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Agglomeration: Economic and Environmental Impacts

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Abstract

Urbanization is taking place at an unprecedented pace and scale in China, India, and many other emerging economies. This will have profound impacts on the world economy and environment. This review provides a critical assessment of the current understanding of the intertwined relationships between agglomeration, economic growth, and environmental quality. We start by providing a brief overview of the extensive literature on the drivers of agglomeration and its economic impact. We then discuss the opposing views on the environmental impact of agglomeration and illustrate the trade-offs involved when choosing among different levels and forms of agglomeration. Finally, we discuss challenges for environmental management in a rapidly urbanizing economy and some lessons learned from history and experiences of urban development and their policy implications. The review concludes with a discussion of key knowledge gaps and future research directions.

1. INTRODUCTION

The relationships between agglomeration, economic growth, and environmental quality are closely intertwined. Although increasing concentration of economic activity will inevitably cause congestion and pollution concentrations in urban areas, the interrelationships between agglomeration, economic growth, and environmental quality are subtle and complex (Henderson 2010). In this article, we aim to provide a critical review of the literature on these interrelationships. As is evident later in this review, regional and urban economists have long studied the economic impact of agglomeration and have made much progress in understanding the sources of agglomeration economies and the mechanisms through which they affect the economy. However, our understanding of the relationship between agglomeration and environmental quality and the implications of the relationship for environmental policy making is much more limited. Therefore, much of this review focuses on the environmental impacts of agglomeration and some of the challenges it poses to the design of environmental policy.

Understanding the interrelationships between agglomeration, economic growth, and environmental quality is critical for designing sustainable development policy. During the past 50 years, the world has seen a steady increase in the level of urbanization. The percent of the population living in urban areas increased from 30% in 1950 to 54% in 2014 (United Nations 2015). This trend is expected to continue in the next 30 years, particularly in developing countries such as China and India. By 2050, the world will be two-thirds urban and the urban economy will generate more than 80% of the global gross domestic product (GDP) (United Nations 2015). In addition, economic activity will be increasingly concentrated in large cities with high densities of development. By 2030, the world is expected to have 41 megacities of 10 million or more inhabitants (28 million today) and 621 large cities of 1 to 10 million inhabitants (460 million today).

The increasing concentration of economic activity in urban areas has raised some interesting questions:

1. What drives agglomeration of economic activity?
2. How does it affect the economy?
3. Is agglomeration good or bad for the environment?
4. How much development should be concentrated in megacities, or more generally, what is the optimal level of concentration?
5. What are the most important lessons learned from the history and experience of urban development and what are their policy implications?

Some of these questions have long been focal points of scholarly inquiries in urban and regional economics, and others are spurred by growing attention to environmental problems in rapidly urbanizing economies.

In this article, we attempt to shed some new light on these issues. We start by providing a brief overview of the extensive literature on the drivers of agglomeration and its economic impact in the next section (for extensive reviews, see Duranton & Puga 2014, Henderson 2010, Rosenthal & Strange 2004). An important insight gained from this literature is that urbanization and economic growth are driven by the same underlying forces known as agglomeration economies. As a result, they are positively correlated. However, it is important to note that a positive correlation does not necessarily mean that urbanization causes economic development per se; they are both outcomes of agglomeration economies.

Section 3 examines the environmental impact of agglomeration. There are two opposing views when it comes to the question of whether agglomeration is good or bad for the environment. One camp, led by some naturalists, believes that crowded cities are ecological nightmares, while the

other camp, led by some urban advocates including some urban economists, believes that cities are green. While the naturalists tend to emphasize the environmental costs of agglomeration, the urban advocates often focus on its environmental benefits. To inform the debate, we discuss both the benefits and costs of agglomeration, including its impact on traffic congestion, resource and energy use, and pollution concentrations and exposures.

In Section 4, we illustrate the trade-offs involved when choosing among different levels and forms of agglomeration. We argue that the level and form of agglomeration matter because of three fundamental features of economic and ecological systems: spatial heterogeneity in geography and physical conditions, spatial interactions and spillovers, and threshold effects. We find that our understanding of environmental implications of different levels and forms of agglomeration is limited. In particular, we know very little about the environmental efficiency of megacities and large urban clusters. Further research is urgently needed on these issues because where and how concentrated urban development will occur will have wide-ranging, long-term environmental implications.

Section 5 discusses challenges for environmental management in rapidly urbanizing economies. Agglomeration economies are engines of economic growth but also pose tremendous challenges to natural resource conservation and environmental protection. We argue that traditional approaches such as environmental performance standards or technological standards may not work in rapidly urbanizing economies such as China and India, and that efficient environmental management must consider agglomeration economies and firms' relocations in response to environmental regulation. How to develop policy to ensure sustainable development is a critical issue faced by many developing countries and an important topic for future research.

In Section 6, we discuss some of the lessons learned from the history and experience of urban development. In particular, we ask why some cities decline, while others continue to thrive. Cities may decline for various reasons; some are related to broad external forces, and others to local environmental, geographical, and institutional factors. Three common causes of urban decline are low educational attainment in the local workforce, lack of economic diversity in local economies, and poor natural and social amenities in local communities. Conversely, a successful city must be able to attract talented people, maintain a diverse industrial structure, and support a high quality of life for its residents. The implications of these results for policy design are also discussed. This review concludes in Section 7 with a discussion of key knowledge gaps and future research directions.

2. AGGLOMERATION AND ECONOMIC GROWTH

2.1. Economic Benefits of Agglomeration

External economies of scale—known as agglomeration economies—have long been a focal point of scholarly inquiry in regional and urban economics. Some date this interest to von Thünen [1966 (1826)], but many credit Marshall (1920) for providing the first careful analysis of agglomeration economies (Rosenthal & Strange 2003). The classic work identifies three "foundation stones" for determining the spatial distribution of economic activity: natural resource advantages, costs of transportation and communication, and economies of concentration (Irwin et al. 2010). Natural resource advantages to a large extent determine the location of agglomeration. For example, it is no coincidence that many cities around the world began as a port because those places provide easy access to transported goods (Ellison & Glaeser 1999). Marshall (1920, p. 269) argues that geography and physical conditions, such as climate, soil quality, abundance of natural resources, and easy access by water or land, determine the location of industries. In contrast, agglomeration economies determine the level of concentration.

Broadly speaking, agglomeration economies are positive externalities generated when a large number of firms or households are located in close proximity to one another. Agglomeration economies can be broadly divided into urbanization economies and localization economies (Rosenthal & Strange 2004). From individual firms' perspectives, urbanization economies are gains obtained from producing in a larger city. For example, the classic work of Marshall (1920) emphasizes the three types of transport costs—cost of moving goods, people, and ideas—that can be saved by producing in a larger city. Localization economies refer to gains from producing in an urban area with more firms in the same industry. For example, it is easier for a firm to learn the best management practices in the industry if it is located in an area with many other firms in the same industry.

There is no shortage of theories on sources of agglomeration economies or mechanisms through which they form. The classic work emphasizes labor market pooling, input sharing, transport cost savings, knowledge spillovers, market effects, and consumer preferences for a variety of goods and services as the primary sources of agglomeration economies (Black & Henderson 1999, Fujita & Ogawa 1982, Fujita & Thisse 2002, Krugman 1991, Lucas 1988, Marshall 1920). For example, the previous studies suggest that a large market allows for (*a*) more efficient sharing of input or workers with similar skills, (*b*) better matching between employers and employees or buyers and sellers, (*c*) more efficient learning from each other through information spillovers and knowledge accumulation, and (*d*) easier access to a variety of goods by consumers and to input and output markets by producers (Puga 2010).

In recent years, an extensive empirical literature has examined the scope and nature of agglomeration economies, as reviewed in Duranton & Puga (2014) and Rosenthal & Strange (2004). Some of the studies test the mechanisms through which agglomeration economies form, and others measure the relative magnitude of different types of agglomeration economies. For example, Rosenthal & Strange (2003) measure the geographic extent of agglomeration economies and find that localization economies attenuate rapidly with distance. Shapiro (2006) and Moretti (2004) provide empirical evidence of labor market pooling effects: Cities with higher concentrations of educated workers tend to have lower labor turnovers and higher adoption rates of new ideas. Feldman & Audretsch (1999) test whether the specialization of economic activity is more conducive to knowledge spillovers or if diversity, by bringing together complementary activities, better promotes innovation; they find considerable supporting evidence for the diversity thesis but little for the specialization thesis. Ellison et al. (2010) and Jofre-Monseny et al. (2011) find that a large market reduces transportation costs and improves information flows between producers and consumers. Ciccone & Hall (1996) examine the relationship between employment density and labor productivity across US counties and find that those with higher employment density also have higher labor productivity. Artz et al. (2016) find that commonly used measures of agglomeration economies increase the probability of new firm entry in both rural and urban areas.

Because of agglomeration economies, firms in a larger market tend to have lower production cost and higher productivity. In addition, agglomeration encourages the formation of new firms. For example, entrepreneurs may have easier access to information, technology, and human capital they need to establish a new firm in a larger market. Agglomeration may also enhance innovation-based, new-entry opportunities because workers in a larger market are more likely to see gaps in manufacturing or services and to establish firms to fill the gaps.

Because of agglomeration economies, urban economies tend to grow faster than rural economies. Faster economic growth in urban areas pulls rural people and assets into cities. This phenomenon is often referred to as the backwash effect. Growth in urban cores also enhances employment and population growth at the surrounding rural periphery through commuting residents. This effect is often referred to as the spread effect (e.g., Partridge et al. 2007). Recent

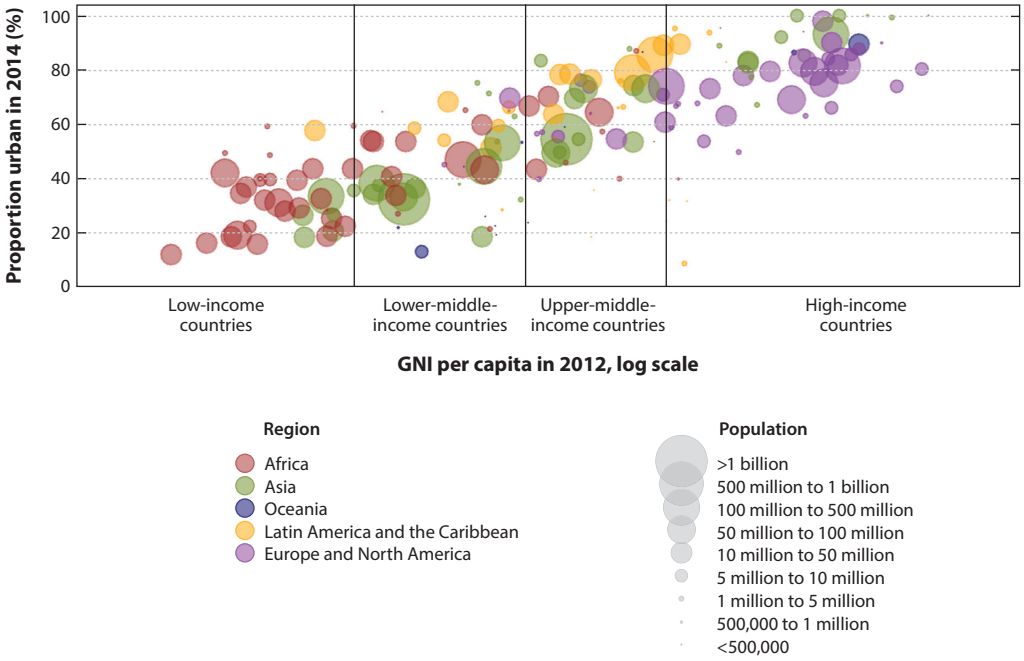

Figure 1

The correlation between the level of urbanization and gross national income (GNI) per capita. Adapted from United Nations (2015).

empirical work suggests that spread effects can extend more than 100 miles from the city when rural communities have sufficiently high quality of life and services for commuting residents (Partridge et al. 2007, Schmitt et al. 1997). Thus, agglomeration economies are fundamental drivers of both urbanization and economic growth in modern economies. For this reason, the levels of urbanization and economic growth tend to be positively correlated.

Indeed, there is empirical evidence for this positive association. **Figure 1** shows the association between the urbanization level and the gross national income per capita across countries in the world. The size of the circle represents the country's population, and the color indicates which continent the country belongs to. **Figure 1** clearly shows that the level of urbanization and the gross national income per capita are positively correlated as predicted by the theory.

2.2. Economic Costs of Agglomeration

Although cities may benefit from agglomeration economies, they also suffer from congestion costs and other types of urban diseconomies. Urban diseconomies can be broadly defined as the external costs generated by agglomeration, such as the prolonged trip times, increased noise, and environmental degradation associated with increased concentrations of population and economic activity. Urban diseconomies can also be thought of as the negative externalities associated with agglomeration. Glaeser (1998) finds that quality of life measures such as commute time and crime rates deteriorate as population increases in US cities.

Urban diseconomies affect not only environmental quality but also economic performance. Au & Henderson (2006) and Broersma & Oosterhaven (2009) find an inverted U-shaped relationship between labor productivity and city size, indicating that urban diseconomies outweigh agglomeration economies in terms of productivity in large cities. Carlino et al. (2007) analyze the

relationship between urban density and the rate of invention (measured by patents per capita) in US metropolitan areas and find that the rate of invention decreases with employment density beyond 2,200 jobs per square mile. Fu & Hong (2011) test whether agglomeration economies stem from urban diversity or urban scale and find that firm productivity decreases with city size when total population is above two million. Saito & Wu (2016) assess the trade-off between agglomeration economies and congestion costs in terms of employment growth in the United States from 2001 to 2010 and find that at the margin, congestion effects dominate localization economies in US urban counties. Broersma & van Dijk (2008) find a similar result when assessing productivity growth in Dutch regions between 1995 and 2002. Together these results suggest that urban diseconomies outweigh agglomeration economies when the city is too large or the density is too high, even without counting the environmental costs of agglomeration.

Agglomeration may affect both urban economies and surrounding rural communities. With urban development, total arable land will decrease at the rural-urban fringe. This will affect agricultural infrastructure. For example, with urban expansion, the demand for agricultural inputs such as fertilizer and seeds will decrease. As the demand decreases below a certain threshold, the nearest input supplier may close its business, and the farmer would have to travel for a longer distance or pay more for input (Wu et al. 2011). This suggests that, even if individual farmers may operate at a constant return to scale, there may be economies of scale at the industry level. Wu et al. (2011) measure the effects of urbanization on agricultural infrastructure and production costs and profit in the United States and find that urbanization reduces the number of input suppliers and output processors after it reaches a certain threshold; however, agriculture-related opportunities of urbanization, such as higher output prices and increased off-farm job opportunities, outweigh the challenges, leading to higher net farm income. Oueslati et al. (2019) evaluate the effect of urbanization on agricultural productivity at the rural-urban fringe for a set of European metropolises and find that, although increasing population density boosts agricultural productivity at the rural-urban fringe, increasing farmland fragmentation may have a detrimental effect on agricultural productivity at low levels of fragmentation.

3. AGGLOMERATION AND ENVIRONMENTAL QUALITY

There is much debate as to whether agglomeration is good or bad for the environment. One camp, led by some naturalists, argues that crowded cities are ecological nightmares, and unplanned urbanization will wreck the environment (Seto et al. 2011). The other camp, led by some urban advocates, believes that the naturalists got it all backward. They argue that cities are good for the environment: "If the future is going to be greener, then it must be more urban" (Glaeser 2011, p. 222). Although both camps can find evidence to support their arguments, they often overstate their cases. The naturalists tend to emphasize the environmental cost of agglomeration, while the city advocates tend to focus on its environmental benefits. The relevance of their arguments also depends on the reference point and the environmental impact considered (e.g., whether one is considering the impact on natural resource use or pollution damage). For example, it may be true that residents in large cities such as New York consume less water and energy per capita; they also suffer more from higher pollution concentrations than residents in many smaller cities. In addition, the urban advocates tend to focus on the pattern of urban development (e.g., urban sprawl versus compact development) and argue that a compact city will have a smaller impact on the environment than a sprawling city. In contrast, the naturalists tend to focus on the level of urbanization (percentage of people living in cities) and its impact on the environment. Below, we first review the environmental benefits of agglomeration and then focus on its environmental costs.

3.1. Environmental Benefits of Agglomeration

Urban advocates argue that with increasing urbanization, more people will live in densely developed cities. This will leave a smaller ecological footprint on Earth (Glaeser 2011, p. 206). Urban advocates can find plenty of evidence to support their arguments. For example, Owen (2004) reports that New Yorkers, on average, consume less gas, electricity, and water; discard less trash; spend far less time in cars; and generate 30% less greenhouse gases (GHGs) than an average American. This led Owen (2004, p. 111) to conclude that "[m]ost Americans, including most New Yorkers, think of New York City as an ecological nightmare, a wasteland of concrete and garbage and diesel fumes and traffic jams, but in comparison with the rest of America…New York is the greenest community in the United States." Glaeser & Kahn (2010) analyze the correlation between development density and gasoline usage and find that the average household living in a census tract with fewer than 1,000 people per square mile uses 70% more gasoline annually than the average household living in a census tract with more than 10,000 people. Whereas people living in suburban communities must drive to go anywhere, whether to grocery stores or restaurants, urbanites often walk to those places. The additional gas consumption by suburbanites can be significant from an environmental perspective because cars account for approximately 20% of the US carbon footprint. Bento et al. (2005) analyze the effect of development patterns on driving using 1990 data on US household commuting trips in 114 urban areas and find that greater population centrality, lower road density, and greater spatial evenness in the distribution of jobs relative to housing reduce a household's likelihood of driving and the average trip length. Grazi et al. (2008) and Vance & Hedel (2008) find that households living in higher-density places generate lower GHG emissions. For these reasons, Glaeser (2011, p. 221) argues that by fighting high-density development close to urban cores, environmentalists are pushing development to suburbs, which means more driving and more emissions. In a recent study, the OECD (2018) develops urban sprawl indicators for more than 1,100 urban areas in 29 OECD countries over the period 1990–2014. The study provides an excellent database for studying the nature of urban sprawl and its environmental and economic consequences.

Increasing concentrations of development can also generate other environmental benefits. For example, some recent ecological studies find that the environmental impacts from exurban development (~1–20 acre lots) are substantial and pose a greater threat to the preservation of biodiversity than urban and suburban development (see Hansen et al. 2005 for a detailed review). Lohse et al. (2008) analyze the relative impacts of urban, exurban, and cropland uses on stream habitat conditions for endangered salmonid species using parcel data for watersheds in coastal California and find that exurban development and agriculture have a much larger overall impact on sediment levels in tributaries used for spawning than does urban development. However, these results do not necessarily imply that urbanization would result in reduced sediment levels in streams unless it reduces the amount of land farmed.

3.2. Environmental Costs of Agglomeration

It is important to note that the relatively low-level consumption of land, water, and energy by urban households is a pecuniary effect of agglomeration. With urbanization, the demand for housing will increase in cities, which will drive up urban housing prices. As a result, urban households, on average, live in smaller homes; consume less land, water, and energy; and leave a smaller carbon footprint than their contemporary suburban or rural counterparts. However, as discussed in Section 2, economic development often accompanies agglomeration. With higher income, households will consume more, which will lead to more emissions. Cities account for 60% of residential

Table 1 Agglomeration and PM 2.5 concentrations and exposures in China, by year[a]

PM 2.5 concentrations and exposures	2000	2005	2010	2015
Annual average of PM 2.5 concentrations ($\mu g/m^3$)				
Population-weighted	30.7	37.0	41.3	38.7
Unweighted mean	22.8	23.2	28.1	26.3
Percent of population living in areas with PM 2.5 concentrations				
>35 $\mu g/m^3$	34.67	57.11	68.02	57.58
<15 $\mu g/m^3$	6.41	4.85	2.16	2.78

[a]The World Health Organization (WHO) Interim Target 1 is 35 $\mu g/m^3$. The US PM 2.5 secondary standard is 15 $\mu g/m^3$ (primary standard 12 $\mu g/m^3$). Data from Gong & Wang (2017).

water use, 76% of wood used for industrial purpose, and 78% of carbon emissions in the world (Grimm et al. 2008); these percentages are much larger than the urban population share.

Even if agglomeration leads to less water and energy use per capita, the concentration of people and economic activity means that cities are ecological hotspots (see Grimm et al. 2008 for a review of the ecology of cities). For example, the reduced vegetation cover, impervious surface area, and morphology of buildings in cityscapes lead to urban heat islands, which means that agglomeration can change local climate (Foley et al. 2005). Cities often experience elevated concentrations of air pollutants such as NO_2, SO_2, and PM 2.5 because cityscapes can change the atmospheric conditions that increase reaction rates, transport, and deposition of pollutants (Grimm et al. 2008). High concentrations of pollutants in cities often exceed nature's assimilative capacity, leading to biogeochemical imbalances. The damages to ecosystems and human health are smaller when pollutants are spread over a large area so that their concentrations are below the ecological and human heath thresholds. Therefore, agglomeration can lead to large environmental damages even if it reduces the total amount of emissions of each pollutant.

To illustrate this point, consider the effect of urbanization on exposures to PM 2.5 in China. **Table 1** reports the annual average of PM 2.5 concentrations in China in 2000, 2005, 2010, and 2015. For each year, the population-weighted average is greater than the unweighted mean, indicating that population tends to concentrate in areas with higher PM 2.5 concentrations. As a result, in 2015, 58% of the population lived in areas with annual average PM 2.5 concentrations above 35 $\mu g/m^3$ [World Health Organization (WHO) Interim Target 1], and less than 3% of the population lived in areas with an annual average below 15 $\mu g/m^3$ (the US secondary standard for PM 2.5, annual mean, averaged over three years). The US primary standard is set to provide public health protection, including protection of the health of sensitive members of the population such as children and the elderly, and the secondary standard is set to provide public welfare protection, including protection against decreased visibility and damages to crops and animals.

Another highly visible cost of agglomeration is traffic congestion. As the population density increases, the city will inevitably experience more congestion. **Figure 2** shows the average speed for cars and public transport during peak hours in Beijing, Shanghai, and London in 2005 (**Figure 2*a***) and the historical trend in Beijing (**Figure 2*b***). As Beijing expands, its congestion level, as measured by the average speed of cars and public transport during peak hours, increased rapidly, from 45 mph in 1994 to 10 mph hour in 2005. Compared to Beijing and Shanghai, London was less congested. However, the average speed for cars and public transport during the peak hours was only 25 km/h in London (McKinsey Global Inst. 2009).

Without policy intervention, individuals tend to drive too much because they do not bear all of the cost associated with their driving. The mere presence of a driver on a congested road will

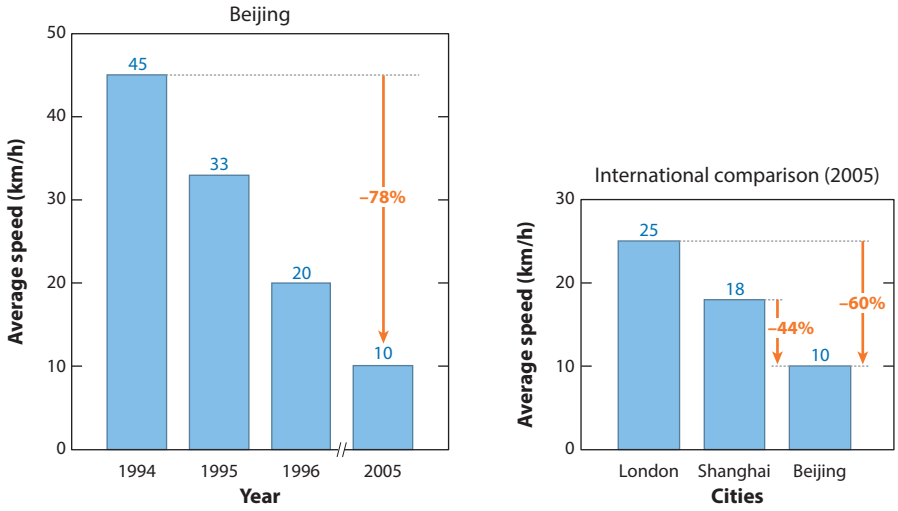

Figure 2

Average speed of cars and public transport during peak hours in km/h. Adapted with permission from McKinsey Global Inst. (2009).

prolong everyone's trip. This suggests that driving may generate a negative externality. Individual drivers, however, may not take this negative externality into consideration when making driving decisions. As a result, people tend to drive too much, and cities grow too big. This has led some economists to propose using congestion tolls to influence the pattern of traffic flows. In a classic paper, Henderson (1974) shows that congestion tolls may induce individual commuters to travel at less congested times, leading to an efficient reorganization of traffic flows relative to a nontoll situation. Other market failures that may cause excessive spatial growth of cities include undervalued open space benefits, environmental externalities, and public service costs that are not fully internalized by private developers (Wu 2006).

Urban hot spots can drive environmental change at regional and global scales (Grimm et al. 2008). Cities are primary sources of GHG emissions and are thus implicated in global climate change. Urban heat islands not only affect local climate but also promote dispersion of pollutants away from the city. Urbanization can alter the species richness and species composition not just within the city but also in the surrounding areas (Grimm et al. 2008). Urbanization can lead to increased fragmentation and loss of wildlife habitat. This, in combination with other human disturbances such as noise, pollution, and light, can disrupt wildlife interactions and change wildlife populations and communities in the surrounding areas. These environmental externalities also cause excessive spatial growth of cities (Irwin et al. 2009).

4. AGGLOMERATION PATTERNS AND ECONOMIC-ENVIRONMENTAL TRADE-OFFS

Increasing concentration of economic activity generates both benefits and costs in terms of economic growth and environmental quality. The overall impact will likely depend on the location, level, and pattern of urban development. In addition, how cities are organized within a country will have long-term economic and environmental implications. Thus, key questions for urban development include: Should urban populations be concentrated in a few supercities or distributed

over a large number of smaller cities? Where should major cities be located? How big and dense should a city be? These questions matter because of three fundamental features of ecosystems (Lewis & Wu 2014). The first fundamental feature is spatial heterogeneity in physical conditions such as land quality and water availability. Spatial heterogeneity affects both the benefit and cost of urban development. The second feature is spatial interactions and spillovers across firms and land parcels. As discussed in Section 2, an important source of agglomeration economies comes from knowledge spillovers across firms. The environmental impact of agglomeration also depends on the patterns of urban development. For example, both the amount of habitat loss and the pattern of fragmentation affect species survival (Ando 2014). Risks such as fire, pests, and diseases also spread across space (Albers 2014). The third fundamental reason why scope and pattern matter is threshold effects, which exist in many environmental contexts. For example, to ensure that northern spotted owls survive in a watershed, the amount of suitable habitat in the watershed must be above a certain threshold (Lamberson et al. 1992). Because of threshold effects, the relationship between the amount of land developed and the loss of ecosystem services can be highly nonlinear. The pattern of agglomeration also affects the value of ecosystem services to society. For example, the value of recreation benefits from conservation depends on locating development in proximity to conserved landscapes.

There are likely trade-offs involved when choosing among different levels and patterns of agglomeration, especially at high levels of concentration. To illustrate these trade-offs, consider the following possible future scenarios for urbanization in China that have been studied by the McKinsey Global Institute (2009):

- Supercities: 15 supercities with average populations of 25 million
- Hub and spoke: 11 urban clusters of cities, linked by strong economic ties, with combined populations of 60-plus million each on average
- Distributed growth: many cities with populations of 1.5 million to 5 million spread throughout China
- Townization: a large number of smaller cities with populations of 500,000 to 1.5 million spread throughout China

The McKinsey Global Institute (2009) estimated per-capita GDP, water and energy demand, and emissions of major air pollutants in urban areas under each of these scenarios. Some of the results are summarized in **Figure 3**. The two most concentrated scenarios would generate

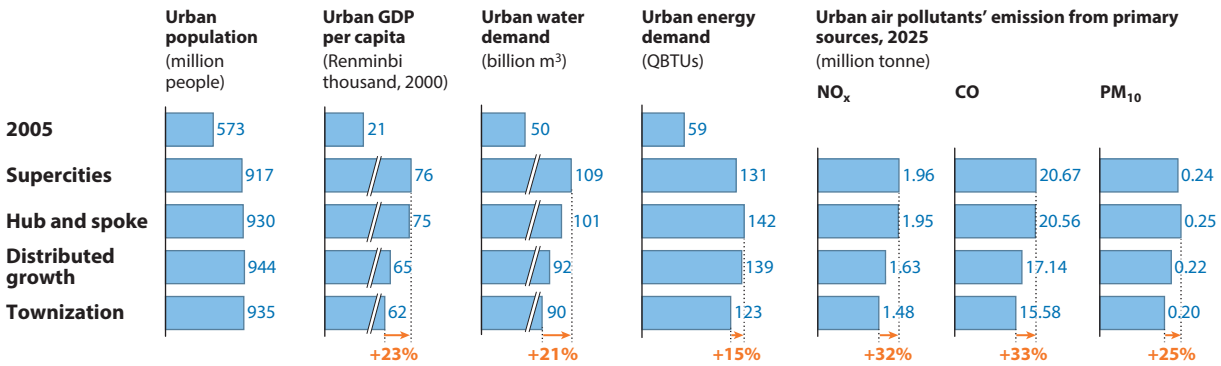

Figure 3

The level and patterns of agglomeration and economic-environmental trade-offs. Adapted with permission from McKinsey Global Inst. (2009).

higher per-capita GDP, but also require more water and energy consumption and generate more emissions of NO_x, CO, and PM 10 in urban areas. Specifically, compared with townization, the supercities scenario would generate 23% more GDP, require 21% more water and 8% more energy, and result in 32%, 33%, and 25% more emissions of NO_x, CO, and PM 10, respectively.

These estimates of economic and environmental impacts should be viewed cautiously because many factors may affect the environmental outcomes under each scenario, and the McKinsey study may not have considered all of these complexities. Nevertheless, the estimates illustrate some of the trade-offs involved when choosing among alternative development scenarios. The large trade-off between economic development and environmental quality suggests that the supercities scenario may not be a good idea even if it generates higher per-capita GDP. A less-concentrated development scenario, such as the hub and spoke or distributed growth, may be more desirable for the following reasons.

First, the supercities scenario may be too risky. As Henderson (2010) pointed out, the efficiency of supercities is essentially unknown because the world has never seen so many such-sized cities in one country before. Theoretically, as a city grows larger, the marginal benefit from agglomeration will eventually decrease, while the marginal cost from urban diseconomies will increase. Although it is difficult to determine when the marginal urban diseconomies will outweigh the marginal agglomeration economies, Henderson (2010) argues that, based on the existing knowledge of the urban development process, the highly concentrated development scenario is likely a bad idea.

Second, the environmental cost is likely too high under the supercities scenario. Few people want to live in a city where one can drive only a few miles per hour and see PM 2.5 above 100 $\mu g/m^3$ for most days of the year. Environmental quality could get much worse in the supercities scenario, not only because the cities would grow much larger, but also because more supercities will emerge in China.

Third, the urban structure under the supercities scenario may be too uniform to satisfy the diverse preferences for ways of living in China. Some people may prefer to live in big cities, while others may prefer to live in small towns or rural areas. The supercities scenario, particularly induced by heavy government intervention, would "force" a large portion of the population to live in those supercities, even though some of them might prefer to live in small cities or rural areas without distortionary government investment in supercities.

Fourth, the supercities scenario may require a lot of government investment and policy favoritism at a cost to the rest of society. Such a development scenario may exacerbate income inequality, which counters one of the proclaimed development goals in China.

Finally, the supercities scenario will likely exacerbate urban diseconomies and urban diseases. Urbanization often accompanies urban problems, such as slums, crime, and economic and racial segregation. Although urbanization does not make people poor, it tends to attract poor people into cities. High poverty concentrations often lead to high crime rates and low school quality, causing some high-income households to leave the city. This flight-from-blight is self-reinforcing, which could lead to a downward spiral. Such problems are more likely to occur in a highly concentrated scenario where there is a high concentration of poverty.

5. AGGLOMERATION AND CHALLENGES FOR ENVIRONMENTAL MANAGEMENT

Environmental economists have long recognized that efficient policy design must consider the geographic dimension of polluting activities (Arnott et al. 2008, Atkinson & Tietenberg 1982, Baumol & Oates 1988, Farrow et al. 2005, Krupnick et al. 1983, Montgomery 1972, Muller & Mendelsohn 2009, Tietenberg 1974). For example, in a classic paper on the efficiency of tradable

permits, Montgomery (1972) found that although an ambient-based tradeable permit system that considers the diffusion from sources to receptor points leads to minimization of total abatement cost, an emission-based permit system cannot achieve the least-cost solution because it ignores the differences in concentrations contributed by various polluters. Muller & Mendelsohn (2009) demonstrated that the US sulfur dioxide allowance trading program would generate much larger social welfare if trading ratios are based on spatially differentiated marginal pollution damages. The magnitude of welfare gains from implementing spatially differentiated policy depends on the spatial heterogeneity in marginal pollution damage and marginal pollution abatement cost (Holland & Yates 2015, Jacobsen et al. 2016). However, these studies typically take firm locations as given and do not allow for endogenous firm location.

It has been widely recognized that firms may relocate in response to spatially differentiated environmental policy, as reflected by the well-known pollution haven hypothesis (see Jeppesen et al. 2002 or Levinson & Taylor 2008 for a review of this literature). For example, Markusen et al. (1993) develop a two-firm and two-region model that allows each firm to choose its plant locations and then use the model to examine optimal environmental taxation. Their results suggest that the optimal tax rate derived from such a model is dramatically different from the tax rate suggested by traditional Pigouvian marginal analysis that takes firms' locations as given. Many studies test the pollution haven hypothesis empirically and in various contexts. Some of the studies consider agglomeration explicitly. For example, Elbers & Withagen (2004) consider the pollution haven hypothesis with a spatial model of monopolistic competition and show that pollution can countervail clustering that would otherwise occur. Zeng & Zhao (2009) show that agglomeration forces can alleviate the pollution haven effect if environmental regulation is more stringent in the larger country. Kyriakopoulou & Xepapadeas (2013) develop a theoretical model to examine the spatial distribution of economic activity. They assume that the cost of environmental policy increases in the concentration of pollution and thus acts as a centrifugal force while positive knowledge spillovers and natural advantages act as centripetal forces. Their simulation results suggest that sites with natural advantages can lose their comparative advantage when the social costs of concentration at those sites are considered.

Firm relocation in response to spatially differentiated policies can cause emission leakage that can substantially offset, or even reverse, the reductions in emissions achieved in the regulated sector. Several studies have examined the effect of alternative policy designs on emissions leakage, industry profits, and social welfare (Demailly & Quirion 2006, Fowlie et al. 2016, Holland 2012, Szabó et al. 2006, Van Oss & Padovani 2003). For example, Fowlie et al. (2016) find that market-based policies that incorporate design features to mitigate emissions leakage can deliver welfare gains, while a policy regime that does not incorporate such design features would result in welfare losses even if it fully internalizes emission externality.

Although these studies consider firm relocation and its effect on the efficiency of policy, they focus on the impact of unilateral policies or regulatory differences in trade-exposed industries across countries rather than the interaction effect between agglomeration economies and environmental regulation. Wu & Segerson (2018) have identified several mechanisms through which agglomeration and environmental regulation may interact with each other. First, they argue that agglomeration can affect the effectiveness of environmental regulation by changing firms' locations. It is well known that urban diseconomies such as traffic congestion and air pollution are major centrifugal forces for decentralization (Fujita & Thisse 2002, p. 146; Glaeser 1998; Henderson 1974). By reducing pollution, environmental regulation can enhance the net benefit from agglomeration and thus may lead to greater concentration of economic activity and pollution. This feedback effect tends to work against the effectiveness of environmental regulation. Second, agglomeration can affect the effectiveness of environmental regulation by changing firms' compliance costs. Because

firms in a larger market may have easier access to information and technologies needed for compliance, they may face lower compliance cost in a larger market. Finally, agglomeration can affect the effectiveness of environmental regulation by changing governments' enforcement costs. For example, governments may not have enough resources to inspect every firm in a region with a large number of polluting firms.

Wu & Segerson (2018) develop a model to analyze the interaction effects between agglomeration economies and environmental regulation. They find that consideration of firms' reactive relocations and agglomeration economies can change some of the classic results from traditional Pigouvian marginal analysis. In particular, environmental regulation may not have the intended result and might instead exacerbate environmental problems at certain stages of development. At such a stage, a performance or technology standard commonly used for pollution control can be counterproductive, i.e., it can lead to more total emissions, higher pollution concentration, and greater pollution damage. The key reason for these results is that adoption of cleaner technology makes agglomeration less costly, which can lead to increased concentrations of firms and pollution that can more than offset the direct effect of regulation. This environmental stagnation can occur at intermediate levels of pollution intensity, a situation characteristic of rapidly urbanizing economies. These results identify conditions under which efforts to improve environmental quality through regulation or taxes may not be effective until the economy reaches a point where the negative feedback effects of agglomeration no longer dominate.

In an empirical analysis, Wu & Wu (2012) estimate the interaction effect between air quality regulation and agglomeration economies in seven major air-polluting industrial sectors in the United States using data from 1998 to 2014. Results indicate that, although air quality regulation has a direct negative effect on plant births in nonattainment areas for some industrial sectors, it also enhances the effect of agglomeration economies, which encourage firm births. As a result, the total effect of the regulation on plant births is minimal for those industries. Wang & Wu (2018) investigate the interaction between agglomeration economies and environmental regulation in the context of water pollution control in China and find similar results. Wang & Wu (2018) also investigate the mechanism through which agglomeration economies affect the effect of water quality regulation and find that polluting firms face lower abatement costs when located in regions with larger urbanization economies.

6. LESSONS LEARNED AND POLICY IMPLICATIONS

In this section, we briefly discuss some of the lessons learned from the history of urban development and their policy implications. Specifically, we ask why some cities decline, while others thrive, and what are the implications of the lessons for urban development policy.

Cities may decline for various reasons. Some are related to broad external forces, whereas others are due to local economic, environmental, and institutional factors. However, the two most common causes of urban decline are a lack of economic diversity in local economies and low educational attainment of local residents. Lack of economic diversity makes a city less resilient to downturns (Glaeser et al. 1992), while low educational attainment makes a city less innovative and less adaptive to external shocks (Black et al. 2005). Detroit, Michigan, the best-known motor city in the world, offers a great example to illustrate this point. Like many other US cities, Detroit began as a port, and the Detroit River was part of the pass from the American heartland to its eastern seaboard. By the time Henry Ford came to Detroit in 1880, it was already a buzzing city; the amount of goods moving along the Detroit River was more than three times as much as the total amount going through the ports of New York or London (Glaeser 2011, p. 46). At the beginning of the nineteenth century, cars were a brand new idea, and Detroit was the United States'

equivalent of today's Silicon Valley. Henry Ford, the Dodge Brothers, David Buick, and other big names in the automobile industry all lived in the motor city at that time (Glaeser 2011, pp. 42–50).

Ford's innovation of assembly lines made it possible to produce many cars at a low cost. The innovation also made it possible for a worker to be highly productive without much education. As a result, Detroit became a city with a dominant industry and a highly productive workforce with relatively low education attainment. When a widespread industrial decline occurred worldwide in the 1970s, many of the old industrial cities in the United States suffered, but some, such as New York and Boston, were able to reinvent themselves and come back, while Detroit continued to decline. Since 1950, Detroit has lost more than one million people or approximately 60% of its population. Detroit's median household income is only about half of the US average, and one-third of its residents live in poverty (Glaeser 2011, pp. 42–50). Detroit's dramatic decline can be attributed, to a large extent, to a lack of economic diversity in its economy and low educational attainment of its workforce.

Other factors that may cause a city to decline include (Wu et al. 2017):

- Environmental degradation and "city diseases" that reduce the quality of life for local residents and cause brain drain from the local labor market;
- High land prices and wages that crowd out economic activities (Corden & Neary 1982);
- Over-construction of infrastructure during the boom period, which creates a fiscal overhang for local governments during the bust (Kelsey et al. 2016);
- Corruption, mismanagement, and counterproductive policy that weaken local institutions and cause the city to miss opportunities to reinvent itself (Acemoglu et al. 2013).

Although a declining city may not suffer from each and every one of these problems, a thriving city must be able to avoid all of the major pitfalls. Specifically, a successful city must be able to attract talented people and create opportunities for them to work collaboratively. A successful city must be able to provide environmental and social amenities for its residents and control urban diseconomies and city diseases. This will not only help attract talented people but also help retain them (Rappaport 2009). Investment in education, urban open space, transport infrastructure, and cultural activities has been shown to be effective in attracting and retaining talented people. A successful city must have a diverse industrial structure and an inviting business environment that encourages innovation, entrepreneurship, and agglomeration economies.

Many cities prefer to attract big firms. A few big firms that employ a large number of unskilled workers may bring short-term growth to a city but maybe at a cost to its long-term growth potential. In addition, such an industrial structure may not be resilient to economic downturns and external shocks. Both New York and Detroit suffered a significant decline in the 1970s, but New York was able to reinvent itself and came back, while Detroit is still struggling. Many believe the tradition of entrepreneurship fostered by a large number of small firms in New York played a big role in its comeback (Glaeser 2011, pp. 61–63). Finally, a successful city must be able to provide an inviting business environment by cutting red tape and applying fair and transparent rules to all firms doing business there.

To achieve those goals, a suite of policy instruments may be needed. For example, in a city with agglomeration economies and environmental pollution, policy makers may need to couple a regional development policy designed to address relocation externalities with incentive-based environmental policy designed to internalize environmental externalities. In such a policy setting, the Buchanan critique (Buchanan 1969) is particularly relevant because the gain in agglomeration economies from increased concentrations of firms could be overwhelmed by environmental costs of agglomeration. On the other hand, an environmental policy that reduces pollution can lead to greater concentration of firms and increased agglomeration economies because urban

diseconomies are major centrifugal forces for decentralization and, by reducing pollution, an environmental policy can enhance the net benefit from agglomeration (Wu & Reimer 2016, Wu & Segerson 2018).

There is a growing body of literature on environmental regulation in a second-best setting characterized by multiple preexisting distortions. The classic work in this literature focuses on the efficiency of environmental regulation in the presence of market power (Buchanan 1969, Oates & Strassmann 1984) and tax distortions (Bovenberg & de Mooij 1994, Fullerton 1997, Fullerton & Metcalf 2001, Goulder 1995). Buchanan (1969) argues that environmental regulation could lead to a welfare loss in a concentrated industry because the industry may be already producing below the socially optimal level, and the loss of consumer and producer surplus induced by further restricting output can overwhelm the gains from pollution reduction. In contrast, Goulder (1995) and Fullerton (1997) argue that taxes on pollution can generate double dividends in the presence of tax distortions. One dividend is an improvement in environmental quality, and the other is an improvement in economic efficiency from the use of environmental tax revenues to reduce other taxes such as income taxes that distort labor supply decisions (Fullerton & Metcalf 2001). The optimal design of a coupled environmental and development policy must recognize these additional benefits and costs.

Other studies in the literature focus on environmental regulation when the marginal pollution damage or marginal pollution control cost varies over space (Holland & Yates 2015, Jacobsen et al. 2016, Mendelsohn 1986, Muller & Mendelsohn 2009). These studies show that welfare gains can be obtained from implementing spatially differentiated policy, and the magnitude of such welfare gains depend on the extent of the spatial heterogeneity in marginal pollution damage and marginal abatement cost (Holland & Yates 2015, Jacobsen et al. 2016, Mendelsohn 1986, Muller & Mendelsohn 2009). However, firm relocation in response to spatially differentiated policy can cause emission leakage that offsets welfare gains (Demailly & Quirion 2006, Fowlie & Muller 2013, Fowlie et al. 2016, Holland 2012, Szabó et al. 2006, Van Oss & Padovani 2003). Market-based policies that incorporate design features to mitigate emission leakage can deliver welfare gains, while policies that do not consider emission leakage could result in social welfare losses even if they fully internalize environmental externalities (Fowlie et al. 2016).

A large body of literature has also evaluated regional development policy (OECD 2010). Such a policy can also have important environmental implications. For example, an effective policy to attract and retain talented people for economic development is to invest in urban parks, green space, and other natural and social amenities. Such a policy can have important environmental and social implications because it affects both the density and patterns of urban development (Wu 2006, 2014; Wu & Plantinga 2003).

Investment in urban infrastructure such as roads and transportation has also been widely used to promote economic development. Urban economists have long recognized that transportation costs affect not only the size, density, and patterns of urban development but also housing prices and relative locations of high- and low-income households. This suggests that investment in urban infrastructure for economic development may also have important environmental and social implications. A coupled environmental and regional development policy must recognize not only the additional economic benefits and costs but also the additional environmental and social implications.

Because of dimensionality problems and lack of counterfactuals, it is difficult, if not impossible, to accurately measure all of the economic and environmental impacts of all perceivable sizes and forms of urban development. However, policy makers must have a good understanding of the sources and magnitude of both positive and negative externalities associated with alternative urban development patterns in order to develop efficient policies. Market-based, coupled environmental

and development policies that incorporate design features to internalize all of the major positive and negative externalities will likely be able to deliver welfare gains, whereas a unilateral environmental policy designed to internalize pollution externalities without considering other preexisting distortions could lead to welfare losses.

7. FUTURE RESEARCH NEEDS

Although urban and regional economists have long studied the economic impacts of agglomeration and made much progress in understanding the sources of agglomeration economies and the mechanisms through which they affect the economy, environmental and resource economists have just begun to explore the environmental impacts of agglomeration and their policy implications. Many pressing questions remain, and making meaningful progress on these questions will require both theoretical and methodological advances and collaboration between economists and natural scientists. Some of the key questions and future research directions are discussed below.

First, our understanding of the nature of environmental externalities associated with agglomeration and the mechanisms through which they affect overall environmental quality is limited. Ecologists have traditionally shunned urban areas, but an increasing number of ecologists are collaborating with other scientists to understand the urban ecology (Grimm et al. 2008). This line of inquiry will likely increase our understanding of how different levels and forms of agglomeration will affect the environmental outcomes. Economists can also play a role in the inquiry. For example, econometric analysis, backed with a solid understanding of biophysical mechanisms, can shed light on the effects of urban forms on air pollution in the city and human exposure to harmful air pollutants. Empirical analyses can also provide a better understanding of the effect of urban development patterns on urban energy consumption and CO_2 emissions. A better understanding of the sources and nature of environmental externalities in different urban settings and environments is necessary, not only for a better understanding of the overall environmental impact of agglomeration, but also for developing efficient policy.

Second, more research is needed on the relationship between urban development patterns and sustainable development. Some argue that compact development is a desirable urban form because it reduces energy consumption and pollution. However, compact development also increases pollution exposure because of the joined concentration of pollution and people in urban areas. In addition, it can affect energy consumption indirectly by changing agglomeration economies and industrial structure. Theoretically, as a city grows larger, the marginal benefit from agglomeration will eventually decrease, while the marginal cost from urban diseconomies will increase. Although recent empirical research has made meaningful advances in answering the question of when the marginal cost of agglomeration will outweigh the marginal benefit, the turning point will likely vary across urban settings and environments. Further research is needed to understand the efficiency of cities of different sizes and forms in terms of both economic development and environmental quality.

Third, recent research suggests that traditional policy approaches such as technological or performance standards commonly used for pollution control may not work well in an economy experiencing rapid urbanization (Wu & Segerson 2018). How to manage environmental quality in a rapidly urbanizing economy is an important issue for future research. Such research is also urgently needed because where and how concentrated urban development will be in emerging economies such as China and India in the next 10 to 15 years will have long-term economic and environmental implications for those countries and the rest of the world.

Finally, our literature review indicates that environmental and urban economists often explore the same reality but employ different methods to study the different aspects of the reality

(Wu et al. 2017). Increasing cross-fertilization between environmental and urban economics will likely provide new insights. For example, agglomeration economies have been a focal point of regional and urban economics, but they have rarely been considered in environmental policy analysis, despite the fact that they can have important environmental implications. Agglomeration represents self-reinforcing dynamics that manifest through many aspects of economic, environmental, and social systems, and some new insights will likely be gained when it is considered in environmental policy analysis.

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