COALITION FOR URBAN TRANSITIONS
A New Climate Economy Special Initiative

BETTER POLICIES FOR BETTER LIVES

Working Paper

Demystifying Compact Urban Growth: Evidence From 300 Studies From Across the World

Gabriel Ahlfeldt and Elisabetta Pietrostefani

CONTENTS

Overview

Most developed countries now pursue policies that implicitly or explicitly aim at promoting compact urban form. This report analyses more than 300 academic papers that study the effects of compact urban form, and finds that 69% of the papers reviewed find positive effects associated with compact urban form. Over 70% of studies find positive effects of economic density (the number of people living or working in an area). A smaller majority of studies attribute positive effects to mixed land use (58%) and the density of the built environment (56%).

These averages hide significant variation across specific dimensions of urban development. In order to understand the effects of compact urban form, the report estimates the monetary per capita value of the change in 15 outcomes in response to a 10% change in economic density. The major benefits of economic density arise from improved productivity and better access to jobs and services. Further benefits are generated through the preservation of urban green space, greater energy efficiency, pollution reduction, and safer urban environments. The major costs of higher economic density are related to congestion, health, and well-being. Increasing compactness can also contribute to higher land values and housing costs, which are borne disproportionately by renters and first-time buyers.

Increasing economic density therefore requires accompanying policy interventions to maximise the benefits and minimise the costs associated with compactness. In particular, policymakers need to facilitate large-scale investment in housing supply and public transport networks to ensure efficient and equitable access to housing, services, and jobs in compact cities.

Photo credit: Visty Banaji

About this working paper

This working paper was prepared for the Coalition for Urban Transitions, a special initiative of the New Climate Economy project. The Coalition is a major international initiative to support decision makers to meet the objective of unlocking the power of cities for enhanced national economic, social, and environmental performance, including reducing the risk of climate change. This research was conducted as part of the economic and business case workstream. The opinions expressed and arguments employed are those of the authors. OECD Working Papers should not be reported as representing the official views of the OECD or of its member countries. This material has been funded by UK aid from the UK government; however the views expressed do not necessarily reflect the UK government's official policies.

Citation

Ahlfedlt, G., and Pietrostefani, E. *The effects of compact urban form: A qualitative and quantitative evidence review.* Coalition for Urban Transitions, London and Washington, DC.Available at: http://newclimateeconomy.net/content/cities-working-papers.

New Climate Economy
c/o World Resources Institute
10 G St NE
Suite 800
Washington, DC 20002, USA
+1 (202) 729-7600

Coalition for Urban Transitions
c/o C40 Climate Leaders Group
North West Entrance, City-Gate House
39-45 Finsbury Square, Level 7
London EC2A 1PX, United Kingdom
+44 (0) 20 7922 0300

WRI Ross Center for Sustainable Cities
10 G St NE
Suite 800
Washington, DC 20002, USA
+1 (202) 729-7600

Executive summary

Cities come in very different forms – some are concentrated around a historic core, some have multiple centres, and others sprawl across vast areas. These physical characteristics greatly affect their economic, social, and environmental performance.

Most developed countries now implicitly or explicitly aim to promote more compact urban forms, as compactness is associated with a wide range of positive effects: increases in productivity due to agglomeration economies, travel time savings, and a smaller ecological footprint due to lower energy and land consumption.

This working paper is the first attempt to comprehensively evaluate the state of evidence on the costs and benefits of compactness. It reviews more than 300 separate analyses to understand how compactness impacts on different dimensions of urban life:

- *Economic dimensions:* productivity, innovation, value of space, efficiency of public services delivery, traffic flow, and access to jobs.
- *Social dimensions:* social equity, safety, health, wellbeing and access to services and amenities.
- *Environmental dimensions:* pollution, sustainable transport options, open space, and energy efficiency.

Overall, 69% of the analyses found positive effects associated with compact urban form. The collected evidence clearly suggests that increasing compactness has positive effects on a city's productivity, innovation, access to services, and amenities, value of space, efficiency of public services delivery, social equity, safety, energy efficiency, and sustainable mode choice. There therefore seems to be a clear economic case for compact urban form.

However, the literature also suggests that compactness may have negative impacts on many social and ecological dimensions, particularly open space preservation and biodiversity, traffic flow, health and well-being. The evidence is mixed for job accessibility and pollution reduction. These findings suggest a need for policy interventions to retain the benefits of compactness while delivering healthier and greener cities.

It is important to note that most research on compactness has been conducted in cities in high-income countries. This makes it more difficult to assess the impacts in low- and middle-income countries. However, the few analyses available find that compactness in the global South has more negative effects on access to jobs, services, and amenities than in the global North. This implies that many of the costs of density are related to the quality of urban transport, underscoring the importance of investment in mass transit, cycling, and walking infrastructure.

There are three characteristics of compactness:

- *Economic density:* the number of people living or working in an area.
- *Morphological density:* the density of the built environment in terms of surface coverage, building footprint, and street connectivity.
- *Mixed land use:* the extent to which residential, employment, retail, and leisure opportunities are located close to each other.

Over 70% of studies reviewed find positive effects of economic density, 56% for morphological density, and 58% for mixed land use.

In order to compare the effects of compact urban form across the different dimensions, this working paper focuses specifically on the effects of economic density (as this characteristic of compactness is most extensively studied in the literature). The paper offers estimates of the per capita monetary value of a 10% increase in economic density. The estimates come with several caveats, and should be seen as reflecting orders of magnitude rather than being highly precise. Nonetheless, they usefully indicate the likely scale of different costs and benefits.

The biggest benefits of economic density arise from improved productivity and accessibility. Increasing density by 10% is worth approximately US$71 per person per year due to higher productivity, US$62 due to higher job accessibility,

and US$49 due to better access to services. Other important benefits associated with compact urban form include the preservation of urban green space (US$41), greater energy efficiency (US$25), reduced pollution (US$14), and safer urban environments (US$8).

However, if urban growth is not well-managed, higher density can cause costs related to traffic congestion, health, and well-being. A 10% increase in economic density on average leads to greater congestion costing US$35 per person per year, negative health effects costing $US32, and a decline in subjective well-being costing US$26. These negative impacts can be minimised through appropriate urban planning and infrastructure investment.

Crucially, increasing compactness can contribute to higher house prices: a 10% increase in economic density raises rent by US$240 per person, which is not fully compensated for by the higher wages associated with compactness. This means that the net effects of higher density depend on whether or not residents own property. Increasing compactness is likely to benefit homeowners, but is potentially harmful to renters and first-time buyers. Given that homeowners tend to be wealthier than renters, this could potentially exacerbate inequality within cities.

These findings underscore the importance of making sure that compact city policies are complemented with strategies to manage the possible costs. Increased density should be accompanied by efforts to expand the housing supply, in order to ease pressure on rents. Investments in sustainable transport will also be necessary to facilitate efficient and equitable access to services and jobs, and minimise negative impacts on mobility or public health.

This working paper therefore suggests that pursuing more compact urban forms can help cities to increase their economic competitiveness and dynamism, as well as reducing the risk of climate change through greater energy efficiency. However, decision-makers will need to carefully design housing and transport policies to accentuate the good parts of compact urban form while minimising the downsides.

1. Introduction

1.1 BACKGROUND

Today, more than 50% of the world's population live in urban areas (United Nations, 2014). This proportion is expected to reach 70% globally by 2050 and 86% within OECD countries (OECD, 2010), reflecting growing demand for economic activities taking place in cities. Beyond the generic definition of urban areas or cities as places of relatively high economic density, there is great variability in observed spatial structures. Although definitions of urban areas vary, they are often characterised as having a population density of at least 400 residents per square kilometre, but some urban areas have densities that exceed this threshold by a factor of 100 (United Nations, 2005). Some cities are highly spatially concentrated around a historic core, while others exhibit a polycentric structure with multiple sub-centres and edge cities, or spread their economic activity horizontally across vast areas of relatively low density.

Cities also differ in terms of the spatial segregation of land use. In some cities, local areas tend to specialise as residential, commercial, or retail locations, while in other cities land uses are more intermixed to exploit local complementarities. These varying spatial patterns are pinned down by geology, culture, historic "accidents", path dependency, levels of economic development, and regulation. Various land use policies aim to shape the spatial structure of cities and the way economic activity is organised within cities, reflecting the concern that unregulated economic markets will fail to deliver efficient and equitable allocation of use and infrastructure. Urban growth boundaries, various forms of zoning, tax incentives for particular forms of urban development, and the subsidised provision of public transport and other public services show that some urban forms are perceived as being more desirable than others. It also makes it obvious that political action is needed to maximise the benefits and minimise the cost of co-location in urban areas.

One of the most prominent concepts to have emerged in the global urban policy debate is the "compact city". The concept has various aspects, but most share the common theme of compactness, as defined by land being used intensively and the distance between different land uses and users being minimised. Briefly summarised, the concept idealises a city that is distinctively urban in terms of density generally, but also in more specific terms such as a contiguous building structure, interconnected streets, mixed land uses, and the way people travel within the city (walking, cycling, public transit). As a policy agenda, the compact city is directly concerned with promoting the most "urban" externalities, namely those

that originate from density and accessibility – the quintessence of cities. The positive effects ascribed to density and accessibility include, among others: increases in productivity due to agglomeration economies; travel time savings due to shorter trips; and a smaller ecological footprint due to lower energy and land consumption.

Urban planners and policy-makers in developed countries have been so engaged with the ideal of a compact city that, by now, most developed countries pursue policies that implicitly or explicitly promote compact urban form (OECD, 2012; Shopping Centre Council of Australia, 2011; IAU-IDF, 2012). Both the concepts of "compact city" and "compact urban development" receive support, but there is a key distinction to be made between them. As the OECD (2012) specifies, "compact city" refers to a metropolitan-level policy, while "compact urban development" is more localised and usually indicates development on a neighbourhood scale (OECD, 2012; Geurs and van Wee, 2006; Burton et al., 2003).[1] Thus, policies to support compact cities may include policies to support compact urban development at the neighbourhood level, but typically go beyond it, for example by also including metropolitan-wide transport policies.

Implicit to the wide support the concepts receive in the urban policy debate is the agreement that, for the most part, the benefits of density and compactness exceed the costs, which can come in the form of reduced affordability, traffic congestion, a high concentration of pollution, and loss of open and recreational spaces. Critiques of the concept of the compact city are consequently scarce in developed countries (Neuman, 2005; Melia et al., 2011). However, more specific instruments of compact city policies, such as densification or green belt policies, have attracted criticism due to their adverse effects on affordability (Cheshire and Hilber, 2008; Thompson, 2013). There is greater debate around compactness and density in developing countries, where many urban residents lack access to basic services and infrastructure, including sanitation, drainage, piped water, waste collection, firebreaks, and emergency services. In these contexts, higher population density exacerbates a range of health risks, particularly water- and vector-borne disease (Mitlin and Satterthwaite, 2013; Ezeh et al., 2016).

It is difficult to ascertain to what extent the ideal concept of a compact city corresponds to the compactness that can be found in reality (Neuman, 2005). There is no consolidated self-contained empirical literature on compact city effects. Instead, most of the relevant evidence is spread across separate literature strands, which are often only implicitly concerned with specific effects and selected aspects of compact urban form.

As a result, the compact city literature tends to differentiate in theoretical terms between various characteristics and effects of the compact urban form, but references to actual empirical evidence often remain casual. To enable the claims in support of the concept to be empirically substantiated, the compact city is often treated as a single entity, although the evidence is specific to outcomes (e.g. productivity, trip times, or affordability) and characteristics (e.g. density or mixed use). This is a problem because different compact city characteristics can have both positive and negative effects on the same outcome, and the same characteristic can affect different outcomes in both positive and negative ways.

For example, high population density and mixed land use are two compact city characteristics. High population density can result in the negative effects of more intense road usage and increased congestion (Burton, 2000; Angel et al., 2005; Churchman, 1999), whereas a mixed land use pattern tends to have the positive effect of reducing the number of car trips and thus road congestion (Burton, 2000; Burton, 2003; Churchman, 1999).

Likewise, economic density in the form of a high spatial concentration of workers and firms is a characteristic that can have positive effects on some outcomes and negative effects on other outcomes. On the one hand, it leads to higher productivity and wages (Neuman, 2005). However, these positive effects directly map to an increased demand for space, which – along with the limitations to creating additional space in already dense areas – puts pressure on house prices and office rents (Alexander, 1993; Churchman, 1999). Thus, it reduces the affordability of urban areas, especially for low-income groups, and can harm the inclusiveness of compact cities.

Because the compact city concept is an umbrella for various urban characteristics that have varying and potentially counteracting effects on different outcomes, an empirical account of the support for compact city policies requires a systematic approach. The evidence base needs to be condensed to enable a comparison of the effects of different compact city characteristics on the same outcome, as well as the effects of the same characteristic on different outcomes. A fair assessment of the evidence on the effects of compact city characteristics needs to be guided by theory. The evidence will only be fully conclusive if there is an understanding of all the theoretically expected channels through which different compact city characteristics impact on distinct outcomes. The gaps in the literature need to be identified in a transparent

manner to understand the limitations of the evidence. Finally, the evidence base needs to be interpreted in light of the nature of the evidence, which can range widely, from anecdotal to well-identified econometric results. To date, an evidence review that satisfies these criteria is not available. This lack of systematic, theory-consistent, and accessible evidence complicates evidence-based policy-making on sustainable urban economic development (Matsumoto, 2011; Angel et al., 2005).

The literature review analyses the effects of compact urban development on existing urban forms. These forms frequently differ from the ideal of the compact city as it is described, for example, in OECD (2012) or Urban Land Institute (2015). Therefore, the literature review does not provide an assessment of a compact city in its ideal form. Rather, it assesses the compact urban forms that can be found today and that have been shaped by decades or even centuries of urban development. This focus on existing urban forms makes it possible to identify areas where greater efforts are needed to reduce the costs of compact urban form. In other words, it provides the knowledge base required to move closer to the ideal form of compact city, which realises the benefits of density while minimising the potential negative costs.

At the same time, it is worth noting that this literature review cannot provide an assessment of the consequences of compact urban form done according to best practice standards. Already today, many of the costs related to compactness can be mitigated by policies that focus on promoting "good density" (Urban Land Institute, 2015). Likewise, policies focused on promoting the benefits of compact urban form may be able to ensure that the benefits created are greater than those that typically exist today. However, this is not captured in the literature, as most of the cities analysed were not developed according to modern principles of compact city or compact urban development. Therefore, the estimates presented in this literature review do not provide an assessment of best practices regarding compact urban form.

1.2 APPROACH

Our contribution to the literature is threefold. First, we review and categorise the theoretical compact city literature. We link the key compact city characteristics (causes) to a range of outcome dimensions (effects). Where they exist, we isolate the economic mechanisms through which causes lead to effects, as well as the theoretically expected direction of the effect. The purpose of this exercise is not to provide an in-depth survey of the theoretical literature, but to present a systematic overview of the literature.

This paves the way for our second contribution, a quantitative review of the empirical evidence on the effects of compact urban form. To ensure that we cover as comprehensively as possible the different dimensions of the relevant evidence and uncover potential gaps in the literature, we conduct separate literature searches for every combination of compact city characteristics and outcome dimensions for which we theoretically expect a causal effect. We quantify the nature of the reviewed evidence and subject the results to a statistical analysis using techniques that we borrow from meta-analytic research.

Our third contribution is a quantitative comparison of the effects of economic density (by far the most intensely analysed aspect of compact urban form) on various outcomes.[2] For a sub-sample of analyses in the evidence base with suitable estimates, we infer the percentage change of the outcome in response to a 1% change in density (i.e. the elasticity of the considered outcomes with respect to density). Using these elasticities, we then compute the monetary equivalents of a 10% increase in economic density for a range of outcome dimensions.

The remainder of this paper is organised as follows. The next section engages with the review of theoretical compact city literature. Sections 3 and 4 present the results of the analyses, including the monetary equivalents of an increase in economic density. Section 5 concludes. There is also an extensive technical Appendix with additional results and explanations, which is essential reading for those wishing to use our quantitative results.

2. Theoretical literature

2.1 HISTORY OF THOUGHT

The OECD defines the compact city as a "spatial urban form characterized by 'compactness'"(OECD, 2012, p.15). It describes the characteristics of the compact city as "dense and proximate development patterns", "urban areas linked by public transport systems", and "accessibility to local services and jobs" (OECD, 2012, p.15). The term compact city is often said to have been first used by Dantzig and Saatay (1973), who were principally interested in a more efficient use of urban resources. It also stems from the critique of modernist planning approaches. Its origins in this theoretical framework

explain the literature's focus on certain outcomes, such as sustainable mode choice and improving accessibility (Thomas and Cousins, 1996). Compact city policies focus, in fact, on holistic approaches to achieve "compactness" by having an impact on the ways in which urban environments are used. It is the comprehensive approach of compact city policies, expected to fulfil a series of urban sustainability objectives by improving economic, social, and environmental dimensions of the city, that have made them so popular.

Churchman (1999) first provided an itemised disentangling of the advantages and disadvantages of compact city features on economic, social, and environmental outcomes, revealing the complexity and heterogeneity of the concept. Neuman (2005) also presents a helpful critique in his juxtaposition of "compactness" and "sprawl"; however, as with other publications that discuss the concept, the presence of varied definitions of the compact city amplifies the difficulties in understanding its characteristics and outcomes, and generates confused debate. The confusion also stems from a rhetoric around whether compact cities are sustainable (through case-study analysis: Neuman, 2005; Williams et al., 2000; Roo and Miller, 2000), instead of addressing potential costs and benefits more specifically (with some exceptions: Churchman, 1999). In discussing specific outcomes, the literature focuses on the reduction of automobile trips and the increase in alternative mode transportation (Burton, 2000; Schwanen et al., 2004; Neuman, 2005), improving the environmental qualities of cities (Burton, 2002; Churchman, 1999), and the provision of high-density housing in the proximity of retail and to support equity (Burton, 2001; Churchman, 1999). Although the rhetoric focuses on these aspects, countless more are mentioned.

There is no consensus on how compactness is measured. What is clear, however, is the presence of three main features: economic density, morphological density, and the mixed use of land. Within each umbrella feature, there is a wide array of possibilities: residential, population, employment, or firm density; and parcel density, street intersection, or road capacity (Hitchcock, 1994; Churchman, 1999). The multiplicity of characteristics is reflected in the empirical evidence collected and underlines the difficulty in comparing much of the evidence.

Burgess and Jenks (2002) address the compact city in the context of developing countries, stressing the dangers of dividing developed and developing countries, following the widely held tenets of urban planning and modernism. It is difficult to say whether we expect the costs and benefits associated with density to be higher, in light of the differences between regions (Gilbert and Gugler, 1992). Specific differences, however, such as higher-density inner cities or a larger presence of urban informality suggest the possibility of less normalised effects, which are difficult to identify given the case-study context-led approach of most compact urban form studies in the global South.

2.2 COMPACT CITY CHARACTERISTICS AND OUTCOME DIMENSIONS

As discussed above, the policy debate on compact urban form associates a range of city characteristics with a multitude of potential outcome dimensions. The multiplicity of characteristics and outcomes results in a high dimensionality of cause-and-effects channels that come under discussion in the theoretical debate. The literature is vast and many contributions are concerned with particular characteristics and outcomes, or do not make clear distinctions between the features of the compact city, its outcome dimensions, and the processes by which they are associated. To guide our empirical review of the compact city literature, we therefore first categorised the theoretical literature into a matrix that presents the

Table 1
Compact city characteristics

Index	Characteristic	Summary
A	Economic density	Refers to the number of economic agents living or working within a spatial unit and is typically measured as population or employment density (Thomas and Cousins, 1996; Churchman, 1999; Burton, 2002; Neuman, 2005).
B	Morphological density	Refers to the density of the built environment and captures aspects of the compact city, such as compact urban land cover, demarcated limits (demarcated urban/rural land borders), street connectivity, impervious surface coverage, and a high building footprint to parcel size ratio (OECD, 2012; Wolsink, 2016; Neuman, 2005; Burton, 2002; Churchman, 1999).
C	Mixed land use	Captures the co-location of employment, residential, retail, and leisure opportunities (Churchman, 1999; Burton, 2002; Neuman, 2005), both horizontally across buildings and vertically within buildings (Burton, 2002).

theoretical links between the most commonly considered classes of characteristics (causes) and outcome dimensions (effects). Three primary classes of compact city characteristics emerge from the theoretical literature.

The selection of the outcome dimensions was guided by both the theoretical literature and policy reports, in particular Churchman (1999) and Neuman (2005) for untangling the concept of density, and the OECD's *Compact City Policies: A Comparative Assessment* (OECD, 2012). The three characteristics are especially important in accounting for the different evolutions of different types of density: between 1950 and 2012, OECD countries increased their built-up areas by 104%, while their population only increased by 66% (OECD, 2012). These characteristics have been defined as the "three Ds" (Cervero and Kockelman, 1997): density (population and employment), diversity (proportion of dissimilar land uses, vertical mixture, proximity to commercial retail uses), and design (street patterns, site design, and pedestrian provisions). Although we have generally followed the spirit of these definitions, which were later re-employed in the literature (Ewing and Cervero, 2010; Cervero and Duncan, 2003), our approach has redefined them so as to avoid the overlapping of compact city characteristics and outcomes. For instance, Cervero and Kockelman's (1997) "density" factors in accessibility to jobs (expressed in a gravity model form) and "design" includes elements such as bicycle lanes per developed acre. In its definition of the built environment, the "three Ds" thus incorporates elements that we aim to untangle as, in fact, outcomes of various urban forms. We aim to cover the full breadth of relevant economic, environmental, and social outcomes. While it is difficult to provide a complete representation, our reading of the theoretical and empirical literature suggests that the list below includes at least the most obvious and popular outcome dimensions.

Table 2
Compact city outcome dimensions

Index	Outcome dimensions	Summary
1	Productivity	The compact city literature alludes to a positive association between economic density and productivity (Neuman, 2005; OECD, 2012). This is in line with literature on agglomeration economies that has emphasised external returns to scale since at least Marshall (1920).
2	Innovation	Pressures (Jones et al., 2010) and urbanisation economies (Maskell and Malmberg, 2007) imply that innovation increases in economic density.
3	Value of space	An increase in demand due to higher productivity or consumption value in denser areas is expected to capitalise into the value of usable space (Alonso–Mills–Muth model; Rosen–Roback) and, eventually, land. Morphological density can also make places more attractive and therefore increase the value of space (Glaeser et al., 2001; Knox, 2011). Construction costs generally increase in height (Epple et al., 2010; Ahlfeldt and McMillen, 2015), although building more densely can be economical in certain instances (Alexander, 1993; Churchman, 1999). Some policies associated with compact urban form (urban growth boundaries) can increase the value of space by restricting supply (Cheshire and Hilber, 2008).
4	Job accessibility	Higher economic density and morphological density (due to demarcated city limits) reduce the separation of home and work and potentially reduce time or money spent on commuting (Neuman, 2005; OECD, 2012), but it may also increase travel times due to increased congestion (see 12). Higher economic density makes public transport more viable, which improves accessibility (Beer, 1994; Laws, 1994; Dieleman and Wegener, 2004).
5	Services/amenities access	Higher economic density results in the clustering of recreational amenities (restaurants, bars, etc.) that require a large consumer base (Churchman, 1999; Burton, 2000; Burton, 2002). Denser areas also have more specialised services available, increasing consumption variety (Schiff, 2015). Morphological density (small, connected and interlinked streets, walkability) makes spaces more attractive to services such as cafes, bars, restaurants, shops, which increases consumption in these areas (Bonfantini, 2013). Mixed land use further reduces distance between services and consumers.
6	Efficiency of public services delivery	Higher economic density increases the comparative advantage of public transport usage, and – because public transport is usually not profitable – the cost of delivery (Matsumoto, 2011; Carruthers and Ulfarsson, 2003). Economic density is associated with returns to scale in public services such as waste collection and recycling, but the effect of morphological density (narrow streets/old town) likely works in the opposite direction (Troy, 1992).

Index	Outcome dimensions	Summary
7	Social equity	It is frequently argued that the compact city ultimately improves social equity (Burton et al., 2003), but the causal channels are typically not worked out explicitly. Economic density tends to increase both wages and rents, with effects that potentially vary across social groups. Economic density may enhance spatial and social mobility (Savage, 1988). Morphological density can lead to segregation as tall buildings are only viable at high rents (Radberg, 1996).
8	Safety	A higher economic density naturally leads to more crime (Burton, 2000; Chhetri et al., 2013), but not necessarily a higher crime rate. Street intersections, mass transit stations, and other elements of morphological density may cause crime and criminals to cluster according to the "hot-spot theory" (Braga and Weisburd, 2010). However, morphological density also facilitates light design, which may prevent crime (Farrington and Welsh, 2008). Economic and morphological density may lead to higher formal (Tang, 2015) and informal (Jacobs, 1961) surveillance and may thus reduce crime.
9	Open space	High economic and morphological density tends to reduce open space and biodiversity within cities due to higher opportunity costs (Neuman, 2005; Wolsink, 2016; Ikin et al., 2013), but has the opposite effect outside the city (Burton et al., 2003; Dieleman and Wegener, 2004).
10	Pollution reduction	Economic density can result in less automobile use, shorter trips, and fewer CO_2 emissions (Bechle et al., 2011). However, concentration of traffic in dense areas can result in a higher density of emissions and noise on main transport axes (Troy, 1996). Morphological density (tall buildings) can be associated with higher local energy efficiency (see 11). Mixed use reduces local automobile trips (and trip length) and emissions (Gordon and Richardson, 1997), but leads to more noisy activities in residential areas, which increases stress levels (WHO, 2011).
11	Energy efficiency	Taller buildings tend to be more energy efficient (Schläpfer et al., 2015). The co-location of residents can result in common energy systems that share local energy-generation technologies (OECD, 2012).
12	Traffic flow	Higher economic density implies a higher density of usage of transport systems and potentially higher road and pedestrian congestion (Burton et al., 2003; Rydin, 1992), but it may also mean less automobile use and shorter trips. Morphological features designed to attract services and people (e.g. improved walkability) tend to slow down cars and increase congestion. Mixed use tends to reduce car trips and road congestion.
13	Sustainable mode choice	Economic density increases the mode share of walking and cycling because of shorter average trip length (Churchman, 1999; Burton, 2000; Thomas and Cousins, 1996). It increases the mode share of public transport since areas are easier to serve by public transport and typically have higher congestion and scarcity of parking (Burton, 2000; Neuman, 2005). Morphological density (walkable street layout, demarcated city limits) and mixed land use have similar effects. Because walking, cycling, and public transport are affordable, this outcome can be considered equitable.
14	Health	Economic and morphological density and mixed land use imply positive health effects due to a higher share of walking and cycling (see 13). Ambiguous effects might occur through lower emissions, but higher density of emissions (see 10). Potentially negative effects could occur through higher density of road traffic and a higher number of accidents (Troy, 1996; Burton, 2000).
15	Well-being	Economic density can have negative effects on well-being due to a lower overall sense of community (Wilson and Baldassare, 1996), anxiety, social withdrawal, and a feeling of loss of control (Churchman, 1999; Chu et al., 2004). Economic and morphological density may negatively affect perceptions of space because a higher cost of space (see 3) results in less domestic space (Burton, 2000), and tall, dense structures obstruct views, cause shadowing, reduce open space, and give a visual sense of lack of proportion (Hitchcock, 1994). Mixed use of space results in noisy activities in residential areas, which increases stress levels (WHO, 2011). Improved access due to density and mixed land use potentially increases social well-being (Churchman, 1999), as do comfortable/agreeable urban environments due to morphological density (walkability) (see 13) (Vorontsova et al., 2016).

The compact city literature frequently refers to intensification as the process of steering development in a direction that is consistent with compact city characteristics. We do not explicitly cover this aspect of the debate because the purpose of this review is to evaluate the effect of compact urban form and not the efficiency of compact city policies. Our results, nevertheless, speak directly to this policy debate, as they reveal how the intensification of certain characteristics (A, B, C) can impact on different outcome dimensions (1–15).

2.3 A BRIEF OVERVIEW OF THE THEORETICAL LITERATURE

The three characteristics (A, B, C) along with the 15 outcome dimensions introduced above result in 45 potential cause–effect relations; however, not all of these are theoretically relevant. In Table 3, we provide an accessible summary of the theoretically anticipated causal links between compact city characteristics and outcomes, which guides our empirical literature review. For this purpose, we link compact city characteristics (causes) to outcome dimensions (effects) via a matrix, in which each outcome-characteristic cell provides a brief description of the nature of the anticipated effect (positive (+), ambiguous (+/-), negative (-)) and the economic mechanism through which an effect materialises. We only consider links between outcomes and characteristics that are commonly discussed in the theoretical literature, which results in 32 theoretically relevant outcome-characteristic relations. References to the relevant theoretical sources are provided in an identically structured table in the Appendix (Table A1). To connect to the empirical part of our review, we add examples of variables that are typically observed in the empirical literature for each category.

Table 3

Theoretically expected effects of compact urban form on various outcome dimensions

COMPACT CITY EFFECTS			COMPACT CITY CHARACTERISTICS		
#	Outcome dimension	Empirically observed	Residential and employment density	Morphological density	Mixed land use
1	Productivity	Rents, wages	+ (agglomeration economies (MAR externalities))	N/A	N/A
2	Innovation	Patents	+ (agglomeration economies (interactions, matching, spill-overs, peer effects))	N/A	N/A
3	Value of space	Land values, house prices, rents	+ (higher productivity and services availability (demand side) and higher cost due to scarcity of land (supply side))	+ (potentially more attractive locations (demand side) and higher cost of building taller (supply side))	N/A
4	Job accessibility	Commuting times, distances, costs	+/– (shorter trip length and improved transport connectivity (lower costs) and more road congestion (higher costs))	+/– (demarcated limits reduce trip length (lower costs) and potentially increase road congestion (higher costs))	N/A
5	Services and amenities access	Distance from services and amenities	+ (clustering of services and amenities requiring a large consumer base, also resulting in greater consumption variety)	+ (favourable street layouts (small interconnected streets) attract consumption amenities (e.g. restaurants))	+ (co-location of uses improves access to amenities and services and consumption variety)
6	Efficiency of public services delivery	Cost of transport services, waste disposal	+ (scale economies (high fixed cost and low marginal costs))	– (high building density increases the cost of, e.g., waste disposal, and high cost of brownfield development)	N/A
7	Social equity	Real wages segregation, social mobility	+/– (potentially positive effects on wages and rents (affordability) and higher social mobility)	– (tall buildings are feasible with high rents, which increases segregation)	N/A

COMPACT CITY EFFECTS			COMPACT CITY CHARACTERISTICS		
#	Outcome dimension	Empirically observed	Residential and employment density	Morphological density	Mixed land use
8	Safety	Crime rates	+/– (very highly frequented places attract criminal activity (hot-spot theory), but more informal surveillance (eyes on the street) increases safety)	+ (formal and informal surveillance in walkable areas and more street lighting)	N/A
9	Open space	Open space, biodiversity	+/– (higher opportunity cost of space within city limits but preserved space outside)	+/– (demarcated city limits increase density within city limits but preserve space outside)	N/A
10	Pollution reduction	Carbon emissions, noise	+/– (less automobile use (fewer emissions), but potentially higher density of emissions due to higher concentration)	+/– (taller buildings tend to emit less pollution particles but could also "trap" pollution)	+/– (co-location of employment, residences, retail, and leisure opportunities reduce trip length but increase noise in residential areas)
11	Energy efficiency	Energy consumption	N/A	+ (apartment buildings tend to be more energy efficient than single-family homes)	+ (co-location of uses allows for sharing local energy-generation technologies)
12	Traffic flow	Road congestion, pedestrian congestion	+/– (higher economic density implies a higher density of potential users and higher opportunity cost of road space, but also potentially shorter trips)	– (morphological designs that improve walkability and attract services tend to reduce road capacity)	+ (mixed use reduces car trips and trip lengths)
13	Sustainable mode choice	Walking, cycling	+ (higher densities imply shorter trip lengths, which makes walking, cycling, and (public transit) more attractive)	+ (demarcated city limits and favourable street layouts make walking and cycling more attractive. High building density creates scarcity of parking space)	+ (co-location of employment, residences, retail, and leisure implies shorter trips)
14	Health	Mortality, disability, morbidity	+/– (higher likelihood of walking and cycling (positive), less emissions (positive), potentially higher emission density (negative), and increased number of traffic accidents (negative))	N/A	N/A
15	Well-being	Subjective well-being, happiness, perception of urban space	+/– (dependent on all other outcomes. Additional channels include less domestic space (due to high rent), lower sense of community and anxiety, social withdrawal, and feeling of loss of control)	+/– (dependent on all other outcomes. Additional channels include less private exterior space and worsened space perception as high-density developments obstruct views, causing shadowing)	+/– (dependent on all other outcomes)

Notes: + : positive; +/- : ambiguous; - : negative; N/A: not applicable.

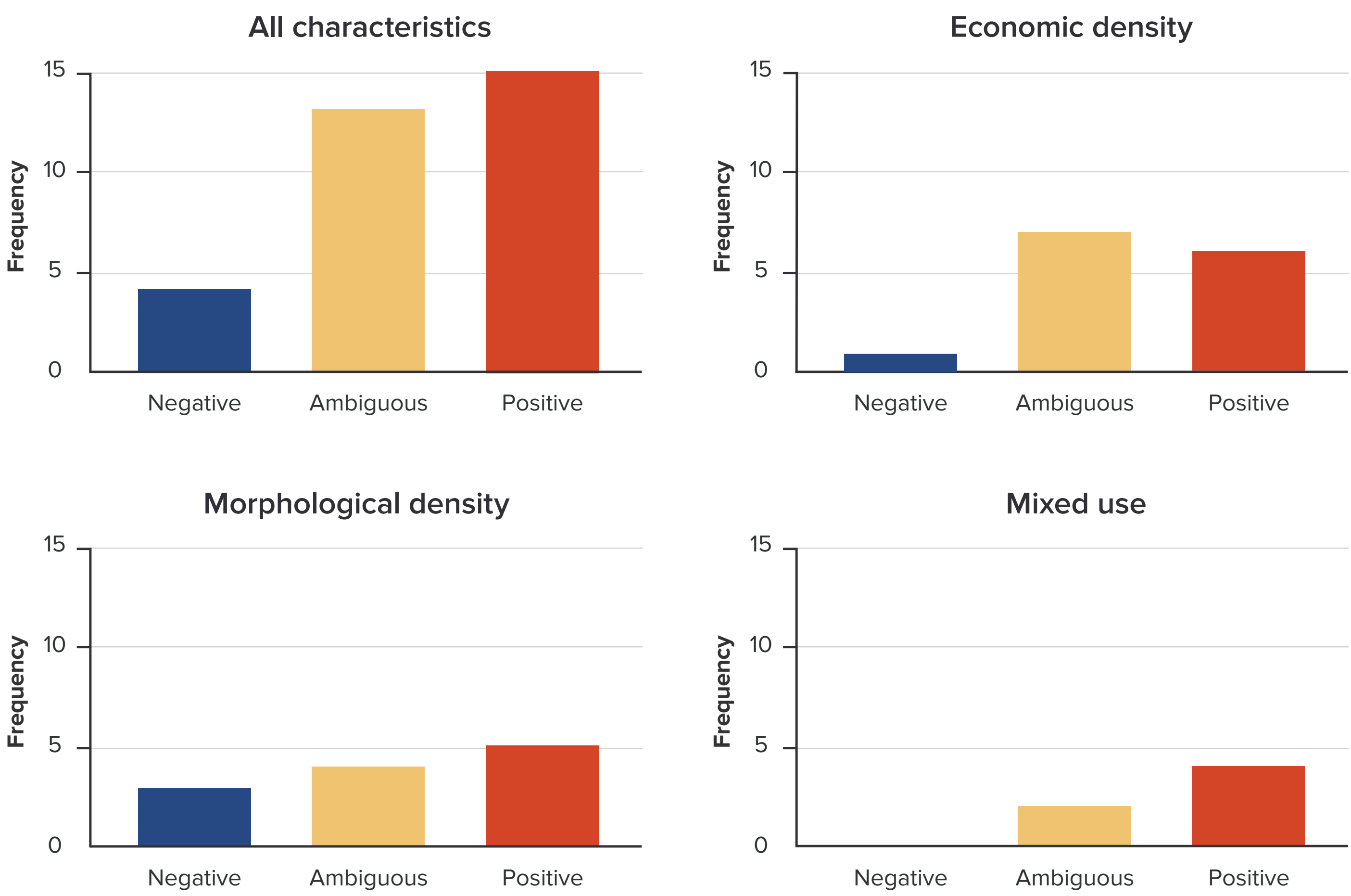
The categories and theoretical channels are potentially non-exhaustive and are restricted to those discussed in the theoretical literature. The direction of the theoretically expected effects is borrowed from the literature. Sources for each outcome-characteristic cell are presented in Table A1 to keep the presentation compact. "Ambiguous" implies that counteracting positive and negative effects are expected and it is not possible to predict theoretically which ones will dominate.

For 15 of the 32 outcome-characteristic relations reviewed in Table 3, the literature expects positive effects, with another 13 associated with ambiguous expectations, and only four channels expected to yield negative effects. In Figure 1, we illustrate the distribution of the nature of the expected effects (positive, ambiguous, negative) on the 15 outcome dimensions by compact city characteristics. Based on this stylised representation, *mixed land use* is perhaps most frequently seen as a positive compact city characteristic in the theoretical literature as unambiguously positive expectations are found for four out of the six outcome dimensions, with the remaining two being ambiguous. The expectations are also generally positive for the two other categories, *economic density and morphological density*, reflecting the generally positive tone of the compact city theory and policy debate. With expected negative effects for three of the 12 categories, *morphological density* is perhaps the most controversial compact city characteristic.

In Figure 2, we summarise the expected direction of the effects of compact city characteristics by outcome dimension. The theoretical literature suggests unambiguously positive compact city effects on *energy efficiency, innovation, productivity, services and amenities access, sustainable mode choice*, and *value of space*. For the remaining nine categories, the expectations are more ambiguous.

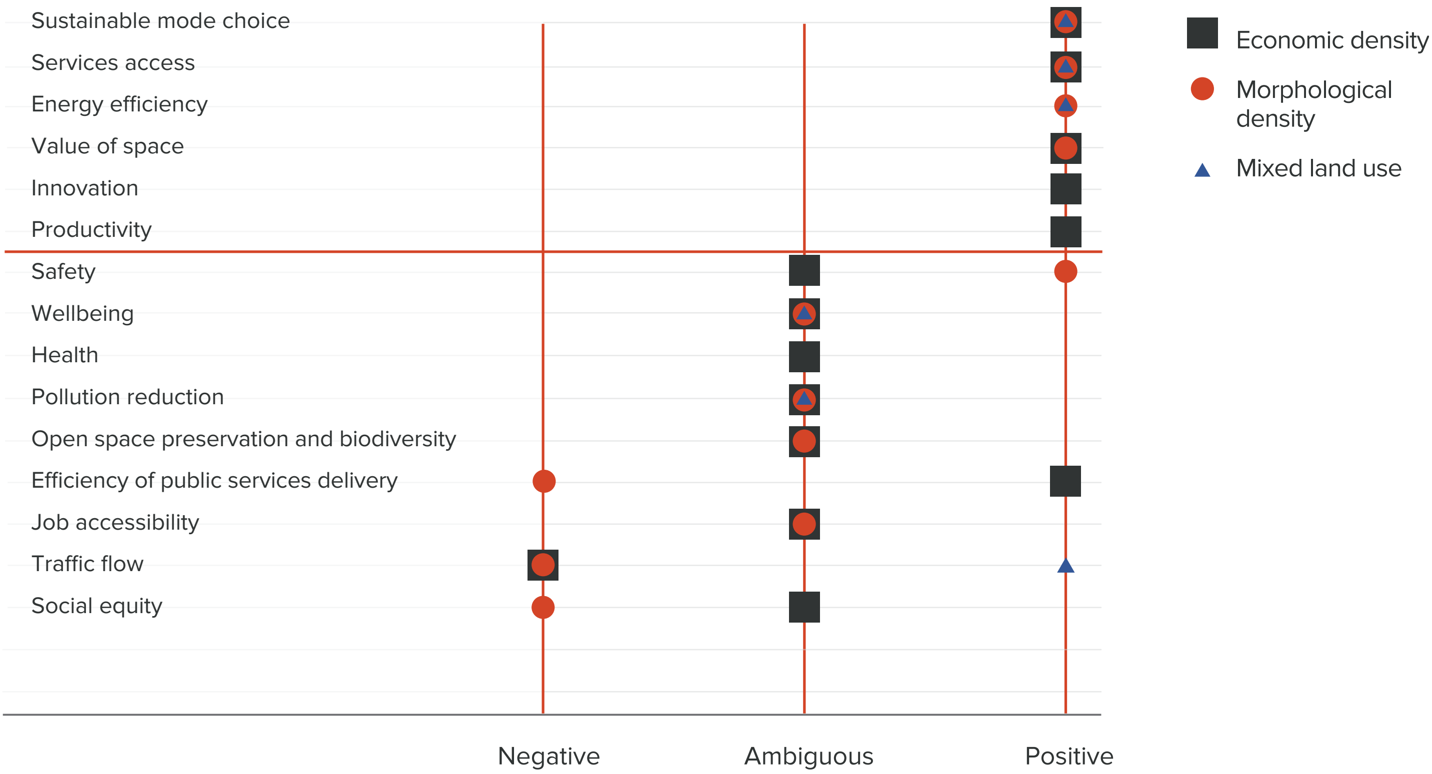
Figure 1

Expected effect of compact city characteristics across compact city characteristics in the theoretical literature



Notes: Stylised representation of the theoretically expected direction of the outcome-characteristic channels described in Table 3. "Ambiguous" implies that counteracting positive and negative effects are expected and it is not possible to predict theoretically which ones will dominate.

Figure 2
Expected effect of compact city characteristics by outcome dimension



Notes: Stylised representation of the theoretically expected direction of the compact city-characteristic on the outcome described in Table 3. "Ambiguous" implies that counteracting positive and negative effects are expected and it is not possible to predict theoretically which ones will dominate.

2.4 DENSITY AND CITY SIZE

Before we proceed to the analysis of our literature, a note is due on the concept of density, arguably the most important and certainly the most investigated feature of urban compactness. The literature sometimes refers to actual density (i.e. the population normalised by the geographic size of a city) and city size (i.e. the total population), interchangeably. Faberman and Freedman (2016), a recent example of a rigorous analysis of agglomeration effects, estimate what they refer to as *density premium*, using *city population* as a density measure.[3]

This ambiguity is not necessarily surprising because the workhorse tools in urban economics, such as the monocentric city model and its many derivatives, predict that an increase in city population results in an increase in density. Yet, some researchers have attempted to disentangle the effects of density and city size (Cheshire and Magrini, 2009). At the heart of such a separation is the idea that different types of agglomeration economies operate at different spatial resolutions (Andersson et al., 2016). Separating the effects of city size and density corresponds to separating the effects of different agglomeration economies (and diseconomies), some of which operate over large distances (so that city size matters), while others are more localised (so that density matters). Separating the effects of density and city size is challenging, because the geographic size of an integrated urban area cannot grow infinitely, which implies that density and city size cannot vary independently. Our reading of the literature is that in most studies identifying density effects from between-city (as opposed to within-city) comparisons, city population implicitly changes as city density changes (and vice versa). Thus, some studies may attribute effects to changes in density that are in fact due to changes in population size. The results discussed here should be interpreted with this in mind, because the implications may be different in a scenario where policy-makers are seeking to change density while keeping the population constant.

3. Qualitative results

Table 4 summarises the distribution of the 321 collected analyses (across 189 studies) by outcome dimensions and compact city characteristics. The large majority of the analyses are concerned with the effects of economic density. Only 12 analyses are explicitly concerned with the effects of mixed land use. Table 4 also reveals the major gaps in the literature. All combinations of outcomes and characteristics for which a causal link is expected in the theoretical literature but no evidence was found are marked by "0". This relates to four out of the total of 32 theoretically expected links, mostly concerning mixed land use effects. Original empirical research addressing these gaps would be desirable.

Table 4
Collected studies by outcome dimension and compact city characteristic

	COMPACT CITY EFFECTS	Number of analyses concerned with the effects of each compact city characteristics on each of the 15 outcome dimensions			
#	**Outcome dimension**	**Economic density**	**Morph. density**	**Mixed land use**	**Total**
1	Productivity	35	–	–	35
2	Innovation	9	1	–	10
3	Value of space	14	8	2	24
4	Job accessibility	13	3	2	18
5	Services and amenities access	15	2	**0**	17
6	Efficiency of public services delivery	14	2	–	16
7	Social equity	10	**0**	–	10
8	Safety	18	4	–	22
9	Open space preservation and biodiversity	2	5	–	7
10	Pollution reduction	12	3	**0**	15
11	Energy efficiency	23	8	1	32
12	Traffic flow	4	2	1	7
13	Sustainable mode choice	60	10	6	76
14	Health	13	3	–	16
15	Well-being	14	2	**0**	16
	TOTAL	**256**	**53**	**12**	**321**

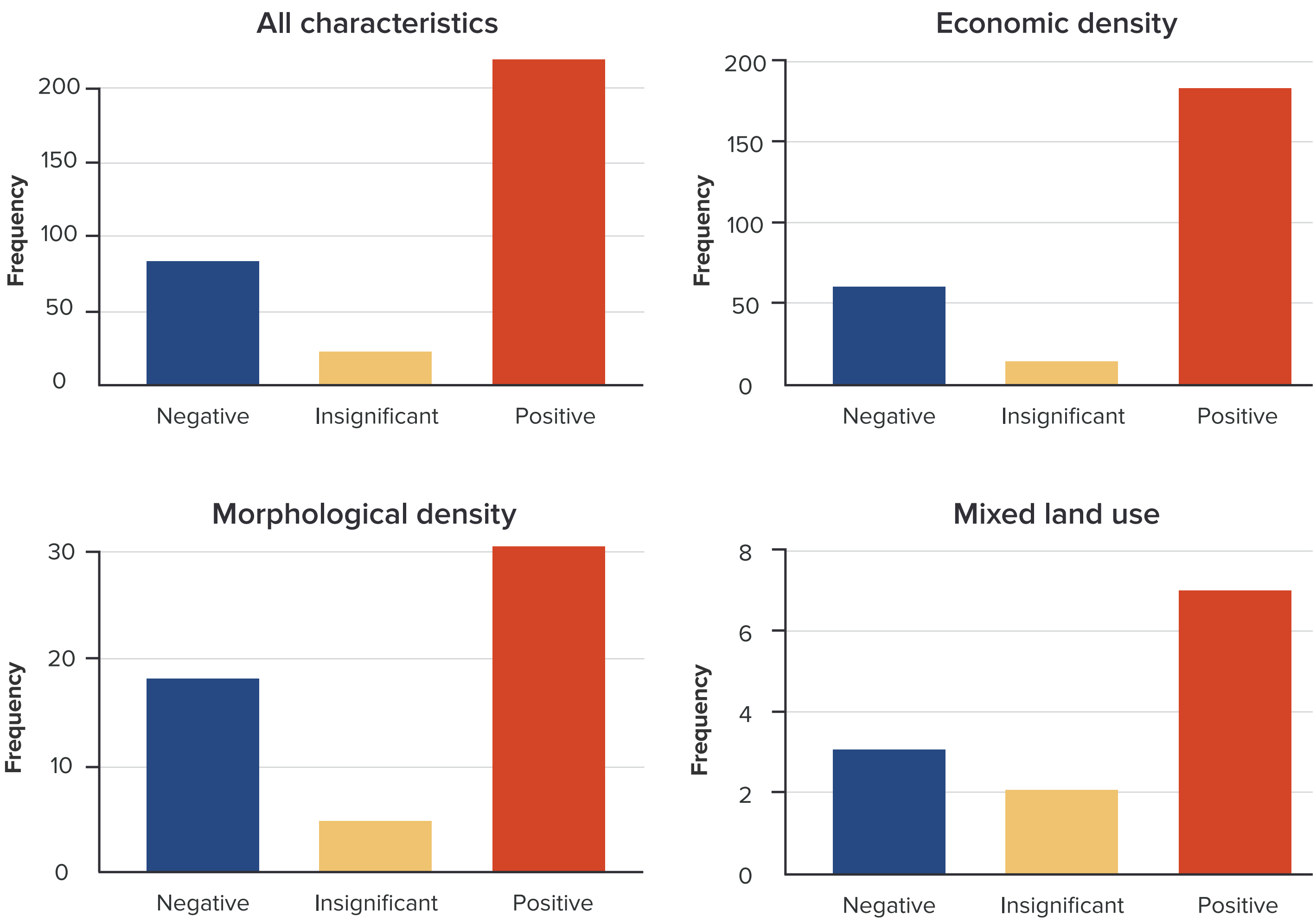
Notes: All numbers indicate the number of analyses collected within an outcome-characteristic cell. "0" indicates missing evidence in a theoretically relevant outcome-characteristic cell. "-" indicates missing evidence in a theoretically irrelevant outcome-characteristic cell.

We began the analysis of the collected literature focusing on qualitative results concluded in the literature of compact city effects. Distinguishing between positive (and significant), insignificant, and negative (and significant) results, we can exploit the entire literature and compare results within and across outcome dimensions, compact city characteristics, independently of the methodological approaches. In particular, studies referring to productivity and innovation tend to find positive effects of compactness, whereas all studies relating to open space and biodiversity find negative effects. Overall, the share of studies that finds positive effects of compactness is increasing over time.

3.1 QUALITATIVE RESULTS BY COMPACT CITY CHARACTERISTICS AND OUTCOME DIMENSIONS

In Figure 3, we summarise the distribution of qualitative results by compact city characteristics. A great majority of more than two-thirds of the analyses in the collected literature found significantly positive effects associated with compact city characteristics. This positive picture is driven by studies on the effects of economic density, which is also the most popular category. While over 70% of the analyses of economic density (often approximated by population density) show significantly positive effects, the two other classes of characteristics yield positive effects in only 56% (morphological density) and 58% (mixed land use) of studies.

Figure 3
Distribution of qualitative results by scale and compact city characteristic



Notes: The characteristic-specific definitions of positive and negative effects from Table 3 have been applied to encode the literature. Positive and negative results are statistically significant.

In Table 5, we summarise the literature on the effects of compactness by outcome dimension. We present the percentage of analyses within each outcome dimension that found positive and significant (pos.), insignificant (ins.), and negative (neg.) results. We also report the number of analyses within each outcome dimension, as well as the average score on the Maryland Scientific Methods Scale (SMS),[4] to illustrate both the quantity and the quality of the study within each outcome dimension. To further describe the nature of the literature, we also report the proportion of analyses using data from high-income countries, being published in academic journals, belonging to the economics discipline, using within-city data, and also the median year of publication.

We find significant variation in the collected literature across outcome dimensions, both with respect to the results and the type of analysis. On average, the collected literature clearly suggests positive effects associated with compactness for the outcomes *productivity, innovation, services and amenities access, value of space, efficiency of public services delivery, social equity, safety, energy efficiency*, and *sustainable mode choice*. For the outcome dimensions *open space preservation and biodiversity, safety, traffic flow, and health* and *well-being*, the majority of analyses find negative effects. The evidence is mixed for *job accessibility* and *pollution reduction*.

With the exception of *efficiency of public services delivery* and *traffic flow*, analyses on all outcome dimensions have median publication dates within the last 10 years, reflecting considerable ongoing research activity. It is notable that economists tend to concentrate on the analysis of *productivity, innovation, and value of space,* all of which belong to the outcomes where effects tend to be particularly positive. Another notable feature is that the collected literature is generally US- and Euro-centric. Only in the outcome dimensions *value of space, job accessibility*, and *traffic flow* do a significant share of analyses use data from non-high-income countries.

There is also significant diversity with respect to the methods of analysis prevailing within studies. An average of more than 3 on the SMS reflects that most researchers are concerned with identification when analysing the effects of density on *productivity*. In contrast, an average of 1.6 or 1.0 on the SMS within the outcome dimensions *energy efficiency* and *open space preservation and biodiversity* reflects that the chosen approaches are more descriptive or simulation-based (as is typical for engineering literature). When interpreting the numbers in Table 5, it should be kept in mind that results for outcome dimensions with a higher number of studies and a higher average score on the SMS are more meaningful and less uncertain than other results.

Table 5
Literature summarised by outcome dimension

SHARE OF PUBLICATIONS							RESULT[c]				
ID	Outcome dimension	Number of studies	Poor countries[a]	Academic journal	Economics	Identifies within-city variation	Med. Year[b]	Average SMS score	Pos.	Ins.	Neg.
1	Productivity	35	11%	94%	60%	14%	2011	3.09	94%	3%	3%
2	Innovation	10	10%	90%	10%	0%	2010	2.40	80%	10%	10%
3	Value of space	24	29%	71%	54%	58%	2013	2.00	71%	4%	25%
4	Job accessibility	18	28%	72%	22%	44%	2010	2.00	56%	11%	33%
5	Services and amenities access	17	18%	82%	59	53%	2015	2.88	76%	6%	18%
6	Efficiency of public services delivery	16	0%	94%	19%	0%	2003	2.13	75%	13%	13%
7	Social equity	10	0%	90%	30%	10%	2006	2.60	70%	0%	30%
8	Safety	22	5%	82%	9%	0.82%	2015	2.05	77%	0%	23%
9	Open space preservation and biodiversity	7	0%	86%	0%	71%	2009	1.00	14%	0%	86%
10	Pollution reduction	15	53%	53%	7%	60%	2013	2.13	53%	0%	47%
11	Energy efficiency	32	13%	97%	31%	25%	2010	1.47	69%	9%	22%
12	Traffic flow	7	29%	57%	57%	29%	2009	2.14	29%	14%	57%
13	Sustainable mode choice	76	11%	89%	3%	79%	2004	2.01	84%	8%	8%
14	Health	16	0%	100%	0%	38%	2005	2.13	19%	6%	75%
15	Well-being	16	0%	63%	38%	25%	2008	2.25	19%	6%	75%
	Average	**21**	**14%**	**81%**	**27%**	**39%**	**2009**	**2.15**	**59%**	**6%**	**35%**

Notes: a. Poor countries include low-income and middle-income countries according to the World Bank definition. b. Median year of publication. c. Qualitative results scale (positive, insignificant, negative) is outcome-characteristic specific and defined in Table 3.

In Table 6 we summarise the qualitative results scores by outcome dimension and compact city characteristic. To allow for a compact presentation despite the higher number of dimensions (15 x 3), we follow Ahlfeldt et al. (2016) and assign numeric values to the qualitative results. In particular, we assign values of -1/0/1 to the qualitative result classifications of *negative and significant* (-1), *insignificant* (0), *positive and significant* (1). This allows us to aggregate the qualitative results to outcome-specific averages, which can vary theoretically from -1 (strictly negative) to 1 (strictly positive) and are comparable across categories. The numbers in Table 6 represent the averages of the accordingly coded studies by outcome dimension. For example, a dimension in which all studies show statistically significant positive effects would have a value of 1, a dimension where half the studies show statistically significant negative effects and the other half are insignificant would have a value of -0.5.

We find some interesting heterogeneity in the results patterns within outcome dimensions, which suggests that the effects of compact city characteristics can qualitatively vary within outcome dimensions. As an example, economic density and morphological density have positive effects on *value of space*, whereas the effect of increased mixed use is negative. Economic density and mixed land use seem to be associated with shorter trip length, whereas the opposite is true for morphological density. Pollution concentrations seem to be lower in economically dense areas (likely due to lower energy consumption and emissions), but higher in morphologically dense areas (possibly because these "trap" pollutants). In line with expectations identified from the theoretical literature, economic density and morphological density hinder smooth traffic, while mixed land use does the opposite (because a proportion of car trips become redundant). These results confirm the theoretical notion that compact city effects are specific to combinations of outcome dimensions and characteristics, and any breakdown by outcome dimensions or characteristics comes at the expense of masking important heterogeneity.

Table 6
Average qualitative results scores by outcome dimension and compact city characteristic

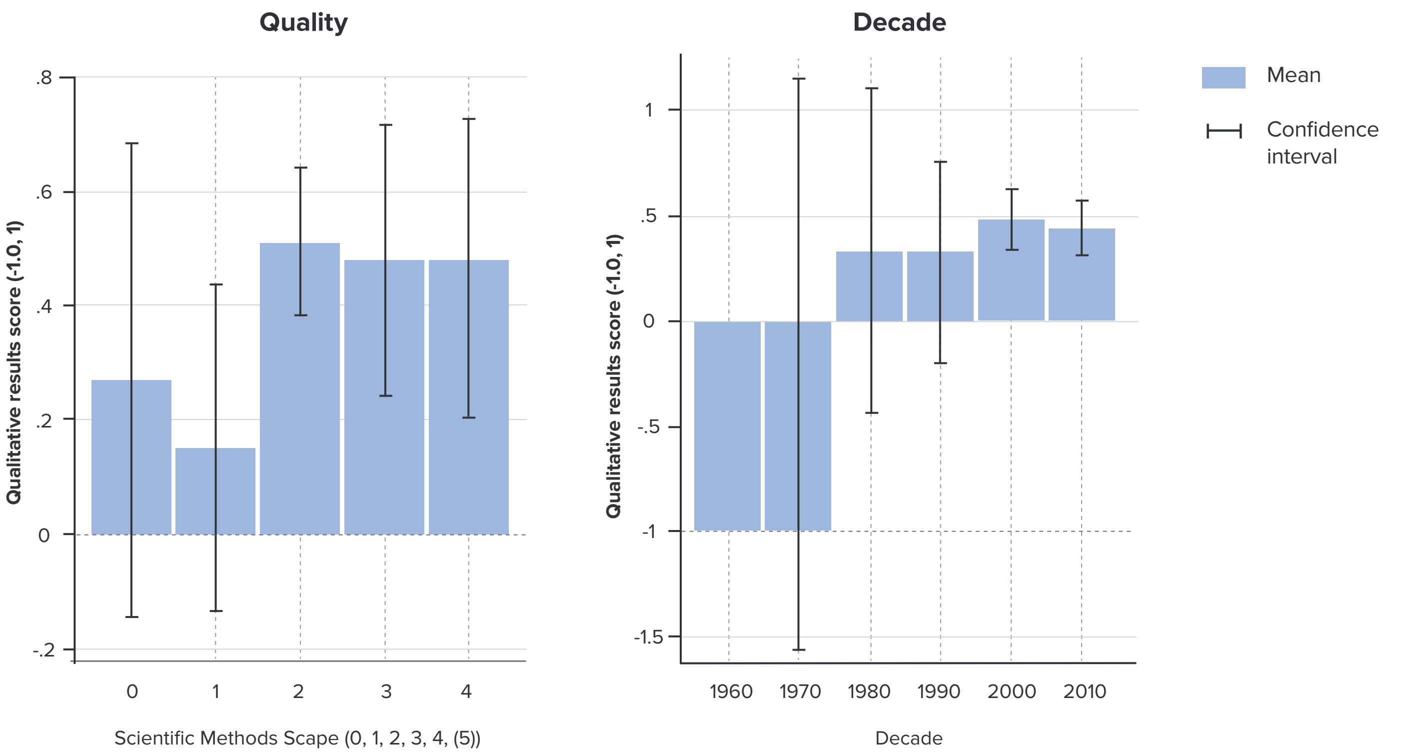
#	Outcome dimension	Economic density	Morph. density	Mixed land use	Average
1	Productivity	0.91	–	–	0.91
2	Innovation	0.78	0.00	-	0.39
3	Value of space	0.57	0.63	-1.00	0.07
4	Job accessibility	0.31	-0.33	0.50	0.16
5	Services and amenities access	0.53	1.00	–	0.77
6	Efficiency of public services delivery	0.57	1.00	–	0.79
7	Social equity	0.40	–	–	0.40
8	Safety	0.67	0.00	–	0.33
9	Open space preservation and biodiversity	-1.00	-0.60	–	-0.80
10	Pollution reduction	0.33	-1.00	–	-0.33
11	Energy efficiency	0.48	0.38	1.00	0.62
12	Traffic flow	-0.50	-0.50	1.00	0.00
13	Sustainable mode choice	0.77	0.90	0.50	0.72
14	Health	-0.62	-0.33	–	-0.47
15	Well-being	-0.64	0.00	–	-0.32
	Average	**0.24**	**0.09**	**0.40**	**0.21**

Notes: Qualitative results scale can take values -1: negative and significant; 0: insignificant; 1: positive, where outcome dimension-specific definitions of positive and negative effects are in line with Table 3. Cells contain averages of evidence scores across all studies with the same outcome-characteristic combinations.

3.2 RESULTS BY STUDY ATTRIBUTES

A standard practice in meta-analytic research is to investigate the sources of heterogeneity in the evidence base. We begin with an exploratory analysis to establish basic facts regarding the distribution of qualitative results across selected attributes. Perhaps the most interesting feature of a piece of evidence, besides the empirical finding itself, is the rigour of the analysis. In Figure 4 (left panel), we illustrate how the results (qualitative results scores) vary across quality scores (as defined by the SMS). Compactness is more often found to be a positive feature in analyses that employ statistical methods scoring at least 2 on the SMS, but results become slightly less positive for analysis of lower quality. The simplest (exploratory and descriptive) methods scoring 0 or 1 on the SMS are not only significantly less likely to yield a positive finding, the variation in results across analyses is also relatively large (as reflected by the large confidence bands). The right panel similarly aggregates the qualitative results scores by decade. The main insight is that over time the effects of the compact urban form found in research tend to become more positive. The positive time trend in results may be driven partially by the application of more rigorous research techniques, which tend to yield more positive results with less volatility.

Figure 4
Distribution of qualitative results by scale and compact city characteristic



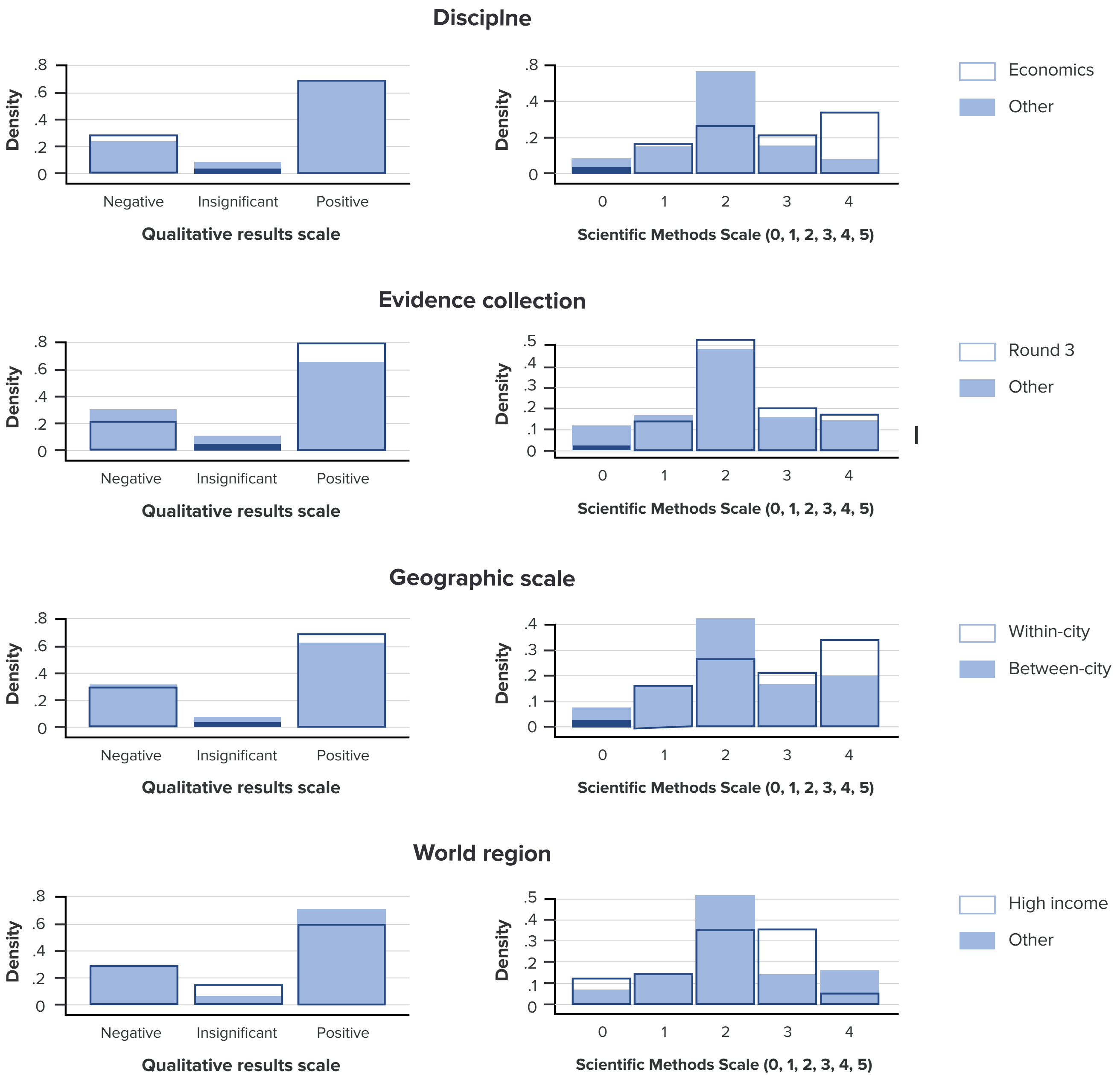
Notes: Unconditional and unweighted averages. Confidence interval is at the 95% level.

In Figure 5, we further analyse the distribution of the qualitative results across selected attributes. In each case, we also illustrate how the distribution of the quality of studies varies in the selected attribute because, as shown above, the quality of the study appears to correlate with the qualitative result score. In the Discipline graphs, we distinguish between analyses published in economics (the most frequent discipline) and all other disciplines. Economics analyses yield positive effects related to compact urban form slightly more often than others. The Evidence collection graphs analyse the literature collected in round three of the collection process described in the Appendix, which includes recommendations from colleagues at various institutions. The proportion of analyses finding positive effects of compact urban form is higher in round three than for the remaining evidence, but the quality of the evidence is also higher. In the Geographic scale graphs, the same pattern is found, once again: within-city analyses yield slightly more positive results, but the quality of the methods is also higher. Thus, it cannot be ruled out that some of the differences found between outcome dimensions are due to differences in methodological quality.

Finally, the World region graphs analyse the literature by study area. As already shown by Table 5, the literature we collected is strongly biased toward high-income countries. Only 43 analyses use data from non-high-income countries, according to the World Bank (2015) definition. The studies use data from Brazil, China, Colombia, Egypt, India, Indonesia, Iran, as well as pooled analyses of several countries in Eastern Asia and South America, and a study that uses non-OECD countries. This relatively small number of non-high-income countries makes it difficult to assess the evidence available for them separately. However, it is notable that the distribution of qualitative results scores in this relatively small sub-sample is slightly less positive than in the remaining sample. The average quality of the methods is also somewhat lower in the analyses using data from non-high-income countries.

Figure 5

Distribution of qualitative results scores and quality of evidence by attributes



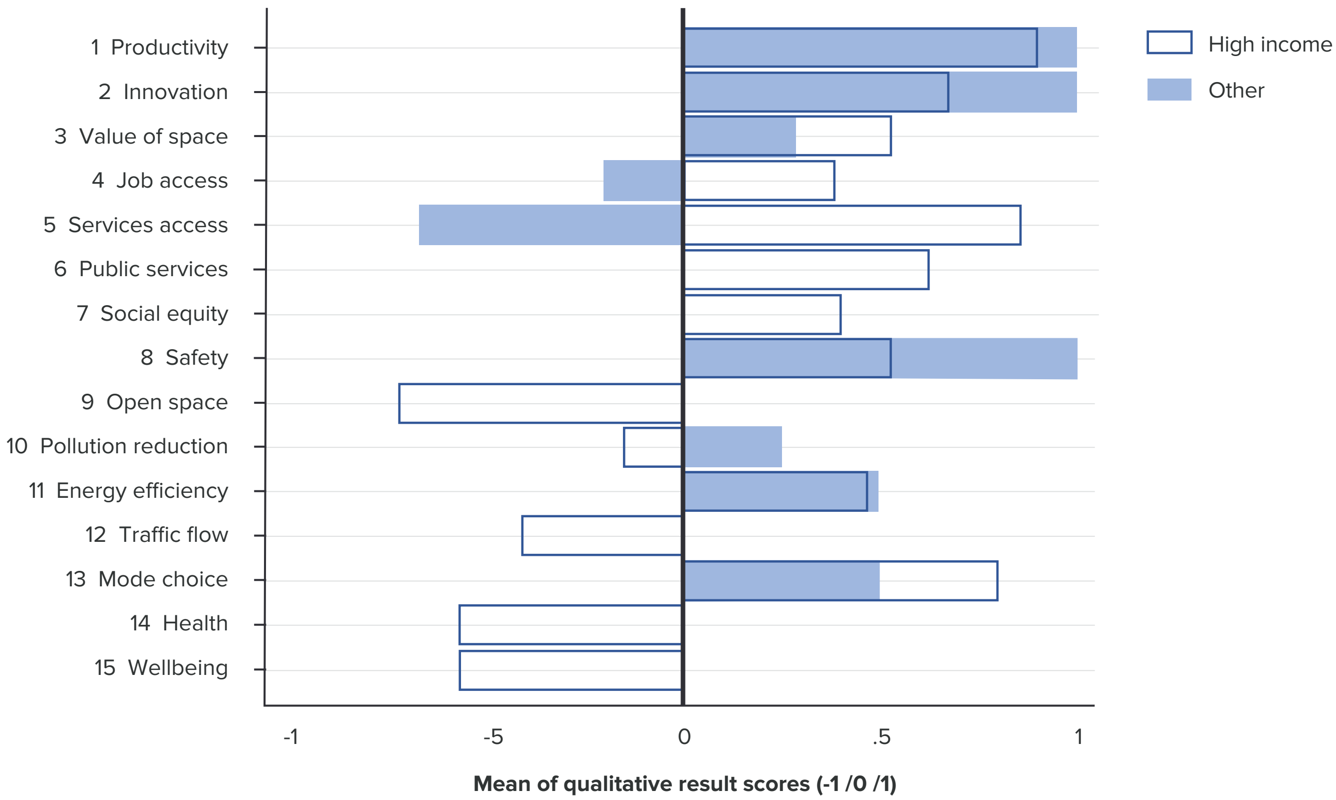
Notes: Outcome dimension-specific definitions of positive and negative (in Table 3) chosen such that they indicate the positive effects of "compactness" across all outcome dimensions. Higher scores on the Scientific Methods Scale imply more rigorous methods as defined by the What Works Centre for Local Economic Growth (2016). High-income definition from the World Bank (2015).

Using the "-1/0/1" numeric equivalent of the qualitative results scale, we next illustrate the distribution of average qualitative results scores by outcome dimension and country income (Figure 6). For several outcome dimensions, evidence on low-income countries is missing in the collected literature.

Perhaps the most notable finding is that the literature for non-high-income countries shows less positive effects for the outcome dimensions *value of space* and *sustainable mode choice*, and more negative effects for *job access* and *services* and *amenities access*, suggesting larger costs of density related to transport. The literature for non-high-income countries shows more positive effects for the outcome dimension safety, suggesting a larger presence of "eyes on the street" (Jacobs, 1961). Some care is warranted with the interpretation, however, due to the limited evidence base for non-high-income countries. For a tabulation of further attributes of studies using data from non-high-income countries, see Table A4 in the Appendix.

Figure 6

Average of qualitative results scores by outcome dimensions and country income



Notes: Unconditional and unweighted averages. High-income definition from the World Bank (2015).

Section 5 in the Appendix contains further discussions of how different study attributes predict whether the study finds a positive, insignificant, or negative effect of compactness.

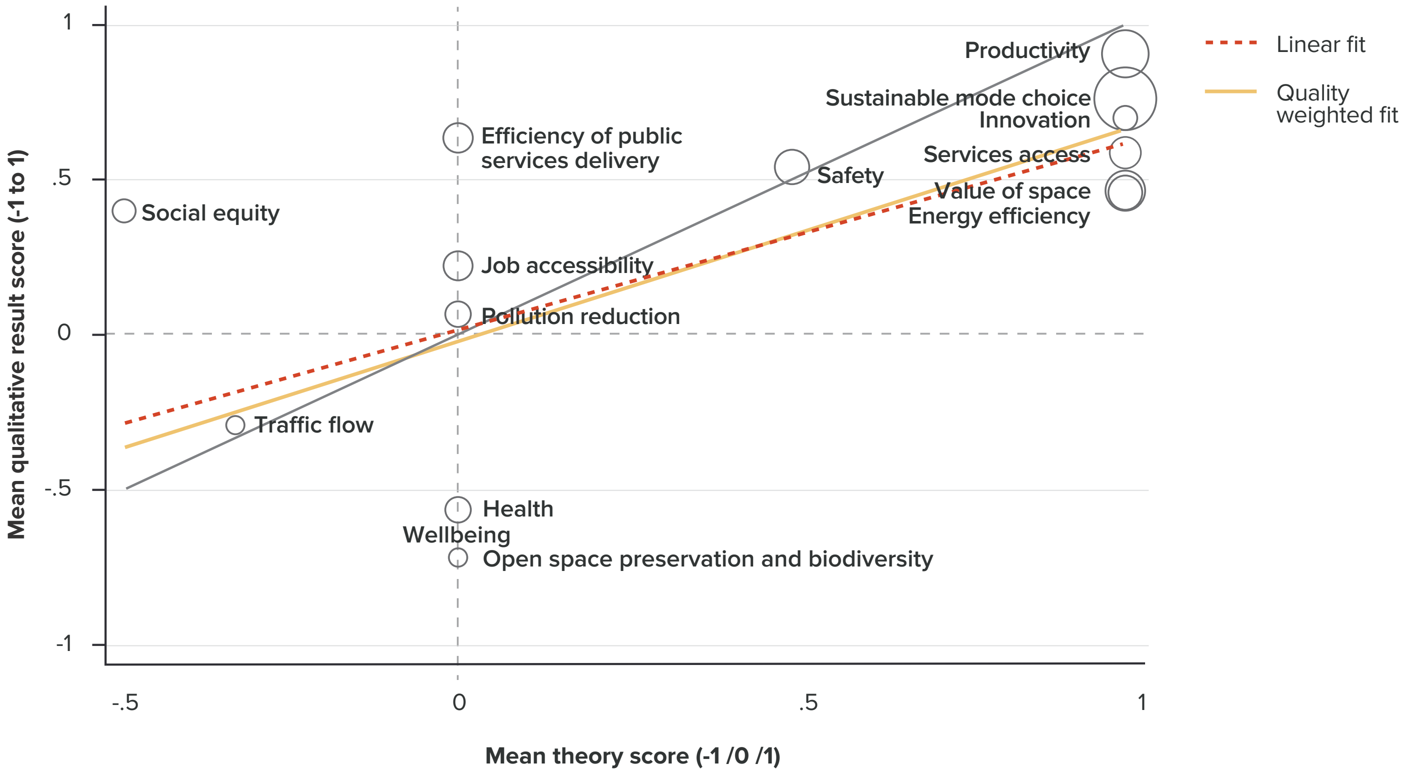
3.3 COMPARISON WITH THE THEORETICAL LITERATURE

In Figure 7, we compare the empirical results in the collected literature with the predictions and expectations prevailing in the theoretical literature. We do this at the level of outcome dimensions, acknowledging that we lose important information on the within-outcome effects of different compact city characteristics. For this purpose, we construct a simple index of theoretical expectations based on the qualitative information summarised in Table 3. In line with the qualitative results index, we assign values of -1/0/1 to each outcome-characteristic cell if the expectations are *negative* (-1), *ambiguous* (0), *positive* (-1). Figure 7 shows the correlation between theoretical expectations and actual results.

We find a clear positive correlation, indicating that the theoretical expectations in the compact city literature generally align well with the evidence base. For the outcome dimensions where the effects are ambiguous in the theoretical literature, we find in the empirical evidence that *efficiency of public services delivery* has positive effects, while the opposite is true for *health, well-being*, and *open space preservation and biodiversity*.

The most notable inconsistency between theory and empirical evidence is for *social equity*. The theoretical literature predicts negative effects, but the empirical evidence is surprisingly positive. Previewing the results presented in the following sections, however, we note that our own analysis of various inequality measures using OECD regional data suggests that economic density (the compact city characteristic primarily considered in the context of inequality analyses) increases social inequality. To reconcile the collected literature with our own findings (and the theoretical literature), we note that the collected literature contains several case studies on a within-city scale, but our analysis is at the cross-regional level. It seems plausible that the mechanisms affecting equity dimensions are different on a within-city and a between-city scale, but further research is required to substantiate this intuition.

Figure 7
Theoretical expectations vs. empirical findings



Notes: Mean theory score is the outcome dimension's average score across the compact city characteristics, in terms of the theoretical expectations illustrated in Figure 2, where positive is coded as 1, ambiguous is coded as 0, and negative is coded as -1. Mean qualitative result score is the outcome dimension's average for the analyses results (in the qualitative results scores defined in Table 6), where positive and significant is coded as 1, insignificant is coded as 0, and negative and significant is coded as -1.

3.4 FOCUS ON SOCIAL AND ENVIRONMENTAL OUTCOME DIMENSIONS

In this section, we elaborate on selected results in social and environmental outcome categories, which exhibit particularly complex results that could not always be captured by the quantitative evidence. These include: safety (outcome dimension 8), pollution reduction (10), energy efficiency (11), and health (14). For this purpose, 62 studies, including 164 quantitative and qualitative analyses, are reviewed separately. The results show that the effects of compact urban form are extremely varied and may also include outcomes that have not yet been systematically studied. This section presents an overview

of selected findings on individual outcomes that go beyond the 15 main outcome dimensions identified in the theoretical review, to demonstrate the complexity of the dimensions, and identify areas where more research is needed.

Safety (outcome dimension 8)

In addition to crime rates, some studies discussed traffic safety and urban resilience, which generally present positive effects. On traffic safety, Ewing and colleagues showed that population density has a negative correlation with traffic fatality and pedestrian fatality: a 1% increase in the compactness index (containing different measures of urban form related to sprawl) is associated with a 1.49% drop in the traffic fatality rate and 1.47% in the pedestrian fatality rate (Ewing et al., 2003; Ewing and Hamidi, 2014). Bramely et al. (2009) showed that density was negatively associated a feeling of safety in UK cities. As for pedestrian casualties, higher population density is associated with increases in pedestrian casualties up to a certain level, and this relationship diminishes in extremely dense areas (Graham and Glaister, 2003). The authors proposed that this is largely because of traffic congestion and greater speed control.

Some studies also discuss urban resilience, including the vulnerability of compact urban form to unexpected extreme events, such as natural disasters, terrorist attacks, or epidemic diseases. In general, studies show that the amount of damages and losses have been concentrated in dense urban areas. Dense urban areas with high-rise buildings are particularly vulnerable to natural disasters, simply because concentrated population and assets are exposed to risks. Chunliang (2011) concluded that city size, density, and built-up area are positively associated with vulnerability, while infrastructure density reduces vulnerability.

Approximately 64% of terrorist attacks occurred in urban areas until 2005. The density of targets (population and property) is a key reason that urban areas attract terrorist attacks (Savitch, 2005).

Despite some studies showing greater vulnerability of urban areas to risks, other researchers argued that urban agglomeration economies contribute to creating better cost–benefit ratios of risk management systems in urban areas. Lall and Deichmann (2011) wrote that high-density areas are likely to be better prepared for extreme events.

Pollution reduction (outcome dimension 10)

In addition to air pollution, urban heat islands (UHI) effects are sometimes studied, generally with mixed results. While most of the studies on GHG emissions and compact urban form are conducted at the metropolitan or city level, UHI studies are specifically targeted at the neighbourhood level. Harlan et al. (2006) compared eight neighbourhoods in Phoenix, and found population density is strongly correlated with UHI, while existence of open space within neighbourhoods is inversely correlated with UHI. The study also stressed that UHI mainly affect lower-income households. Jusuf et al. (2007) found that among places with similar densities, such as industrial areas, places with a greater rate of impervious land covers are highly likely to be exposed to higher urban heats. In contrast, Stone et al. (2010) analysed extreme heat events in large US cities using sprawl indexes. They offered quantitative evidence that the increase rate of the number of extreme heat events per year in sprawl regions was more than double the rate observed in compact regions. Obviously, such patterns do not necessarily imply any causality and may simply be related to the geographical patterns of heatwaves and the distribution of sprawling cities across the US.

Energy efficiency (outcome dimension 11)

In addition to energy efficiency, resource efficiency has been discussed concerning sustainable urban metabolism. Most studies present positive effects of compact urban form mainly because it is less land-intensive. Burchell and Mukherji (2003) studied 15 metropolitan areas in the US with 25-year-long projection modelling, and found that nearly 4 million acres can be preserved from development by controlling urban sprawl. The 4 million acres consisted of 1.5 million acres of environmentally fragile land and 1.5 million acres of agricultural land. As for resources and costs relating to infrastructure supply, Burchell and Mukherji (2003) also argued that more than 150 million gallons of water and sewer demand per day are possibly saved with sensible growth patterns, which corresponds to US$12 billion in savings for total infrastructure costs.

Schiller (2007) studied material flows relating to buildings and infrastructure across the globe and in Germany specifically. He concluded that higher building and infrastructure density is linked to less material intensity. Areas with lower building densities are associated with greater material consumption for infrastructure, which is similarly applied to future trends for material flows. Liu and Arp (2012) asserted that resource efficiency is greater in high-density cities based on empirical studies of 30 Chinese cities, while too high population density tends to degrade overall environmental conditions.

Water consumption and quality are also correlated with morphological density. Chang et al. (2010) found that an average increase of one house per acre was linked to a reduction in water consumption of 34,320 litres, up to the threshold of four houses per acre. Domene and Sauri (2006) also found that the water consumption rate is higher in single-family residential areas in Barcelona. Hatt et al. (2004) found that the level of water pollution and impervious land cover had a strong negative correlation, based on case studies in Australia. Jacob and Lopez (2009) found that total water consumption and run-off volume tend to increase with density, but per capita consumption and run-off volume decreases with density. This result also showed that compact urban areas, especially those with transit-oriented developments, tend to outperform other traditional stormwater management practices.

Health (outcome dimension 14)

This category perhaps presents the most complex results. Most authors argued that, although compact urban form is associated with a higher level of physical activity, population density negatively affects urban health as a result of concentrated pollution. However, at the regional level, studies found that lower population densities are associated with decreased physical activity and increased obesity rates (Lopez, 2004; Ewing, 2003). Ewing and Hamidi (2014) also found that people living in compact areas are likely to live longer; life expectancy increases by 4% as the compactness score is doubled. At the city or local level, connectivity, land use, and sidewalk designs are positively correlated with improving urban health, especially physical activity. Frank et al. (2010) found a positive correlation between mixed land use and physical activity. More recently, Stevenson et al. (2016) observed that compact city scenarios improve health conditions in their six case cities. They analysed compact city scenarios that were modelled to increase density and diversity, reduce the distances to public transport, and promote modal shifts from motorised mobility to walking and cycling. While changes in health gains vary across the cities, in all cases cardiovascular disease, respiratory disease, and diabetes were reduced under the compact city scenarios.

3.5 FOCUS ON LOW- AND MIDDLE-INCOME COUNTRIES

In this section, we elaborate on the results on the basis of one of the study attributes – country income. We discuss how the characteristics of urban form are different in high-income and non-high-income countries and how compact urban forms fit the diverse needs of cities. Given that the urban challenges that emerging cities in developing countries face are different from those that developed countries need to address, such as retrofitting matured or deteriorated cities, the implications of compact urban form may differ accordingly (Burgess and Jenks, 2002; OECD, 2012). For this purpose, 28 studies are reviewed separately.

An important starting point in understanding the difference in urban form between high-income and non-high-income countries is that urban population densities in developing countries are significantly higher than those in developed countries (Knox and McCarthy, 2012; Angel et al., 2012). According to Angel et al. (2012), population density in urban areas in developing countries in 2000 reached 129 persons per hectare, whereas land-rich developed countries such as the US had urban population densities of only 25 persons per hectare. Notably, cities in Latin America have the densest urban centres with concentric road networks that have been influenced by European planning practices (Knox and McCarthy, 2012). However, the empirical evidence of 120 global cities proves that densities in developing countries have decreased from 170 persons per hectare in 1990 to 135 in 2000 (Angel, 2011). In other words, urban sprawl occurs across developing countries, as it did earlier in developed countries (Blokford, 2016).

Important differences between developed and developing countries are also observed in the levels of population and morphological densities. Morphological density in Asian cities is relatively low, although they traditionally have a greater level of mixed-land uses consisting of religious buildings, commercial areas, and other public facilities, and high-density living (Williams, 2004). David's empirical studies in India (2010) also confirmed that there are considerable differences between residential population densities and morphological densities. This gap between population densities and morphological densities may explain in part why compact urban form in developing countries shows less positive effects for sustainable mode choice, services and amenities access, and health in non-high-income countries. For example, Mumbai has one of the highest levels of residential density, but with relatively low morphological density. This was associated with the Indian government's land use regulations that kept building density low in order to control overcrowded cities. This resulted in forcing people to live in very small spaces (4.5m^2 per capita), and still encouraging urban sprawl. Dense settlements without sufficient space in buildings also face privacy and quality-of-life challenges, although David (2010) argues that high social bonds and a greater level of cohesion makes reduced privacy in high-density areas less of an issue in some Asian societies.

Street connectivity and other urban transport infrastructure are also important characteristics of morphological density that have an impact on the type of effect seen from compact urban form in developing countries. Dodman (2009) found that high population density has an insignificant association with share of sustainable transport modes in developing countries. Importantly, dense settlements in developing countries are heavily reliant on informal or on-demand transport services, such as motorcycles and rickshaws (Vlahov, 2010; Turok, 2012), instead of safer and more environmentally friendly public transport modes.

Besides, high population density with poor public service access is directly linked to environmental, health, and well-being problems. The population concentration in Kenya has negatively affected urban health, because of concentrated pollution (Kinney et al., 2011). The extremely high population densities in China have also contributed to environmental health problems (Chunliang et al., 2011). Therefore, Dodman (2009) stresses that dense settlements can contribute to sustainability and resilience only if they are accompanied by well-planned and effectively managed infrastructure and design. These findings underscore the lack of morphological density (streets and other transport infrastructure in particular) in developing countries, which may have resulted in negative effects in several outcome dimensions.

High- and middle-income countries seem to experience more positive effects from compact urban form than non-high-income countries, due to adequate urban infrastructure and services/amenities. In medium-sized cities in Thailand, higher population density is positively associated with reducing transport emission and energy consumptions (Kunvitaya and Dhakal, 2016). Chen et al. (2008) analysed Chinese cities, and concluded that population density affects resource efficiency positively.

Finally, lifestyle may also explain the different effects of compact urban form in developed and developing countries. While most studies report that compact urban form has positive effects on pollution reduction, some studies for developing countries indicate reverse implications. Dodman (2009) asserts that denser settlements in developed countries are likely to have lower per capita GHG emissions associated with higher infrastructure density and a greater variety of sustainable transport modes. However, residents of denser settlements in developing countries tend to have a greater amount of GHG emissions per capita, as they have wealthier residents who consume more energy and private transport modes (Dodman, 2009). Lankao (2007) also found that wealthy people tend to consume more energy in Latin American cities. More generally, these findings illustrate the empirical challenges in distinguishing the effects of compact urban form from other trends that often go hand-in-hand with it.

4. Quantitative results on economic density

In this section, we concentrate on a sub-sample of analyses whose results can be summarised in a simple quantitative metric: the percentage change of an outcome in response to a 1% change in economic density. This so-called elasticity is a standardised way to express the effects of a small change in density. It allows for comparison between studies that use different metrics. Economic density is the most commonly analysed compact city characteristic, it is easy to compute and interpret, and also “objective, quantitative, and neutral” (Churchman, 1999). As discussed previously, economic density is often approximated by the density of economically active persons or, even more commonly, simply by the population density of an area. Thus, the following section will generally refer to population density.

For about a quarter of the 202 quantitative analyses considered, we approximated the elasticity from the reported results. A detailed discussion is in Section 6 of the Appendix. In some instances, authors kindly provided elasticity estimates not reported in the original papers.

4.1 ESTIMATING ELASTICITIES

In Table 7, we condense the quantitative evidence into singular elasticities with respect to density, which we provide for each outcome dimension. If no corresponding estimates could be found in the literature, we have calculated our own estimates based on OECD data. Further details on this can be found in Section 7 in the Appendix.

Specific to each outcome dimension, we either calculate an average across the elasticities in our collected literature, the result of a dedicated meta-analysis, or use an estimate from a high-quality original research paper or one of our own estimates. In general, we prefer the results of good expert meta-analyses over our own summary of the collected literature, and estimates from dedicated high-quality original research papers over our own estimates. We also prefer estimates from dedicated high-quality papers over the average of the collected literature if the evidence base is limited or inconsistent or inclusive.

Our aim is to provide a compact and accessible comparison of density effects across outcome dimensions. Note that this comes at the cost of substantial context-specific heterogeneity. Moreover, the quality and quantity of the collected literature base is highly heterogeneous across categories. Section 7 in the Appendix provides a discussion of the origin of each of the recommended elasticities against the quality and quantity of the literature, for those who may want to apply any of the elasticities reported in Table 7 in further research. We stress that significant uncertainty surrounds the effects of density on income inequality, open space preservation, pollution concentration, health, and subjective well-being.

4.2 CALCULATING THE MONETARY EFFECT OF ECONOMIC DENSITY

While the elasticities reported in Table 7 all represent the response to a 1% change in density, the implied effects of density are still difficult to compare as they materialise in very different outcomes (e.g. better health and higher speed on roads).

Table 7
Elasticities estimated by outcome dimension

ID	Elasticity	Value	Source
1	Wage	0.04	Median elasticity in review, roughly in line with Combes et al. (2013) and Melo et al. (2009)
2	Patent intensity	0.13	Average elasticity in review, in line with own analysis of OECD data
3	Rent	0.21	From dedicated high-quality paper (Combes et al., 2013)
4	Vehicle miles travelled (VMT) reduction	0.085	From dedicated high-quality paper (Duranton and Turner, 2015), between average and median elasticity in review
5	Variety value (price index reduction)	0.12	Dedicated analysis on request (Couture, 2016), in line with Ahlfeldt et al. (2015)
6	Local public spending	0.144	From dedicated high-quality paper (Carruthers and Ulfarsson, 2003)
7	Wage gap[a] reduction	-0.035	Own analysis of OECD data (literature thin and inconsistent)
8	Crime rate reduction	0.08	Dedicated analysis on request (Tang, 2015)
9	Green density	0.23	Own analysis of OECD data (literature non-existent)
10	Pollution reduction	0.03	Average elasticity in review
11	Energy use reduction	0.11	Average elasticity in review
12	Average speed	-0.11	Average from evidence review. Two high-quality papers (Duranton and Turner, 2015; Couture et al., 2016)
13	Non-car mode choice	0.07	Meta-analysis by Ewing and Cervero (2010)
14	Mortality rate reduction	-0.09	From dedicated paper (Reijneveld et al., 1999)
15	Subjective well-being	-0.0037	Only direct estimate in literature (Glaeser et al., 2016)

Notes: a. 80th vs. 20th percentile. 1: Productivity; 2: Innovation; 3: Value of space; 4: Job accessibility; 5: Services and amenities access; 6: Efficiency of public services delivery; 7: Social equity; 8: Safety; 9: Open space preservation and biodiversity; 10: Pollution reduction; 11: Energy efficiency; 12: Traffic flow; 13: Sustainable mode choice; 14: Health; 15: Well-being.

To allow for a better comparison, we conducted a series of approximations to express all the effects in terms of a per capita per year dollar effect that would result from a 10% increase in density. We summarise the results in Table 8. Because most of the parameters used in these calculations are context-dependent, the table is designed to allow for straightforward adjustments. The monetary effect in the last column (8) is simply the product of the elasticity (3), the base value (5), the unit value (7), and a 10% increase in density (e.g., 4% × $35,000 × 1 × 10% for the wage effect). In other words, it shows the monetary value of the change in a given outcome in response to a 10% increase in density.

To our knowledge, Table 8 represents an unprecedented attempt to condense the state of empirical knowledge on a great variety of density effects into a compact, accessible, and quantitative format. This is an ambitious exercise and there are some limitations.

First, to monetise the effects of density on the various outcomes, we have to make strong assumptions, which are laid out in detail in the Appendix (Section 9). As a result, the monetary equivalents are best understood as illustrative examples that refer to an average person in an average metropolitan area in a high-income country. Several caveats should be taken into account before evaluating them. In particular, we strongly advise that the assumptions made in Appendix Section 9 are evaluated with respect to their applicability.

Second, the results in Table 8 correspond to a comparison of an actual situation to a hypothetical counterfactual with 10% lower density, assuming an overall adjustment to density that corresponds to the average in the data (i.e. no specific policies). This is not necessarily the same as increasing the density of a given city by 10%. As an example, a denser city does not necessarily have a greater supply of housing than a less dense city. However, increasing the density of a city by 10% would likely lead to a greater housing supply. Since we measure the so-called *ceteris paribus* effect (i.e. we assume that all other things are equal), we assume that the housing supply remains unchanged when we estimate the effect of a 10% increase in density. In other words, we compare two hypothetical cities with varying density, but the same population and housing supply. When computing monetary equivalents, we do not take into account any of the changes that occur in parallel if a city increases in density.

Third, the estimated elasticities typically refer to the average distributions observed in the data. They represent less plausible approximations for extreme scenarios (e.g. places with very high or low values of an outcome or density). Also, the effects implied by the elasticities apply to marginal (i.e. small) changes only. They should not be used to evaluate the likely effects of extreme changes (e.g. a 100% increase in density) in particular settings.

Fourth, as discussed in Section 3 of the Appendix, the collected literature from which the outcome elasticities are inferred is more mature for some categories than for others. Section 8 in the Appendix provides a more detailed discussion of the literature that should be consulted before using the calculated monetary equivalents in Table 8. Given the quantity and the quality of the collected literature, we consider the results in the categories urban green, income inequality, pollution, health, and well-being as, at best, preliminary.

Table 8

Monetised effects of a 10% increase in economic density: Outcome dimension-specific effects

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
CATEGORY			QUANTITY, P.C., YEAR		UNIT VALUE		$ equivalent 10% inc. dens.
ID	Outcome	Elast.	Variable	Value	Unit	Value	
1	Wage	0.04	Income ($)	35,000	-	1	140
2	Patent intensity	0.125	Patents (#)	2.06E-04	Patent value ($/#)	793K	2.1
3	Rent	0.21	Income ($)	35,000	Expenditure share	0.33	242.6
4	VMT[a] reduction	0.085	VMT[a] (mile)	10,658	Priv. cost $/mile	0.83	75.6
5	Variety value[b]	0.12[b]	Income ($)	35,000	Expenditure share[c]	0.14	57.7
6	Local public spending	0.144	Total spending ($)	1,463	-	1	21.1
7	Wage gap[d] reduction	-0.035	Income ($)	35,000	Inequality premium	0.048	-5.9
8	Crime rate reduction	0.085	Crimes (#)[e]	0.29	Full cost ($/#)	3,224	8
9	Green density	0.23	Green area (p.c., m^2)	540	Park value ($/$m^2$)	0.3	41
10	Pollution reduction	0.04	Rent ($)	11,550	Rent-poll. elasticity	0.3	13.9
11	Energy use reduction	0.11	Energy (1M BTU)	121.85	Cost ($/1M BTU)	18.7	25.1
	(private and social effects)	0.11	CO_2 emissions (t)	25	Social cost ($/t)	43	11.8
12	Average speed	-0.12	Driving time (h)	274	VOT ($/h)	10.75	-35.3
13	Non-car mode choice	0.07	VMT[a]	10,658	Social cost ($/mile)[f]	0.016	1.2
14	Health	-0.09	Mortality risk (#)	5.08E-04	Value of life ($/#)[g]	7M	-32
15	Subjective well-being[i]	-0.004	Income ($)	35,000	Inc.-happ. elasticity	2	-25.9

Notes: a. Vehicle miles travelled. b. Reduction in price index of consumption varieties. c. Local non-tradables: home, entertainment, and apparel and services. d. 80th vs. 20th percentile. e. All crimes against individual and households. f. Emissions externality. g. Statistical value of life. h. Pre-mature (>70) mortality rate. i. Self-reported subjective well-being.

Despite these limitations, Table 8 offers novel insights into the direction and the relative importance of density effects. The density effect on wages, which has been thoroughly investigated in the agglomerations literature, is quantitatively large, but not as large as the effect on rents, on average.[5] Density generates costs in the form of higher congestion and lower average road speeds, which are, however, more than compensated for by the cost reductions due to shorter trips. Agglomeration benefits on the consumption side due to larger and more accessible consumption variety are quantitatively important and amount to more than one-third of agglomeration benefits on the production side (wages). Other quantitatively relevant benefits arising from density include cost savings in the provision of local public services, preserved green spaces, and reduced energy use, which creates a sizeable social benefit (reduced carbon emissions) in addition to private cost savings. Other benefits relate to lower crime rates and lower pollution externalities. Besides the congestion effects already mentioned, the cost of density comes in the form of increased inequality, adverse health effects, and reduced well-being.

Given that we have gone a long way in computing outcome-specific measures of costs and benefits that are comparable across outcomes, a natural question arises: Do the benefits of density exceed the costs and, if so, by how much? To address this question, we conduct a simple accounting exercise in Table 9. We distinguish between private (columns 1–5) and external (column 6) costs and benefits, where we note some external effects that residents do not directly experience and likely do not pay for via rents (such as reductions in carbon emissions that have global rather than local effects). To avoid double-counting, we exclude gasoline costs in computing the benefits of shorter average trips as this cost-saving is already accounted for by reduced energy consumption. Also, we correct consumption benefits to reflect the pure gains from variety rather than the savings due to shorter car trips, which are already itemised in dimension 4. The external effect from sustainable mode choice (outcome dimension 13) is already itemised in the external benefit of reduced energy use (outcome dimension 11) and is thus not counted separately.

The standard urban economics framework builds on the spatial equilibrium assumption, which implies that individuals are fully mobile, and competition in all markets is perfect. Rents, in this framework, reflect the capitalised values of productivity and utility so that the sum of rents and wages (column 1), amounting to close to US$400 per capita, can be interpreted as a welfare gain. Depending on whether the items in column 6 are expected to capitalise into rents (e.g. if local public services are financed through local taxes) or not (e.g. if local public services are financed through national taxes), they can be added to the welfare balance. The spatial equilibrium framework is also the theoretical basis for the economic quality-of-life literature mentioned above, which infers place-specific amenity values from compensating differentials. The implication is that an increase in rent that is above and beyond a disposable income is the result of a positive quality-of-life effect.

An alternative theoretical view is that increases in rents at least partially reflect the costs of economic frictions. If mobility is not perfect and/or there is heterogeneity in the preference for locations, rents will not only reflect demand-side conditions (here, amenities), but also supply-side conditions (Arnott and Stiglitz, 1979). Density – or the policies that enforce density – can then increase rents because of the restricted supply of space, in which case the rent can be suggestive of deadweight loss (Hilber and Vermeulen, 2016; Cheshire and Hilber, 2008). Distinguishing these scenarios is notoriously difficult, but it is informative to compare the quality-of-life effect inferred from wages and rents to the aggregate amenity effects across outcome dimensions. If the accounting was precise and complete and there were no frictions, we would expect the aggregate amenity effect to equal the quality-of-life effect.

The amenity value reported in column 3, with about US$100 per capita per year, is sizeable, but is less than two-thirds of the compensating differential (Δrent-Δwage), suggesting a role for the supply side. The role of subjective well-being is controversial as it is either regarded as a proxy for individual utility (Layard et al., 2008) or as a component in the utility function that is traded against the consumption of goods and amenities (Glaeser et al., 2016). However, excluding the well-being effect as a (dis)amenity category is not sufficient to align the amenity effect with the quality-of-life effect. Likewise, treating local public services as fully locally financed, which implies that the savings are passed on to individuals and are capitalised into rents, leaves a sizeable difference between the quality-of-life effect and the amenity effect. Even if we ignore the quality-of-life effect and assume locally financed public services, a notable gap remains (US$150 vs. US$132).

In columns 4 and 5, we change the perspective and ask how a small increase in the density of a city would affect residents in the long run (compared with the counterfactual of having no increase). Because costs and benefits of density capitalise into rents, the individual net benefit depends on housing tenure. Given the positive amenity affect from column 3, it is clear that homeowners gain, on average, as they receive an amenity benefit without having to pay a higher rent. If they

were moving to another city, they would leave the amenity gain behind, but would benefit from a higher housing value. In contrast, renters will have to pay for the amenity gain by higher rents, making the implications more ambiguous (Ahlfeldt & Maennig, 2015). The net benefit to homeowners is positive and sizeable with a combined amenity and wage effect of US$177 or more (if there are tax savings or we abstract from the well-being effect). There is a net cost to renters of up to US$65.5 if we include well-being effects and assume that there are no tax effects due to savings in public services. Even if we exclude the well-being effect and allow for cost savings in public services to be passed on to renters via lower taxes, the net benefit remains negative.

Just as with all other estimates, the effect of higher density on rent is estimated *ceteris paribus* (i.e under the assumption that no other circumstances change). In practice, densification is likely to be associated with an increase in the supply of

Table 9

Monetized effects of a 10% increase in economic density: Accounting

		(1)	(2)	(3)	(4)	(5)	(6)
OUTCOME		Factor Incomes	Quality of life	Amenity value	EFFECT ON		External welfare
ID	Outcome dimension				Owner	Renter	
1	Productivity	140	-71.4	0	71.4	71.4	0
2	Innovation	0	0	0	0	0	2.1
3	Value of space	242.6	242.6	0	0	-242.6	0
4	Job accessibility	0	0	61.7[a]	61.7[a]	61.7[a]	0
5	Services and amenities access	0	0	49.3[b]	49.3[b]	49.3[b]	0
6	Eff. of pub. services delivery	0	0	0	0	0	21.1
7	Social equity	0	0	0	0	0	-5.9
8	Safety	0	0	8	8	8	0
9	Open space preservation	0	0	41	41	41	0
10	Pollution reduction	0	0	13.9	13.9	13.9	0
11	Energy efficiency	0	0	25.1	25.1	25.1	11.8
12	Traffic flow	0	0	-35.3	-35.3	-35.3	0
13	Sustainable mode choice	0	0	0	0	0	0[c]
14	Health	0	0	-32	-32	-32	0
15	Subjective well-being	0	0	-25.9	-25.9	-25.9	0
	Sum	382.6	171.2	105.6	177	-65.5	0
	Excl. subj. well-being	–	–	131.5	202.9	-39.6	29.1
	Locally financed public services	–	150.1	–	198.1	-44.5	–
	Factor incomes and externality	415.3	–	–	–	–	–
	Locally financed public services	394.2	–	–	–	–	–

Notes: All values in $. a Excludes US$139 of driving energy cost (US$0.15/mile gasoline cost), which is itemised in 11. b Assumes a 10.2% elasticity to avoid double-counting of road trips already included in 4. c Set to zero to avoid double-counting with 11.

housing, which is likely to reduce rents and therefore counteracts the rent-increasing effect of higher density. Especially in cities where housing supply has been severely constrained, for example due to land use regulations or due to geographical characteristics, the rent-decreasing effect of a greater housing supply may be significant and could potentially outweigh the rent-increasing effects of higher density. Most likely, the magnitude of this effect depends on each specific case, and further research into the issue is required.

Overall, the evidence suggests that density is a net amenity. However, this does not imply that everybody is a net beneficiary from increases in density. Renters may be the net losers of denser cities because of rent effects that exceed amenity benefits. The negative net effect is consistent with a negative density effect on well-being if individuals are attached to some areas more than others. If one is willing to believe that there are strong forces that prevent renters from moving, a supply-constraining effect of density can shift renters to a lower utility level, consistent with a negative effect on well-being (or happiness). This is, however, an ambitious interpretation of the evidence as it is impossible to claim full coverage and perfect measurement of amenity effects. It is important to acknowledge that the difference between the amenity effect (column 3) and the quality-of-life effect (column 2) of density could simply be due to measurement error (e.g. missing items in column 3). Research into the well-being effects of density differentiated by tenure would be informative, but to our knowledge, such research has yet to be conducted.

5. Conclusion

We provide the first quantitative evidence review of the effects of compact urban form on a broad range of outcomes. In line with theoretical implications, the empirical evidence suggests that compact urban form generally has positive effects. Of 321 reviewed analyses of 189 studies, 69% report positive effects. The average result is positive in 11 out of 15 outcome dimensions. For eight of these 11 outcome dimensions, the positive average result is statistically significant. Only three outcome dimensions, however, pass the same test once we control for the various attributes of the analyses and weight the results by the rigour of the applied methods.

Across the entire literature collected, the positive effects of urban compactness on productivity and innovation are the least controversial. There is also some consensus that compact urban form is associated with sustainable transport modes (non-automobile), improved services access (including consumption amenities), lower crime rates, social equity, higher value of space, shorter trip lengths, lower energy consumption, and more efficient provision of local public services. Negative effects are reported for health, subjective well-being, traffic flow (congestion), and open space preservation. Evidence is mixed regarding the effects on pollution concentration.

These outcome-specific tendencies mask significant heterogeneity within them as the effects of the three compact city characteristics – economic density, morphological density, and mixed land use – can show qualitatively different results on the same outcome. The evidence is more ambiguous when considered for combinations of the three compact city characteristics and the 15 outcome dimensions. Of the 33 outcome-characteristic combinations in the collected literature, the average result is positive for 19 and negative for 14 combinations. Characteristics effects vary qualitatively within six out of 15 outcome dimensions, while all characteristics have positive and negative effects on selected outcomes. A major insight from our theoretical and empirical review is that the effects of compact urban form are best described at this disaggregated level (outcome-characteristic combinations).

For a subset of 202 analyses, we infer quantitative estimates of the elasticity of an outcome with respect to economic density, by far the most intensely investigated compact city characteristic. These elasticities express the effect of density on an outcome in unit-free percentage terms and are thus suitable for comparisons across empirical studies analysing data in different contexts and geographies. In about a quarter of the cases, we approximate these elasticities based on the results reported in the considered studies or in collaboration with the authors who provide estimates not reported in their papers.

We condense the quantitative evidence base to a set of elasticities (one for each outcome dimension), selecting either the average result from our collected literature, a result from an existing dedicated meta-analysis or original research piece, or an own estimate if the quantitative evidence is thin or inconclusive. The recommended elasticities are qualitatively consistent with the average qualitative results reported above, with two exceptions. Given thin or inconsistent quantitative evidence, our preferred elasticity estimates are from our own analysis of OECD.Stat functional economic area and regional

data. These analyses suggest that density is associated with less equal income distribution and is positively associated with preserved green space. To reconcile our own estimates with the collected literature, it is useful to consider the scale of the analyses. While the within-city analyses in the literature likely capture effects related to social segregation (a greater mix in dense neighbourhoods) and opportunity cost of space (less open space in densely developed neighbourhoods), our between-city analyses likely capture the effects of skill-complementarity (higher urban wage premium for highly skilled people) and open space preservation (due to an overall reduced urban footprint).

Using these elasticities and an illustrative scenario that roughly corresponds to an average city in a high-income country in terms of per capita wages, rents, amenities, and other characteristics, we compute the monetary effect that arises from a 10% increase in density for each of the 15 dimensions. Given the assumptions made, we find that a 10% increase in density leads to an increase in factor incomes of US$140 per capita per year (US$71.4 net for workers) and a respective increase in rent of US$242.6. We find economically sizeable effects of job accessibility (US$61.7) that more than compensate for the cost of lower average road speeds (US$35.3). Consumption benefits (greater and more accessible services and amenities, US$49.3), reductions in local public spending per capital (US$21.1), lower crime rates (US$8), preserved green space (US$41), lower levels of pollution (US$13.9), and energy consumption (US$25.1 private benefits due to lower energy cost plus US$11.8 external benefit due to lower carbon emissions) also have sizeable positive effects. Besides lower average road speeds, significant monetised costs come in the form of larger income inequality (US$5.9), adverse health effects (US$32), and lower subjective well-being (US$25.9). Summing over the monetary equivalents of all amenity categories and avoiding double-counting, we find a positive amenity value, which is, however, not as large as the "compensating differential" (rent effect – disposable income effect).

While density seems to be a net amenity, our admittedly imperfect accounting also suggests that part of the rent increase is attributable to the higher cost of providing space and not exclusively to enjoyable amenities.[6] Policies aiming at making cities more compact are likely to benefit homeowners, but are potentially harmful to renters and first-time buyers. Given that homeowners tend to be wealthier than renters, this could potentially exacerbate inequality and reduce the affordability of urban living for low- and middle-income households.

To avoid inefficient and unequitable effects through rising housing costs, it is important to ensure that compactness is not achieved at the cost of constraining the supply of space to a degree that it prevents the construction of new housing. This is especially important in growing urban areas, where new housing has to be built to accommodate increasing populations. As an example, restrictions of developable land (e.g. due to urban growth boundaries) should not be coupled with restrictive height or floor-area constraints as this would lead to a rent increase due to a shortage of space, a so-called "regulatory tax" (Cheshire and Hilber, 2008).

These results are our best attempt to categorise a heterogeneous literature on heterogeneous effects into a compact and accessible quantitative format. It is important to acknowledge that the interpretations made are ambitious given the quantity and the quality of the evidence. Researchers wishing to apply our quantitative results in further research are advised to consult Sections 7 and 8 in the Appendix for a critical assessment of the collected literature and an evaluation of the transferability of the assumptions made. In general, much work lies ahead of the related research fields to consistently bring the collected literature to the quantity and quality levels of the outcome dimensions of productivity and sustainable mode choice. For all other dimensions, more research is required – even if selected high-quality evidence exists – to substantiate the calculated elasticities and to explore heterogeneity across contexts. At this stage, significant uncertainty surrounds any quantitative interpretation in the outcome dimensions *open space preservation, income inequality, pollution, health,* and *well-being*. More research is also required to better understand the effects of morphological density (characteristics of the built environment) and mixed land use.

APPENDIX

1. Introduction

This appendix complements the main paper by providing additional detail not reported in the main paper for brevity. It is not designed to replace the reading of the main paper.

2. Theory

Table A1 provides the sources underlying Table 3 in the main paper. To allow for straightforward cross-reference Table A1 uses the same structure as Table 3.

Table A1
Theoretically expected effects of compact urban development on various outcomes: Sources

	OUTCOME CITY EFFECTS	COMPACT CITY CHARACTERISTICS		
#	**Outcome dimensions**	**Residential and employment Density**	**Morphological Density**	**Mixed use**
1	Productivity	(Marshall 1920; Neuman 2005; OECD 2012)	–	–
2	Innovation	(Jones et al. 2010; Maskell & Malmberg 2007)	–	–
3	Value of space	(Alonso-Mills-Muth model; Rosen and Roback framework)	(Alexander 1993; Churchman 1999; Glaeser et al. 2001; Knox 2011; Epple et al. 2010)	–
4	Job accessibility	(Beer 1994; Laws 1994; Dieleman & Wegener 2004)	(Neuman 2005)	–
5	Services and amenities access	(Churchman 1999; Burton 2000; Burton 2002)	(Bonfantini 2013)	(Churchman 1999)
6	Efficiency of public services delivery	(Matsumoto 2011; Troy 1996; Carruthers & Ulfarsson 2003)	(Troy 1992)	–
7	Social equity	(Burton 2000; Savage 1988; Grusky & Fukumoto 1989; Gordon & Richardson 1997; Breheny 1997)	(Radberg 1996)	–
8	Safety	(Burton 2000; Chhetri et al. 2013; Braga & Weisburd 2010; Jacobs 1961)	(Tang 2015; Farrington & Welsh 2008)	–
9	Open space preservation and biodiversity	(Neuman 2005; Wolsink 2016)	(Chhetri et al. 2013; Dieleman & Wegener 2004; Ikin et al. 2013; Burton et al. 2003)	–
10	Pollution reduction	(Bechle et al. 2011; Troy 1996)	(Churchman 1999; Troy 1996)	(Bechle et al. 2011; World Health Organization (WHO) 2011)

	OUTCOME CITY EFFECTS	COMPACT CITY CHARACTERISTICS		
#	Outcome dimensions	Residential and employment Density	Morphological Density	Mixed use
11	Energy efficiency	–	(Neuman 2005; Gordon & Richardson 1997)	(OECD 2012)
12	Traffic flow	(Burton et al. 2003; Rydin 1992)	(Churchman 1999)	(Churchman 1999)
13	Sustainable mode choice	(Churchman 1999; Burton 2000; Neuman 2005)	(Thomas & Cousins 1996; Neuman 2005; Churchman 1999)	(Thomas & Cousins 1996; Neuman 2005; Churchman 1999)
14	Health	(Troy 1996; Burton 2000; Matsumoto 2011)	–	–
15	Wellbeing	(Churchman 1999; Wilson & Baldassare 1996; Chu et al. 2004)	(Burton 2000; Hitchcock 1994)	(Churchman 1999; Vorontsova et al. 2016; World Health Organization (WHO) 2011)

Notes: The categories and theoretical channels are potentially non-exhaustive and are restricted to those discussed in the theoretical literature. The direction of the theoretically expected effects are borrowed from that literature. References for each effects-characteristics cell are presented in Table A1 to keep the presentation compact.

3. Evidence base for meta-analysis

3.1 COLLECTING THE LITERATURE

We aim at collecting an evidence base that covers, as broadly as possible, the theoretically relevant links between compact city characteristics and the outcomes discussed in section 2.2 of the main text. We do not impose any geographical restrictions, i.e., we cover studies from the global North and South (to the extent that they exist) and consider various geographic layers of analysis (from micro-geographic scale to cross-region comparisons).

In collecting the evidence base for our quantitative literature review, we follow standard best-practice approaches of meta-analytic research, as reviewed by Stanley (2001).[7] To prevent publication bias, we explicitly consider studies that were published as edited book chapters, in refereed journals or in academic working paper series (we were also open to other types of publications).

In searching for an evidence base, we pursue a three-step strategy. We begin with the standard practice of a keyword search in academic databases (EconLit, Web of Science, and Google Scholar) and specialist research institute working paper series (NBER, CEPR, CESIfo, and IZA). To allow for a transparent and theory-consistent literature search, the selection of keywords is guided by our theory matrix as summarised in Table 2. We run searches that are specific to combinations of outcomes and characteristics. In each case, we use combinations of keywords that relate to the outcome (where appropriate, we use empirically observed variables listed in Table A1) and the compact city characteristic. We usually use the term density in reference to economic density and a more specific term to capture the relevant aspect of morphological density. In several instances, we run more than one search for an outcome-characteristics combination to cover different empirically observed variables and, thus, maximise the evidence base. We note that because this way our search focuses directly on specific features that make cities "compact," we exclude the phrase 'compact city' itself in all searches. Adding related keywords did not improve the search outcome in several trials, which is intuitive given that, by itself, "compactness" is not an empirically observable variable. In total, we consider the 52 keyword combinations (for 32 theoretically relevant outcome-characteristic combinations) summarised in Table A4 which we apply to five databases, resulting in a total of 260 keyword searches.

We note that Google Scholar, unlike the other databases, tends to return a vast number of documents, ordered by potential relevance. In several trials preceding the actual evidence collection, we found that the probability of a paper being relevant for our purposes was marginal after the 50th entry. Therefore, in an attempt to keep the literature search efficient we generally did not consider documents beyond this threshold.

In a limited number of cases we reassign a paper returned in a search for a specific outcome dimension to another category if the fit is evidently better (see Table A2 for details). Occasionally, a study contains evidence that is relevant to more than one category in which case it is assigned to multiple categories. We generally refer to such distinct pieces of evidence within our study as analyses. We do not double count any publication when reporting the total number of studies throughout the paper. Based on the evidence collected in step one, we then conduct an analysis of citation trees in the second step of our literature search. In particular, we select a random sample of studies within each category and evaluate to what extent these studies refer to empirically relevant work that was not picked up by our keyword search. For all but two categories, we find that the evidence is reasonably self-contained in the sense that the studies identified by the keyword search tend to cite each other but no other relevant work. Only for *health and well-being* did the analysis of citation trees point us to additional literature strands. This systematic literature search resulted in 285 studies. Upon inspection (excluding empirically irrelevant work, duplications of working papers, and journal articles, etc.) we were left with 135 studies and 201 analyses.

Up to this point, our evidence collection is unbiased in the sense that it mechanically follows from the theory matrix discussed in section 2.3 and is not driven by our possibly selective knowledge of the literature, nor that of our research networks. For an admittedly imperfect approximation of the coverage we achieve with this approach we exploit the fact that the search for theoretical literature already revealed a number of empirically relevant studies that were not used in the compilation of the theory matrix unless they contained significant theoretical thought. From 19 empirically relevant papers known before the actual evidence collection, we find that step one (keyword search) and two (analysis of citation trees) identified six, i.e., 31%.

Table A2
Organization of keyword search

	COMPACT CITY EFFECTS	COMPACT CITY CHARACTERISTICS		
#	**Outcome dimensions**	**Residential and employment Density**	**Morphological Density**	**Mixed use**
1	Productivity	density; productivity; wages; urban density; productivity; rent; urban	– –	– –
2	Innovation	density; innovation; patent; urban density; innovation; peer effects, urban	– –	– –
3	Value of space	density; land value; urban density; rent; urban density; prices; urban	building height; land value; urban building height; rent; urbanbuilding height; prices; urban	– – –
4	Job accessibility	density; commuting; urban	land border; commuting; urban	–
5	Services and amenities access	density; amenity; distance; urban density; amenity; consumption; urban	street; amenity; distance; urban	mixed use; amenity; distance; urban
6	Efficiency of public services delivery	density; public transport delivery; urban density; waste; urban	street; amenity; consumption; urban building height; public transport delivery; urban	mixed use; amenity; consumption; urban –
7	Social equity	density; waste; urban density; real wages; urban density; segregation; urban density; "social mobility"; urban	street; waste; urban building height; real wages; urban building height; segregation; urban street; "social mobility"; urban	– – – –
8	Safety	density; crime; rate; urban density; open; green; space; urban	building height; crime; urban land border; open; green; space; urban	–
9	Open space	density; green; space; biodiversity; urban	land border; green; space; biodiversity; urban	–
10	Pollution reduction	density; pollution; carbon; urban density; pollution; noise; urban	building height; pollution; carbon; urban building height; pollution; noise; urban	mixed use; pollution; carbon; urban mixed use; pollution; noise; urban
11	Energy efficiency	–	building height; energy; consumption; urban	mixed use; energy; consumption; urban
12	Traffic flow	density; congestion; road; urban	Street layout; congestion; road; urban	mixed use; congestion; road; urban
13	Sustainable mode choice	density; mode; walking; cycling; urban	treet; mode; walking; cycling; urban	mixed use; mode; walking; cycling; urban
14	Health	density; health; risk; mortality; urban	–	–
15	Well-being	density; well-being; happiness; perception; urban	space; well-being; perception; urban	mixed use; well-being; perception; urban

Notes: Each outcome- characteristics cell contains one or more (if several rows) combinations of keywords each used in a separate search. In each cell we use a combination of keywords based on effects (related to the outcome category or typically observed variables) and characteristics (related to residential and employment density, morphological density or mixed use).

In the final step 3 of the evidence collection we add all relevant empirical studies known to us before the evidence collection (including those we came across in the search for theoretical literature) as well as studies that were recommended to us by colleagues working in related fields. To collect recommendations, we reached out by circulating a call via social media (Twitter) and email (to researchers within and outside LSE). Twenty-two colleagues contributed by suggesting relevant literature. This step increases the evidence base to 189 studies and 321 analyses. The evidence included at this stage may be selective due to particular views that prevail in our research community. However, recording the stage at which a study is added to the evidence base allows us to test for a potential selection effect.

In Table A3 we summarise the collection process of the evidence base. We present the number of studies found by category and the stage at which they were added to the evidence base.

Table A3

Evidence collection: Distribution of analyses

#	Outcome	Google Scholar	Web of Science	EconLit	CesIfo	Step 2	Step 3	Total
1	Productivity	11	3	5	0	3	10	32
2	Innovation	4	1	2	1	0	1	9
3	Value of space	6	1	6	1	1	7	22
4	Job accessibility	3	1	3	0	3	5	15
5	Services and amenities access	2	0	1	0	0	7	10
6	Efficiency of public services delivery	2	0	1	0	0	3	6
7	Social equity	3	1	0	0	4	1	9
8	Safety	2	3	0	0	3	2	10
9	Open space preservation and biodiversity	4	1	0	0	0	0	5
10	Pollution reduction	2	1	1	0	1	2	7
11	Energy efficiency	5	2	2	0	7	5	21
12	Traffic flow	2	0	1	0	1	1	5
13	Sustainable mode choice	7	2	1	0	8	4	22
14	Health	2	1	0	0	4	1	8
15	Well-being	2	0	1	0	0	5	8
	Total	**57**	**17**	**24**	**2**	**35**	**54**	**189**

Notes: Google Scholar, Web of Science, EconLit, CesIfo searches all part of evidence collection step 1. Step 2 contains results from the analysis of evidence from step 1 and studies which were collected during step 1, but corresponded to a different outcome to the one suggested by the keyword search they were found with. Step 3 consists of previously known evidence and recommendations by colleagues.

3.2 ATTRIBUTES OF THE COLLECTED LITERATURE

We choose a quantitative approach to synthesise our broad and diverse literature collected. Our aim is to provide an accessible synthesis of the literature on the effects of compact city characteristics within and across outcome dimensions. As with most quantitative literature reviews we use statistical approaches to test whether existing empirical findings vary systematically in the selected attributes of the studies, such as the context, the data, or the methods used. In line with the standard approach in meta-analytic research (Stanley 2001) we encode the attributes as well as the results, below, of the collected literature into variables that can be analysed using statistical methods.

i. The outcome dimension, one for the 15 dimensions defined in section 2.2

ii. The compact city characteristic, i.e., economic density, morphological density, mixed use

iii. The stage (1–3) at which an analysis is added to the evidence base

iv. The publication venue, e.g., academic journal, working paper, book chapter, report

v. The disciplinary background, e.g., economics, regional sciences, planning, etc.

vi. The dependent variable, e.g., wages, land value, crime rate

vii. The study area, including the continent and the country

viii. The period of analysis

ix. The spatial scale of the analysis, i.e., within-city vs. between-city

x. The quality of studies as defined by the Maryland Scientific Methods Scale (SMS) used by the What Works Centre for Local Economic Growth (2016)

The quality can take the following values:

1. Exploratory analyses (e.g., charts). This score is not part of the original SMS
2. Unconditional correlations and OLS with limited controls
3. Cross-sectional analysis with appropriate controls
4. Good use of spatiotemporal variation controlling for period and individual effects, e.g., difference-in-differences or panel methods
5. Exploiting plausibly exogenous variation, e.g., by use of instrumental variables, discontinuity designs or natural experiments
6. Reserved to randomised control trials (not in the evidence base)

A typical approach in meta-analytic research is to analyse the findings in a very specific literature strand. The results that are subjected to a meta-analysis are directly comparable, and are often parameters that have been estimated in an econometric analysis. Recent examples in urban economics include the meta-analysis of the several estimates of the output elasticity of transport (Melo et al. 2013), the density elasticity of wages (Melo et al. 2009), or the rank-size coefficient, which summarises the city size distribution (Nitsch, 2005). In contrast, the scope of our analysis is much broader. In an attempt to maximise the evidence base, we consider studies that relate to different outcome dimensions and compact city characteristics and use different empirical approaches. Therefore, the evidence collected is often not directly comparable across studies, not even within outcome dimensions. In analyzing this heterogeneous evidence base, we face a trade-off between increasing the comparability of the evidence and increasing the evidence base. We respond to this trade-off by defining three different metrics with distinct strengths.

I. *Qualitative result scores:* To allow for comparison across the entire literature, guided by the theory matrix in Table 3 in the main text, we categorise the results into three discrete classes. The empirical result is classified as *positive* if it is in line with the direction of the effect on an outcome that we define as positive in Table 3 and statistically significant. The

empirical result is classified as *negative* if it points in the opposite direction and is statistically significant. The remaining cases are classified as *insignificant*. This metric is qualitative in the sense that we are unable to infer the magnitude of the effects on outcomes. Yet, it allows a summarising of the entire body of evidence in transparent and accessible form. The metric is comparable within and across outcome dimensions and can also be compared to the theoretical expectations. To facilitate further analyses, we assign the numeric values 1 / 0 / -1 to *positive/insignificant/negative*, which, by taking the average, allows us to summarise the evidence into a qualitative result index that can range from -1 to 1, where positive values imply positive effects on average.

II. *Outcome elasticities with respect to density:* For a quantitative interpretation, we focus on the by far most commonly investigated compact city characteristic: Economic density. We compute the so-called elasticity of an outcome (e.g., productivity) with respect to economic density (either employment or population). In economics, an elasticity is a measure of the percentage change in one variable in response to a 1% change in another variable. Elasticities have the advantage that they are independent from a unit of measurement. We convert the results of as many analyses as possible into this metric using back-of-the-envelope calculations. Details are in section A5. The resulting reveals the magnitude of the effects on outcomes and not only the direction. This metric does also not allow for a comparison across outcome dimensions.

III. *Monetary equivalents:* To arrive at a quantitative metric that is comparable across outcome dimensions, we condense the quantitative evidence base (II) into a set of category-specific recommended elasticities. These recommended elasticities can be the average elasticity in our evidence base, borrowed from existing meta-analyses or original research or an own estimate, which we contribute to the evidence base, depending on the quality and quantity of the evidence base. Next, we compute the monetary equivalent of the effect of a 10% increase in economic density per capita and per year terms. This step requires ambitious assumptions regarding values and per capita quantities of outcomes that we lay out in detail in section A8 . While this metric is quantitative and comparable across outcome dimensions, it is naturally selective because it is based on the quantitative results sample.

In Table A4 we tabulate the distribution of 'analyses' by selected attributes (as discussed above, one study can include several 'analyses'). While the collected literature covers most world regions to some extent, including the global South, there is a strong concentration of studies from high-income countries and, in particular, from North America. The clear majority of studies have been published in academic journals. The collected literature is diverse with respect to disciplinary background, with economics as the most frequent discipline, accounting for a share of about one-fifth.

In Figure A1, we illustrate the distribution of publication years, the study period, and the quality of study according to the SMS. The collected literature, overall, is very recent, with the great majority of studies having been published within the last 15 years, reflecting the growing academic interest in the topic. Most studies use data from the 1980s onwards. A clear majority of studies score two or more on the SMS, which means there is usually a serious attempt to disentangle effects related to "compactness" from other factors, often including unobserved fixed effects and period effects. Distinguishing between studies published before or after the median year of publication (2009) reveals a progression toward more rigorous methods that score three or four on the SMS.

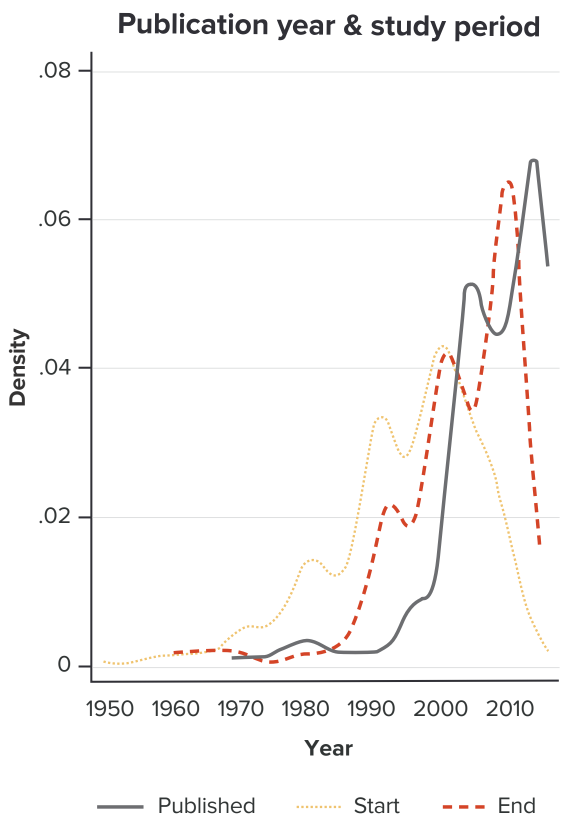
Table A5 compares the subsample of analyses for which we were able to compute an outcome elasticity with respect to density to all analyses that we collected, revealing only moderate differences. The analyses in the quantitative subsample have a slightly higher propensity of being added in the third evidence collection stage, a slightly higher average SMS score, and a somewhat higher propensity of showing positive (qualitatively) results.

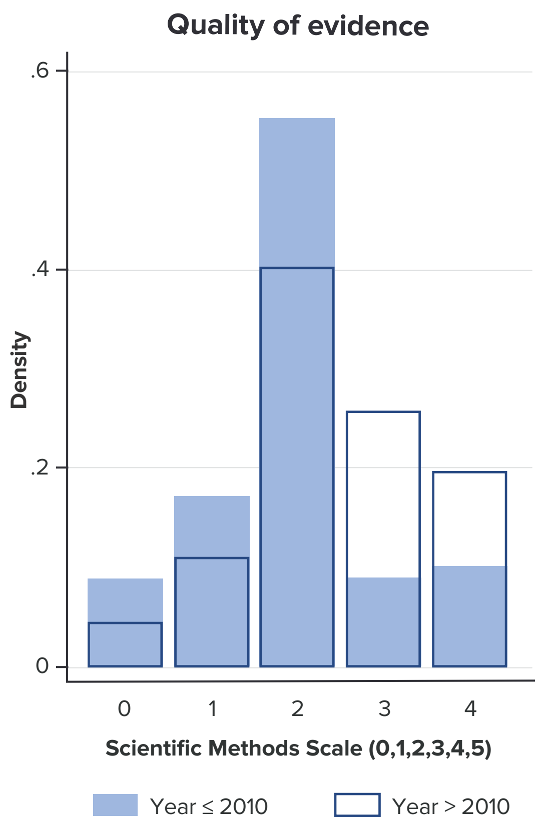
Table A4
Evidence collection: Distribution of analyses

World region	No. of analyses	Publication	No. of analyses	Discipline	No. of analyses
North America	161	Academic Journal	271	Economics	80
Europe	83	Working Paper	45	Planning	55
Asia	47	Book chapter	5	Transport	47
South America	11	-	-	Urban Studies	43
OECD	7	-	-	Regional Studies	37
World	4	-	-	Health	26
Oceania	4	-	-	Economic Geography	14
non-OECD	3	-	-	Energy	11
Africa	1	-	-	Other	8

Notes: Assignment to disciplines based on publication venues.

Figure A1
Distribution of publication year, study period and quality of study





Notes: Kernel in the left panel is Gaussian. A small number of analyses with study periods before 1950 are excluded in the left panel to improve readability.

Table A5
Distribution of studies by selected attributes (All analyses vs. quantitative sample)

World region	All analyses	Quantitative sample
Share of publications concerning non-high-income country[a]	13%	11%
Share of publications in academic journal	84%	84%
Share of publications in economics	25%	29%
Share of publications analysing within-city effects	46%	47%
Share of publications obtained through recommendations	37%	51%
Average year of publication	2008	2009
Average quality of study score	2.20	2.40
Share of publications reporting positive & significant effects[b]	69%	74%
Share of publications report insignificant effects[b]	6%	4%
Share of publications reporting negative & significant effects[b]	25%	22%
Average qualitative result score[c]	0.43	0.51
Number of publications (analyses)	321	202

Notes: a. Non-high-income include low-income and median-income countries according to the World Bank definition. b. Qualitative results (positive, insignificant, negative) is a category-characteristics specific and defined in Table 3. c. Qualitative results scale takes the values of 1 / 0 / -1 for positive / insignificant / negative.

4. Qualitative results scale

Table A6 summarises the qualitative evidence for non-high-income countries (World Bank definition) by outcome dimension. Its structure is identical to Table A5 in the main paper, which summarises the entire evidence base.

Table A6
Evidence summarised by outcome dimension: Non-high-income countries

			PROPORTION						RESULT		
#	Outcome dimension	#	Poor[a]	Acad.	Econ.	With.[b]	Med. year[c]	Average SMS	Pos.	Ins.	Neg.
1	Productivity	4	1.00	1.00	0.75	0.00	2016	3.00	100%	0%	0%
2	Innovation	1	1.00	1.00	0.00	0.00	2009	4.00	100%	0%	0%
3	Value of space	7	1.00	0.57	0.57	0.71	2015	2.14	57%	14%	29%
4	Job accessibility	5	1.00	0.60	0.40	0.60	2010	1.80	40%	0%	60%
5	Services and amenities access	3	1.00	1.00	1.00	0.00	2016	3.00	0%	33%	67%
6	Efficiency of public services delivery	–	–	–	–	–	–	–	.%	.%	.%
7	Social equity	–	–	–	–	–	–	–	.%	.%	.%
8	Safety	1	1.00	1.00	0.00	1.00	2014	0.00	100%	0%	0%
9	Open space preservation and biodiversity	–	–	–	–	–	–	–	.%	.%	.%
10	Pollution reduction	8	1.00	0.63	0.00	0.50	2012	2.25	63%	0%	38%
11	Energy efficiency	4	1.00	0.75	0.00	0.25	2013	0.75	75%	0%	25%
12	Traffic flow	2	1.00	1.00	0.00	0.50	1994	1.50	50%	0%	50%
13	Sustainable mode choice	8	1.00	0.75	0.00	1.00	2014	2.00	50%	50%	0%
14	Health	–	–	–	–	–	–	–	.%	.%	.%
15	Well-being	–	–	–	–	–	–	–	.%	.%	.%
	Average	**4**	**1.00**	**0.83**	**0.27**	**0.46**	**2011**	**2.04**	**63%**	**10%**	**27%**

Notes: a. Poor countries include low-income and middle-income countries according to the World Bank definition.
b. Within-city analyses c. Year of publication.

5. Multivariate analysis of qualitative results

The descriptive analysis above reveals several dimensions along which the qualitative results in the evidence base seem to vary. To explore how different attributes are conditionally correlated with the results in the literature we employ two simple multivariate regression models:

Formula 2a

$$L_{S,D,E} = F_{Sa} + \mu_D + \eta_{E \neq A} + \epsilon_{S,D,E}$$

Formula 2b

$$L_{S,D,E} = F_{Sa} + (\mu_D \times \eta_E) + \epsilon_{S,D,E}$$

, where $L_{SCD} = (-1,0,1)$ is the qualitative result score of an analysis S, concerned with an outcome dimension $D = (1,2, \dots ,15)$ and a compact city characteristic $E = (A,B,C)$, both of which are discussed in more detail in section 2.2 of the main paper. F_S is a vector of study attributes such as the ones considered in the previous section, a is a vector of associated marginal effects, μ_C and η_D are category and characteristics fixed effects, and $\varepsilon_{S,C,D}$ is an error term. Model (2a) is designed to provide estimates of the conditional means of the qualitative result scores by outcome dimension (the category fixed effects μ_C) treating compact city characteristics analysed as further attributes that are controlled for (with economic density A being the baseline category). Since it is likely that the characteristics (A,B,C) effects are specific to outcome dimensions (1–15), we use category x characteristics fixed effects $(\mu_D \times \eta_E)$ in model 2b. The conditional averages are then estimated for each category-characteristics combination.

The estimation results of model (2a) are in Table A7. The first model (1) provides estimates of category-specific conditional means controlling exclusively for compact city characteristics. Model (2), in addition controls for the study area (non-high-income country data), discipline (economics), geographic scale of analysis (within-city), publication venue (journal), the stage at which a study was added to the evidence base (Round 3), the publication year (a time trend with a zero value in 2000), and the quality of the evidence (SMS dummies, base category SMS=2). With the exception of the time trend, all control variables are encoded as dummy variables that take a value of one if they belong to the listed category, and zero otherwise. Instead of controlling for quality, Model (3) weights observations by the quality of the evidence. The standard practice of weighting observations inversely to standard errors of estimated coefficients is not applicable to and not appropriate for an evidence base as diverse as the one analysed here. More generally, the quality-weighting is desirable because, unlike a standard error of an estimated coefficient, it takes into account the strength of the identification of a result.

The results of the multivariate regressions confirm the notion emerging from the descriptive evidence that there is a positive time trend in the propensity of research finding positive compact city effects. Similarly, our discretionary additions to the evidence base (including recommendations by our networks) are significantly more favorable than the analyses identified in the systematic search. Within-city analyses have a significantly higher propensity of finding positive results than between-city analyses, pointing to a special role of compactness at local level. The results further confirm that the effects of compact urban form tend to be less positive when inferred from data from non-high-income countries. The effects of these attributes are relatively large as they correspond to a shift in the index value of one-tenth (Round 3) to one-sixth (non-high-income, within-city, 25 years) of the index range (-1 to 1). As for the compact city characteristics, the quality-weighted mix-adjusted results in column (3) suggest that mixed land use is generally found to have less positive effects than other compact city characteristics in the empirical literature. The effect on the index is large even compared to the largest attribute effects.

The category effects offer a number of novel insights when compared to the unconditional distributions reported in Table A7. The mean of the (-1/0/1) qualitative result score is not statistically significantly and positive for *value of space*, *job accessibility*, *services and amenities access*, *social equity*, *safety*, *energy efficiency*, *and sustainable mode choice*, once we control for the characteristics and attribute mix and take into account the evidence quality. *Productivity*, *innovation*, and *efficiency of public services delivery* have significantly positive mean index scores and can be regarded as the categories where the positive effects of compact urban form are least controversial. In line with descriptive evidence, *open space preservation*, *traffic flow*, *health*, and *well-being* are the outcome dimensions where compactness has negative effects. The conditional *pollution reduction* index mean is not statistically significantly different from zero, but is more negative than the descriptive evidence would suggest.

Table A7
Multivariate analysis of results I

	(1)		(2)		(3)	
Outcome	**Result: -1: Negative; 0: Insignificant; 1: Positive**					
01 Productivity	0.914***	(0.06)	0.763***	(0.25)	0.721***	(0.20)
02 Innovation	0.707***	(0.21)	0.583**	(0.29)	0.709***	(0.24)
03 Value of space	0.499***	(0.18)	0.283	(0.26)	0.280	(0.24)
04 Job accessibility	0.257	(0.23)	-0.034	(0.26)	-0.006	(0.27)
05 Services and amenities access	0.596***	(0.19)	0.244	(0.26)	0.159	(0.23)
06 Efficiency of public services delivery	0.634***	(0.18)	0.432*	(0.24)	0.441**	(0.22)
07 Social equity	0.400	(0.30)	0.265	(0.36)	0.407	(0.30)
08 Safety	0.558***	(0.18)	0.123	(0.24)	0.214	(0.23)
09 Open space preservation and biodiversity	-0.665**	(0.28)	-1.092***	(0.33)	-1.337***	(0.24)
10 Pollution reduction	0.081	(0.26)	-0.283	(0.32)	-0.231	(0.32)
11 Energy efficiency	0.493***	(0.15)	0.205	(0.25)	0.209	(0.24)
12 Traffic flow	-0.236	(0.36)	-0.402	(0.40)	-0.703**	(0.32)
13 Sustainable mode choice	0.789***	(0.07)	0.288	(0.21)	0.275	(0.21)
14 Health	-0.549***	(0.20)	-0.835***	(0.26)	-0.926***	(0.26)
15 Well-being	-0.554***	(0.20)	-0.824***	(0.24)	-0.850***	(0.17)
B Morphological density	-0.069	(0.13)	-0.017	(0.14)	0.072	(0.14)
C Mixed land use	-0.208	(0.28)	-0.181	(0.30)	-0.596*	(0.34)
Non-high-income country			-0.182	(0.15)	-0.253*	(0.15)
Economics			-0.120	(0.14)	-0.089	(0.11)
Within-city			0.333***	(0.11)	0.329***	(0.12)
Academic journal			0.099	(0.14)	0.126	(0.13)
Round 3			0.221**	(0.10)	0.202**	(0.09)
Year - 2000			0.010*	(0.01)	0.005	(0.01)
SMS = 0			-0.016	(0.20)		
SMS = 1			-0.028	(0.17)		
SMS = 3			-0.141	(0.15)		
SMS = 4			-0.033	(0.15)		
Weighted by Quality	–		–		Yes	
Observations	321		321		321	
R^2	0.421		0.463		0.524	

*Notes: Standard errors in parentheses. Quality weights are proportionate to SMS except for SMS = 0, which receives a weight of 0.5. * p < 0.1, ** p < 0.05, *** p < 0.01.*

The estimation results of Model (2b) are in Table A8. We only report our preferred specification in which we control for attributes and weight by quality. Because of this and due to the great variety of information contained in Table A8, to save space we refrain from discussing every individual effect. We concentrate on the novel findings that emerge from the results and refer to the discussion around Table A9 for other effects that still apply. One of the few novel insights is the effect of morphological density on *innovation*, which is negative and statistically significant. Another important insight arises from the comparison to Table A10. While mixed land use appears as a less favorable compact city characteristic in Table A10, the disaggregation of mixed-use effects by category reveals that the average negative effect is driven by a singular category: *value of space*. In three of the five outcome dimensions for which mixed-use effects have been investigated, the effects tend to be positive (for two the effects are significant). The important conclusion from Table A8 is that even after controlling for attribute mix and adjusting for quality, the effects of urban compactness are specific to combinations of outcomes and characteristics. With few exceptions, generalising the evidence to averages within outcome dimensions comes at the cost of losing important information.

Table A8
Multivariate analysis of results II

	(1)					
OUTCOME	**RESULT: -1: NEGATIVE; 0: INSIGNIFICANT; 1: POSITIVE**					
	A Economic density		**B Morph. Density**		**C Mixed land use**	
01 Productivity	0.690***	(0.19)				
02 Innovation	0.728***	(0.25)	-0.432**	(0.19)		
03 Value of space	0.359	(0.26)	0.560**	(0.28)	-1.421***	(0.19)
04 Job accessibility	0.040	(0.28)	-0.637	(0.44)	0.056	(0.28)
05 Services and amenities access	0.093	(0.24)	0.548***	(0.17)		
06 Efficiency of public services delivery	0.383	(0.23)	0.845***	(0.13)		
07 Social equity	0.386	(0.30)				
08 Safety	0.338	(0.23)	-0.600	(0.54)		
09 Open space preservation and biodiv.	-1.382***	(0.19)	-1.201***	(0.27)		
10 Pollution reduction	-0.101	(0.35)	-1.394***	(0.19)		
11 Energy efficiency	0.235	(0.25)	0.109	(0.39)	0.509**	(0.18)
12 Traffic flow	-1.040***	(0.26)	-0.259	(0.25)	0.566**	(0.24)
13 Sustainable mode choice	0.207	(0.21)	0.567***	(0.19)	-0.198	(0.46)
14 Health	-0.959***	(0.27)	-0.717	(0.55)		
15 Well-being	-0.934***	(0.17)	-0.134	(0.67)		
Non-high-income country	-0.248*	(0.14)				
Economics	-0.046	(0.11)				
Within-city variation	0.310**	(0.12)				
Academic journal	0.149	(0.13)				
Round 3	0.248***	(0.09)				
Year – 2000	0.002	(0.01)				
Weighted by Quality	Yes					
Observations	321					
R2	0.573					

*Notes: Standard errors in parentheses. Quality weights are proportionate to SMS except for SMS = 0, which receives a weight of 0.5. * p < 0.1, ** p < 0.05, *** p < 0.01*

6. Quantitative results scale

6.1 ELASTICITY OF DENSITY WITH RESPECT TO POPULATION

We estimate the elasticity of density with respect to population using the following straightforward econometric specification.

$$\ln\left(\frac{P_i}{A_i}\right) = \alpha \ln\left(P_i\right) + \mu_c + \epsilon_{ic}$$

, where P_i is the population of city, A_i is the respective land area, and μ_C is a country fixed effect. While the data theoretically allows us to estimate the elasticity from within-city variation over time, we are concerned about the very limited within-city variation in land area in the data. An imperfect measurement of the land area leads to an upward bias in the elasticity. In the extreme case, where land area does not change at all over time, the elasticity would be mechanically one as the only variation on the left-hand side and the right-hand side originates from population. To mitigate this problem, we prefer to estimate the elasticity from cross-sectional between-city variation. Yet, there is still a potential mechanical endogeneity as population (left-hand side) is also a component of density (right-hand side) so that any measurement error in population will upward bias the elasticity. To address this problem we exploit that, mechanically, there is a negative relationship between the population of a city and their rank in the population distribution within a city system. This negative relationship has been analysed in a vast literature on city size distributions (Nitsch 2005). The rank of a city in the distribution of a country city-size distribution is naturally a strong instrument. It is also a valid instrument in this particular context because it effectively removes the population level from the right-hand side of the estimation equation. We note that it is straightforward to solve $\ln\left(\frac{P_i}{A_i}\right) = \alpha \ln(P_i)$ for $\ln(A_i) = (1-\alpha)\ln(P_i)$. Thus, the elasticity of density with respect to city size can also be estimated from a regression of the log of land area against the log of population.

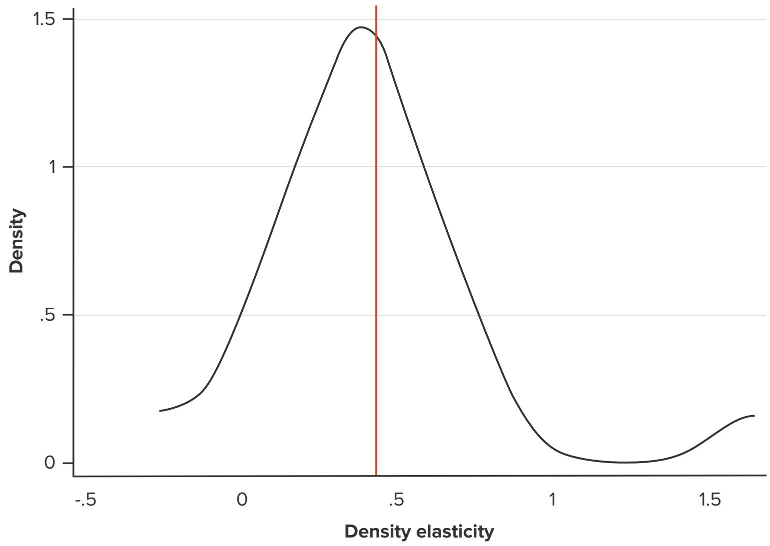
The results are reported in Table A9. The elasticity increases significantly as the country fixed effects are added to the equation (from 1 to 2). As expected, given the presumed absence of measure, using an IV for population hardly affects the results (3). The results from the alternative specification using the city log of area and log of population are identical to the baseline, as expected (4 and 5 vs. 1 and 2, resp. 3). Our preferred estimate of the elasticity of density with respect to city size is 0.43. The distribution of country-specific elasticities estimated by country using the same model as in Table A9, column (3) (excluding country fixed effects), is illustrated in Figure A2 and Table A10. We note that our result is within close range of Combes et al. (2013), who report an elasticity of land area with respect to population of about 0.7 for French cities, implying an elasticity of density with respect to city size of 0.3. Our results are also close to Rappaport (2008) who estimates an elasticity of 0.34 across US metropolitan areas.

Table A9
Elasticity of density with respect to population

	(1)	(2)	(3)	(4)	(5)
	Ln population density	Ln population density	Ln population density	Ln geographic area	Ln geographic area
Ln population	0.304*** (0.07)	0.427*** (0.05)	0.431*** (0.04)	0.696*** (0.07)	0.573*** (0.05)
Country effects IV	– –	Yes –	Yes Yes	– –	Yes –
Density elasticity	0.3	0.43	0.43	0.3	0.43
N r2	281 0.057	281 0.614	281	281 0.239	281 0.689

*Notes: Standard errors in parentheses. Population density and population are averages over the 2000–2014. IV is rank of a city in the population distribution within a country. * p < 0.1, ** p < 0.05, *** p < 0.01*

Figure A2
Elasticity of density with respect to population: Distribution across countries



Notes: The vertical line represents the elasticity estimated in Table A9, column 2 model. The black curved line is the kernel density distribution across 19 countries with sufficient metropolitan areas estimated using Table A9, column 1 model by country.

Table A10
Elasticity of density with respect to population by country

Country code	N	Elasticity of density with respect to population	Standard error
AT	3	0.27	0.07
AU	6	0.06	0.15
BE	4	0.30	0.16
CA	9	0.74	0.39
CH	3	1.65	0.17
CL	3	0.55	0.15
CZ	3	-0.26	0.56
DE	24	0.08	0.18
ES	8	0.65	0.62
FR	15	0.39	0.17
IT	11	0.40	0.17
JP	36	0.40	0.10
KR	10	0.50	0.18
ME	33	0.71	0.25
NL	5	0.19	0.57
PL	8	0.43	0.28
SE	3	0.35	0.06
UK	15	0.11	0.17
US	70	0.43	0.13

Notes: Elasticity estimated for 19 countries with sufficient metropolitan areas estimated using Table A9, column 1 model by country.

6.2 CONVERTING MARGINAL EFFECTS INTO ELASTICITIES

In this subsection we discuss how we adjust the density effects reported in the literature into a consistent format. Our aim is to express as many as possible estimates in terms of an elasticity of an outcome measure Y with respect to density P/A:

$$\beta = \frac{\frac{dY}{Y}}{\frac{d(P/A)}{(P/A)}}$$

, where *P* (population) and *A* (area) are defined as in the previous section. Authors of the studies included in the evidence base frequently report marginal effects of the following forms:

Marginal effects in levels:

$$\gamma = \frac{dY}{d(P/A)}$$

Log-lin semi-elasticities estimated using log-lin models:

$$\delta = \frac{\frac{dY}{Y}}{d(P/A)}$$

Lin-log semi-elasticities estimated using lin-log models:

$$\vartheta = \frac{dY}{\frac{d\left(\frac{P}{A}\right)}{(P/A)}}$$

Hence, we can compute β at the mean of the distributions of Y and P (denoted by bars) from reported estimates of γ or δ or ϑ as follows:

$$\beta = \delta\ \overline{(P/A)}$$

$$\beta = \gamma\ \frac{\overline{(P/A)}}{\overline{Y}}$$

$$\beta = \vartheta\ \frac{1}{\overline{Y}}$$

We note that in some instances, a conversion into an elasticity requires further auxiliary steps such as removing a standardisation (normalization by standard deviations) or the auxiliary estimation of elasticities based on results reported for discrete categories. In some cases, we infer a marginal effect from graphical illustrations (in particular in the health category).

6.3 CONVERTING CITY SIZE ELASTICITIES INTO DENSITY ELASTICITIES

In several instances the authors of the considered analyses use population as a proxy of density. The elasticity of an outcome with respect to population (city size proxy) takes the following form (after transformation as described in 5.2, if necessary):

$$\theta = \frac{\frac{dY}{Y}}{\frac{d(P)}{(P)}}$$

As we have shown in 5.1, the elasticity of density with respect to city size is not unity. It is therefore necessary to adjust the estimates in order to make them comparable to elasticities with respect to density. Given that we have an estimate of the elasticity of density with respect to city size

$$\alpha = \frac{\frac{d(P/A)}{(P/A)}}{\frac{dP}{P}}$$

we can easily compute the elasticity of an outcome with respect to density as:

$$ß = \frac{\theta}{\alpha}$$

6.4 CONVERTING LAND VALUE ELASTICITIES INTO DENSITY ELASTICITIES

Density effects on the value of real estate are often reported in terms of house price capitalization, which is linearly related to rent capitalization (assuming a constant discount factor). Sometimes, authors report the effects in terms of land price capitalization. Land price elasticities are not directly comparable to house price elasticities because house prices generally move less than land prices due to factor substitution (developers substitute away from land as land prices increase).

To allow for a simple micro-founded translation of land price capitalization effects into house price capitalisation effects, it is useful to assume a Cobb-Douglas housing production function and a competitive construction sector. Assume that housing services H are produced using the inputs capital K and land L as follows: $H = K^{\rho} L^{1-\rho}$. Housing space is rented out at bid-rent ψ while land is acquired at land rent Ω . From the first-order condition $K/L = \rho/(1-\rho)\,\Omega$ (the price of capital is the numeraire) and the non-profit condition $\psi H = K+\Omega L$, it is immediate that $\log(\psi) = (1-\rho)\ \log(\Omega)+c$, where c is a constant that cancels out in differences, i.e., $d\ln(\psi) = (1-\rho)\, d\ln(\Omega)$.

It is, therefore, possible to translate an elasticity of land price with respect to density into an elasticity of rent (house price) with respect to density as follows:

$$\frac{d\ln\Psi}{d\ln\left(\frac{P}{A}\right)} = (1-\rho)\ \frac{d\ln\Omega}{d\ln\left(\frac{P}{A}\right)}$$

, where we set $(1-\rho) = 0.25$, following Ahlfeldt, Redding, et al. (2015).

6.5 RESULTS BY OUTCOME DIMENSION

In Table A11 we summarise the quantitative results in our evidence base. We made an effort to condense the elasticity estimates into a limited number of outcome groups. Because of the great variety of outcomes in the evidence base we frequently report more than one elasticity for an outcome dimension (indicated by ID). Given the variety of outcomes we do not discuss each result here, but leave it to the interested reader to pick their finding of relevance. We note, however, that there is significant variation in the quantity of the evidence base and the quality of the underlying evidence (as well as other attributes) and we urge that these differences are taken into account when considering the evidence. Caution is warranted, not only when the evidence base is quantitatively small, but also when it is inconsistent. A useful indicator is a standard deviation that is large compared to the average effect, as is the case, for example, for the outcome pollution reduction.

Table A11
Percentage changes in outcomes with respect to a 1% change in population density (outcome elasticies)

ELASTICITY OF OUTCOME		SHARE OF PUBLICATIONS				MED. AVERAGE ELASTICITY			
with respect to density	Number of studies	Poor countries[a]	Academic journal	Economics	Identifies within-city variation	year[b]	SMS	Mean	S.D.
Wages	22	18%	95%	64%	14%	2013	3.23	0.05%	0.04
Total factor productivity	6	0%	100%	83%	33%	2012	2.83	0.08%	0.04
Patents p.c.	2	0%	100%	50%	0%	2009	4.00	0.13%	0.11
Rent	9	13%	78%	56%	56%	2014	2.56	0.11%	0.11
Commuting reduction	8	0%	63%	25%	38%	2011	2.25	0.07%	0.14
Non-work trip reduction	2	0%	100%	0%	50%	2000	2.00	0.15%	0.12
Metro rail density	3	43%	100%	0%	100%	2008	3.33	0.01%	0.02
Quality of life	7	0%	86%	100%	14%	2016	2.86	0.01%	0.07
Variety (consumption amenities)	1	0%	100%	0%	0%	2015	4.00	0.19%	-
Variety price reduction	2	0%	0%	100%	100%	2016	4.00	0.12%	0.06
Public spending reduction	13	0%	100%	8%	0%	2003	2.00	0.16%	0.31
90th-10th pct. wage gap reduction	1	0%	100%	0%	0%	2004	4.00	0.17%	-
Black-white wage gap reduction	1	0%	0%	100%	0%	2013	2.00	0.00%	-
Diss. index reduction	3	0%	100%	33%	0%	2009	3.33	1.10%	1.28
Gini coef. reduction	1	0%	100%	0%	0%	2010	4.00	4.56%	-
Crime rate reduction	12	0%	67%	17%	100%	2015	2.50	0.43%	0.23
Foliage projection cover	1	0%	100%	0%	100%	2015	1.00	-0.06%	-
Noise reduction	1	0%	100%	0%	0%	2012	1.00	0.04%	-
Pollution reduction	12	67%	42%	8%	58%	2014	2.42	0.04%	0.90

ELASTICITY OF OUTCOME		SHARE OF PUBLICATIONS				MED. AVERAGE ELASTICITY			
With respect to density	Number of studies	Poor countries[a]	Academic journal	Economics	Identifies within-city variation	year[b]	SMS	Mean	S.D.
Energy reduction: Domestic & driving	19	11%	95%	42%	26%	2010	1.74	0.10%	0.12
Energy reduction: Public transit	1	0%	100%	100%	0%	2010	1.00	-0.37%	-
Speed	2	0%	0%	100%	0%	2016	4.00	-0.12%	0.01
Car usage (incl. shared) reduction	21	0%	95%	0%	86%	2004	2.00	0.07%	0.09
Non-car use	28	14%	89%	0%	93%	2004	2.07	0.21%	0.41
Serious disease reduction	5	0%	100%	0%	60%	2006	2.40	-0.23%	0.22
KSI & casualty reduction	4	0%	100%	0%	0%	2003	2.00	0.01%	0.61
Mental-health	1	0%	100%	0%	100%	2015	2.00	0.01%	-
Mortality reduction	2	0%	100%	0%	0%	2016	2.00	-0.29%	0.20
Reported health	2	0%	100%	0%	0%	2013	1.00	-0.27%	0.11
Reported safety	1	0%	100%	0%	100%	2015	2.00	0.07%	-
Reported social interaction	6	0%	17%	83%	0%	2006	3.50	-0.10%	0.16
Reported well-being	1	0%	100%	100%	0%	2016	3.00	0.00%	-
Sum	**202**								

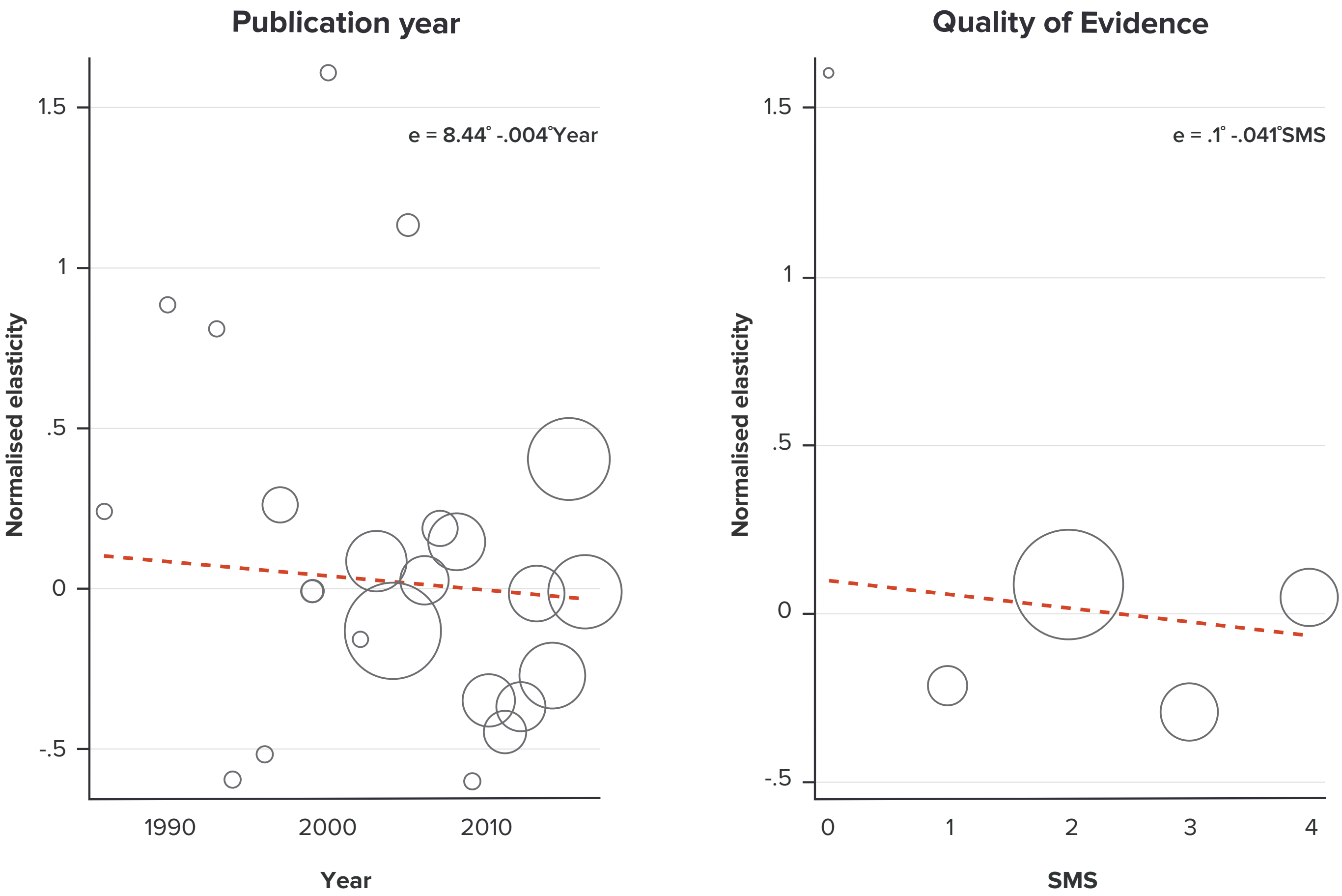
Note: a. Poor countries include low-income and median-income countries according to the World Bank definition. b. Year of publication. 1: Productivity; 2: Innovation; 3: Value of space; 4: Job accessibility; 5: Services and amenities access; 6: Efficiency of public services delivery; 7: Social equity; 8: Safety; 9: Open space preservation and biodiversity; 10: Pollution reduction; 11: Energy efficiency; 12: Traffic flow; 13: Sustainable mode choice; 14: Health; 15: Well-being. Interquartile wage gap.

6.6. RESULTS BY ATTRIBUTES

It is common for meta-analytic research to investigate the reasons behind differences in the evidence (similar to our models in section A5). For this purpose researchers often collect a large number of estimates of the same parameter (normally several from the same study) and subject the evidence base to multivariate analysis to uncover how specifics of the data and the empirical design are correlated with the result (Melo et al. 2009; Stanley 2001; Disdier & Head 2008). In contrast, we collect evidence on a variety of different parameters, which comes at the expense of having a smaller number of estimates of the same parameters. This is because instead of collecting all the estimates of the same parameter from each individual study, we only collect the baseline estimate of a parameter of interest provided in a study. Due to the relatively small number of observations per outcome dimension, it is difficult to analyse the distribution of elasticity estimates by category. We therefore pool all the elasticity estimates, normalising them to have a zero mean and a unity standard deviation within category.

Figure A3 plots the normalised elasticity estimates against the year of publication and the quality of the evidence as well as the SMS score. The results of the bivariate regressions reported at the bottom of the panels confirms the visual impression of a weakly negative but not statistically significant relationship between estimated elasticities on the one hand and the year of publication and the quality of the evidence on the other.

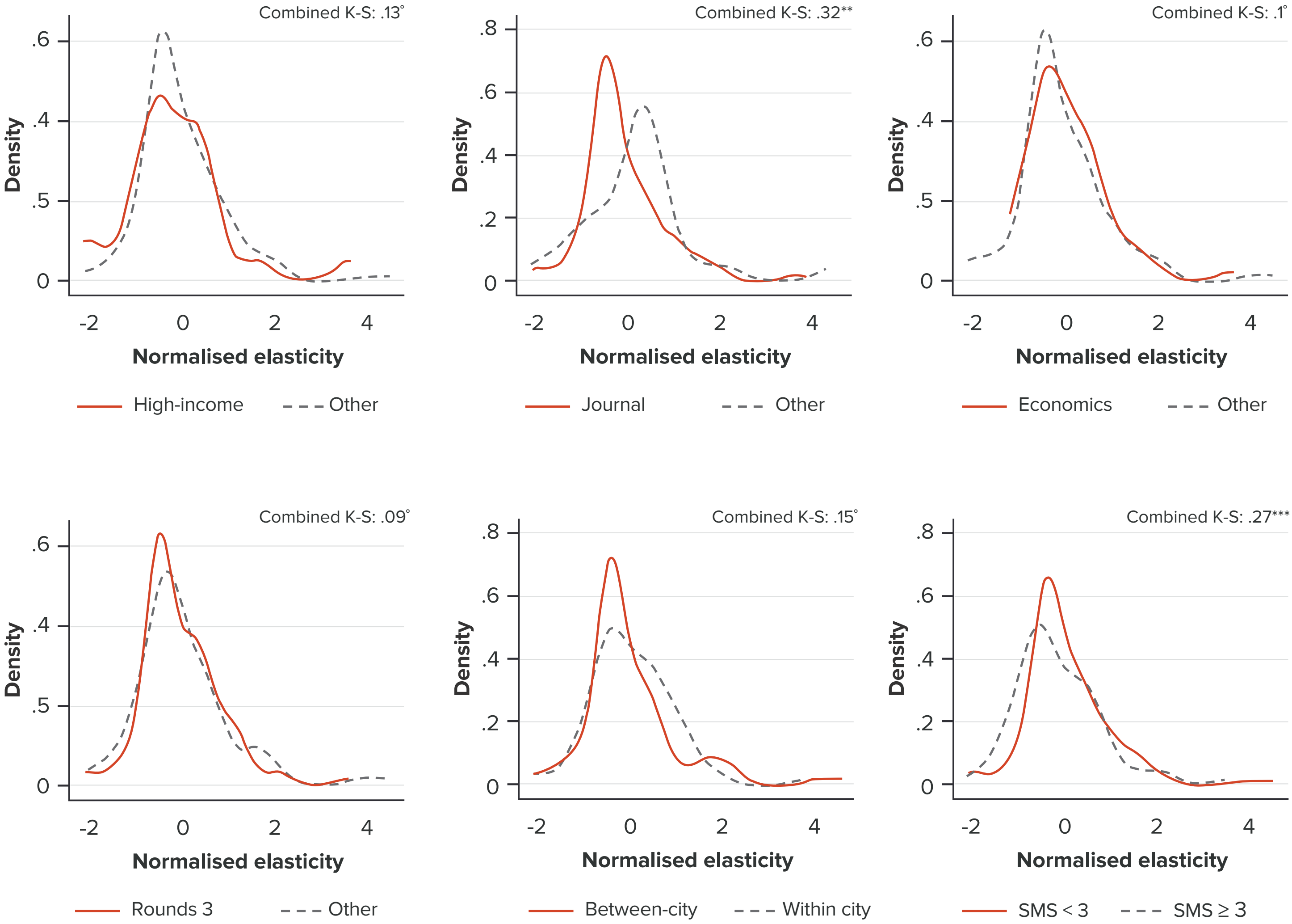
Figure A3
Normalised elasticities vs. publication year and quality of evidence



Notes: Elasticities normalised within outcome elasticity categories (in Table A12) to have a mean of zero and a standard deviation of one. Marker size proportionate to number of observations. Linear fits (dashed lines, parametric results at the bottom) are frequency weighted by observations. °//**/*** indicates insignificant / significant at the 10%/5%/1% level (robust standard errors).*

In Figure A4 we illustrate how the distribution of normalised elasticities varies in selected attributes. At the bottom of each panel we report (two-sided) Kolmogorov-Smirnov test statistics and significance levels. We find statistically significant differences in the distributions with respect to publication venue (smaller elasticities in journals) and quality of evidence (smaller elasticities for higher quality). Because the effect of journal publication and evidence quality work in the same direction it is difficult to conclude whether the former represents publication bias or quality of peer-review. In a multivariate analysis (controlling for all attributes in Fig. 3 simultaneously) the differences in the respective conditional means is only significant with OLS standard errors. With more conservative standard errors (robust or clustered on outcome groups in an outcome fixed-effect model using raw elasticities as a dependent variable) the effects are insignificant, as are the effects for all other attributes. Overall, we do not find strong evidence that the quantitative results in the literature are systematically related to the considered attributes.

Figure A4
Distribution of normalised elasticities by attributes



Notes: Elasticities normalised within outcome elasticity groups (listed in Table A7 of the main text) to have a mean of zero and a standard deviation of one. °//**/*** indicates insignificant / significant at the 10%/5%/1% level based on a two-sample Kolmogorov-Smirnov test for equality of distribution functions.*

6.7 OWN ESTIMATES

While the evidence base on the quantitative effects of density summarised above is rich and reasonably consistent for outcome dimensions like *productivity* or *sustainable mode choice*, it is thinner and less consistent for many other outcome dimensions. To enrich the evidence base in some of the less-developed categories, we contribute some simple and transparent elasticity estimates using data from the OECD functional economic areas and regional statistics database and the following regression model:

Formula 3

$$\ln(Y_i) = \beta \ln + \left(\frac{P_i}{A_i}\right) \tau \ln\left(\frac{G_i}{P_i}\right) + \mu_c + \epsilon_{ic}$$

, where Y_i is an outcome, P_i, A_i, μ_C are population, geographic area, and country fixed effects as in equation (1), and G_i is GDP. The coefficient of interest is β, which gives the elasticity of an outcome with respect to population density controlling for GDP per capita and unobserved cross-country heterogeneity. Where either population or area forms part of the dependent variable we instrument population density using the rank within the national population density distribution as an instrument. Table A12 summarises the key results. Full estimation results of a greater variety of models are found in section A7. We find a negative association between well-being and density, which seems to be more pronounced across than within countries. Still, the results support the singular comparable result found in the literature (Glaeser et al. 2016). Our results further support the average findings in the evidence base, in that innovation (number of patents) increases in density and crime rates, energy use (carbon emissions), and average road speeds decrease in density.

Conflicting with the mean elasticities in the evidence base reported in Table A13, we find that pollution concentrations are higher in denser cities and that the mortality rate is lower. Our results further consistently point to a positive association of income inequality and density. This is in line with the typical finding in urban economics research that the high-skilled benefit disproportionately from agglomeration (Glaeser & Resseger 2010). But there is some contrast to a literature that has found mixed results, with many studies pointing to lower inequalities at higher levels of economic density.

With the exception of a descriptive case study, our estimates of the relationship between green coverage and population density are without precedent. The elasticity of green density with respect to population density qualitatively depends on the spatial layer of analysis. At regional level (administrative boundaries) the spatial units cover both urban and rural areas. The negative elasticity likely reflects that an increase in population implies a larger share of urban, at the expense of non-urban land.

Table A12
Own elasticity estimates

	Ln patents p.c.[a]		**Ln broadband p.c.[b]**		**Ln income quintile ratio[b]**		**Ln Gini coefficient[b]**	
Ln dens.	0.349***	0.129*	0.034***	0.01	0.024	0.035**	-0.007	0.025***
FE	-	Yes	-	Yes	-	Yes	-	Yes
IV	-	Yes	-	Yes	-	-	-	-
	Ln poverty rate[b]		**Ln homicides p.c.[b]**		**Ln green density[b] (administrative)**		**Ln urban green density[a]**	
Ln dens.	-0.013	0.032	-0.166***	-0.048	-0.267***	-0.245***	0.283**	0.761*
FE	-	Yes	-	Yes	-	Yes	-	Yes
IV	-	Yes	-	Yes	-	Yes	-	Yes
	Ln green p.c.[c]		**Ln pollution (PM2.5)[b]**		**Ln CO2 p.c.[b]**		**Ln speed[a,d] Freeway**	**Arterial**
Ln dens.	-0.717***	-0.239	0.220***	0.124***	-0.224***	-0.173***	-0.008	0.063***
FE	-	Yes	-	Yes	-	Yes	-	-
IV	-	Yes	-	-	-	Yes	-	-
	Ln mortality rate[b]		**Ln mortality rate: transport[b]**		**Ln life expectancy at birth[b]**		**Ln subjective well-being[b]**	
Ln dens.	-0.046***	-0.017	-0.150***	-0.099***	0.013***	0.007*	-0.023***	-0.007**
FE	-	Yes	-	Yes	-	Yes	-	Yes
IV	-	Yes	-	Yes	-	-	-	-

Notes: Density (dens.) is population density (population / area). All models control for ln GDP p.c. Fixed effects (FE) are by country. IV is rank of a city in the population density distribution within a country. a Data from OECD.Stat functional economic areas. b Data from OECD.Stat administrative boundaries (large regions). c Data from OECD.Stat administrative boundaries (small regions, excluding GDP control due to unavailability of data for the US) d Speed data from Lomax et al (2011). Poverty line is 60% of the national median income. Speeds are measured during peak time.
** $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$, with standard errors clustered on FE where applicable.*

Functional economic areas are designed to cover exclusively urban areas. The positive elasticity likely reflects that within an urbanised area, increasing population density preserves space for urban parks and suburban forests. Because we focus on the effects of urban form in this paper, the latter is our preferred estimate. We note that the relatively large elasticity estimated conditional on country fixed effects is driven by a suspiciously large elasticity across US cities (>1.4), whereas the within-country elasticity for the rest of the world is in line with the baseline elasticity from the cross-sectional model excluding fixed effects. Therefore, we prefer the non-fixed effects model in this case. The elasticity of per capital green area with respect to population is negative, as expected. Our preferred elasticity estimate (-0.293) is within the range of the elasticity of green space value with respect to a population density of 0.3 (Brander & Koetse 2011) suggesting that congestion (number of users) and the value of green space increase roughly at the same rate.

6.8 DENSITY ELASTICITIES: WEIGHTED AVERAGES

In the table below we compare the mean elasticities within selected outcome dimensions to the respective means weighted by quality (SMS) and the inverse of the number of estimates added from a study. The latter is to ensure that studies (not estimates) receive the same weights, i.e., studies reporting various useful estimates are deflated. In the last column, we report the median for comparison.

Table A13
Weighted average density elasticities

		NO WEIGHTS		QUALITY		INV. FREQUENCY		
ID	**Elasticity of outcome with respect to density**	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**	**Median**
1	Labor productivity	0.05	0.04	0.05	0.04	0.05	0.03	0.04
1	Total factor productivity	0.08	0.04	0.07	0.03	0.08	0.04	0.07
2	Patents p.c.	0.13	0.11	0.13	0.11	0.13	0.11	0.13
3	Rent	0.11	0.11	0.09	0.11	0.11	0.11	0.07
4	Commuting reduction	0.07	0.14	0.07	0.14	0.04	0.14	0.10
4	Non-work trip reduction	0.15	0.12	0.15	0.12	0.18	0.11	0.15
5	Metro rail density	0.01	0.02	0.02	0.02	0.01	0.02	0.00
5	Quality of life	0.01	0.07	0.01	0.08	0.03	0.06	-0.01
5	Variety (consumption amenities)	0.19	-	0.19	-	0.19	-	0.19
5	Variety price reduction	0.12	0.06	0.12	0.06	0.12	0.06	0.12
6	Public spending reduction	0.16	0.31	0.16	0.31	0.19	0.33	0.14
7	90th-10th pct. wage gap reduction	0.17	-	0.17	-	0.17	-	0.17
7	Black-white wage gap reduction	0.00	-	0.00	-	0.00	-	0.00
7	Diss. index reduction	1.10	1.28	0.80	1.08	1.10	1.28	0.39
7	Gini coef. reduction	4.56	-	4.56	-	4.56	-	4.56
8	Crime rate reduction	0.43	0.23	0.41	0.23	0.36	0.24	0.41

		NO WEIGHTS		QUALITY		INV. FREQUENCY		
ID	**Elasticity of outcome with respect to density**	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**	**Median**
9	Foliage projection cover	-0.06	-	-0.06	-	-0.06	-	-0.06
10	Noise reduction	0.04	-	0.04	-	0.04	-	0.04
10	Pollution reduction	0.04	0.90	0.02	1.00	-0.03	0.66	0.23
11	Energy consumption red.: Domestic & driving	0.10	0.12	0.12	0.13	0.14	0.13	0.07
11	Energy consumption reduction: Public transit	-0.37	-	-0.37	-	-0.37	-	-0.37
12	Speed	-0.12	0.01	-0.12	0.01	-0.12	0.01	-0.12
13	Car usage (incl. shared) reduction	0.07	0.09	0.07	0.09	0.20	0.19	0.04
13	Non-car use	0.21	0.41	0.20	0.40	0.21	0.42	0.10
14	Cancer & other serious disease reduction	-0.23	0.22	-0.28	0.22	-0.15	0.19	-0.19
14	KSI & casualty reduction	0.01	0.61	0.01	0.61	0.01	0.61	0.17
14	Mental-health	0.01	-	0.01	-	0.01	-	0.01
14	Mortality reduction	-0.29	0.20	-0.29	0.20	-0.24	0.21	-0.29
15	Reported health	-0.27	0.11	-0.27	0.11	-0.27	0.11	-0.32
15	Reported safety	0.07	-	0.07	-	0.07	-	0.07
15	Reported social interaction	-0.10	0.16	-0.05	0.10	-0.11	0.17	-0.03
15	Reported well-being	0.00	-	0.00	-	0.00	-	0.00

Notes: "No weights" replicates the results from Table A7 in the main paper for comparison. "Quality" weights are SMS scores. "Inv. frequency" weights are one over the number of estimates included per study.

6.9 DETERMINANTS OF ELASTICITIES: MULTIVARIATE ANALYSIS

Table A14 presents the results of a multivariate regression analysis, which complements the tests of equality of distributions reported in Figure A3. With our preferred standard errors (2 and 4), none of the considered attributes have a significant effect on elasticities.

Table A14
Multivariate analysis of elasticities

	(1) Normalised elasticity	(2) Normalised elasticity	(3) Elasticity with respect to density	(4) Elasticity with respect to density
Non-high-income country	-0.063 (0.22)	-0.063 (0.26)	-0.151 (0.09)	0.151 (0.13)
Academic journal	-0.355* (0.20)	-0.355 (0.25)	-0.153 (0.09)	-0.153 (0.17)
Economics	0.147 (0.18)	0.147 (0.19)	-0.071 (0.08)	-0.071 (0.08)
Round 3	-0.096 (0.14)	-0.096 (0.14)	-0.023 (0.06)	-0.023 (0.09)
Within-city variation	-0.025 (0.15)	-0.025 (0.15)	-0.042 (0.08)	-0.042 (0.06)
SMS >= 2	-0.317* (0.16)	-0.317* (0.16)	-0.187** (0.08)	-0.187 (0.11)
Constant	0.429* (0.25)	0.429 (0.31)	0.385*** (0.11)	0.385* (0.20)
Outcome effects	-	-	Yes	Yes
Standard errors	OLS	Robust	OLS	Clustered
N	192	192	202	202
r2	0.034	0.034	0.589	0.589

*Notes: Normalised elasticities are normalised to have a zero mean and a unity standard deviation. Standard errors in parentheses. Clustered standard errors are clustered on outcome groups. * p < 0.1, ** p < 0.05, *** p < 0.01*

7. Own estimates

In this section we complement the existing literature on the effect of density using OECD.Stat functional economic areas or regional statistics data and the following regression model:

$$\ln(Y_i) = \beta \ln + \left(\frac{P_i}{A_i}\right) \tau \ln \left(\frac{G_i}{P_i}\right) + \mu_c + \epsilon_{ic}$$

, where Y_i is an outcome as defined in the table below P_i, A_i, μ_C are population, geographic area, and country fixed effects as in equation (1), and G_i is GDP per capita. The coefficient of interest is β, which gives the elasticity of an outcome with respect to population density controlling for local GDP p.c. and unobserved cross-country heterogeneity. Where either population or area forms part of the dependent variable we instrument population density using the rank within the national population density distribution as an instrument. In the following subsection, we present estimates of this model including and excluding the GDP controls and fixed effects, as well as with and without using the instrumental variable. Because the interpretation of the parameter on population density as an elasticity is straightforward, we generally present the results without further discussion. The exception is our estimate of the elasticity of speed with respect to density, which follows a slightly different structure.

7.1 INNOVATION

Table A15
Elasticity of patents per capita with respect to population density

	(1) Ln patents per capita	(2) Ln patents per capita	(3) Ln patents per capita	(4) Ln patents per capita	(5) Ln patents per capita	(6) Ln patents per capita
Ln population density	0.170 (0.11)	0.349*** (0.06)	0.122** (0.06)	0.129* (0.07)	0.164* (0.09)	0.036 (0.10)
Ln GDP per capita		2.953*** (0.11)	1.426*** (0.21)	1.425*** (0.39)	2.028*** (0.34)	1.053*** (0.35)
Country effects	–	–	Yes	Yes	–	Yes
Sample	Non-US	Non-US	Non-US	Non-US	US	Non-US
IV	–	–	–	Yes	Yes	Yes
N	218	218	218	218	70	148
r2	0.010	0.723	0.894		0.408	

*Notes: Standard errors in parentheses. Unit of observation is functional economic area. All variables are averaged over 2000–2014. IV is rank of a city in the population density (and population where included) distribution within a country. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$*

7.2 SERVICES ACCESS (BROADBAND)

Table A16
Elasticity of broadband per capita with respect to population density

	(1) Ln broadband per capita	(2) Ln broadband per capita	(3) Ln broadband per capita	(4) Ln broadband per capita	(5) Ln broadband per capita	(6) Ln broadband per capita
Ln population density	0.033*** (0.01)	0.034*** (0.01)	0.011 (0.01)	0.010 (0.01)	-0.000 (0.00)	0.013 (0.01)
Ln GDP per capita		0.474*** (0.04)	0.305*** (0.06)	0.306*** (0.06)	0.119 (0.07)	0.327*** (0.06)
Country effects	–	–	Yes	Yes	–	Yes
IV	–	–	–	Yes	Yes	Yes
N	343	343	343	343	51	292
Sample	All	All	All	All	US	Non-US
r2	0.020	0.576	0.862		0.186	

*Notes: Standard errors in parentheses. Unit of observation is large regions (OECD definition). All variables are averaged over 2000–2014. IV is rank of a city in the population density distribution within a country. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$*

7.3 SOCIAL EQUITY

Table A17
Elasticity of income quintile ratio with respect to population density

	(1) Ln disposable income quintile ratio (pct. 80 vs 20)	(2) Ln disposable income quintile ratio (pct. 80 vs 20)	(3) Ln disposable income quintile ratio (pct. 80 vs 20)	(4) Ln disposable income quintile ratio (pct. 80 vs 20)	(5) Ln disposable income quintile ratio (pct. 80 vs 20)
Ln population density	0.023 (0.02)	0.024 (0.03)	0.035** (0.01)	0.057*** (0.02)	0.032** (0.01)
Ln GDP per capita		-0.233*** (0.09)	0.469 (0.29)	0.197* (0.11)	0.503 (0.32)
Country effects	–	–	Yes	–	Yes
IV	–	–	–	–	–
N	275	269	269	51	218
Sample	All	All	All	US	Non-US
r2	0.004	0.042	0.734	0.352	0.718

Notes: Standard errors in parentheses. Unit of observation is large regions (OECD definition). All variables are averaged over 2000–2014.
** p < 0.1, ** p < 0.05, *** p < 0.01*

Table A18
Elasticity of Gini coefficient with respect to population density

	(1) Ln Gini coefficient	(2) Ln Gini coefficient	(3) Ln Gini coefficient	(4) Ln Gini coefficient	(5) Ln Gini coefficient
Ln population density	-0.007 (0.01)	-0.007 (0.01)	0.025*** (0.01)	0.020*** (0.01)	0.026*** (0.01)
Ln GDP per capita		-0.133*** (0.03)	0.026 (0.02)	0.025 (0.04)	0.028 (0.03)
Country effects	–	–	Yes	–	Yes
IV	–	–	–	–	–
N	275	269	269	51	218.
Sample	All	All	All	US	Non-US
r2	0.003	0.118	0.880	0.237	0.880

*Notes: Unit of observation is large regions (OECD definition). Standard errors in parentheses. Unit of observation is large regions (OECD definition). All variables are averaged over 2000–2014. * p < 0.1, ** p < 0.05, *** p < 0.01*

Table A19
Elasticity of poverty rate with respect to population density

	(1) Ln poverty rate (poverty line 60%)	(2) Ln poverty rate (poverty line 60%)	(3) Ln poverty rate (poverty line 60%)	(4) Ln poverty rate (poverty line 60%)	(5) Ln poverty rate (poverty line 60%)
Ln population density	-0.014 (0.01)	-0.013 (0.01)	0.032 (0.02)	0.034** (0.02)	0.027 (0.03)
Ln GDP per capita		-0.280*** (0.05)	-0.590*** (0.11)	-0.396** (0.18)	-0.617*** (0.13)
Country effects	–	–	Yes	–	Yes
IV	–	–	-	–	–
N	275	269	269	51	218
Sample	All	All	All	US	Non-US
r2	0.004	0.148	0.547	0.156	0.549

Notes: Standard errors in parentheses. Unit of observation is large regions (OECD definition). All variables are averaged over 2000–2014.
** $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.*

7.4 SAFETY

Table A20
Elasticity of homicides p.c. with respect to population density

	(1) Ln homicides p.c.	(2) Ln homicides p.c.	(3) Ln homicides p.c.	(4) Ln homicides p.c.	(5) Ln homicides p.c.	(6) Ln homicides p.c.
Ln population density	-0.204*** (0.03)	-0.166*** (0.03)	-0.033 (0.04)	-0.048 (0.04)	0.105** (0.05)	-0.076** (0.04)
Ln GDP per capita		-0.918*** (0.07)	0.086 (0.06)	0.086 (0.07)	0.312 (0.48)	0.058 (0.07)
Country effects	–	–	Yes	Yes	–	Yes
IV	–	–	–	Yes	Yes	Yes
N	481	474	474	474	51	423
Sample	All	All	All	All	US	Non-US
r2	0.088	0.393	0.879		0.139	

*Notes: Standard errors in parentheses. Unit of observation is large regions (OECD definition). All variables are averaged over 2000–2014. IV is rank of a city in the population density distribution within a country. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.*

7.5 URBAN GREEN

Table A21
Elasticity of vegetation density with respect to population density

	(1) Ln vegetation density	(2) Ln vegetation density	(3) Ln vegetation density	(4) Ln vegetation density	(5) Ln vegetation density	(6) Ln vegetation density
Ln population density	-0.199*** (0.02)	-0.267*** (0.02)	-0.257*** (0.04)	-0.245*** (0.05)	0.034 (0.10)	-0.261*** (0.05)
Ln GDP per capita		0.388*** (0.06)				
Country effects	–	–	Yes	Yes	–	Yes
IV	–	–	–	Yes	Yes	Yes
N	583	410	583	583	45	538
Sample	All	Non-US	All	All	US	Non-US
r2	0.142	0.262	0.381			

*Notes: Standard errors in parentheses. Unit of observation is small regions (urban and intermediate, OECD definition). US GDP data not available at this scale. All variables are averaged over 2000–2014. IV is rank of a city in the population density distribution within a country. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$*

Table A22
Elasticity of green area density with respect to population density

	(1) Ln green area density	(2) Ln green area density	(3) Ln green area density	(4) Ln green area density	(5) Ln green area density	(6) Ln green area density
Ln population density		0.283** (0.14)	0.683** (0.31)	0.761* (0.40)	1.446*** (0.38)	0.197 (0.43)
Ln GDP per capita		0.496** (0.23)	0.035 (0.94)	0.022 (0.86)	1.178 (0.96)	-0.857 (0.69)
Country effects	–	–	Yes	Yes	–	Yes
IV	–	–	–	Yes	Yes	Yes
N	280	280	280	280	70	210
Sample	All	All	All	All	US	Non-US
r2	0.021	0.040	0.283		0.246	

*Notes: Standard errors in parentheses. Unit of observation is functional economic area. All variables are averaged over 2000–2014. IV is rank of a city in the population density (and population where included) distribution within a country. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$*

Table A23
Elasticity of green area per capita with respect to population density

	(1) Ln green area per capita	(2) Ln green area per capita	(3) Ln green area per capita	(4) Ln green area per capita	(5) Ln green area per capita	(6) Ln green area per capita
Ln population density	-0.754*** (0.14)	-0.717*** (0.14)	-0.317 (0.31)	-0.239 (0.40)	0.446 (0.38)	-0.803* (0.43)
Ln GDP per capita		0.496** (0.23)	0.035 (0.94)	0.022 (0.86)	1.178 (0.96)	-0.857 (0.69)
Country effects	–	–	Yes	Yes	–	Yes
IV	–	–	–	Yes	Yes	Yes
N	280	280	280	280	70	210
Sample	All	All	All	All	US	Non-US
r2	0.170	0.186	0.392		0.027	

*Notes: Standard errors in parentheses. Unit of observation is functional economic area. All variables are averaged over 2000–2014. IV is rank of a city in the population density (and population where included) distribution within a country. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$*

7.6 POLLUTION CONCENTRATION

Table A24
Elasticity of air pollution with respect to population density

	(1) Ln air pollution (level PM2.5)	(2) Ln air pollution (level PM2.5)	(3) Ln air pollution (level PM2.5)	(4) Ln air pollution (level PM2.5)	(5) Ln air pollution (level PM2.5)
Ln population density	0.221*** (0.02)	0.220*** (0.02)	0.124*** (0.03)	0.111*** (0.03)	0.128*** (0.03)
Ln GDP per capita		-0.208*** (0.04)	0.020 (0.19)	0.053 (0.14)	0.018 (0.21)
Country effects	–	–	Yes	–	Yes
IV	–	–	–	–	–
N	343	343	343	51	292
Sample	All	All	All	US	Non-US
r2	0.407	0.456	0.708	0.247	0.720

*Notes: Standard errors in parentheses. Unit of observation is large regions (OECD definition). All variables are averaged over 2000–2014. IV is rank of a city in the population density distribution within a country. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$*

7.7 ENERGY

Table A25
Elasticity of Ln CO_2 emissions p.c. with respect to population density

	(1) Ln CO_2 emissions p.c.	(2) Ln CO_2 emissions p.c.	(3) Ln CO_2 emissions p.c.	(4) Ln CO_2 emissions p.c.	(5) Ln CO_2 emissions p.c.	(6) Ln CO_2 emissions p.c.
Ln population density	-0.225*** (0.02)	-0.224*** (0.02)	-0.189*** (0.04)	-0.173*** (0.04)	-0.190*** (0.05)	-0.170*** (0.05)
Ln GDP per capita		0.503*** (0.04)	0.283*** (0.08)	0.282*** (0.07)	0.354 (0.27)	0.280*** (0.07)
Country effects	–	–	Yes	Yes	–	Yes
IV	–	–	–	Yes	Yes	Yes
N	570	562	562	562	51	511
Sample	All	All	All	All	US	Non-US
r2	0.176	0.358	0.597		0.300	

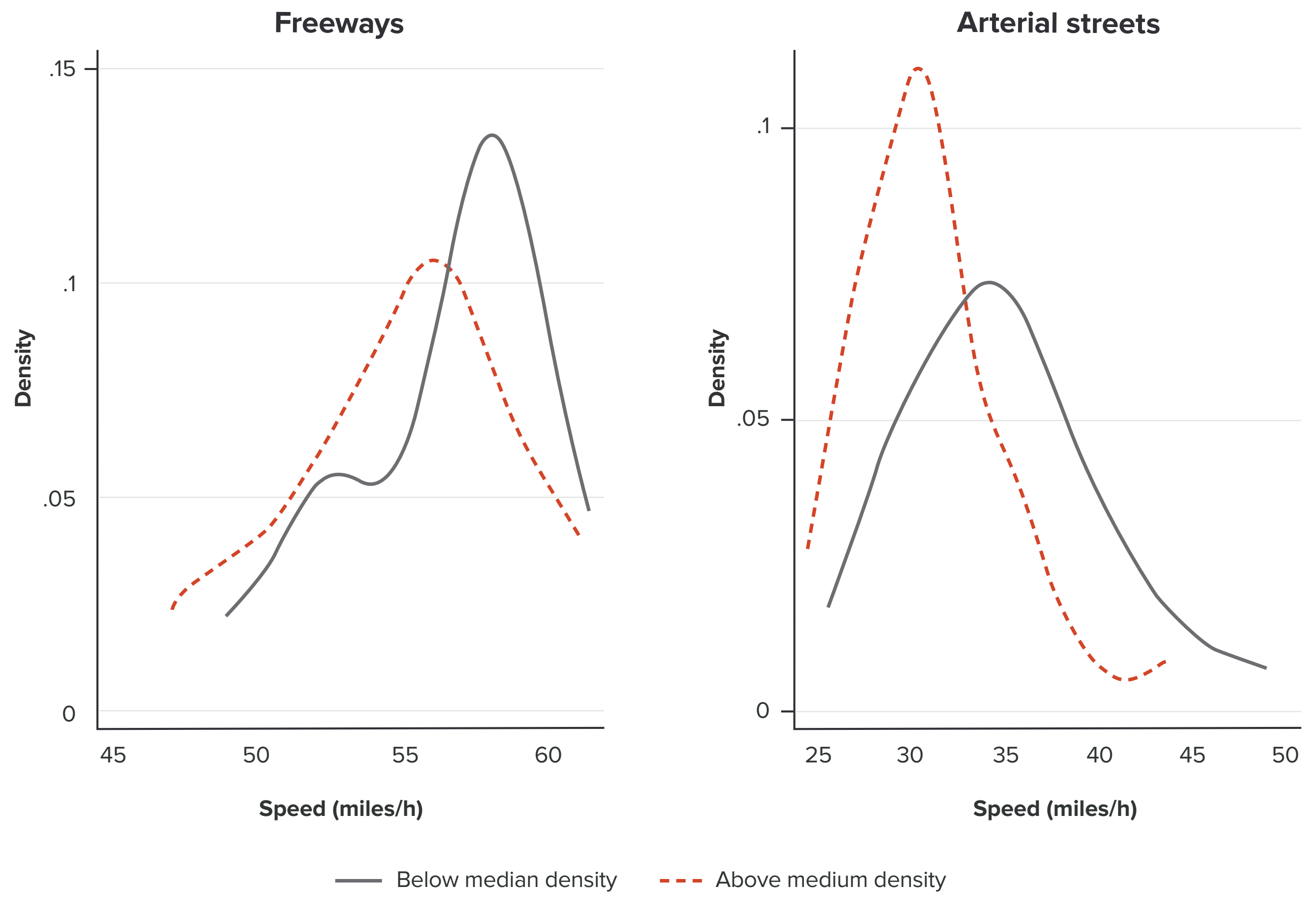
*Notes: Standard errors in parentheses. Unit of observation is large urban regions (OECD definition). All variables are averaged over 2000–2014. IV is rank of a city in the population density distribution within a country. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$*

7.8 TRAFFIC FLOW

In the figure below we compare the peak time (with congestion) speeds on freeways and arterial roads across metros that are above and below the median population density. Both distributions seem to suggest that metros with a higher population density have lower average speeds, which is in line with congestion.

However, regressing the freeway speed against population density does not yield a significant relationship during peak time (with congestion) or off-peak time (free flow). There is also no population density effect on congestions, i.e., on peak time speeds controlling for free-flow speeds. There is, however, a significantly negative effect of population size on congestion, suggesting that freeway congestion is determined by the size of the city and not its density.

Figure A5
Distribution of peak time speeds by population density



Notes: Data from OECD (population density) and Lomax.

Table A26
Elasticity of speed with respect to population density: Freeways

	(1) Ln freeway speed (miles/h): Peak time	(2) Ln freeway speed (miles/h): Peak time	(3) Ln freeway speed (miles/h): Peak time	(4) Ln freeway speed (miles/h): Peak time	(5) Ln freeway speed (miles/h): Peak time	(6) Ln freeway speed (miles/h): Peak time.
Ln population density	-0.008 (0.01)	0.003 (0.01)	0.001 (0.00)	0.003 (0.00)	-0.001 (0.01)	0.011 (0.01)
Ln GDP per capita		-0.097*** (0.03)		-0.015 (0.02)	-0.078** (0.03)	-0.037 (0.03)
Ln freeway speed (miles/h): Free flow Ln population					1.312*** (0.18)	1.315*** (0.16) -0.042*** (0.01)
N	62	62	62	62	62	62
r2	0.012	0.113	0.001	0.013	0.420	0.630

*Notes: Standard errors in parentheses. Data from OECD and Lomax (2010). * p < 0.1, ** p < 0.05, *** p < 0.01.*

For arterial streets, in contrast, we find a significant elasticity of peak time speed with respect to population density of -0.063. Interestingly, we find an elasticity within the same range for free-flow speeds. This suggests that the lower speed is primarily a morphological density effect. Different street layouts result in a generally lower speed, but not higher congestion. This effect is confirmed by the model controlling for free-flow speeds, which yields no significant congestion effect (on peak time speeds). As with freeway speeds, there is a significant population size effect, although it is relatively smaller.

Table A27
Elasticity of speed with respect to population density: Arterial streets

	(1) Ln arterial streets speed (miles/h): Peak time	(2) Ln arterial streets speed (miles/h): Peak time	(3) Ln arterial streets speed (miles/h): Peak time	(4) Ln arterial streets speed (miles/h): Peak time	(5) Ln arterial streets speed (miles/h): Peak time	(6) Ln arterial streets speed (miles/h): Peak time
Ln population density	-0.063*** (0.02)	-0.041** (0.02)	-0.050*** (0.02)	-0.034** (0.02)	-0.001 (0.00)	0.003 (0.00)
Ln GDP per capita		-0.192*** (0.06)		-0.139*** (0.05)	-0.029 (0.02)	-0.018 (0.02)
Ln arterial streets speed (miles/h): Free flow Ln population					1.182*** (0.03)	1.142*** (0.03) -0.017*** (0.00)
N	62	62	62	62	62	62
r2	0.138	0.217	0.130	0.192	0.966	0.972

*Notes: Standard errors in parentheses. Data from OECD and Lomax et al. (2010). * p < 0.1, ** p < 0.05, *** p < 0.01*

7.9 HEALTH

Table A28
Elasticity of standardised mortality rate with respect to population density

	(1) Ln standardised mortality rate	(2) Ln standardised mortality rate	(3) Ln standardised mortality rate	(4) Ln standardised mortality rate	(5) Ln standardised mortality rate.	(6) Ln standardised mortality rate
Ln population density	-0.056*** (0.01)	-0.046*** (0.01)	-0.015 (0.01)	-0.017 (0.01)	-0.005 (0.01)	-0.019 (0.01)
Ln GDP per capita		-0.140*** (0.02)	0.039 (0.02)	0.039* (0.02)	-0.017 (0.12)	0.040 (0.02)
Country effects	-	-	Yes	Yes	-	Yes
IV	-	-	-	Yes	Yes	Yes
N	528	528	528	528	51	477
Sample	All	All	All	All	US	Non-US
r2	0.107	0.223	0.882		.	

*Notes: Standard errors in parentheses. Unit of observation is large regions (OECD definition). All variables are averaged over 2000–2014. IV is rank of a city in the population density distribution within a country. * p < 0.1, ** p < 0.05, *** p < 0.01*

Table A29
Elasticity of life expectancy at birth with respect to population density

	(1) Ln life expectancy at birth	(2) Ln life expectancy at birth	(3) Ln life expectancy at birth	(4) Ln life expectancy at birth	(5) Ln life expectancy at birth
Ln population density	0.016*** (0.00)	0.013*** (0.00)	0.007** (0.00)	-0.001 (0.00)	0.008*** (0.00)
Ln GDP per capita		0.055*** (0.00)	0.002 (0.00)	0.023 (0.02)	0.002 (0.00)
Country effects	–	–	Yes	–	Yes
IV	–	–	–	–	–
N	496	496	496	51	445
Samle	All	All	All	US	Non-US
r2	0.157	0.496	0.922	0.065	0.931

*Notes: Standard errors in parentheses. Unit of observation is large regions (OECD definition). All variables are averaged over 2000–2014. IV is rank of a city in the population density distribution within a country. * p < 0.1, ** p < 0.05, *** p < 0.01*

Table A30
Elasticity of mortality in transport p.c. with respect to population density

	(1) Ln mortality in transport p.c.	(2) Ln mortality in transport p.c.	(3) Ln mortality in transport p.c.	(4) Ln mortality in transport p.c.	(5) Ln mortality in transport p.c.	(6) Ln mortality in transport p.c.
Ln population density	-0.162*** (0.02)	-0.150*** (0.01)	-0.103*** (0.03)	-0.099*** (0.03)	-0.119*** (0.02)	-0.093*** (0.03)
Ln GDP per capita		-0.278*** (0.04)	-0.111** (0.04)	-0.110*** (0.04)	-0.484* (0.25)	-0.087** (0.04)
Country effects	–	–	Yes	Yes	–	Yes
IV	–	–	–	Yes	Yes	Yes
N	420	414	414	414	51	363
Samle	All	All	All	All	US	Non-US
r2	0.260	0.375	0.819		0.534	

*Notes: Standard errors in parentheses. Unit of observation is large regions (OECD definition). All variables are averaged over 2000–2014. IV is rank of a city in the population density distribution within a country. * p < 0.1, ** p < 0.05, *** p < 0.01*

7.10 WELL-BEING

Table A31
Elasticity of subjective well-being with respect to population density

	(1) Ln subjective life satisfaction	(2) Ln subjective life satisfaction	(3) Ln subjective life satisfaction	(4) Ln subjective life satisfaction	(5) Ln subjective life satisfaction
Ln population density	-0.021*** (0.00)	-0.023*** (0.00)	-0.007** (0.00)	-0.001 (0.01)	-0.008** (0.00)
Ln GDP per capita		0.114*** (0.01)	0.069*** (0.01)	0.012 (0.04)	0.074*** (0.01)
Country effects	-	-	Yes	-	Yes
IV	-	-	-	-	-
N	339	339	339	51	288
Samle	All	All	All	US	Non-US
r2	0.073	0.410	0.850	0.003	0.859

*Notes: Standard errors in parentheses. All variables are averaged over 2000–2014. IV is rank of a city in the population density distribution within a country. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$*

8. Recommended elasticities

8.1 WAGE ELASTICITY

The literature reports both wage and TFP elasticities with respect to density, the former being the by far most frequently reported parameter. While we find a significant difference between the wage and the TFP elasticity in our review, it is notable that good work analyzing both wage and TFP within a consistent framework does not support the existence of such a difference (Combes et al. 2010). We choose the median value of the wage elasticities in our sample of 4%, which is close to recent high-quality work (Combes et al. 2012) and meta analyses (Melo et al. 2009). We do note, however, that there is a tendency for within-city analyses (Ahlfeldt et al. 2015) and TFP analyses to yield larger estimated elasticities, but we recommend further work to substantiate this impression.

8.2 PATENTS

While there is a sizeable literature engaged with the effects of urban form on innovation, we only found two studies that provided estimates that either directly corresponded to or could be converted into an elasticity of patents with respect to density (Carlino et al. 2007; Echeverri-Carroll & Ayala 2011). Some studies report marginal effects that cannot be converted into elasticities due to missing descriptive statistics. Our ancillary analysis of OECD functional economic area data suggests that the elasticity of patents with respect to density is around 20% for the US, which is thus in line with Carlino et al. (2007), and around 12.5% across all countries in the data, which is in line with the mean across the two analyses found. The consistency of our own estimates and the estimates in the literature is reassuring. However, the evidence base is very thin and more work aiming at comparable elasticity estimates would clearly be desirable.

8.3 RENTS

Our recommended rent elasticity of 21% is from Combes et al. (2013), a dedicated high-quality paper. While the estimate is specific to France, other good work shows that the magnitude generalises to the US (Albouy & Lue 2015). The estimate is also within the range of the works that we consider good and relevant. We are thus reasonably confident in recommending this elasticity

even though the evidence base is not as well developed as it is, e.g., for wages. It should be noted, however, that there is evidence suggesting that the elasticity increases in city size (Combes et al. 2013).

8.4 VEHICLE MILES TRAVELED

Our recommended elasticity of driving distance reductions with respect to a density of 8.5% is from Duranton & Turner (2015), a dedicated high-quality paper. The estimate is within the range of the mean and the median elasticities found in our review. We are, thus, reasonably confident in recommending this elasticity even though the evidence base is not as well developed as it is, e.g., for wages.

8.5 VARIETY BENEFITS

The literature on consumption benefits arising from agglomeration is underdeveloped relative to the production side. However, there are some good papers which suggest a sizeable relevance. Victor Couture kindly provided estimates of the elasticity of restaurant price indices with respect to population density not reported in his paper (Couture 2016). Expressed in terms of price reductions (gains from variety) the elasticities take the values of 0.08 for driving and 0.16 for walking. These elasticities roughly generalise when estimated exploiting between-city variation (0.05–0.11 and 0.1–0.22). We recommend the naïve average of the two elasticities, stressing that the exact elasticity will depend on the relative importance of the two modes in a setting. In support of the recommended elasticity we highlight that other good work has pointed to a positive impact of density on consumption variety (Schiff 2015) and that Couture's result is close to the elasticity of urban amenity value with respect to density provided by Ahlfeldt et al. (2015). The recommended elasticity is based on a small sample of high-quality evidence. More research is required to substantiate the findings.

8.6 LOCAL PUBLIC SPENDING

The recommended elasticity of total local public spending reduction with respect to density of 14.4% is from a good analysis (Carruthers & Ulfarsson 2003). It is within close range of the mean across all estimates (for all spending types) in our review. Many of these estimates are from Carruthers & Ulfarsson (2003). Few other studies have contributed comparable results and the variance of the findings across these studies is significant. Overall, the evidence base is relatively thin and is not entirely consistent. More research is required in this area.

8.7 INCOME INEQUALITY

The literature on the effects of density on inequality is relatively inconsistent in the sense that a small number of studies use different inequality measures (e.g., dissimilarity index, wage gaps, Gini coefficient), different geographic scales (within-city, between-city) and different density measures (e.g., population density, relative centralisation, clustering). The results are, therefore, hard to compare and are also qualitatively inconsistent. Our analysis of OECD regional data suggests that inequality increases in density, irrespective of the inequality measure we use (Gini, poverty ratio, interquartile wage gap). This finding is consistent with broader evidence in urban economics suggesting that the highly skilled (high-wage earners) benefit relatively more from agglomeration benefits. We acknowledge that we may be capturing different phenomena than studies that find a negative association between density and inequality at a within-city scale (Galster & Cutsinger 2007). However, we believe that our own estimates are closer to the thought experiment conducted here, which refers to an increase in overall urban density. Therefore, we choose the -3.5% elasticity of the income quintile wage gap reduction with respect to density from Table 7 in the main paper as the basis for a monetary quantification described in the next section. Of course, we must stress that this estimate should be considered preliminary as a sizeable evidence base with comparable results has yet to be developed.

8.8 CRIME RATE REDUCTION

The literature of the effects of urban form on crime rates is small, but consistently points to a positive effect of compactness on crime rates (crimes, p.c. as opposed to crimes per area) of sizeable magnitudes. The interpretation of the results is somewhat complicated as authors typically consider various dimensions of compact urban forms at the same time. While separating the effects of different shades of compactness is interesting, it also complicates the evaluation of an overall density effect as any dimension can only be varied under the ceteris paribus condition (while most measures effectively change at the same time). Our recommended elasticity, therefore, is from Cheng Keat Tang, who kindly provided estimates of the elasticity of crime rates with respect to population density (without controlling for other dimensions of urban form) not reported in his paper (Tang 2015).

Reassuringly, the elasticities implied from his estimates (level-level mode) are almost identical for crimes against persons and property. While we consider the recommended elasticity to be a good estimate suitable for our purposes, more comparable evidence is required to substantiate the estimate.

8.9 URBAN GREEN

As discussed in the context of the presentation of our own results in the main paper, quantitative evidence suitable for our purposes is essentially non-existent. We are thus left with no choice but to recommend our own elasticity of green space density with respect to population density of 23%. Of course, we must stress that this estimate should be considered preliminary as a sizeable evidence base with comparable results has yet to be developed.

8.10 POLLUTION REDUCTION

The literature on the effects of density on pollution concentrations is small. Moreover, the quantitative results prevailing in the literature are highly inconsistent as reflected by a standard deviation of 90% relative to a mean elasticity of pollution reduction with respect to a density of 4%. Given that the literature is small, it is difficult to identify common features that explain the large differences. Our own cross-sectional estimate of about -12% (using OECD data) is close to the elasticity reported by Albouy & Stuart (2014) and roughly within the range of the cross-sectional estimates by Hilber & Palmer (2014). Their panel fixed effects results, which should come with improved identification, however, take the opposite sign and are even larger in terms of magnitude, with similarly large variation. Sarzynski (2012) finds results that are similar to Hilber and Palmer's panel-fixed effects estimates using a cross-sectional research design, suggesting that the estimation method cannot account for the inconsistency of the evidence base. Given that it is not possible to identify any consensus estimate we use the mean elasticity across the reviewed studies. But we stress that, to date, the evidence base is highly unsatisfactory, and we caution against an uncritical application of the chosen elasticity. More research is required to allow for a better understanding of the inconsistency in the existing estimates and to settle on a consensus estimate.

8.11 ENERGY CONSUMPTION

We interpret CO_2 emissions as reflecting energy usage, assuming that the elasticity of energy mix with respect to density is zero. CO_2's social cost is primarily incurred through global warming. This is different from the pollutants considered in category 10, which have much more localised effects. The literature on the effects of density on energy consumption is relatively well developed and reasonably consistent, both qualitatively and quantitatively. We therefore choose the mean elasticity of energy use reduction with respect to density across the reviewed analyses of 9% as a recommended elasticity. We note that the respective elasticity of public transport seems to be negative (meaning more energy is consumed) and large, -37%, which is consistent with higher transit usage in denser cities (see category 13). Given the relatively small proportion of overall energy consumption, the effects on aggregate outcomes are limited.

8.12 TRAFFIC FLOW

The quantitative literature on the effects of density on average speed is surprisingly small. Most related analyses focus on the effects of road usage on speed on individual road segments. We found only two studies providing estimates of the elasticity of speed with respect to density, both of which, however, are of high quality (Couture et al. 2016; Duranton & Turner 2015). They yield very similar elasticities with a mean of -12%. Because the evidence base is quantitatively thin we contribute an own analysis using OECD functional urban area (density) and speed data from Lomax et al. (2010). We find no effect of urban density on speeds on highways where the metropolitan population is the more important predictor. This is intuitive because highways represent a transport system which is used to overcome relatively large distances and which is separate from the local street network. As long as the length of the highway network grows with the population in the metro area, density flows on highways are not necessarily determined by population density. In contrast, for the arterial road network, density is predicted to be a more explicit determinant of flow as more people per area are expected to congest local roads as it is more difficult to increase the overall road density proportionately in population density. In line with these expectations, we find an elasticity of speed with respect to population density of -6.3%, which is at least roughly in line with Couture et al. (2016). Given the consistency of the estimates we are reasonably confident in recommending the -11% elasticity from the small literature. More research, however, is required to substantiate the evidence and to allow for us to differentiate by road types and geographies. In particular, evidence from outside the US is desirable.

8.13 MODE CHOICE

The literature on the effects of urban form on mode choice is quantitatively well developed, although there is significant variability in the methodological approaches, which complicates the comparability of results across studies. Our recommended elasticity of non-car mode choice with respect to density is from a dedicated meta-analysis from experts in the field (Ewing & Cervero 2010). They find that the elasticity of walking and public transit use with respect to density is 7% in each case. We note that this elasticity of non-car usage with respect to density is consistent with the elasticity of car usage reduction of 7% we find in our evidence review if car trips account for roughly 50% of overall trips. The elasticity of non-car use with respect to density of 21%, in contrast, is consistent with our 7% car usage reduction elasticity if automobile trips account for more than 50%. We note that the relatively large mean elasticity of non-car use with respect to density of 21% across the reviewed studies is driven by outliers. The median value is 10%. We are therefore confident in recommending Ewing & Cervero's estimates. We further note that the authors provide a range of elasticities with respect to other dimensions of compact urban form such as diversity or design, which may well be more appropriate in particular contexts and are worth considering.

8.14 HEALTH

The evidence based on the effects of density is small and difficult to interpret. The results are mostly published in the field of medicine with a presentation that differs significantly from social sciences. None of the considered studies estimates marginal effects with respect to density. Instead, adjusted (by individual characteristics) rates (e.g., pre-mature mortality or mortality by disease) are reported by density categories. In some instances, such categories refer to density terciles or quintiles, which are not specified further so that admittedly heroic assumptions have to be made regarding density distributions in a study setting. In other instances, rates are only reported graphically and numeric values must be entered after a visual inspection. We conduct ambitious back-of-the-envelope calculations to compute marginal effects, which can be converted into elasticities with respect to density as otherwise we would virtually be left without any evidence base. The nature of this evidence base needs to be critically acknowledged when working with the results. In particular, because the relatively large negative effects of density on health are not confirmed by our own analysis of OECD regional data. In our preferred specification, we do not find a significant effect of density on overall mortality rates. If anything, the effect is negative (meaning, positive health effects) as we find significantly negative effects in simpler specifications that do not control for cross-country heterogeneity. Moreover, there is a robust negative effect of density on mortality in transport rates and a robust positive association between density and life expectancy at birth. Following our rule, that we generally prefer evidence from the literature over our own estimates – unless the evidence is highly inconsistent or inconclusive – we use the elasticity of mortality rate reduction with respect to density, implied by Reijneveld et al.'s (1999) findings in the further calculations: their research focuses specifically on density and the overall mortality rate is particularly amenable to back-of-the-envelope calculations using the statistical value of life (see next section). We note however, that the evidence base is not sufficiently developed to allow for a confident recommendation of a consensus estimate. More research is required, ideally research using methods that are closer to the conventions in social sciences urban research to allow for a more immediate cross-category comparison.

8.15 WELL-BEING

Except for reported safety (in line with the evidence reviewed in category 8), the literature finds a negative association between reported satisfaction indicators and density, including reported satisfaction with social contacts, health (consistent with 14) and healthy environment (inconsistent with 9, but consistent with 10). Our evidence base contains surprisingly little analysis of the relationship of life satisfaction (subjective well-being or happiness) with respect to density. Moreover, we were not able to convert the presented results into an elasticity of well-being with respect to happiness (Brown et al. 2015). We found one estimate which we were able to convert (from a lin-log semi-elasticity) in Glaeser et al. (2016). This estimate referred to city size instead of density and we converted it using the elasticity of density with respect to city size estimated in section 4.1. The resulting elasticity of reported life satisfaction with respect to density is -0.37%, which is roughly within the range of our own analysis of OECD data of -0.7%. While we proceed using -0.37% elasticity implied by Glaeser et al.'s (2016) analysis, we caution against uncritical application of this elasticity unless further research substantiates our quantitative interpretation.

9. Monetary equivalents

To convert Pound and Euro values into Dollar values we apply the average exchange rates over the 2000–2016 (October) period (1.64 and 1.22).

9.1 PRODUCTIVITY

A value of $35,000 is set as the worker wage, which is slightly below the US real disposable household income during 2010 (US Bureau of Economic Analysis 2016), but above the level of most high-income countries.

9.2 INNOVATION

We use the mean number of patents per year and 10,000 of population over 1990–1999 (2.057) as reported by Carlino et al. (2007). Valuing patents is difficult because prices are not usually directly observed. To analyse the distribution of patent values, the literature uses patent renewal data (Pakes 1986), event studies (Austin 1993), inventor surveys (Giuri et al. 2007), and census data (Balasubramanian & Sivadasan 2010), typically facing a trade-off between representativeness and identification. Recent estimates of an average patent value range from a simple average of transaction prices of patents of $288K ($233K median) to well-identified but much more specific estimates of $20M–30M inferred from the economic success of startups (Gaulé 2016). A common theme emerging from the literature is that the distribution of patent values is skewed, i.e., the majority of patents have low values, while a small number of patents achieve extremely high values. Given these challenges, our preferred approximation of the value of a representative patent is a reservation price (the price at which inventors report being willing to sell their patent) of $793,000 (€650,000) from Giuri et al. (2007). This value is in the middle of the median category (300K–1M) of reported patent reservation prices and the broader distribution of patent value estimates in the literature. We prefer self-reported reservation prices to observed transaction prices because the latter subsample is likely prone to adverse selection due to severe information asymmetries.

9.3 VALUE OF SPACE

We assume that the expenditure share on housing is one-third, which is in line with empirical evidence (Combes et al. 2013) and conventional assumptions made in urban economics (Chauvin et al. 2016; Albouy & Lue 2015). The total rent paid per year thus corresponds to one-fourth of the disposable income. This expenditure share is an average and seems to increase in city size (Combes et al. 2013).

9.4 JOB ACCESSIBILITY

Total vehicle miles p.c. are taken from the American Driving Survey (Triplett et al. 2015). The total (private) per mile driving costs are from the American Automobile Association (American Automobile Association 2015).

9.5 AMENITIES AND SERVICES ACCESS

Assuming that similar gains from variety arise in the consumption of other non-tradables, we apply the resulting elasticity to household expenditures in food away from home, entertainment, and apparel and services (based on shares reported in the 2015 Consumer Expenditure Survey) (Bureau of Labor Statistics 2015). In Table A7 we use an adjusted elasticity to avoid a double counting of reduced costs of road trips that are already itemised in category 4. Couture reports that about 56% from the gains are pure gains from variety, with the remaining share result from travel cost reductions. Since the overall reduction in vehicle miles traveled is already accounted for in 4, we multiply the car elasticity by 0.56 to capture purely the gains from variety, resulting in an elasticity of 0.045. Assuming that each of the modes accounts for half of the restaurant trips made, we use the naïve average over the adjusted car and the walking elasticity in our calculations.

9.6 EFFICIENCY OF PUBLIC SERVICES DELIVERY

The per capita expenditures on local public services are from Carruthers & Ulfarsson (2003).

9.7 SOCIAL EQUITY

Valuing income inequality is even more challenging than measuring income inequality. To value income equality as it arises from density we compute the premium an individual would be willing to pay to insure themselves against uncertain realisations of

incomes. In doing so we assume a concave relationship between utility and income that implies certain outcomes are preferred over uncertain outcomes, which is in line with risk-aversion. We compute the difference between the expected income E and the certainty equivalent (which a risk-averse individual would accept to avoid uncertainty) across the 20th (I^{20pct}) vs. the 80th (I^{80pct}) percentiles in the income distribution after taxes. The expected income is simply the mean across the two potential outcomes.

$$E = \frac{1}{2} I^{20pct} + \frac{1}{2} I^{80pct}$$

The certainty equivalent is computed as,

$$CE = U^{-1}\left[\frac{1}{2} U(I^{20pct}) + \frac{1}{2} U(I^{20pct})\right]$$

where $U(I)=I^{\aleph}$ is the utility function in which $\aleph$ determines the degree of concavity. We set $\aleph=0.5$, which is in the middle of the range of the elasticity of happiness (viewed as a proxy for utility) with respect to income estimates reported by Layard, Mayraz, & Nickell (2008). We use the distribution of incomes after taxes of the UK, a country that is arguably neither among the most equal nor unequal countries in the world (Survey of Personal Incomes 2013–14) (HM Revenue & Customs 2016). In dollar terms the resulting inequality premium corresponds to CE-E=$1,793 or (E-CE)/CE=4.8%. To analyse the effects of density on inequality we apply the estimated the elasticity of the interquartile wage gap with respect to density to this uncertainty premium (and the disposable income in our scenario).

9.8 SAFETY

The average crime rate (p.c.) as well as the estimated cost of crime are from Brand & Price (2000).

9.9 URBAN GREEN

The green area p.c. of 540 m^2 we use is the mean across functional economic areas in the OECD.Stat data. The value of a m^2 green area per year is based the meta-analysis of contingent valuation estimates by Brander & Koetse (2011). Based on the reported meta-analysis coefficients we compute the average per m^2 and year value of a park in a functional economic area with a population density and a per capita GDP that corresponds to the mean in the OECD.Stat data.

9.10 POLLUTION CONCENTRATION

We use an elasticity of rent with respect to density of 0.25, which is in the middle of the range of estimates reported by Chay & Greenstone (2005) with respect to the total suspended particles (TSPs).

9.11 ENERGY REDUCTION

The total energy consumption per year is from the US Energy Information Administration (2012). We consider residential and transport energy consumption, which corresponds to 40% of all energy consumed according to Glaeser & Kahn (2010). To compute the p.c., annual consumption, we normalise by the total population (320M). This results in a p.c. energy consumption of 121M BTU. We use an average over the price of all individual energy sources of $18.7 per 1M BTU from the U.S. Energy Information Administration (2012). To compute the corresponding CO_2 emissions, we first convert p.c. energy consumption into KWH, to which we apply a factor of 25T/KWH and a social cost of $43/T (Glaeser & Kahn 2010).

9.12 TRAFFIC FLOW

We obtain the total travel time p.c. per year by multiplying the average daily car trip length of 45 minutes (Triplett et al. 2015) by 365. The value of time is set to 50% of the average hourly wage of $21.5 as in Anderson (2014).

9.13 SUSTAINABLE MODE CHOICE

In computing the economic benefits of changes in mode we operate under the assumption that the marginal user is indifferent between modes, thus, there are no private costs and benefits to be considered above and beyond those already considered in outcome dimensions 4, 5, and 12. However, a switch in mode may be associated with external benefits. Since the effects on congestion are already captured by the outcome category 12, we focus exclusively on the emission externalities. To compute the average emissions economised by switches away from car trips we proceed as follows. First, we compute the average energy consumed per passenger km by mode across the US, EU, high-income Asian, and Latin American countries. Weighted by the average modal split the average energy consumed per passenger km corresponds 0.49 MJ/pkm for non-car trips and 3.73 MJ/pkm for a car trip (Bohler-Baedeker & Huging 2012). These figures can be converted into KWH/mile, CO_2/mile, and eventually $/mile using the same conversation rates as in 11.

9.14 HEALTH

The premature mortality risk refers to OECD countries and is taken from (OECD 2011). The statistical value of life is to $7,000,000 according to Viscusi & Aldy (2003) and confirmed in later studies (Hammitt & Haninger 2010; Viscusi 2010).

9.15 WELL-BEING

We use an elasticity of self-reported well-being with respect to an income of 0.5, which in the middle of the range reported by Layard et al. (2008) who estimate this elasticity through survey data on both happiness and life satisfaction from a wide range of geographical locations (US, Europe, and worldwide). Due to the concavity of the happiness function in income a 2% change in income is required to trigger a 1% change in happiness.

10. Further ancillary findings

The evidence considered in our review stems from a variety of disciplines. In the table below we analyse whether there are tendencies across disciplines to view the effects of compart urban form more or less positively. We find that the results, on average, are more positive in social sciences than in other fields (e.g., health, energy) and are particularly positive in planning and transport. There are no stark differences across social sciences, despite notable differences in the methods used (reflected by the adjusted average SMS in the last column).

Table A32
Effects by discipline

	(1) Result: -1: Negative; 0: Insignificant; 1: Positive	(2) Result: -1: Negative; 0: Insignificant; 1: Positive	(3) Elasticity with respect to density	(4) Elasticity with respect to density	(5) Quality of Evidence (SMS)	(6) Quality of Evidence (SMS)
Economic Geography	0.818*** (0.18)	1.058*** (0.27)	0.071*** (0.02)	-0.182 (0.21)	3.273*** (0.19)	3.549*** (0.40)
Economics	0.400*** (0.10)	0.841*** (0.07)	0.059*** (0.02)	-0.028 (0.06)	2.675*** (0.13)	3.184*** (0.09)
Energy	0.250 (0.30)	0.729** (0.26)	0.061 (0.05)	0.061 (0.09)	1.500*** (0.18)	2.754*** (0.10)
Health	-0.500** (0.22)	0.428 (0.33)	-0.192*** (0.07)	-0.074 (0.14)	2.143*** (0.14)	2.728*** (0.22)
Other	0.043 (0.15)	0.781*** (0.19)	-0.082 (0.19)	-0.172 (0.11)	1.681*** (0.16)	2.266*** (0.33)
Planning	0.709*** (0.09)	1.259*** (0.17)	0.160 (0.11)	0.132 (0.30)	1.782*** (0.10)	2.359*** (0.26)
Regional Studies	0.692*** (0.13)	1.020*** (0.12)	0.335*** (0.13)	0.340 (0.20)	2.346*** (0.19)	2.694*** (0.26)
Transport	0.674*** (0.10)	1.118*** (0.16)	0.198*** (0.05)	0.204 (0.16)	1.907*** (0.17)	2.553*** (0.15)
Urban Studies	0.405*** (0.14)	0.923*** (0.19)	0.300*** (0.10)	0.086 (0.11)	2.216*** (0.11)	2.761*** (0.25)
Category effects	–	Yes	–	Yes	–	Yes
Characteristics effects	–	Yes	–	Yes	–	Yes
N	321	321	202	202	321	321
r2	0.299	0.447	0.135	0.350	0.840	0.861

*Notes: Regressions excluding constant to allow for category-specific intercepts. Category effects defined for 15 outcome dimensions. Characteristics effects defined for three compact city characteristics. Standard errors clustered on category effects where category effects are included. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.*

ENDNOTES

1 This does not imply that the effects of "compact city" policies cannot be observed within cities or those of "compact urban development" policies across cities.

2 In the empirical literature, economic density is typically approximated by the number of economically active persons in an area or more simply by population density. While this approximation is not perfect, it should be a reasonable proxy, given that for a majority of the population levels of productivity are reasonably similar. It is also one of the few measures of economic density that is systematically available for most cities.

3 The authors analyse the density effects using a panel framework. If the geographic area was inelastic in the short run, population would indeed be a density measure in an area fixed effect model.

4 See: What Works Centre for Local Economic Growth (2016).

5 The results by Combes at al. (2013) suggest that this result may not apply to small cities as the rent elasticity increases in city size.

6 To be theoretically consistent, this interpretation requires that residents are not fully mobile (e.g. because they have location-specific preferences).

7 Recent examples of classic meta-analyses in economics include studies by Eckel and Füllbrunn (2015), Melo et al. (2009), and Nitsch (2005). Given the breadth of topics and the nature of the quantitative information analysed, our quantitative literature review shares similarities with Ahlfeldt et al. (2016).

REFERENCES

Literature studied

Ahlfeldt, G.M. and McMillen, D.P., 2015. *The Vertical City: The Price of Land and the Height of Buildings in Chicago 1870-2010*. London: LSE Spatial Economics Research Centre.

Ahlfeldt, G.M. and Maennig, W., 2015. Homevoters vs. leasevoters: A spatial analysis of airport effects. *Journal of Urban Economics*, 87. 85-99.

Ahlfeldt, G.M., Maennig, W. and Steenbeck, M., 2016. *Après nous le déluge ? Direct democracy and intergenerational conflicts in ageing societies*. Working Paper. CESifo Group Munich.

Ahlfeldt, G.M., Redding, S.J., Sturm, D.M. and Wolf, N., 2015. The Economics of Density: Evidence from the Berlin Wall. *Econometrica*, 83(6). 2127–2189.

Albouy, D. and Lue, B., 2015. Driving to opportunity: Local rents, wages, commuting, and sub-metropolitan quality of life. *Journal of Urban Economics*, 89. 74–92.

Alexander, E., 1993. Density measures: A review and analysis. *Journal of Architectural and Planning Research*, 10(3). 181–202.

Andersson, M., Klaesson, J. and Larsson, J.P., 2016. How Local are Spatial Density Externalities? Neighbourhood Effects in Agglomeration Economies. *Regional Studies*, 50(6). 1082–1095.

Angel, S., 2011. *Making room for a planet of cities*, Cambridge: Lincoln Institute of Land Policy.

Angel, S., Parent, J. and Civco, D. L., 2012. The fragmentation of urban landscapes: global evidence of a key attribute of the spatial structure of cities 1990−2000. *Environment and Urbanization*, 249-283.

Angel, S., Sheppard, S.C., Civco, D.L., Buckley, R., Chabaeva, A., Gitlin, L., Kraley, A., Parent, J. and Perlin, M., 2005. The *Dynamics of Global Urban Expansion*. Washington D.C. World Bank.

Arnott, R.J. and Stiglitz, J.E., 1979. Aggregate Land Rents, Expenditure on Public Goods, and Optimal City Size. *The Quarterly Journal of Economics*, 93(4). 471–500.

Bechle, M.J., Millet, D.B. and Marshall, J.D., 2011. Effects of income and urban form on urban NO2: global evidence from satellites. *Environmental Science and Technology*, 45(11) 4914–4919.

Beer, A., 1994. Spatial inequality and locational disadvantage. *Urban Policy and Research*, 12(3). 181–199.

Blokford, G., 2016. *Transit Oriented Development in the South African context: An analytical review of Johannesburg's recent urban policy and strategy*. Cape Town: University of Cape Town.

Bonfantini, B., 2013. Centri Storici: infrastrutture per l'urbanità contemporanea. *Territorio*, 64. 153–161.

Braga, A.A. and Weisburd, D., 2010. Policing *Problem Places: Crime Hot Spots and Effective Prevention*. Oxford and New York: Oxford University Press.

Bramely, G., Dempsey, i., Power, S., and Brown, C., 2009. Social sustainability and urban form: evidence from five British cities. *Environment and Planning A*, Volume 41, 2125-2142.

Brander, L.M. and Koetse, M.J., 2011. The value of urban open space: Meta-analyses of contingent valuation and hedonic pricing results. *Journal of Environmental Management*, 92. 2763–2773.

Burchell, R. W., and Mukherji, S., 2003. Conventional Development Versus Managed Growth: The Costs of Sprawl, *American Journal of Public Health*. 93(9): 1534–1540.

Burgess, R. and Jenks, M., 2002. *Compact cities: sustainable urban forms for developing countries*, London; New York: E. F.N. Spon.

Burton, E., 2000. The Compact City: Just or Just Compact? A Preliminary Analysis. *Urban Studies*, 37(11). 1969–2006.

Burton, E., 2001. The Compact City and Social Justice. *Housing, Environment and Sustainability*, (April). 1–16.

Burton, E., 2002. Measuring urban compactness in UK towns and cities. *Environment and Planning B: Planning and Design*, 29(2). 219–250.

Burton, E., 2003. Housing for an Urban Renaissance. *Housing Studies*, 18(4). 537–562.

Burton, E., Jenks, M. and Williams, K., 2003. *The compact city: a sustainable urban form?* London and New York: E. & F.N. Spon.

Carruthers, J.I. and Ulfarsson, G.F., 2003. Urban sprawl and the cost of public services. *Environment and Planning B: Planning and Design*, 30(4). 503–522.

Cervero, R. and Duncan, M., 2003. *Walking, Bicycling, and Urban Landscapes: Evidence from the San Francisco Bay Area*. [[place of publication: publisher?]]

Cervero, R. and Kockelman, K., 1997. Travel demand and the 3Ds: Density, diversity, and design. *Transportation Research Part D: Transport and Environment*, 2(3). 199–219.

Chang, H., Parandvash, H., and Shandas, V., 2010. Spatial Variations of Single-Family Residential Water Consumption in Portland, Oregon,. *Urban Geography*, 31(7). 953-972.

Chauvin, J.P., Glaeser, E.L., Ma, Y. and Tobio, K., 2016. What is different about urbanization in rich and poor countries? Cities in Brazil, China, India and the United States. *Journal of Urban Economics*. 1–33. 98. 17-49.

Chen, H., Jia B. and Lau S. S. Y.,, 2008. Sustainable urban form for Chinese compact cities: Challenges of a rapid urbanized economy. Habitat International, 32 (2008). 28-40.

Cheshire, P.C. and Hilber, C.A.L., 2008. Office Space Supply Restrictions in Britain: The Political Economy of Market Revenge. *The Economic Journal*, 118(529). F185–F221.

Cheshire, P. and Magrini, S., 2009. Urban growth drivers in a Europe of sticky people and implicit boundaries. *Journal of Economic Geography*, 9(1). 85–115.

Chhetri, P., Han, J.H., Chandra, S. and Corcoran, J., 2013. Mapping urban residential density patterns: Compact city model in Melbourne, Australia. *City, Culture and Society*, 4(2). 77–85.

Chu, A., Thorne, A. and Guite, H., 2004. The impact on mental well-being of the urban and physical environment: an assessment of the evidence. *Journal of Mental Health Promotion*, 3(2). 17–32.

Chunliang, X. 2011. Vulnerability of large city and its implication in urban planning: A perspective of intra-urban structure, *Chinese Geographical Science*, 21(2). 204-210.

Churchman, A., 1999. Disentangling the Concept of Density. *Journal of Planning Literature*, 13(4). 389–411.

Combes, P., Duranton, G. and Gobillon, L., 2013. *The Costs of Agglomeration: Land Prices in French Cities*. NBER Working Paper, (7027). 28.

Couture, V., 2016. *Valuing the Consumption Benefits of Urban Density*. University of California, Berkeley, Working Paper.

Couture, V., Duranton, G. and Turner, M.A., 2016. *Speed*. Working Paper. Paris: SciencePo Laboratoire Interdisciplinaire D'évaluation des Politiques Publiques.

David, S., 2010. High Urban Densities in Developing Countries: A Sustainable Solution?. *Built Environment*. 9-27.

Dantzig, G.B. and Saatay, T.L., 1973. *Compact city: a plan for a liveable urban environment*. San Francisco: Freeman and Co.

Dieleman, F. and Wegener, M., 2004. Compact City and Urban Sprawl. *Built Environment*, 30(4). 308–323.

Disdier, A.-C. and Head, K., 2008. The Puzzling Persistence of the Distance Effect on Bilateral Trade. *Review of Economics and Statistics*, 90(1). 37–48.

Dodman, D., 2009. Blaming cities for climate change? An analysis of urban greenhouse gas emissions inventories. *International Institute for Environment and Development*, 21(1). 185-201.

Domene, E. and Saurı, D., 2006. Urbanisation and Water Consumption: Influencing Factors in the Metropolitan Region of Barcelona. *Urban Studies*, 43(9). 1605– 1623.

Duranton, G. and Turner, M.A., 2015. *Urban form and driving: Evidence from US cities*. Working Paper. Wharton School, University of Pennsylvania and Department of Economics, Brown University.

Eckel, C. C., and Füllbrunn. S. C., 2015. Thar SHE Blows? Gender, Competition, and Bubbles in Experimental Asset Markets. *American Economic Review*, 105(2): 906-20.

Epple, D., Gordon, B. and Sieg, H., 2010. American Economic Association A New Approach to Estimating the Production Function for Housing. *American Economic Review*, 100(3). 905–924.

Ewing, R. and Cervero, R., 2010. Travel and the Built Environment: A Synthesis. *Journal of the American Planning Association*, 76(3). 265–294.

Ewing, R. and Hamidi, S., 2014. *Measuring Sprawl 2014*, Utah: Smart Growth America.

Ewing, R., Schieber, R. and Zegeer, C., 2003. Urban Sprawl as a Risk Factor in Motor Vehicle Occupant and Pedestrian Fatalities. *American Journal of Public Health*, 93(9). 1541-1545.

Faberman, R.J. and Freedman, M., 2016. The urban density premium across establishments. *Journal of Urban Economics*, 93. 71–84.

Farrington, D.P. and Welsh, B.C., 2008. Effects of improved street lighting on crime: a systematic review. *Campbell Systematic Reviews* (13).

Frank, L. D., Sallis, J. F., Saelens, B. and Leary, L., 2010. The development of a walkability index: application to the Neighborhood Quality of Life Study. *British Journal of Sports Medicine*, 44(2010. 924-933.

Geurs, K. and van Wee, B., 2006. Ex-post evaluation of thirty years of compact urban development in the Netherlands. *Urban Studies*, 43(1). 139–160.

Gilbert, A. and Gugler, J., 1992. *Cities, Poverty and Development: Urbanization in the Third World*. Oxford: Oxford University Press.

Glaeser, E.L., Gottlieb, J.D. and Ziv, O., 2016. Unhappy Cities. *Journal of Labor Economics*, 34(2). S129–S182.

Glaeser, E.L., Kolko, J. and Saiz, A., 2001. Consumer city. *Journal of Economic Geography*, 1(1). 27–50.

Glaeser, E.L. and Resseger, M.G., 2010. The complementarity between cities and skills. *Journal of Regional Science*, 50(1). 221–244.

Gordon, P. and Richardson, H.W., 1997. Are Compact Cities a Desirable Planning Goal? *Journal of the American Planning Association*, 63(1). 95–106.

Graham, D. and Glaister, S., 2003. Spatial Variation in Road Pedestrian Casualties: The Role of Urban Scale, Density and Land-use Mix. *Urban Studies*, 40(8).1591-1607.

Harlen, S., Brazel, A.J., Prashad, L., Stefanov, W.L., and Larsen L., 2006. Neighborhood microclimates and vulnerability to heat stress. *Social Science & Medicine*, 63(2006). 2847–2863.

Hatt, B., Fletcher, T., Walsh, C., and Taylor, S., 2004. The influence of urban density and drainage infrastructure on the concentrations and loads of pollutants in small streams. *Environmental Management*, 34(1). 112-124.

Hilber, C.A.L. and Vermeulen, W., 2016. The Impact of Supply Constraints on House Prices in England. *The Economic Journal*, 126(591). 358–405.

Hitchcock, J., 1994. *A primer on the use of density in land use planning*. Toronto, Canada.

IAU-IDF, 2012. *Document d'orientations stratégiques pour le fret en Ile-de-France à l'horizon 2025*, Direction régionale et interdépartementale de l'Équipement et de l'Aménagement d'Île-de-France: Paris.

Ikin, K., Beaty, R.M., Lindenmayer, D.B., Knight, E., Fischer, J. and Manning, A.D., 2013. Pocket parks in a compact city: how do birds respond to increasing residential density? *Landscape Ecology*, 28(1). 45–56.

Jacob, J., and Lopez, R., 2009, Is Denser Greener? An Evaluation of Higher Density Development As An Urban Stormwater-Quality Best Management Practice, *Journal of The American Water Resources Association*, 45 (3). 687-701

Jacobs, J., 1961. *The death and life of great American cities*, New York: Random House.

Jones, C., Leishman, C., MacDonald, A. and Watkins, D., 2010. Economic viability. In *Dimensions of the Sustainable City*. Jenks, M. and Jones, C. Oxford: Springer.

Jusuf, S., Wong,N.H., Hagen, E., Anggoro, R., Hong, Y., 2007. The influence of land use on the urban heat island in Singapore. *Habitat International*, 31(2007). 232-242.

Kinney, P. L., Gichuru, M.G., and Volavka-Close, N., 2011. Traffic Impacts on PM2.5 Air Quality in Nairobi, Kenya. Environmental Science Policy, 14(1). 369-378.

Knox, P.L., and McCarthy, I., 2012. *Urbanization: an introduction to urban geography*. 3rd ed. Boston: Pearson.

Knox, P.L., 2011. *Cities and design*, New York: Routledge.

Kunvitaya, A. and Dhakal, S., 2016. Household energy requirements in two medium-sized Thai cities with different population densities. *Environment and Urbanization*, 29(1). 1-16.

Lall, S. and Deichmann, U., 2011. *Density and Disasters*. Oxford: Oxford University Press.

Lankao, R., 2007. Are we missing the point? Particularities of urbanization, sustainability and carbon emissions in Latin American cities. *Environment and Urbanization*, 19(2007). 159-175.

Laws, G., 1994. Oppression, knowledge and the built environment. *Political Geography*, 13. 7–32.

Layard, R., Mayraz, G. and Nickell, S., 2008. The marginal utility of income. *Journal of Public Economics*, 92(8–9). 1846–1857.

Liu, Y. and Arp, H., 2012. Examination of the relationship between urban form and urban eco-efficiency in china. *Habitat International Volume*, 36(1). 171-177.

Lopez, R., 2004. Urban Sprawl and Risk for Being Overweight or Obese. *American Journal of Public Health*, 94(9). 1574-1579.

Marshall, A., 1920. *Principles of Economics; An Introductory Volume*. London: Macmillan and Co.

Maskell, P. and Malmberg, A., 2007. Myopia, knowledge development and cluster evolution. *Journal of Economic Geography*, 7(5). 603–618.

Matsumoto, T., 2011. Compact City Policies: Comparative Assessment. In *Compact City Policies: Comparative Assessment*, 47th ISOCARP Congress 2011, 1–12.

Melia, S., Parkhurst, G. and Barton, H., 2011. The paradox of intensification. *Transport Policy*, 18(1). 46–52.

Melo, P.C., Graham, D.J. and Brage-Ardao, R., 2013. The productivity of transport infrastructure investment: A meta-analysis of empirical evidence. *Regional Science and Urban Economics*, 43(5). 695–706.

Melo, P.C., Graham, D.J. and Noland, R.B., 2009. A meta-analysis of estimates of urban agglomeration economies. *Regional Science and Urban Economics*, 39(3). 332–342.

Neuman, M., 2005. The Compact City Fallacy. *Journal of Planning Education and Research*, 25(1). 11–26.

Nitsch, V., 2005. Zipf zipped. *Journal of Urban Economics*, 57(1). 86–100.

OECD, 2010. *Cities and Climate Change*. OECD Publishing.

OECD, 2012. *Compact City Policies: A Comparative Assessment*. OECD Green Growth Studies, OECD Publishing.

OECD, 2016. OECD *Metropolitan area data*. Available at: https://stats.oecd.org/Index.aspx?DataSetCode=CITIES [accessed 15 October 2016].

Radberg, J., 1996. Towards a theory of good urban form. In: 14th *Conference of the International Association for People Environment Studies 30 July–3 August*. Stockholm: Sweden.

Reijneveld, S.A., Verheij, R.A. and de Bakker, D.H., 1999. Relative importance of urbanicity, ethnicity and socioeconomic factors regarding area mortality differences. *Journal of epidemiology and community health*, 53(7). 444–445.

Roback, J., 1982. Wages, Rents, and the Quality of Life. *Journal of Political Economy*, 90. 1257–1278.

Roo, G. de. and Miller, D., 2000. *Compact cities and sustainable urban development: a critical assessment of policies and plans from an international perspective*. Aldershot, Hampshire; Burlington VT: Ashgate.

Rosen, S., 1979. Wages-based Indexes of Urban Quality of Life. In *Current Issues in Urban Economics*. P. Mieszkowski and M. Straszheim (eds.). Baltimore: John Hopkins University Press.

Rydin, Y., 1992. Environmental dimensions of residential development and the implications for local planning practice. *Journal of Environmental Planning and Management*, 35(1). 43–61.

Savage, M., 1988. London School of Economics The Missing Link? The Relationship between Spatial Mobility and Social Mobility. *The British Journal of Sociology*, 39(4). 554–577. [[is the LSE bit at the front ok here?]]

Savitch, H., 2005. An Anatomy of Urban Terror: Lessons from Jerusalem and Elsewhere. *Urban Studies*, 42(3). 361-395.

Schiff, N., 2015. Cities and product variety: Evidence from restaurants. *Journal of Economic Geography*, 15(6). 1085–1123.

Schiller, G., 2007. Urban infrastructure: challenges for resource efficiency in the building stock. *Building research and Information*, 35(4). 299-411.

Schläpfer, M., Lee, J. and Bettencourt, L.M.A., 2015. Urban Skylines: building heights and shapes as measures of city size. , pp.1–17. Working Paper. Santa Fe Institute.

Schwanen, T., Dieleman, F. and Dijst, M., 2004. Policies for urban form and their impact on travel: the Netherlands experience. *Urban Studies*, 41(3). 579–603.

Shopping Centre Council of Australia, 2011. *Activity Centres Policy Benefits: Final Report*.

Stanley, T.D., 2001. Wheat From Chaff: Meta-Analysis As Quantitative Literature Review. *Journal of Economic Perspectives*, 15(3). 131–150.

Stone, B., Hess, J. & Frumkin, H., 2010. Urban From and Exterme Heat Events: Are Sprawling Cities More vulnerable to Climate Change than Compact Cities?. *Environmental Health Perspectives*, 118 (10). 1425-1428.

Tang, C.K., 2015. *Urban Structure and Crime*. Working Paper.

Thomas, L. and Cousins, W., 1996. A new compact city form: concepts in practice. In: *The Compact City: A Sustainable Urban Form?* M. Jenks, E. Burton and K. Williams (eds.), London: E & FN Spon.

Thompson, H., 2013. *Green Belt Critique*. Cambridge South Consortium.

Troy, P., 1992. The evolution of government housing policy: The case of new south Wales 1901–41. *Housing Studies*, 7(3). 216–233.

Troy, P., 1996. *The perils of urban consolidation*, Sydney, Australia: The Federation Press.

Turok, I., 2012. Urbanisation and Development in South Africa: Economic Imperatives, Spatial Distortions and Strategic Responses, London: International Institute for Environment and Development.

Urban Land Institute, 2015. *The Density Dividend: Solutions for Growing and Shrinking Cities*. Technical Report.

United Nations, 2005. Definition of "Urban". In: *Demographic Yearbook 2005*. New York.

United Nations, 2014. *World Urbanization Prospects: The 2014 Revision*. New York.

Vlahov, D., 2010. *Urban health: global perspectives*. 1st ed. San Francisco: Josse-Bass.

Vorontsova, A.V., Vorontsova, V.L. and Salimgareev, D.V., 2016. The Development of Urban Areas and Spaces with the Mixed Functional Use. *Procedia Engineering*, 150. 1996–2000.

What Works Centre for Local Economic Growth, 2016. *Guide to scoring evidence using the Maryland Scientific Methods Scale*. London.

Williams, K., Jenks, M. and Burton, E., 2000. *Achieving Sustainable Urban Form*. Routledge. New York.

Williams, K., 2004. *Can Urban Intensification contribute to sustainable cities? an international perspective*, Oxford: UN Habitat Partnership Initiative.

Wilson, G. and Baldassare, M., 1996. Overall "sense of community" in a suburban region: The effects of localism, privacy and urbanization. *Environment and Behavior*, 28(1). 27–43.

Wolsink, M., 2016. "Sustainable City" requires "recognition": The example of environmental education under pressure from the compact city. *Land Use Policy*, 52. 174–180.

World Bank, 2015. New Country Classifications | The Data Blog. Available at: http://blogs.worldbank.org/opendata/new-country-classifications [accessed 14 October 2016].

WHO, 2011. *Health co-benefits of climate change mitigation-Transport sector: Health in the green economy*. Geneva: World Health Organization.

Other references cited

Albouy, D. and Stuart, B., 2014. *Urban Population and Amenities*. National Bureau of Economic Research, Inc. NBER Working Papers: 19919.

American Automobile Association, 2015. *Your driving costs*. Available at: http://newsroom.aaa.com/2015/04/annual-cost-operate-vehicle-falls-8698-finds-aaa-ar [accessed 27 October 2016].

Anderson, M.L., 2014. Subways, Strikes, and Slowdowns: The Impacts of Public Transit on Traffic Congestion. *American Economic Review*, 104(9). 2763–2796.

Austin, D.H., 1993. An Event-Study Approach to Measuring Innovative Output: The Case of Biotechnology. *The American Economic Review*, 83(2). 253–258.

Balasubramanian, N. and Sivadasan, J., 2010. What Happens When Firms Patent? New Evidence from U.S. Economic Census Data. *Review of Economics and Statistics*, 93(1). 126–146.

Bohler-Baedeker, S. and Huging, H., 2012. *Urban Transport and Energy Efficiency. Module 5h. Sustainable Transport: A Sourcebook for Policy-makers in Developing Cities*. Federal Ministry for Economic Cooperation and Development (BMZ).

Brand, S. and Price, R., 2000. The economic and social costs of crime. *Home Office Research Study 217*. Available at: http://webarchive.nationalarchives.gov.uk/20110218135832/rds.homeoffice.gov.uk/rds/pdfs/hors217.pdf [accessed 1 November 2016].

Breheny, M., 1997. Urban compaction: feasible and acceptable? *Cities*, 97(4). 209–217.

Brown, Z.S., Oueslati, W. and Silva, J., 2015. *Exploring the Effect of Urban Structure on Individual Well-Being*. OECD Environment working papers No. 95.

Bureau of Labor Statistics, 2015. *Consumer Expenditure Survey*. Available at: http://www.bls.gov/cex/ [accessed 11 November 2016].

Carlino, G.A., Chatterjee, S. and Hunt, R.M., 2007. Urban density and the rate of invention. *Journal of Urban Economics*, 61(3). 389–419.

Chay, K. and Greenstone, M., 2005. Does Air Quality Matter? Evidence from the Housing Market. *Journal of Political Economy*, 113(2). 376–424.

Combes, P.-P., Duranton, G., Gobillon, L., Puga, D. and Roux, S., 2012. The Productivity Advantages of Large Cities: Distinguishing Agglomeration From Firm Selection. *Econometrica*, 80(6). 2543–2594.

Combes, G., Duranton, P.-P., Gobillon, L. and Roux, S., 2010. Estimating Agglomeration Economies with History, Geology, and Worker Effects. In: *Agglomeration Economics*. E.L. Glaeser (ed.) Chicago: Chicago University Press. 15–66.

Couture, V., 2016. *Valuing the Consumption Benefits of Urban Density*. Working Paper: University of California, Berkeley.

Echeverri-Carroll, E.L. and Ayala, S.G., 2011. Urban Wages : Does City Size Matter? *Urban Studies*, 48(2). 253–271.

Galster, G. and Cutsinger, J., 2007. Racial Settlement and Metropolitan Land-Use Patterns: Does Sprawl Abet Black-White segregation? *Urban Geography*, 28(6). 516–553.

Gaulé, P., 2016. *Patents and the Success of Venture-Capital Backed Startups: Using Examiner Assignment to Estimate Causal Effects*. Working Paper, pp.1–42. Prague: Center for Economic Research and Graduate Education- Economics Institute (CERGE-EI).

Giuri, P., Mariani, M., Brusonib, S., Crespic, G., Francozd, D., Gambardellae, A., Garcia-Fontes, W., Geunac, A., Gonzalesf, R., Harhoff, D., Hoislg, K., Le Bash, C., Luzzii, A., Magazzinia, L., Nestac, L., Nomalerj, O., Palomerasi, N., Patel, P., Romanellik, M. and Verspagenj, B., 2007. Inventors and invention processes in Europe: Results from the PatVal-EU survey. *Research Policy*, 36(8). 1107–1127.

Glaeser, E.L. and Kahn, M.E., 2010. The greenness of cities: Carbon dioxide emissions and urban development. *Journal of Urban Economics*, 67(3). 404–418.

Grusky, D.B. and Fukumoto, I.K., 1989. Social History Update: A Sociological Approach to Historical Social Mobility. *Journal of Social History*, 23(1). 221–232.

Hammitt, J.K. and Haninger, K., 2010. Valuing fatal risks to children and adults: Effects of disease, latency, and risk aversion. *Journal of Risk and Uncertainty*, 40(1). 57–83.

Hilber, C.A.L. and Palmer, C., 2014. Urban Development and Air Pollution: Evidence from a Global Panel of Cities. *SSRN Electronic Journal 175*.

HM Revenue and Customs, 2016. *Personal Incomes Statistics 2013-2014*. London.

Lomax, T., Schrank, D., Turner, S., Geng, L., Li, Y. and Koncz, N., 2010. Real-Timing the 2010 Urban Mobility Report. Available at: http://utcm.tamu.edu/publications/final_reports/Lomax_10-65-55.pdf [accessed 1 November 2016].

OECD, 2011. Premature mortality. In: *Health at a Glance 2011: OECD Indicators*. Paris: OECD Publishing.

Pakes, A., 1986. Patents as Options: Some Estimates of the Value of Holding European Patent Stocks. *Econometrica*, 54(4). 755–784.

Rappaport, J., 2008. Consumption amenities and city population density. *Regional Science and Urban Economics*, 38. 533–552.

Sarzynski, A., 2012. Bigger Is Not Always Better: A Comparative Analysis of Cities and their Air Pollution Impact. *Urban Studies*, 49(14). 3121–3138.

Triplett, T., Santos, R. and Rosenbloom, S., 2015. *American Driving Survey: Methodology and Year 1 Results*, May 2013 – May 2014. Washington, DC.

US Energy Information Administration, 2012. *Annual Energy Review 2011*. Washington, DC.

US Bureau of Economic Analysis, 2016. Real Disposable Personal Income: Per Capita, retrieved from FRED, Federal Reserve Bank of St Louis. Available at: https://fred.stlouisfed.org/series/A229RX0 [accessed 27 October 2016].

Viscusi, W.K., 2010. The heterogeneity of the value of statistical life: Introduction and overview. *Journal of Risk and Uncertainty*, 40(1). 1–13.

Viscusi, W.K. and Aldy, J.E., 2003. The Value of a Statistical Life: A Critical Review of Market Estimates Throughout the World. *Journal of Risk and Uncertainty*, 27(1). 5–76.

ABOUT THE NEW CLIMATE ECONOMY

The Global Commission on the Economy and Climate, and its flagship project The New Climate Economy, were set up to help governments, businesses and society make better-informed decisions on how to achieve economic prosperity and development while also addressing climate change.

In September 2014, the Commission published *Better Growth, Better Climate: The New Climate Economy Report*. Since then, the project has released a series of country reports on the United States, China, India and Ethiopia, and sector reports on cities, land use, energy and finance. In July 2015, the Commission published *Seizing the Global Opportunity: Partnerships for Better Growth and a Better Climate*. In October 2016, the Commission published *The Sustainable Infrastructure Imperative: Financing for Better Growth and Development*. It has disseminated its messages by engaging with heads of governments, finance ministers, business leaders and other key economic decision-makers in over 40 countries around the world.

ABOUT THE COALITION FOR URBAN TRANSITIONS

The Coalition for Urban Transitions - launched in May at the Climate Leaders' Summit in New York - is a major new international initiative to support decision makers to unlock the power of cities for enhanced national economic, social, and environmental performance, including reducing the risk of climate change. The Coalition will provide an independent, evidence based approach for thinking about 'well managed' urban transitions to ensure that the growth of urban areas, and the accompanying process of economic, social, and environmental transformation, maximises benefits for people and the planet.

The initiative is jointly managed by the C40 Climate Leadership Group (C40) and World Resources Institute (WRI) Ross Center for Sustainable Cities, with a Steering Group comprising of 20 major institutions spanning five continents including leaders from think-tanks, research institutions, city networks, international organizations, infrastructure providers, and strategic advisory companies. The initiative will be overseen by a Global Urban Leadership Group to champion the work, drawing on members of the Global Commission on the Economy and Climate, as well as other prominent individuals as Ambassadors.

Acknowledgements

Hyunji Lee provided inputs to the draft. Tadashi Matsumoto and Abel Schumann revised and edited the paper. The authors acknowledge the help of 22 colleagues, who have contributed by providing comments, suggesting relevant research or assisting with quantitative interpretations of their work, including Rudiger Ahrend, David Albouy, Victor Couture, Gilles Duranton, Sarah Colenbrander, Paul Cheshire, Patrick Gaule, Nick Godfrey, Christian Hilber, Laura Jay, Filip Matejka, Tristan More, Charles Palmer, Philipp Rode, Andrew Sudmant, Xiao Zhao, Ferzina Banaji, Joel Jaeger, Rachel Spiegel and Talia Calnek-Sugin.