<td>230</td>
<td>26.97</td>
<td>46.27</td>
<td>239</td>
<td>44.33</td>
<td>65.68</td>
</tr>
</tbody>
</table>

Note: POP, GDP, IND, ROAD, and GRNpc are measured for the area of urban districts. CARB is measured for the non-agricultural sectors within each prefecture’s administrative boundary.
5 Results

As discussed previously, this study pays specific attention to the relationship between the longitudinal variations in urban compactness and those in urban greenness indicators for more reliable inference of causal effects. For the purposes of understanding the existence and magnitudes of biases, and making use of data that are cross-sectional only (e.g., some cities only have data from a single year), we discuss the similarities and differences between our key findings and corresponding results based on cross-sectional variations.

5.1 Air Quality

Columns (1)-(4) in Table 2 present panel fixed effects results on the median API scores and the number of polluted (API > 100) days using city-level observations in 2005 and 2010. Restricted by the sample of city-level air quality data, the longitudinal analyses are based on samples of fewer than 60 cities. In general, an increase in density tends to benefit air quality by lowering median API and reducing the number of polluted days per year, consistent with earlier findings in the U.S. (Frank et al., 2000; Stone et al., 2007) and also with the cross-sectional results based on our data (not reported here).\(^4\) According to the results in columns (2) and (4), a ten-percent increase in density roughly reduces median daily API by 0.9 (or on average about 1.4%) and polluted days by 2.7 (or on average about 8%). This suggests that an increase in density improves air quality more effectively when air pollution is severe. Nevertheless, density’s beneficial effects on urban air quality are statistically significant only when density is calculated based on satellite data. Results of mean API are very similar to those of median API.

| TABLE 2 Air Quality and Carbon Emissions 2005-2010 Fixed Effects |
|------------------|------------------|------------------|------------------|------------------|------------------|
|                  | (1)              | (2)              | (3)              | (4)              | (5)              | (6)              |
|                  | API\(_{med}\)    | API\(_{med}\)   | API\(_{100+}\)  | API\(_{100+}\)  | ln(CARB)         | ln(CARB)         |
| ln(POP)          | -0.595           | 9.542            | -18.98           | 11.32            | 0.557***         | 0.718***         |
|                  | (5.293)          | (9.891)          | (12.52)          | (26.13)          | (0.0681)         | (0.0774)         |
| ln(DEN\(_{yb}\))| -1.457           | -2.894           | -0.0713*         | (2.405)          | (4.720)          | (0.0422)         |
| ln(DEN\(_{rs}\))| -24.9*           | -72.69*          | -0.453**         | (13.74)          | (37.65)          | (0.181)          |
| ln(GDP)          | -11.84***        | -21.39***        | -57.94***        | -0.518***        | 0.518***         | 0.340***         |
|                  | (3.989)          | (7.327)          | (20.48)          | (0.0375)         | (0.0552)         |
| IND              | 0.184            | 0.238            | -0.175           | 0.0576           | -0.00314         | -0.000566        |
|                  | (0.208)          | (0.240)          | (0.610)          | (0.680)          | (0.00270)        | (0.00223)        |
| No. of cities    | 58               | 55               | 58               | 55               | 181              | 92               |
| Adj. R\(^2\)    | 0.401            | 0.403            | 0.469            | 0.482            | 0.968            | 0.969            |

Note: standard errors in parentheses; * p<0.10, ** p<0.05, *** p<0.01; coefficients of constants omitted.

\(^4\) Cross-sectional OLS regressions include the variables from the fixed effects model and local climate variables – long-run average January temperature, annual precipitation, wind speed, and year fixed effects.
Among other covariates, as cities get richer (higher in per capita GDP), API scores drop significantly (air quality gets better). In fact, as per capita GDP doubles, the number of days with polluted skies reduces by 20 days to 40 days according to columns (3) and (4), respectively. On the other hand, a change in urban population bears no power in explaining longitudinal variation in urban air quality. The results regarding income level and population size differ from previous cross-sectional analyses of correlations such as Sarzynski (2012), which finds that across urban areas worldwide, urban population positively correlates with air pollution, while income growth appears to be weakly correlated with air quality improvement. Perhaps surprisingly, the share of the industrial sector in urban economy does not explain longitudinal variation in air quality either. A potential explanation for this might be technological changes associated with industrialization. That is, due to technological advances and/or scale economies, greener technologies (e.g., those adopted by plants established by foreign direct investments) replace older and dirtier capital (e.g., legacy state-owned firms or small private firms) as the industrial sector expands.

5.2 Carbon Emissions

We find that density tends to reduce per capita carbon emissions, as shown in columns (5) and (6) in Table 2. While the magnitudes of the estimated elasticities in columns (5) (ε=-0.07) and (6) (ε=-0.45) differ, an increase in urban density does seem to reduce per capita carbon emissions, though less than proportionately. While much weaker than the longitudinal results, cross-sectional evidence also suggests that denser cities tend to be more carbon efficient on the per capita basis. Overall our results on the density-carbon emissions relationship are consistent with previous studies, although most of which focus on the transportation sector instead of total urban carbon emissions.

Different from the decarbonization effect of density, both population and income growth tend to increase carbon emissions per capita. This suggests that even compact urban development may still result in an increase in per capita carbon emissions as population and income grow. Similar to the findings in the air quality results, the share of the industrial sector in local economy has little, if not a negative effect on per capita carbon emissions. Again, innovation and/or scale economies may have contributed to such findings.

5.3 Motorization

Table 3 shows that an increase in density consistently reduces per capita stocks of both road and vehicle capitals. Per capita road space shrinks by 3.7% to 5.5% as density increases by 10% according to results of columns (1) and (2), respectively. This is intuitive because road expansion in a city costs increasingly more as population density increases. Similarly, as density increases, road congestion and increased cost of parking may deter people from owning cars. A 10% increase in density reduces private automobile ownership rate by up to 18.6%, as shown in column (4). These results are qualitatively consistent with the results obtained from the cross-sectional evidence based on our data. They are also consistent with the overall findings of Ingram and Liu (1997) both across cities and over time within cities across the world.

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5 The cross-sectional regressions also control for winter temperature and year fixed effects.
TABLE 3 Road Space (2000-2010) and Vehicle Ownership (2005-2010) Fixed Effects

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ln(ROAD)</td>
<td>-0.18</td>
<td>0.17</td>
<td>1.117***</td>
<td>1.631***</td>
</tr>
<tr>
<td></td>
<td>(0.255)</td>
<td>(0.171)</td>
<td>(0.282)</td>
<td>(0.323)</td>
</tr>
<tr>
<td>ln(ROAD)</td>
<td>-0.373***</td>
<td>-0.276</td>
<td>-0.555***</td>
<td>-1.859***</td>
</tr>
<tr>
<td></td>
<td>(0.0862)</td>
<td>(0.173)</td>
<td>(0.153)</td>
<td>(0.473)</td>
</tr>
<tr>
<td>ln(PEVH)</td>
<td>0.490***</td>
<td>0.458***</td>
<td>1.087***</td>
<td>0.602**</td>
</tr>
<tr>
<td></td>
<td>(0.0786)</td>
<td>(0.0767)</td>
<td>(0.138)</td>
<td>(0.236)</td>
</tr>
<tr>
<td>No. of cities</td>
<td>202</td>
<td>105</td>
<td>175</td>
<td>98</td>
</tr>
<tr>
<td>No. of years</td>
<td>2-3</td>
<td>2-3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Adj. R^2</td>
<td>0.714</td>
<td>0.749</td>
<td>0.793</td>
<td>0.811</td>
</tr>
</tbody>
</table>

Note: standard errors in parentheses; * p<0.10, ** p<0.05, *** p<0.01; coefficients of constants omitted.

As expected, per capita GDP growth positively affects both stocks of road and vehicle capitals. The estimated elasticities of private vehicle ownership range from 0.6 to 1.1, likely due to the difference in the samples of columns (3) and (4). Compared to road space, vehicle ownership is estimated to be more elastic to income, indicating a reason for the increasing congestion as income grows in Chinese cities. Population growth does not affect road capital, but associates with a significant rise in per capita private vehicles, with an elasticity greater than one. This is understandable because as cities grow larger in population and area (note that population density is controlled), travel distances of various trips increase, which may motivate people to purchase private vehicles.

Unfortunately, we lack the longitudinal data to shed light on urban compactness’ effects on travel behavior. As a partial remedy, we present some cross-sectional evidence to supplement the above longitudinal results. Table 4 presents results from comparing the shares of commuters walking and by car across Chinese cities using data from the 2010 China Urban Household Survey (UHS), which is a large-scale stratified random survey of more than half a million urban households in Chinese cities. We find that while urban population density’s relationship with the share of commuters by car is inconclusive, density positively associates with the percentage of commuters walking. This suggests that while increasing density in Chinese cities reduces the

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6 The small sample of column (4) includes larger and on average higher-income cities. Our result that these cities have smaller income elasticity is consistent with previous studies showing that income elasticity depends on income level (e.g., Dargay and Gately, 1999).

7 We obtained mode split data from 245 cities at the prefecture and above levels. While we do not have the exact sample size of each city, we know that most cities have more than a thousand households in their effective samples. For example, Beijing, a provincial-level city, has a sample of 15,000 households; Changzhou, a city with 3.2 million residents in 2010, has more than 2,000 households in its sample.

8 This is different from early cross-sectional studies (e.g., Kenworthy and Laube, 1996, 1999) showing strong negative correlation between automotive use in cities and population density across the world. However, a more comprehensive worldwide analysis (JICA, 2011) suggests that while higher density reduces car ownership and use, the correlations are only strong when per capita GDP exceeds US$10,000, which is higher than that of almost all Chinese cities.
supply of road and car ownership, it may have limited effects on the use of cars. Instead, density may contribute to urban greenness by allowing more walking trips. Expected effects are found for the controlling variables including population size, GDP per capita, and a dummy variable indicating the four cities with operational urban rapid rail transit in 2010 (Guangzhou, Nanjing, Shenzhen, and Wuhan).

**TABLE 4** Commuter Mode Split Cross-Sectional Estimates

<table>
<thead>
<tr>
<th></th>
<th>(1) WALK</th>
<th>(2) WALK</th>
<th>(3) CAR</th>
<th>(4) CAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>ln(POP)</td>
<td>-0.0433*** (0.0123)</td>
<td>-0.0395** (0.0160)</td>
<td>0.0261*** (0.00614)</td>
<td>0.0499*** (0.0101)</td>
</tr>
<tr>
<td>ln(DEN_y)</td>
<td>0.0528** (0.0227)</td>
<td></td>
<td>0.007 (0.0113)</td>
<td></td>
</tr>
<tr>
<td>ln(DEN_n)</td>
<td></td>
<td>0.0745*** (0.0193)</td>
<td></td>
<td>-0.00314 (0.0122)</td>
</tr>
<tr>
<td>ln(GDP)</td>
<td>-0.0703*** (0.0185)</td>
<td>-0.0450* (0.0230)</td>
<td>0.0647*** (0.00923)</td>
<td>0.0773*** (0.0145)</td>
</tr>
<tr>
<td>RAIL</td>
<td>0.0956 (0.0657)</td>
<td>0.0815 (0.0581)</td>
<td>-0.0388 (0.0328)</td>
<td>-0.0787** (0.0368)</td>
</tr>
</tbody>
</table>

Sample cities: 240 133 240 133
Sample years: 1 1 1 1
Adj. R²: 0.227 0.255 0.341 0.409

Note: standard errors in parentheses; * p<0.10, ** p<0.05, *** p<0.01; coefficients of constants omitted.

5.4 Park and Green Space

While urban park and green space is an important component of urban greenness, urban compactness has a different implication for park and green space from the previous aspects of urban greenness. Table 4 shows that increasing density reduces per capita park and green space, with elasticity ranges from -0.51 to -1.38, according to columns (1) and (2), respectively. Even when measured as percentages of urban area, park and green space seems to be negatively affected by density increase, although the effect is statistically insignificant, as indicated in columns (3) and (4). The cross-sectional regressions result in similar findings – denser cities have smaller per capita park and green space and statistically indifferent from less dense cities in terms of the ratio of land used for parks and green space.¹⁰ Thus, the fixed effects and cross-sectional results are consistent overall.

**TABLE 4** Park and Green Space 2000-2010 Fixed Effects

<table>
<thead>
<tr>
<th></th>
<th>(1) ln(GREEN_pc)</th>
<th>(2) ln(GREEN_pc)</th>
<th>(3) GREEN%</th>
<th>(4) GREEN%</th>
</tr>
</thead>
<tbody>
<tr>
<td>ln(POP)</td>
<td>0.211 (0.236)</td>
<td>0.869*** (0.350)</td>
<td>9.723*** (2.016)</td>
<td>8.505*** (2.906)</td>
</tr>
</tbody>
</table>

⁹ The mode shares of walk and car by commuters are 30.08% (s.d.: 13.9%) and 11.11% (s.d.: 7.44%), respectively.
¹⁰ 30-year average January temperature, annual precipitation of each city, and year fixed effects are controlled in the cross-sectional regressions.
As for the effects of population and income growths, both seem to increase park and green space in cities. The GDP effect is intuitive because richer cities may demand more parks and green space and are more capable to provide them. The city size effect, on the other hand, may reflect that new growth areas are on average planned with more park and green space compared to older parts of cities.

### 6 Conclusion

Many aspects of the urban environment important for public and ecosystem health, global climate change, and quality of life may relate to the choice of compact or sprawling development. However, systematic and robust evidence, especially evidence based on longitudinal data, remains insufficient, in particular in the rapidly urbanizing economies. Our study strengthens the urban policy and planning literature with the much needed longitudinal evidence and fills the gap of empirics in the Chinese context.

Using longitudinal data of Chinese cities during 2000-2010, we investigate the relationship between the compactness of urban growth, measured by the average population density, and various indicators of urban greenness. We estimate panel fixed effect models while controlling for major city-level demographic and economic characteristics. Our results support the widely held belief that compact urban growth can improve air quality and reduce per capita energy use and carbon footprint. This is crucial as cities contribute to 84% of China’s commercial energy usage and about 75% of its total energy usage (Dhakal, 2009). Results also suggest that compact development reduces the growth in road capital and vehicle ownership, although its contribution to urban greenness may be more important in terms of promoting walking instead of reducing driving. While increasing density may not negatively affect the proportion of urban area used for park and green space, it reduces its per capita amount. Of course, denser cities may compensate for the reduction with better access to park and green space, as suggested by Ståhle (2008), which finds that citizens in some dense inner city districts experience higher green space accessibility than citizens in some low-density “green” suburbs in Stockholm. It is worth to note that although the estimated fixed effects and cross-sectional coefficients (results available upon request) differ for the control variables, they are relatively consistent regarding the urban compactness – greenness relationships. This suggests that for the specific empirical question we
investigate, evidence based on cross-sectional data may not subject to serious bias from endogeneity.\(^{11}\)

While the key results are qualitatively consistent between models using alternative measures of urban BUA (official statistics and satellite image-based data), differences in terms of magnitude and statistical significance remain. We suspect that the satellite image-based urban area estimates are more accurate because the regressions’ goodness-of-fit statistics (adjusted R-squares) are generally bigger when density is calculated based on satellite data, especially given that the sample sizes are usually smaller when we do so. We further perform robustness checks by restricting the samples to be the same between the models using different density measures. The results are only marginally different from our main findings, suggesting that it is the difference between the two BUA data sources, rather than the samples, that resulted in the quantitative differences found.

Overall, this study finds that all else equal, compact urban growth is likely to make Chinese cities greener. This provides Chinese cities supportive evidence for higher density as opposed to lower density development. It may also inform urban policy makers and planners in emerging economies with similar income and density levels. Nevertheless, one should keep in mind that per capita spatial resources such as road, park, and green space will likely shrink as cities get denser, especially since Chinese cities have been historically less abundant in these resources (e.g., See Ng et al., 2010 for the gap in per capita road space between Chinese cities and major western cities). It is important thus for the government to improve the efficiency of the use of these resources to offset the potentially negative consequences of compact development. For example, land use planning may emphasize transit-oriented and non-motorized modes-friendly development. Creating better access to urban parks and green space will also help maintain the quality of life in dense cities.

Needless to mention, additional research in the future is necessary, especially given the constraints in the quantity and quality of data available to us. It is important to explore more and have better measurements of urban greenness (or sustainability). Aspects such as the availability and quality of fresh water, heat island effect, and land contamination are arguably missing from our examination. More detailed data on travel behavior can help further reveal the direct connection between compactness and energy/carbon footprint of urban transportation. Innovative sources of data such as satellite-based land use information could provide crucial information regarding the quality of statistics that are more subjected to manipulation while often unchecked by researchers. Last but not least, repeated observations of important variables should greatly increase the robustness of inference.

\(^{11}\) Some may argue that in this case, we should use both the within (longitudinal) and the between (cross-sectional) dimensions of data to estimate the density-greenness relationship. That is, we should report the more efficient random effects (RE) instead of fixed effects (FE) results. However, the Hausman test (Hausman, 1978) results we obtained indicate that only about half of the null hypotheses are not rejected, meaning there is still some non-negligible differences between the RE and FE results. Even when the RE specifications pass the Hausman test, there is no guarantee that the within and between variations represent the same mechanisms of causal effects. Given the significant differences between the estimated coefficients of the control variables, and the fact that we have significant longitudinal variation in urban density already in our data, we choose to rely solely on the more conservative FE results.
References


