Sustainability **2014**, *6*, 5876-5897; doi:10.3390/su6095876

OPEN ACCESS

sustainability

ISSN 2071-1050

www.mdpi.com/journal/sustainability

Article

Understanding Density in an Uneven City, Santiago de Chile: Implications for Social and Environmental Sustainability

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Received: 29 April 2014; in revised form: 14 August 2014 / Accepted: 15 August 2014 / Published: 2 September 2014

Abstract: Efforts to promote infill development and to raise densities are growing in many cities around the world as a way to encourage urban sustainability. However, in cities polarized along socio-economic lines, the benefits of densification are not so evident. The aim of this paper is to discuss some of the contradictions of densification in Santiago de Chile, a city characterized by socio-spatial disparities. To that end, we first use regression analysis to explain differences in density rates within the city. The regression analysis shows that dwelling density depends on the distance from the city center, socioeconomic conditions, and the availability of urban attributes in the area. After understanding the density profile, we discuss the implications for travel and the distribution of social infrastructures and the environmental services provided by green areas. While, at the metropolitan scale, densification may favor a more sustainable travel pattern, it should be achieved by balancing density rates and addressing spatial differences in the provision of social services and environmental amenities. We believe a metropolitan approach is essential to correct these spatial imbalances and to promote a more sustainable and socially cohesive growth pattern.

Keywords: density; urban sustainability; socio-spatial segregation; travel; social services; green areas; Santiago de Chile

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1. Introduction

Looking at the big picture, building dense cities and densifying urban areas are desirable planning goals. In several parts of the world densification policies are being implemented to contain population growth within the built area and to reduce suburbanization. The rationale for infill development and densification, is that high-density, compact developments are meant to be more sustainable, socially cohesive, and economically efficient urban forms since they help protecting farmland and open space, they encourage walking and the use of mass transportation, they contribute to social cohesion by bringing together people from different social backgrounds, and they allow a more efficient and intensive use of urban resources because less public expenditure is required to support services and infrastructures (see [1–4] for an overview of this debate and [5,6] for a critique of the arguments for densification and compact urban forms).

However, density is a multifaceted concept. Depending on its meaning and definition, the rationale, the specific objectives, and the scale, density, and densification, can have several meanings. Moreover, the distribution of buildings and population within a city is very uneven, thus, although increasing overall density rates may be a desirable planning goal at the metropolitan scale, it can deepen contradictions within the city depending on how it is obtained. For instance, promoting infill development and containing suburban sprawl may contribute to a more efficient use of services and a more sustainable transportation choice, but at the expense of housing affordability and more access to green space in particular areas of the city [7]. Density also allows for a better access to services because social infrastructures are closer, but it may worsen neighborhood problems and area dissatisfaction [8].

These contradictions are further complicated in cities polarized along socio-economic lines. In Latin American cities (and in much of the non-Western world), density rates differ dramatically across areas and, as such, there are strong differences in mobility, accessibility and the use of social infrastructures and amenities. In this social context, the debate on density and sustainability should go beyond the coordinates "suburbanization" *vs.* "compactness" and consider, critically, the living conditions and the accessibility to opportunities for people from different social strata due to the spatial distribution of houses, jobs, services, and urban amenities.

The aim of this paper is to provide a framework for discussing densification in cities where strong socio-spatial disparities persist. We illustrate these issues for Santiago de Chile, a socio-spatially segregated city [9], where the debate on densification as a mean to contain built-up area sprawl is going on. To that end, we first analyze the relationship between density and several urban attributes, in order to understand what the drivers of densification are. Economic theory has shown that the density profile of a city is basically a function of income, accessibility, and living space, *i.e.*, as income rises, households tradeoff between accessibility and living space, thus, density declines with the distance from the city center, where workplaces, services, and amenities are closer to each other. However, residential choices also vary depending on the availability of urban attributes, thus, the density profile may also be explained by the distribution of these urban features across the city. Our hypothesis is that density depends on the distance from the center and the functional organization of the city, as well as on the availability of urban attributes, such as social equipment and green areas, and the neighborhood conditions. In a city polarized along socio-economic lines, where the distribution of urban attributes and the neighborhood condition vary strongly across areas, the access to social opportunities is severely affected. Thus, our research aims at understanding the role of these urban features in explaining the density profile, in order to discuss its implications for social equity and environmental sustainability.

We focus on two issues we believe deserve particular attention. First, on accessibility and travel. The academic literature has advocated for densification as a way to reduce automobile usage and to encourage a more sustainable transportation pattern. In Santiago, the spread of the built-up area and rising incomes are leading to a rapid motorization that has major consequences for congestion and air pollution, thus, land use intensification could help containing population and foster the use of mass transit, walking, and cycling. However, given the strong disparities in density rates, densification policies may need to be compensated in high-density areas to attain a more rational transportation pattern. Second, we discuss the implications for the distribution of social infrastructures and the environmental services provided by green areas. High-density areas of the periphery lack adequate social infrastructures and green areas, thus, understanding the implications of density and densification policies is a key question for redressing these deficits in the provision of social and environmental services.

We support our claims on Geographic Information System (GIS), regression and statistical analysis. The geographical analysis lied in mapping the density profile and the distribution of economic activities, social equipment and green areas. The distribution of these urban features was analyzed at the census district level, the scale that fits best the neighborhood. Regression analysis correlated dwelling density with neighborhood attributes and socioeconomic variables. In addition, mobility and socioeconomic indicators were analyzed at the *comuna* (municipality) level, to discuss the implications of the density profile for mobility and accessibility to economic activities, social infrastructures, and the environmental services provided by green areas.

The remainder of the paper is organized in eight sections. Section two provides a literature review of the relationship between density and sustainability, underlying the implications of densification for sustainable planning. We focus on three issues: the theories that explain the density profile of a city; the impacts of density on the environmental, social, and economic dimensions of sustainability; and the problems and contradictions that arise when promoting densification. After the literature review, the density profile of Santiago is explained. In Section 4 the research methodology and the data are explained. Section 5 presents the results of the regression analysis. In Sections 6 and 7, the implications for accessibility and the urban living conditions of the density profile are discussed. Finally, the paper concludes by raising some key issues that should be considered when discussing densification in cities characterized by socio-spatial polarization.

2. Literature Review

2.1. Explaining the Density Profile of a City

Density is probably, the single variable that summarizes best the urban form [10]. In general terms, density can be defined as the number of physical units or people in a given geographical unit, but this simple definition masks an elusive concept that depends on what is being considered in the numerator (people, dwellings, jobs, *etc.*) and the denominator (total area or residential area, gross or net), the data source and the analytical tools (census statistics, GIS, satellite images), and the scale (the dwelling, the block, the neighborhood, the district, the municipality, the city, the metropolitan area, the country) (see [11] for an exhaustive overview).

In fact, although density provides a first approach to a city's growth pattern, the distribution of people in different parts of the city can vary significantly. The density profile reflects the spatial variations in density rates within a city. In cities with market-oriented economies population density usually declines with the distance from the city center. As explained by the Alonso-Mills-Muth model, households tradeoff between accessibility to workplaces and services, which are usually set in central areas, and living space. Consequently, densities are higher closer to the Central Business District (CBD) as competition for land increases prices and living space has to be reduced to make real estate investments profitable, whereas in the suburbs lower pressure on land allows bigger dwellings. In theoretical terms, this location pattern has been summarized by a population density distribution in which density declines exponentially with the distance from the city center [12,13]. However, cities are increasingly complex, thus, rather than a single center, a polycentric structure fits better the contemporary city's functional organization. As a result, high-density areas may be close to the several subcenters. On the other hand, distance alone fails to explain much of the spatial variation of densities, but these are also related to the spatial distribution of other urban attributes. Indeed, neighborhood amenities and services play an important role in the determination of densities, not only at the intra-metropolitan level [14,15] but also between metropolitan areas [16].

2.2. Density and Sustainability

Density is a key dimension of urban sustainability. It reflects the intensity of land use and thus has major consequences for a sustainable use of urban resources. Densification, for instance, is seen as an alternative to contain population within the already built area, which allows for a more efficient use of previously developed urban area and helps protecting agricultural and undeveloped land. It can also favor more sustainable transportation choices. In dense and compact urban areas people usually walk, cycle and use mass transit more frequently because of the better connectivity and the shorter distance to final destinations. In social terms, density is related to social equity and diversity because it favors access to social infrastructures and encourages a more diverse, inclusive, and livable urban environment by facilitating opportunities for social interaction. Economically, a minimum density is necessary for an efficient use of urban resources and to reduce the cost of providing infrastructure. These arguments have been very influential in planning and there have been widespread claims to raise density as a mean to achieve a more sustainable urban growth pattern, although they have also been criticized for not being empirically grounded and not guaranteeing the alleged benefits. Let us discuss, in more detail, some of the implications of density and densification for sustainable planning.

The relationship between density and travel is probably the most widely studied. In their seminal work, Newman and Kenworthy [17] associated transport energy consumption to density. Other studies confirmed that density is related to distance [18], modal choice [19], and energy consumption [20]. The density effect is due to better walking conditions, shorter distances to transit service, and less free parking in dense areas compared to low-density, suburban areas [21]. The impact on travel time is ambiguous because shorter distances are offset by congestion [22], but ultimately fuel consumption per capita is usually less because people drive much less in densely populated areas [4]. These arguments have been criticized in several ways. Some argue that the impact of urban form on travel cannot be reduced to a single variable because other variables also have influence [23]. In addition, density and travel may be correlated but this does not necessarily mean causality between them [24]. Last, the implications of density and compactness have been very influential in urban planning, although their benefits were not fully tested [6].

Dense residential developments may also contribute to a more efficient use of land, resources, and infrastructure. Higher density benefits land preservation by putting less pressure to convert habitat and farmland to urban uses [25]. Nevertheless, high density may also result in the loss of open and recreational space within the built-up area [1]. Less open space is likely to have adverse effects on urban biodiversity and on the ecosystem services provided by green areas; additionally, it can also limit recreational opportunities. There is also evidence that high-density development patterns require lesser public expenditures to support services and infrastructures than do low-density developments [26–28]. The relationship, however, may not be linear, but U-shaped, that is, expenditures decrease first as density increases, but, beyond a threshold, expenditures increase with higher densities [29].

Other dimensions that are linked to density are social equity and the quality of urban life, although the direction of this relationship is far from clear. Higher residential density promotes resident interaction and sense of community if well combined with other physical design attributes (architectural design, streets that encourage urban life, public space, mixed land use) [30]. In this sense, it can reduce social segregation and isolation by enhancing local social capital [11]. The impacts on social integration depend, however, on how density is combined with other urban attributes and infrastructures since otherwise can limit equal access to social opportunities. In this vein, Bramley and Power found contradictory results on the impacts of compact urban forms on social sustainability; according to their analysis, density worsens neighborhood problems and area dissatisfaction, while improving access to services [8].

2.3. Densification Policies

Despite the, sometimes, ambiguous effects of high-density, concerns about raising densities are growing in several parts of the world [2,3]. There are essentially three ways to densification [31]: direct state-driven interventions (through, for example, public housing provision); supply-side policies via stimuli (incentives) to market producers or, contrary, land use regulations; or demand-side measures, for example using taxation to influence households' location preferences (*i.e.*, taxing differently various housing types, or increasing the cost of using car).

However, densification is a complex process that often faces several problems. Housing consumption patterns in Europe, North and South America reveal that a large part of the population prefers low-density, suburban developments, although certainly there are groups who seem to attach relatively more value to centrality and live at higher densities than would be expected from their incomes. If this is the case, urban planning has to reorient individual preferences and correct market outcomes in the name of improving social, economic, and environmental performance. In addition, fostering infill development may be particularly troublesome in already built-up areas, as people often oppose densification because it is associated with crowding and thus perceived by residents as a factor that erodes the aesthetic quality of the neighborhood [32]. Lastly, densification may not be the most effective solution in every case. The potential of fostering infill development is limited because it operates at the margins represented by new construction since new buildings are just a small portion of the housing stock [33]. In fact, depending on the specific planning objective other tools may be more effective, for example, changes in transportation costs for reducing car dependency or zoning and land use regulations for preserving natural land [34].

3. The Density Profile of Santiago

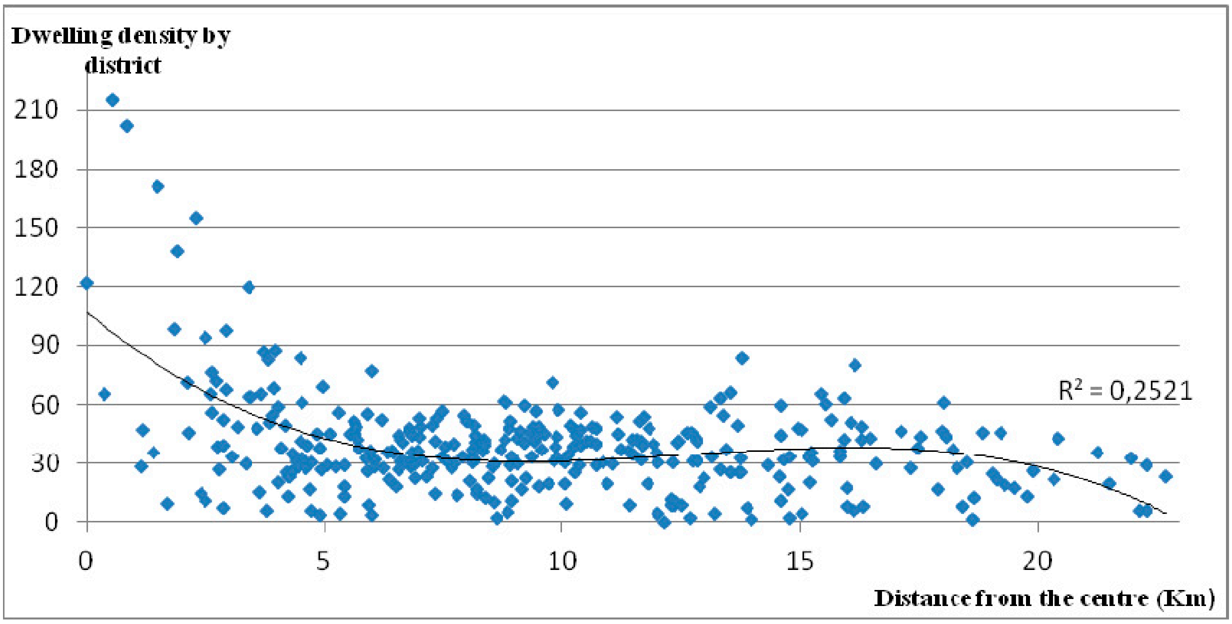
The Santiago Metropolitan Area (SMA) is an urban area of 6.1 million inhabitants, the 35% of the total population of Chile (INE, Estimated population density 2012). SMA is composed of the 32 *comunas* (municipalities) of the Santiago province, plus the adjacent *comunas* of San Bernardo and Puente Alto, and covers 84,000 ha and a continuous urban area that is estimated to slightly exceed 60,000 ha [35]. Population and the built footprint have expanded steadily over the past three decades driven by the economic dynamism of the city, although the built area has grown at a higher rate than population, meaning a decrease in density rates [36]. Nevertheless, residential density within the built-up area is 84 inhabitants per ha, which is medium by international standards (see demographia for international comparisons).

There are strong differences in density rates within the metropolitan area. As mentioned above, for most cities with market-oriented economies density declines with the distance from the city center. This pattern holds for Santiago (Figure 1). However, density also depends on households' socio-economic conditions. Figure 2 shows dwelling density at the census district level in 2011 (mind that the darkest areas represent the 75, 90, and 99 percentiles, respectively, to show where the very high density areas are). Although residential density indicates better than dwelling density the distribution of population across space, the latest residential density data comes from the 2002 census, too old for an updated density profile; nevertheless, residential density and dwelling density are strongly correlated, thus, Figure 2 fairly reflects the spatial distribution of population. The densest districts are located in the city center and the low-income peripheral *comunas* of the South and the Northwest. Accessibility to employment and services explain the density of the central area, whereas social housing is responsible for the high-density rates in the periphery. In Chile the housing facilities provided by the state have been extensive since its main objective was to reduce the housing deficit [37], but the emphasis on reducing the housing deficit neglected the impacts on the urban form. Maximizing housing supply led to peripheral locations and numerous houses per project in order to reduce construction costs, thus spreading the urbanized land and concentrating large parts of population in these areas.

The density profile of SMA reflects the spatial distribution of households along socio-economic lines. Santiago stands among the most unequal cities in the world, with an income-based index GINI of 0.55 (the UN set the alert line of inequality on an income based GINI of 0.40; other Latin American cities above this line are Bogotá (0.61), Mexico City (0.56), Quito (0.54), Rio de Janeiro (0.53), Buenos Aires (0.52), Guatemala City (0.50) and Montevideo (0.45), whereas, below, stands Caracas (0.39)) [38]. In Figure 3 the spatial distribution of household income is displayed (mind that the scale is the *comuna* because the latest income data at the census district level comes from the 2002 census). Santiago is socio-spatially segregated [9,39]: richest *comunas* are clustered in the northeast cone (Providencia, Vitacura Las Condes, Lo Barnechea) whereas the poorest spread to the south and the northwest.

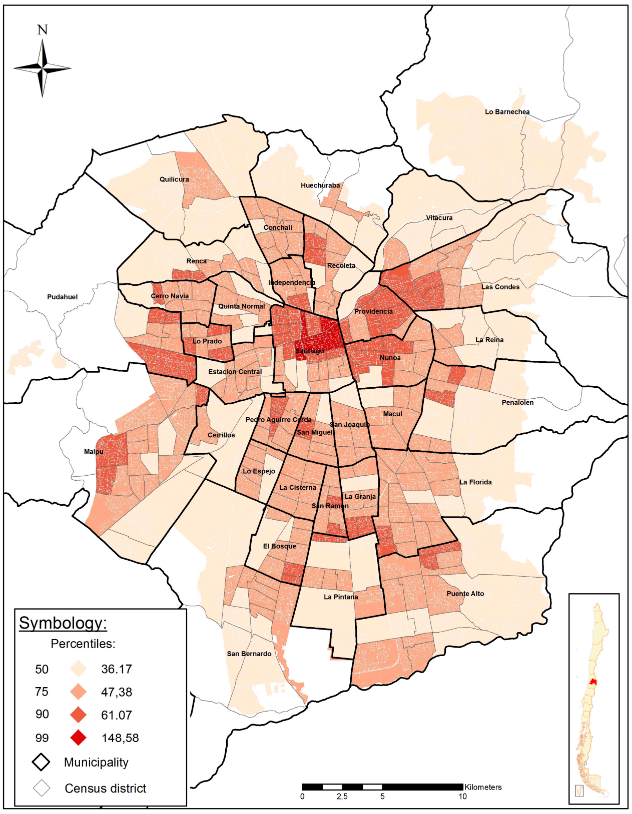
Residential segregation in Santiago, as well as in other Latin American cities, has historical roots, but it seems that recent changes in the urbanization pattern by both the public and the private sector are changing its dimension and characteristics. Social housing is being decentralized further out from the metropolitan area, which is deepening accessibility related inequalities and worsening living conditions since they often lack basic social services and infrastructures [40]. Additionally, new residential patterns for the elite are also emerging on peri-urban land and some working-class *comunas*. Since the 1990s, intra-metropolitan migration from inner city to the periphery has been taking place (almost every central *comunas* lost population, whereas some peripheral *comunas* experienced population growth rates of 200%). New residential developments in peri-urban areas include low-density, scattered mega-projects (up to 50,000 inhabitants), many of them designed as gated-communities [36,41]. Along with the urban fringe, upper-income groups are also moving to traditional *comunas* where social housing prevails. This is quite a new phenomenon since historically socio-spatial division was at the *comuna* scale, but the new residential patterns of middle- and high-income dwellers are transforming the homogeneous social structure of these *comunas*. This phenomenon, however, is not leading to a social mix but to a reduction on the geographical scale of segregation [9]. Richer and poorer neighbors locate closer to one another but this *results in 'tectonic' juxtapositions of polarized socioeconomic groups rather than in socially cohesive communities* [42] (pp. 2458). Nevertheless, some positive effects for social integration have also been pointed out, such as bringing jobs into the neighborhoods, improving public services and even sparking a renewed sense of pride among lower-class residents [43]. Regarding densities, the new location pattern of upper-classes is balancing density rates at the *comuna* level but increasing fragmentation inside the *comunas*, as lower density residential developments cluster close to high-density housing for low-income dwellers.

Figure 1. Relationship between dwelling density and the distance from the center (km), sorted by district.



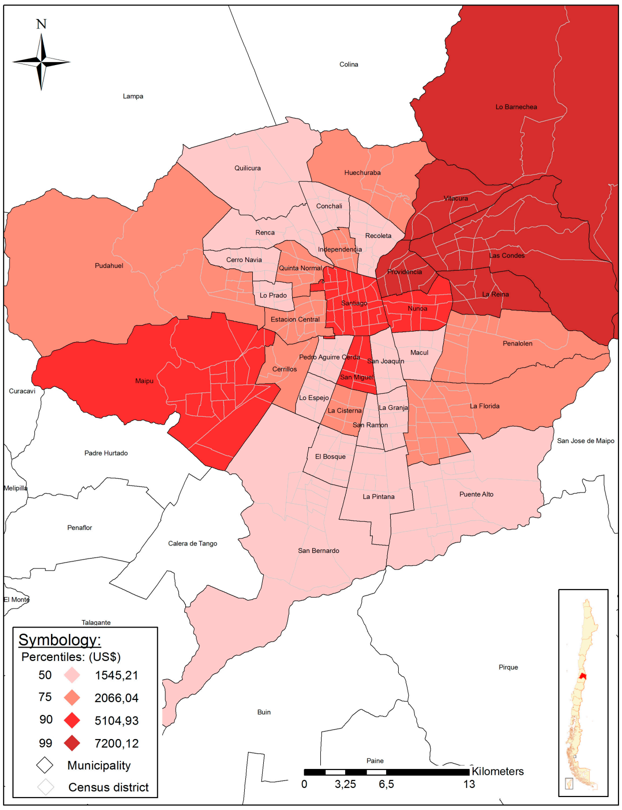
Source: Author's own elaboration based on the Pre-census data.

Figure 2. Dwelling density at the census district level (2011).



Source: Author's own elaboration based on the Pre-census data.

Figure 3. Household income by *comuna* (2011).



Source: Author's own elaboration based on SINIM data.

Along with the housing policy and households' location preferences, planning has been a major force in shaping the density pattern of Santiago, particularly since the orthodox neoliberal reforms of the late seventies. In 1979, the Military Government launched the so-called "National Policy of Urban Development", which incorporated free market principles into urban planning. The land market was the mechanism to decide between agricultural or urban uses and thus, market forces guided the spread of the urban fringe [44]. In fact, an urban growth boundary of 100,000 ha was established, when, at that time, the built-up area was around 40,000 ha. These radical changes had major consequences as the boundary had no real effect in controlling the spread of the urbanized area and low-density residential patterns emerged in the periphery and along main transportation axis. In 1994, a new plan was approved to correct some of the spatial imbalances produced by the neoliberal policies. The Santiago Metropolitan Regulatory Plan (SMRP) was committed to control the excessive spatial growth and the urban area was reduced to 60,000 ha. It also increased density rates to 150 inhabitants per ha and reinforced central government's role in planning [45]. However, in 1997, the SMRP was modified to extend the urban area 17,000 ha and to stop the densification process started three years before. It also introduced conditional planning, by which the private sector was responsible for providing the infrastructures needed in the new residential developments. Conditional planning introduced the private sector into planning and contributed to a further segmentation of the housing market since the new residential areas were targeted for middle- and high-income households, whereas almost no social housing was constructed in these areas [46]. In 2003, the SMRP was again updated to include some southern and western areas within the city limit and in 2013 a new amendment was approved to extend the city other 10,000 ha and to define average and maximum density rates.

The many changes in metropolitan planning during the past two decades reflect the difficulties of regulating the spatial growth pattern of Santiago. The successive extensions of the urban area were aimed at regulating the inorganic growth of some areas but, on the other hand, encouraged new residential developments in the periphery, contributing further to the spread of the urban footprint. By contrast, densification was not considered as a mean to reorient urban growth within the city limits, with the exception of the 1994 SMRP and some local plans. In the central *comuna* of Santiago an inner-city recovery program was implemented to attract middle- and high-income residents, but, at the metropolitan scale, densification has not been a priority. The latest amendment included average and maximum density rates for different areas of the city, but these were intended to meet technical norms, not strategic goals.

4. Data, Research Strategy and Variables

After characterizing the density profile of SMA, in this section we deal with the research strategy and the data used to understand the role of urban attributes in explaining density and its social and environmental implications.

The research strategy comprised three stages. First, a geographical analysis was conducted at the neighborhood level to understand the density profile of SMA. The census district was chosen as the scale for the analysis because it is the geographic unit closest to the neighborhood. Block and census district data came from the 2011 pre-census, the information gathered previously for the 2012 census. The 2012 census data was not available due to technical problems in the census design and the previous 2002 census was considered too old given the socio-demographic changes of the past decade, so the 2011 pre-census information was judged as optimal. The pre-census compiled physical information of dwellings, commercial and productive activities, social infrastructures, green areas, and the streets' state of conservation. This information was geocoded and analyzed at the block and census district level using ArcGIS 10 software. Geographical analysis included mapping the density profile of Santiago, the distribution of productive and commercial activities, green areas, social equipment, and transport infrastructures.

In addition, regression analysis was carried out to analyze what neighborhood attributes have an influence on the density profile. As mentioned, the academic literature has explained density variations as a product of the functional organization of the city, *i.e.*, the distance to the city center, the distribution of productive activities, and the availability of services and amenities in the area. Given this theoretical framework, the following equation was considered to investigate the relationship between density and urban characteristics in Santiago

$$d = f(FO, SE, NC, GA) \tag{1}$$

where d, dwelling density, is a function of: the functional organization of the city (FO), including the distance to the city center and the distribution of productive and commercial activities; the social equipment (SE), including schools, sport facilities and other social services; the neighborhood condition (NC), including the quality of streets and sidewalks and the availability of facilities; and the green areas (GA). Dwelling density was considered as the dependent variable instead of population density, because it reflects land use intensity and, besides, it was the only variable available from the pre-census (nevertheless, in the 2002 census, dwelling and population density were correlated, R^2 = 0.84). The distance to the city center was calculated as straight-line (Euclidean) distance between census district centroids and the city center (Plaza Italia). For the distribution of productive, commercial, educational, social, sport and neighborhood facilities densities were used, *i.e.*, number of units per census district area. The density of neighborhood facilities included the amount of bike lanes, benches, garbage bins, street lights, roofed bus stops, and playgrounds per area, so this variable, as well as the quality of streets and sidewalks, were deemed as proxies of the neighborhood condition. The quality of streets and sidewalks was derived from the number of streets and sidewalks in bad conditions reported in the pre-census, *i.e.*, the lower the amount of streets and sidewalks in bad state, the better the neighborhood condition. Last, green areas were calculated as total vegetation per square meter, including designated and non-designated green space. This information was provided by the Ministry of Housing and Urbanism (MINVU). Although just designated areas would be a better indicator of the social and aesthetic services provided by parks and green areas, total vegetation was considered because it reflects better the environmental services provided by urban vegetation.

As little is known about the exact nature of the relationship between neighborhood attributes and the density profile of a city, extent testing was conducted to determine the best possible fit between dependent and independent variables. The following model was estimated, as it seemed satisfactory with respect to the theoretical framework and the empirical fit:

$$\begin{aligned} Lg\ (dens)_i = \beta_0 + \beta_1(dist) + \beta_2(\lg(prod)) + \beta_3(\lg(com)) + \beta_4(\lg(edu)) + \beta_5(\lg(soc)) + \\ \beta_6(\lg(sp)) + \beta_7(\lg(neigh)) + \beta_8(\lg(str)) + \beta_9(\lg(sidew)) + \beta_{10}(veg) + \varepsilon_i \end{aligned} \tag{2}$$

where ε represents the stochastic error term. The model was estimated with Ordinary Least Squares (OLS), given the linear relationship between variables.

Apart from neighborhood characteristics, a second regression model was estimated introducing socioeconomic variables. Model 2 incorporated the following variables: disposable budget per capita, in order to understand the influence of municipal expenditures; and a dummy variable for neighborhoods belonging to rich and poor *comunas* to analyze whether household's average income has a different influence on dwelling density depending on socioeconomic status. These variables were only available at the *comuna* level since the pre-census did not provide socio-economic information. Santiago is divided at the local level into *comunas* that, despite their size (from 50,000 to 850,000 inhabitants), represent the lowest statistical unit. Using data from different scales entailed some limitations. The analysis would benefit if socioeconomic data would have been available at the census district level because the potential influence of a wider range of socioeconomic variables could have been tested. Moreover, *comuna*-level socioeconomic data may soften spatial inequalities since disparities between neighborhoods are somewhat compensated at an aggregate level. While acknowledging these limitations, the research strategy and the data used provided an adequate framework for understanding the influence of the functional organization of the city, the availability of urban attributes and the neighborhood condition in explaining the density profile.

Table 1. Descriptive statistics of the variables.

Variable name	N	Mean	S.D.	Min	Max
Neighborhood-level	339				
Density	339	38.76	25.82	0.128	215.2
Distance	339	9518.3	4975.1	0	22718
Productive facilities	339	61.203	92.785	0	935
Commercial facilities	339	219.50	188.31	3	1731
Educational facilities	339	18.133	15.206	0	118
Sport facilities	339	5.2212	4.9627	0	39
Public services	339	3.9911	8.2316	0	107
Neighborhood facilities	339	121.6	106.06	0	809
Streets in bad condition	339	385.76	299.46	5	2324
Sidewalks in bad condition	339	371.83	277.13	5	2153
Vegetation	339	64.696	61.739	0	475
Comuna-level	34				
Household Income (USD)	34	2204	1617.3	924.5	7464.6
Disposable budget per capita (USD)	34	361.5	331.5	112.6	1182.3

5. Understanding Density in Santiago

The estimation of the relationship between neighborhood attributes and dwelling density is displayed in Table 2 (Model 1). It is worth noting that all variables are measured in densities except distance (meters) and vegetation (square meters) to reflect the relative intensity of urban attributes in an area. Similar to other cities, in Santiago also density declines with the distance from the city center, although probably less because of the housing policy, which located large segments of population away from the urban core, and because of the inorganic growth pattern of the city; in fact, the coefficient relating density and distance is small in absolute values (0.06 percentage points per km). The other two variables of the functional organization of the city, the density of productive and commercial activities show a negative and positive relationship, respectively. Dwelling density declines where more productive facilities are located because some industries are designated in non-residential areas. By contrast, commercial activities are a magnet for residents, so dwelling density increase in denser commercial areas. Regarding the variables related to social equipment, the density of schools and sport facilities increase dwelling density, whereas public services decrease density. This is so because the stock of school and sport facilities depend on population, but the distribution of public services in the metropolitan area is decided mainly by the regional or the national government. Authorities cluster public services in the center of the neighborhood to ease accessibility, causing dwelling density to be lower where public services are concentrated. The availability of neighborhood facilities and the quality of sidewalks also have positive impacts on density, while the quality of streets has a negative impact; beware, that the fewer streets and sidewalks in bad state, the better the neighborhood condition, thus, the negative coefficient reflects that dwelling density rises where sidewalks are in better condition, whereas it declines where streets are in worse state. This may be due to the distribution of responsibilities among authorities at different spatial scales. Local governments are responsible for neighborhood facilities and sidewalks, whereas regional and national governments are mainly in charge of streets. As a result, neighborhoods vary in their state of conservation depending on local authorities' expenditures. Thus, local governments' expenditure on facilities has an impact on density since the better the neighborhood condition, the higher the density. Last, vegetation is negatively related to density. This is the expected outcome since in neighborhoods where large designated and non-designated green areas exist there is less urban land for residential uses.

The results are basically explained by diverse location preferences and complex interactions underlying market outcomes, land use planning and the distribution of responsibilities among authorities at different scales. Distance and the density of commercial activities reflect the priority given by households to accessibility to work (proxied by distance) and shops relative to space. Other urban attributes also influence location choices and concentration in particular areas of the city, such as the density of schools, sport facilities, neighborhood infrastructures and sidewalks' condition. On the other hand, land use planning and zoning is the reason why density decreases where productive activities are located, since large part of industrial activities are located just in designated areas. Vegetation also is more abundant where density rates are lower due to zoning, but also because less land has been converted to urban uses. Last, local governments' expenditure help to understand the distribution of urban attributes across neighborhoods, thus, influencing residential location choices and dwelling density.

In fact, Model 2 supports the positive influence of municipal expenditures on dwelling density, as illustrated by the coefficient relating dwelling density and disposable budget per capita. Model 2 also shows that income and density are inversely related in high- and low-income areas, *i.e.*, while in rich *comunas*, the higher the income the lower the density, in low-income areas the opposite is true, the higher the income the higher the density. The results suggest high-income household's preferences for low-density living whereas low-income households value accessibility and the greater availability of urban attributes in dense areas at the expense of reduced living space and environmental services. This is reasonable considering the lack of social services, infrastructures and connectivity in low-income peri-urban areas [40], reflecting low-income households' preferences for living in better connected dense areas where basic services are available.

Table 2. Regression of neighborhood level attributes and economic condition on dwelling density (N = 339).

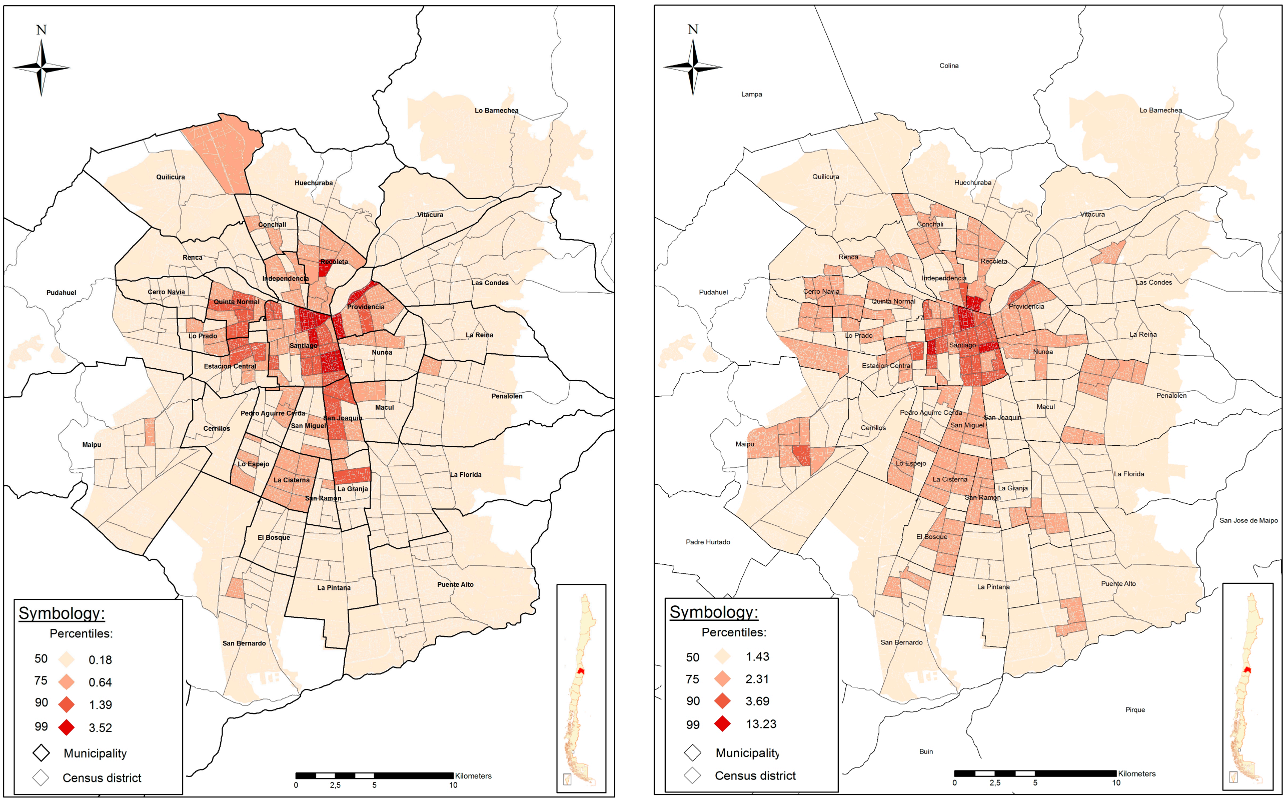
Variables	Model 1		Model 2	
	Coeff.	**P > |t|**	**Coeff.**	**P > |t|**
distance	−0.0000678	0.000	−0.0000612	0.000
lg_ prod	−0.1725768	0.000	−0.1647651	0.000
lg_ comer	0.2867376	0.000	0.2328639	0.001
lg_ edu	0.3235016	0.000	0.3133129	0.000
lg_sport	0.1337914	0.026	0.1233934	0.040
lg_ pub_serv	−0.0963492	0.043	−0.0944277	0.045
lg_neighb_facil	0.2277922	0.037	0.2294492	0.039
lg_sidewalk	−2.106483	0.000	−2.224725	0.000
lg_streets	2.0396	0.000	2.204095	0.000
vegetation	−0.0048482	0.000	−0.0045535	0.000
budget_sq			0.0000011	0.023
poor_dummy			0.3305232	0.023
rich_dummy			(dropped)	
cons	1.829137	0.000	1.424186	0.008
R-squared	0.4129		0.4312	
Adj R-squared	0.3874		0.4013	

6. Implications for Accessibility and Travel

Mobility is a critical issue that has far reaching social and environmental implications. In the past three decades, Santiago has undergone a rapid motorization that has increased traffic congestion and air pollution. Nowadays Santiago suffers from among the worst air pollution problems in Latin American cities, due to the high concentration of PM 10, PM 2.5, CO and NOx [35]. From a social perspective, there are significant differences in motorization and mobility rates depending on socioeconomic status despite the rapid increase in auto ownership of all income groups, thus, affecting equal access to social opportunities [47].

The urban growth pattern and neighborhood characteristics influence accessibility and travel. On the one hand, although income dominates the household vehicle ownership decision, some built environment characteristics also have an influence, such as dwelling unit density, local land use mix, street layout, distance to CBD and proximity to Metro [48]. On the other, the modal choice, the time spent travelling, and the environmental impact are also affected by the urban form and the spatial organization of the city [49]. Despite the urban outgrowth that is gradually transforming the city into a metropolitan region with several employment nodes, Santiago today remains, to a large extent, monocentric. Productive activities cluster in Santiago and some other *comunas* of the first ring, whereas commercial activities are even more centralized (Figure 4). The spatial organization of economic activities defines the commuting pattern and, thus, over 40% of the commutes at peak hours end in the CBD [50]. As mentioned, the city center also hosts densest districts because of the priority given by residents to accessibility to employment and commerce. Consequently, the city center is where a higher percentage of commuting is contained within the area.

Figure 4. The distribution of productive (**a**) and commercial (**b**) activities.



(**a**) (**b**)

Source: Author's own elaboration based on the Pre-census data.

However, the mobility pattern is not only from the periphery to the center, but also from low- to high-income areas. If *comunas* are classified by income quintiles, the richest areas (*comunas* of the 4th and 5th quintiles), attract almost 70% of commuting trips. Moreover, the commuters from the richest *comunas* move within their area and there are almost no work-trips to the poorest areas. By contrast, almost 60% of the commuters of the first quintile and 50% of the second travel to the richest *comunas*. This is particularly important for populated *comunas* of the periphery. Maipú, San Bernardo, Puente Alto, La Florida, where more than 2.3 million people live, lack productive and commercial activities so people have to commute to the CBD or cross-commute to rich areas. As a result, average work-trip time in these *comunas* exceeds 40 minutes, more than twice the time of richer *comunas* [50].

This mobility pattern has far-reaching implications for social and environmental sustainability. As the city expands while functionally remaining monocentric, travel time increases, especially for those living further out, and the environmental impact of commuting worsens [49]. From a social perspective, the time spent on working trips is an important source of inequality for those workers that have to commute to the city center or have to cross-commute from poor to rich *comunas*. In fact, the uneven distribution of jobs could be used as a proxy for measuring conditions of social exclusion since people living in job-poor neighborhoods would have to travel greater distances to participate in the workforce than people in job-rich areas, holding other effects constant [51].

Land use policy could be used to achieve a more sustainable and fairer mobility pattern. At the metropolitan scale, containing the spread of the built-up area and promoting infill development could reduce the environmental impact of commuting. On a previous work we showed that, like in other cities, in Santiago also densification favors a more environmental friendly transportation pattern because of the wider use of mass transportation [49]. However, in dense areas trips are also longer due to the peripheral location and the traffic congestion, although the overall environmental impact is lower because the wider use of public transport offsets the negative impact of longer trips. Thus, while for the metropolitan area promoting infill development would contain suburbanization, at the *comuna* level balancing density rates would support more rational transportation choices, meaning increasing density in some areas and reducing density in others. Reducing density rates in the periphery and promoting densification in areas close to the city center is no easy task. The housing policy, responsible for much of the residential developments of the periphery, considered only the price of the land and building costs, but not the cost of communications nor other social infrastructure, so social housing areas have high density rates but lack adequate accessibility, social infrastructures and amenities [52]. Redressing these deficits would reduce traffic congestion while improving the living conditions in these areas. Additionally, there is room for densifying some areas of the well-communicated *comunas* of the north and the well-off northeast. To that end, a combination of incentives and regulations on the housing supply and demand, and direct state-driven interventions (*i.e.*, public housing provision) may need to be employed.

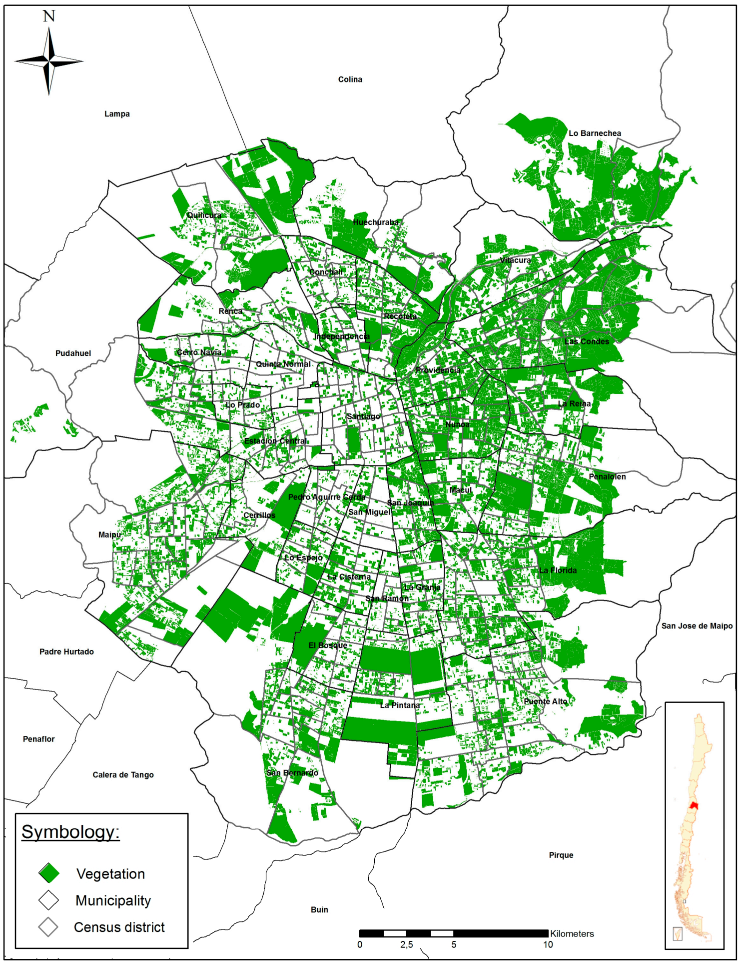
Along with infill development and balanced density rates, a better jobs-housing balance would allow commuters to move within their area of residence. While the decentralization of some industries could lead to a new spatial equilibrium, we believe promoting more compact areas where residential and economic activities are mixed would be more effective. Our regression analysis showed that dwelling density is related to the density of productive and commercial activities, so creating compact areas where residential spaces mingle with productive and commercial activities could also help balancing density rates. Obviously, the conditions and the scale of localization economies should be weighted. Firms seek localization advantages in their location decisions and these depend on proximity to other firms. Nevertheless, the positive effects should be considered, not only for mobility, but also for reducing residential segregation and improving the living conditions through more compact communities.

7. Implications for the Provision of Social and Environmental Services

Dwelling density is also relevant for the distribution of social infrastructure and the environmental services provided by urban vegetation. According to our estimations, social services are related to dwelling density, meaning densest areas have the densest network of social, educational, sport, and neighborhood facilities. This may be the expected outcome since the distribution of social services and infrastructures depend on population, but it is somewhat interesting given the socio-spatial polarization that characterizes the SMA. Nevertheless, differences in access to social services are not due to their spatial distribution but to their quality in different areas of the city. The northeast cone hosts high quality services typical of a global city, whereas social infrastructures in other *comunas*, particularly in the periphery, lack quality standards [53].

By contrast, the distribution of vegetation is more uneven. Regression model showed that dwelling density and the urban vegetation are inversely related. The east and, particularly, the low density northeast cone hosts the greatest amount of urban vegetation, whereas in high density areas such as the central *comuna* of Santiago and some *comunas* of the west and the south, green areas are significantly scarcer (Figure 5). However, rather than on density, the distribution of vegetation depends on income. The five richest *comunas* have 34% of total surface, while in the five *comunas* with the lowest income barely exceeds 8%. If, instead of total vegetation, only parks are considered it holds that the higher the household income, the greater the total green surface, the bigger the size and the better the accessibility [54].

Figure 5. The distribution of urban vegetation.



Source: Author's own elaboration based on MINVU data.

Land use policy favors the proliferation of green areas in low-density settlements. Current regulation for calculating the amount of green surface sets different minimum standards for low- and high-density settlements. In areas where residential density is below 70 inhabitants per ha the required minimum green surface is 10 square meters per inhabitant, whereas in high-density settlements minimum surface is much less [55]. As such, in high-density *comunas* where social housing is localized average green area is 1.3–3.5 square meters per inhabitant [56]. Another significant side-effect is the scatterization of small areas at the expense of big parks because a minimum size is not defined [54].

While small parks are usually more accessible, social and ecological functions of green areas require a minimum surface, as well as vegetation cover and design characteristics [54].

Green areas are essential for the quality of life and urban sustainability. Contemporary research has shown the aesthetic, psychological, health, social, economic, and environmental benefits of natural features [57]. The latter are particularly important in Santiago considering the scope of the environmental problems, particularly air pollution. Green areas provide basic environmental services, such as air and water purification, wind and noise filtering, and microclimate stabilization, key functions for the urban metabolism. As such, the uneven distribution of vegetation does not allow fulfilling these functions in particular areas of the city. In addition, the east and the south, where low-income families reside, also present worst environmental conditions, such as higher concentration of air pollutants and lower protection levels against natural hazards like floods [58]. While the distribution of environmental conditions is the result of the urbanization process and more affluent peoples' location choices in areas of better environmental standards (under the Andean cordillera, where air pollutants and water flow downstream), the uneven distribution of urban vegetation does not provide adequate natural conditions to alleviate environmental problems in low-income settlements, thus, reinforcing environmental injustice and segregation [59].

A major limitation to overcome inequalities in social and environmental service provision is the governance structure. *Comunas* are responsible for budget, land use planning and public service delivery, but in practice municipal autonomy is limited. This is particularly harmful for lower-income *comunas* where social housing is located, since while the central government decides its location in a top-down process, municipalities remain responsible for providing public services as paving, lighting, drainage, basic health care, and primary and secondary education. Local authorities rely on property and other local taxes (*i.e.*, business, vehicular taxes, *etc.*) but the tax scheme reinforces income gaps between wealthier and poorer urban areas because tax revenues are much lower in low-income areas [60]. Wealthier municipalities are able to levy more resources through the property tax because land and asset prices are much higher [61] and because they can also obtain more revenues from other taxes (for instance vehicular taxes, since more residents own a car). Complementary funding sources exist but they do not compensate for income and revenue disparities, in part because money transfers from the central government do not fully account for the social services provided by low-income *comunas* given their limited revenues, and also because wealthier municipalities have more negotiating power with the central government [53]. The result is a self-reinforcing mechanism for socio-spatial disparities in which wealthier municipalities are able to provide better public goods and services.

Different institutional mechanisms could be adopted to reduce spatial disparities in social and environmental services provision, from reforming cooperation mechanisms between *comunas* to re-shaping or even creating new governance structures at the metropolitan scale. While the former could yield some partial benefits if compensatory mechanisms are well designed and rich areas are efficiently enforced to redistribute wealth, a metropolitan governmental authority can favor policy coherence and improve service delivery across municipal boundaries [60]. Currently there are no strategic, metropolitan-wide planning mechanisms, despite major metropolitan problems, such as urban sprawl, transportation, housing policy, the spatial dimension of social services' provision, or the environmental problems. A metropolitan authority would provide a comprehensive, city-wide, approach to urbanism, thus better coping with the challenges that pose urban growth and densification with respect to mobility, accessibility, the distribution of social opportunities and the environmental conditions.

8. Conclusions

The aim of this paper has been to introduce some issues that should be borne in mind when considering densification in cities characterized by socio-spatial polarization. To that end, we first have analyzed the role urban conditions have for explaining density in different areas of the city. Leaving aside the uncertainty about causality, regression analysis has shown that dwelling density in the SMA is related to the functional organization of the city, the availability of urban attributes in the area, the neighborhood condition, local authorities' expenditures and the socioeconomic conditions. The city center hosts the densest districts due to the high concentration of commercial activities in the area, although some peripheral *comunas* also have very high-density rates because of the housing policy. On the other side, high-income areas adjacent to the CBD have low-density rates, thus, having better access to employment, services and amenities while maintaining good environmental standards. Given this density profile, density declines with the distance from the city center, although less than in other cities with market-oriented economies. Commercial activities are a magnet for residents, thus increasing density, whereas productive activities decrease density because much of them are clustered in non-residential areas. Other urban attributes also help understanding dwelling density. The availability of social services, collective facilities, and good neighborhood conditions have positive impacts on density, while the quality of streets has a negative impact. This may be due to the distribution of responsibilities among authorities at different spatial scales, since *comunas* are responsible for providing public services and neighborhood infrastructures whereas regional and national governments are in charge of streets. Thus, *comunas*' expenditure on social services attracts residents to the area and, in fact, regression analysis' results show that municipal budget also has a positive influence on dwelling density. On the other hand, vegetation is negatively related to dwelling density because where urban space is designated as green area, less land is available for residential use. Last, income has the opposite influence on density in rich and poor areas, *i.e.*, in rich areas density decrease as income rise whereas in poor areas the reverse happens. This points out to divergent preferences for the rich and the poor, the former valuing low-density living and the latter better accessibility and availability of urban attributes at the expense of higher density rates.

These results suggest that any policy related to densification needs to be taken cautiously and should consider the scale, its objectives and the specific benefits of a density policy. While at the metropolitan scale promoting infill development and increasing density rates could help containing urban sprawl and favor a more sustainable mobility pattern by reducing travel distance and encouraging public transport usage, it may deepen disparities between *comunas* if specific objectives and density targets in different areas of the city are not considered. As such, raising density at the metropolitan scale should be complemented by balancing density rates between *comunas* and favoring a more decentralized organization of economic and commercial activities, in order to favor the jobs-housing balance. Certainly, computing land use density and job density variables in the regression analysis would have enriched the discussion about how to achieve a better balance between workplaces and housing, but it was beyond the scope of this paper a deeper analysis of these variables. We bear in mind for future work.

Regarding the provision of social services and environmental amenities, the priority should be correcting spatial imbalances. In some peripheral *comunas* where social housing is located, density is too high and lack adequate social and environmental conditions, so reducing density rates would improve the living conditions while facing socio-spatial segregation. By contrast, density could be raised in some areas close to the city center with better social and environmental conditions, dealing with spatial imbalances in these *comunas*, while coping with the general goal of densification at the city level. A metropolitan approach is essential for a comprehensive urban planning that aims at tackling the implications of the urban growth pattern for environmental sustainability and socio-spatial equity. Major challenges, such as suburban sprawl, transportation, the housing policy, the distribution of social services and environmental amenities are metropolitan in scope, thus, metropolitan-wide governance mechanisms should be considered. While reforming actual coordination mechanisms could yield some benefits if richer *comunas* are efficiently enforced to transfer resources to poorer *comunas* to compensate for their lack of adequate social and environmental conditions, we believe a metropolitan authority would be a better institutional response for the challenges the city faces.

Acknowledgments

This work was supported by Planning Directorate of Public Works Ministry of Chile, Department of Applied Economics I of Basque Country University. We thank Stefano Toledo Aquino for research assistance, Guillermo Tapia and Raul Ponce for sharing information and data. Finally, we would like to thank Uwe Gehrels, Roberto Riveros, Christian Lopez and three anonymous referees for their comments and suggestions on an earlier version of this paper.

The views and opinions are, nevertheless, entirely our own and do not represent those of any of the above-mentioned institutions.

Conflicts of Interest

The authors declare no conflict of interest.

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