THE IMPACT OF POPULATION CHANGE AND DEMOGRAPHY ON FUTURE INFRASTRUCTURE DEMAND

NATIONAL
INFRASTRUCTURE
COMMISSION

CONTENTS

INTRODUCTION

The National Infrastructure Commission has been tasked with putting together a National Infrastructure Assessment once a Parliament. This discussion paper, focused on population and demography, forms part of a series looking at the drivers of future infrastructure supply and demand in the UK. Its conclusions are designed to aid the Commission in putting together plausible scenarios out to 2050.

The National Infrastructure Assessment will analyse the UK's long-term economic infrastructure needs, outline a strategic vision over a 30-year time horizon and set out recommendations for how identified needs should begin to be met. It will cover transport, digital, energy, water and wastewater, flood risk and solid waste, assessing the infrastructure system as a whole. It will look across sectors, identifying and exploring the most important interdependencies.

This raises significant forecasting challenges. The Assessment will consider a range of scenarios to help understand how the UK's infrastructure requirements could change in response to different assumptions about the future. Scenarios are a widely-used approach to addressing uncertainty. Quantifying scenarios also allows modelling of policy options.

In the absence of a known probability distribution for future outcomes, the scenarios will be based on available empirical evidence about past trends and quantitative and qualitative forecasts of changes in four key drivers of infrastructure services: the economy, population and demography, climate and environment, and technology. Understanding trends and discontinuities in the past can help identify where variation in the set of scenarios may be most helpful. Given the scope of the topics, the focus is on considering the most important past trends and projections/forecasts. The drivers also should not be thought of in isolation: the impact of changes in population and demography will need to be considered in context alongside other drivers of infrastructure demand and supply, notably technological, economic and environmental change.

An important objective for the NIC's analysis of population and demographic change is to inform the inputs that we will use in our forecasting scenarios in respect of population growth and associated factors such as household size. The starting point for the population and demography inputs into these scenarios are Office for National Statistics (ONS) UK population projections. The ONS are the main provider of UK population projections and provide a range of variant projections which include the NIA forecasting window to 2050.

Based on the analysis in this paper, using the following population projections as inputs into scenario development should reflect the significant uncertainty around future population. These variants are not inherently more likely than others, but should rather span the range of plausible outcomes:

- The ONS central population projection
- The ONS low migration population variant
- The ONS high fertility population variant
- A projection based on the aggregate population in the ONS central projection, but with sub-national populations less skewed towards London, with the shift in population distribution motivated by trends in house building

The Commission would welcome comments on this discussion paper, including the proposed inputs set out above. In particular, references to further sources of evidence on these issues would be helpful. Please send any comments to **NICdiscussionpapers@nic.gsi.gov.uk** by 10th February 2017.

Further information on the overall scope and methodology of the National Infrastructure Assessment is available **here**.

The rest of this paper is set out as follows: Section 1 describes how usage of infrastructure services is affected by population and demography, in particular total population, location and age and household size; Section 2 assesses what the historic evidence and available forecasts suggest about the possible path of the total population. Section 3 assesses where people might live. Section 4 considers age, household size and behaviour change. Section 5 considers how infrastructure in turn might feed-back to affect population and demography. Section 6 concludes.

1. HOW POPULATION AFFECTS THE DEMAND FOR INFRASTRUCTURE SERVICES

Infrastructure services, such as heating or communication, are provided by infrastructure assets, such as power stations, and networks such as fibre optic cables. Infrastructure services are consumed by households, business and government and third sector organisations.

The number of people has a direct impact on demand for infrastructure services, as people use infrastructure to communicate, stay warm, do washing etc, mostly in their homes (although e.g. travel and mobile communication, are not based at home). A greater number of people means more or bigger households, both of which will drive up demand for infrastructure services, although not necessarily by the same amount, and more people making journeys and using mobile communications.

Household consumption of infrastructure services makes up between 14% (in the waste sector) and 63% (in the gas sector) of total demand. **Figures 1–2** below set out the split for the energy, water, and solid waste sectors between household demand and demand from other parts of the economy. **Figure 3** sets out the split of journeys between passengers and freight.

The link between population growth and business, government and third sector demand is more indirect than that between population and household or individual demand. Some firms, including some with high infrastructure service demand such as the petrochemicals industry, employ relatively few workers and sell much of their product abroad. However, a substantial proportion of business demand will be related to the population, since around 70% of UK output is consumed by UK consumers (the remainder is exported)[1] and because employment is partly determined by the working age population. Government and the third sector predominantly serve the UK population, although some services, such as defence or overseas aid, are not directly linked to the size of the population.

Figure 1: Energy (electricity and gas) consumption by sector[2] (UK, 2015)[3]

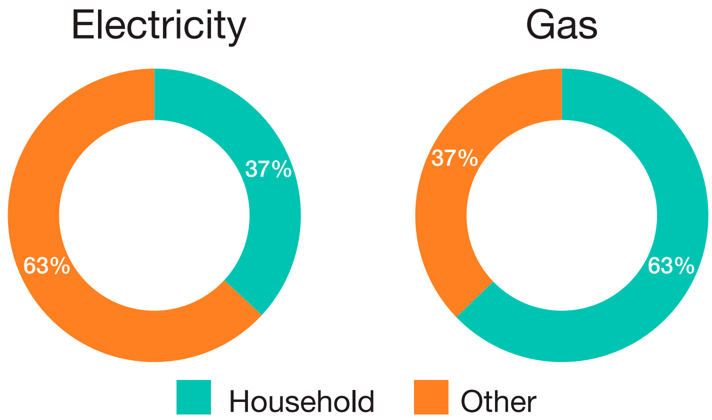


Figure 2 (left): Water abstractions for public water supply by sector[4] (England and Wales, 2014)[5]

Figure 2 (right): Waste generation by sector[6] (UK, 2012)[7]

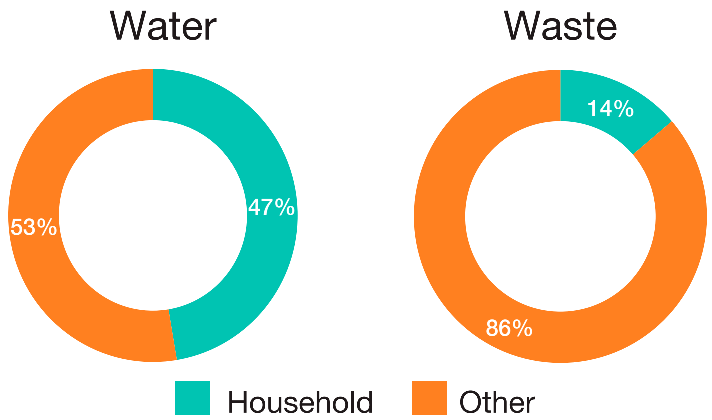
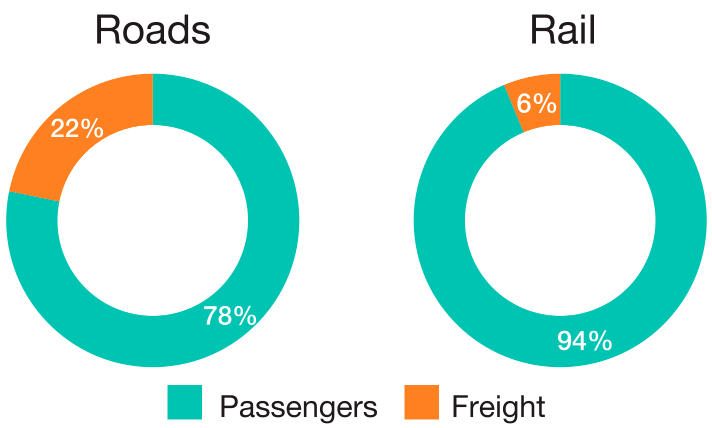


Figure 3 (left): Road traffic by passengers/freight[8] (GB, 2015)[9]

Figure 3 (right): Rail use by passengers/freight (GB, 2015)[10]



The pace of population growth can also influence the infrastructure investment required to deal with the variation in demand. A small increase in population growth can often be addressed by making incremental improvements to existing infrastructure or by accepting higher congestion. Larger and relatively faster changes in population growth require new and bigger investment.

People's demand for infrastructure services is not however uniform or fixed, so overall population growth is not the only factor that needs to be taken into account. Infrastructure is inherently spatial: most infrastructure services are provided directly to homes, offices and other buildings. Even where infrastructure assets, such as power stations or reservoirs, serve much larger areas, there is typically a need for transmission and distribution networks to deliver the infrastructure services to where they are needed. Infrastructure service demand will therefore vary across the country depending on where people choose to live and where businesses locate.

Patterns of service use can also vary significantly by location. In particular, transport use varies significantly between big cities and more rural or suburban areas. London and other big cities have more public transport, and often high levels of road congestion, which make driving less attractive. For example, in 2014/15, people in London used cars for 38% of their trips and public transport for 31%, whereas people living in rural areas used cars for 77% of their trips and public transport for only 5%.[11] A number of studies have shown that population density has a statistically significant effect on reducing road travel per capita.[12]

Similarly, available broadband speed and quality vary significantly between urban, suburban and rural areas and within broader regions. Average download speeds in urban areas were about 50 Megabits per second in 2015 versus 14 Megabits per second in rural areas.[13]

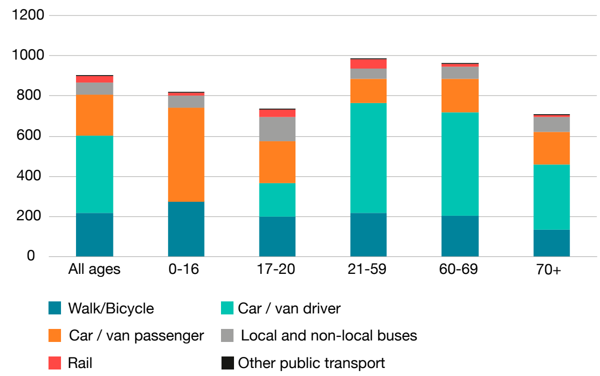
Demand also varies within the population. Demand for most infrastructure services tends to increase with higher incomes and to reduce with higher prices. These issues are explored in the economy driver paper. Demand also varies to some extent by age and household size, although these appear to have been studied less than income and price effects. In particular:

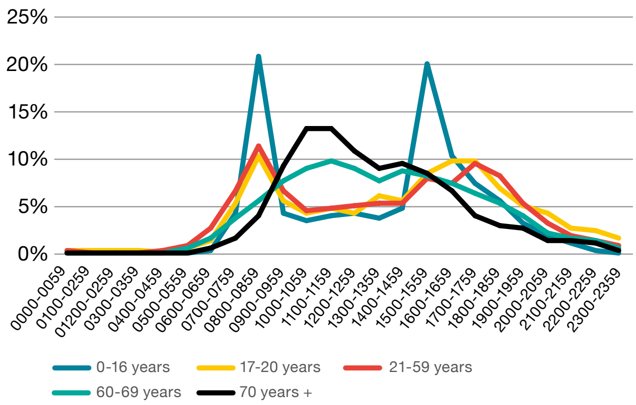
- On average, as shown in **Figure 4** below, older people travel less, even if some evidence suggest that road mileage from the elderly is increasing.[14] More of their journeys are by car or local buses and fewer by walking, cycling or rail/underground relative to younger groups. **Figure 5** below shows that older people are also less likely to travel during peak times.
- On average older people and those not in work use less energy during the after-work peak demand hours.[15] Some evidence shows however that households containing older people may use more energy overall.[16]
- Larger households have been shown to use less energy on a per person basis.[17] There is some evidence that the same is true for water usage[18] and solid waste.[19]
- Older people, particularly those aged over 65, are much less likely to use mobile and fixed broadband, than the rest of the population. Older people's use of the internet, and especially mobile phones, is also skewed away from data-intensive services, such as video streaming. However, the rate at which take-up is increasing is faster for those in the older age groups.[20] The elderly of the next generation may not have the same low rates of internet use relative to their younger peers.

Two data limitations are worth noting. Firstly, usage data is relatively widely available but rarely controls for other relevant factors. For example, if older people have lower incomes or are more likely to live in rural areas this might affect their demand for infrastructure services independently of their age. Bus usage and London underground are subsidised for older people, which is likely to affect their transport choices. Without controlling for these effects, the impact of age on demand would be exaggerated. Secondly, most of what is measured are infrastructure outputs, such as Kilowatt hours of electricity or litres of water. These are proxies for the infrastructure services, such as lighting or washing, that are ultimately the source of demand. Changes in efficiency may mean that patterns of output demand and service demand do not match: homes today are on average 5.6 degrees Celsius warmer than in the 1970s but use no more energy for heating.[21]

Figure 4 (left): Number of trips per person per year by age/mode (England, 2014)[22]

Figure 5 (right): Weekday trips in progress by time of day, by age group (England, 2014)[23]





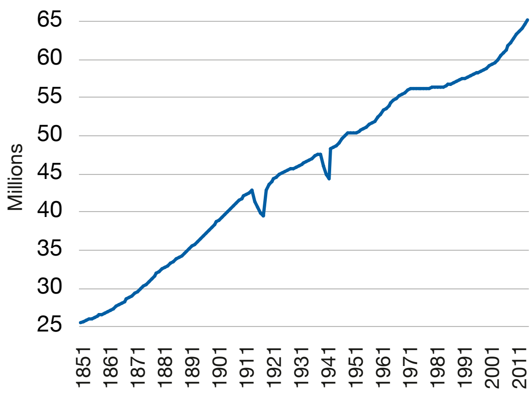
2. HOW MANY PEOPLE WILL THERE BE?

Trends in total population

Figure 5 below shows the UK's population since 1851. **Table 1** shows average annual growth rates over selected periods.

Over the last 10 years, UK population has been growing at 0.8% per year.[24] This is somewhat faster than the long-run rate of change, but follows nearly 30 years of exceptionally low growth from the early 1970s to the late 1990s. Natural change – more births than deaths – was the primary driver of population growth until the mid 1990s. Since then, net migration and natural change have each made up roughly half of population growth (as shown in **Table 2**).

Figure 6 (left), and Table 1 (right): Population (UK, 1851-2015)[25]



Period	Compounded average annual growth rate
1851-1910	0.84%
1921-1938	0.46%
1946-1948	1.06%
1949-1959	0.32%
1960-1971	0.60%
1972-1984	0.05%
1985-2003	0.30%
2004-2015	0.80%

Table 2: Population growth rates including natural growth and net international migration by period (UK, 1971-2015)[26]

Period	% Growth due to natural change	% Growth due to net int. migration	Total growth %	Annual growth %
1971-1981	1.4%	-0.6%	0.77%	0.08%
1981-1991	1.8%	0.1%	1.92%	0.19%
1991-2001	1.6%	1.3%	2.91%	0.29%
2001-2011	3.1%	3.9%	7.06%	0.68%
2009-2015	2.3%	2.3%	4.6%	0.75%

Population projections

The Office for National Statistics (ONS) produce projections of the UK population out for 100 years. By 2050, the UK population is projected to be 77.5 million.[27]

As shown in **Figure 7** below, the ONS produce projection variants based on different assumptions for net migration, fertility, and life expectancy. The central projection is for an increase in population by 12.9 million (20%) from an estimated 64.6 million in 2014 to 77.5 million in 2050. Of this growth, about half is due to migration, and half due to more births than deaths. The main variants range between 73.7 million (low migration) to 81.3 million (high migration) by 2050.

As **Table 3** below shows, the implied annual growth rates range between 0.37% and 0.64%, apart from the zero net migration variant which is much lower. These rates are more in line with the long-run average rate since the 1950s, with population growth slowing down compared to the last 15 years, but without reaching the extremely low rate from the early 1970s to the late 1990s.

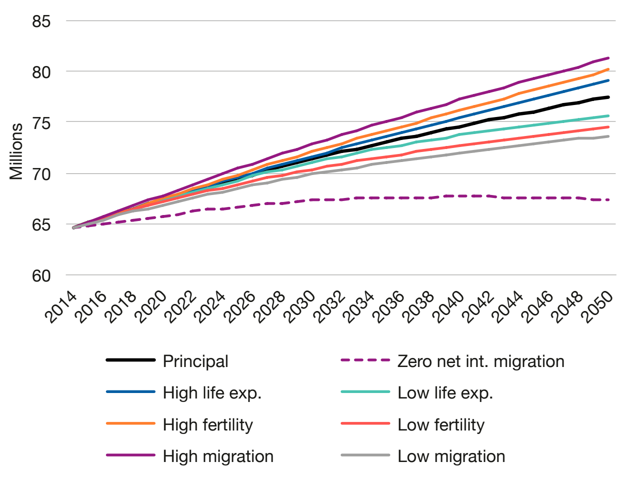
Table 3: ONS population projections including variants and implied growth rates (UK, 2014-2050)[28]

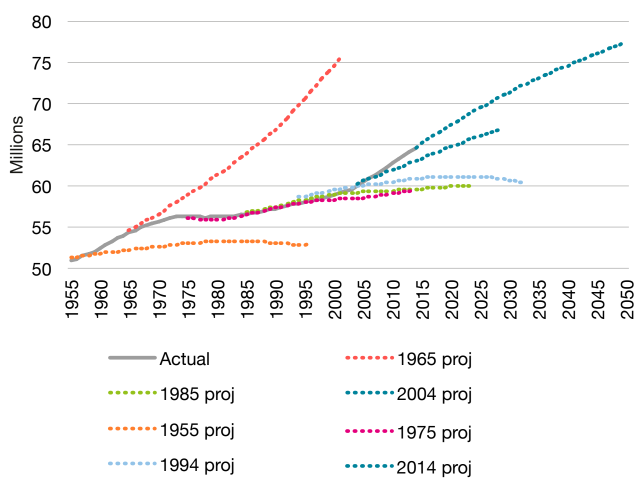
	2014	2050	Growth rate	Avg annual growth
Principal	64.6m	77.5m	19.9%	0.51%
Zero net int. migration	64.6m	67.4m	4.3%	0.12%
High life expectancy	64.6m	79.2m	22.5%	0.57%
Low life expectancy	64.6m	75.7m	17.1%	0.44%
High fertility	64.6m	80.1m	24.0%	0.60%
Low fertility	64.6m	74.5m	15.3%	0.40%
High migration	64.6m	81.3m	25.8%	0.64%
Low migration	64.6m	73.7m	14.0%	0.37%

Figure 8 below shows how historic ONS projections have fared. Some projections proved wide of the mark. The 1955 projection missed the baby boom, the 1965 projection assumed a continuation of the baby boom fertility rates, and the 1994 projection missed the late 1990s increases in immigration. Projections between the 1970s and late 1990s, however, appear to have performed relatively better as population increased along the trend line, albeit with greater variation in the components of population change.[29]

Figure 7 (left) – ONS population projections including variants (UK, 2014-2050)[30]

Figure 8 (right) – Previous ONS projections versus actual population (UK, 1955-2050)[31]





Trends in net international migration

Historic errors in the population projections have been substantially driven by 'shocks': the baby boom and the rise in migration. The projections are not forecasts and cannot be expected to anticipate future shocks. By definition, shocks are hard to forecast in any methodology. However, in identifying scenarios, it is useful to consider the most plausible and interesting shocks to model. For the total population, migration shocks seem an obvious focus. The most recent ONS projections, for example, were made before the decision to leave the European Union, which may have a significant impact on migration rates, although that is far from certain, as discussed below.

The ONS principal projection assumes that net migration will fall from a high of 330,000 people in 2015 to a stable level of 185,000 people per year by 2021. The high and low immigration scenarios stabilise in 2020 with 265,000 and 105,000 people per year (i.e. +/- 80,000 from the principal projection).[32] Migrants have different characteristics to the general population. As **Figure 9** shows, migrants are typically of working age. Migrants are also more likely to live in London than the general population. Both age and location of the population affect the demand for infrastructure services. So changes in the level of future net migration – whether because of Brexit or for other reasons – will affect the demand for infrastructure, both through their effect on the overall population and because of compositional factors.

Policy, wage and income differences between countries are the primary drivers of international immigration to countries including the UK.[33] The most commonly stated reasons for immigration to the UK are work and formal study.[34] Factors such as social networks (including existing communities of immigrants), culture (including language), and economic ties can change the financial, social, and psychological costs of immigration and affect flows.[35]

International migration is difficult to predict. Although the prediction accuracy of models for different time periods and groups of migrants vary widely (for example, British citizens present a relatively more stable series than EU or non-EU migrants), forecasts of total net migration remain imprecise due to significant potential shocks including government policy, the economic environment in different countries, social factors and military conflicts.[36,37]

Figure 9: Annual net migration flows by age group (UK, 1975-2014)[38]

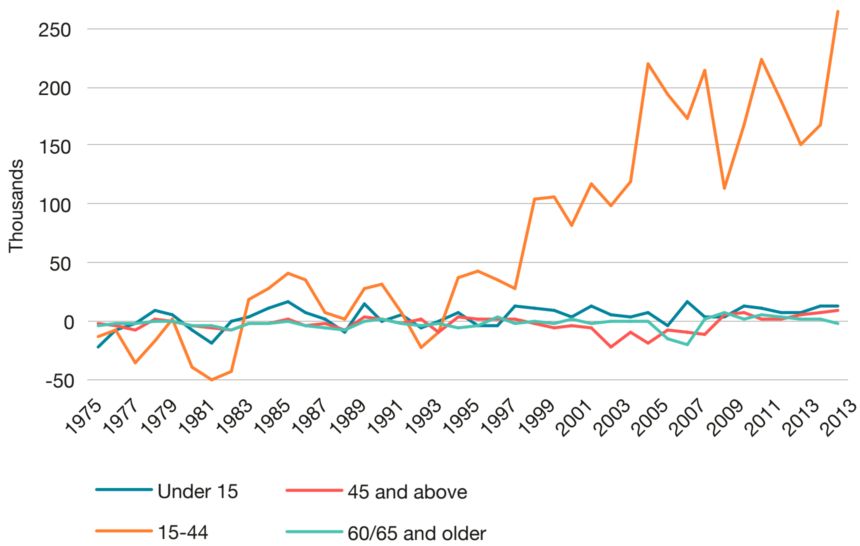
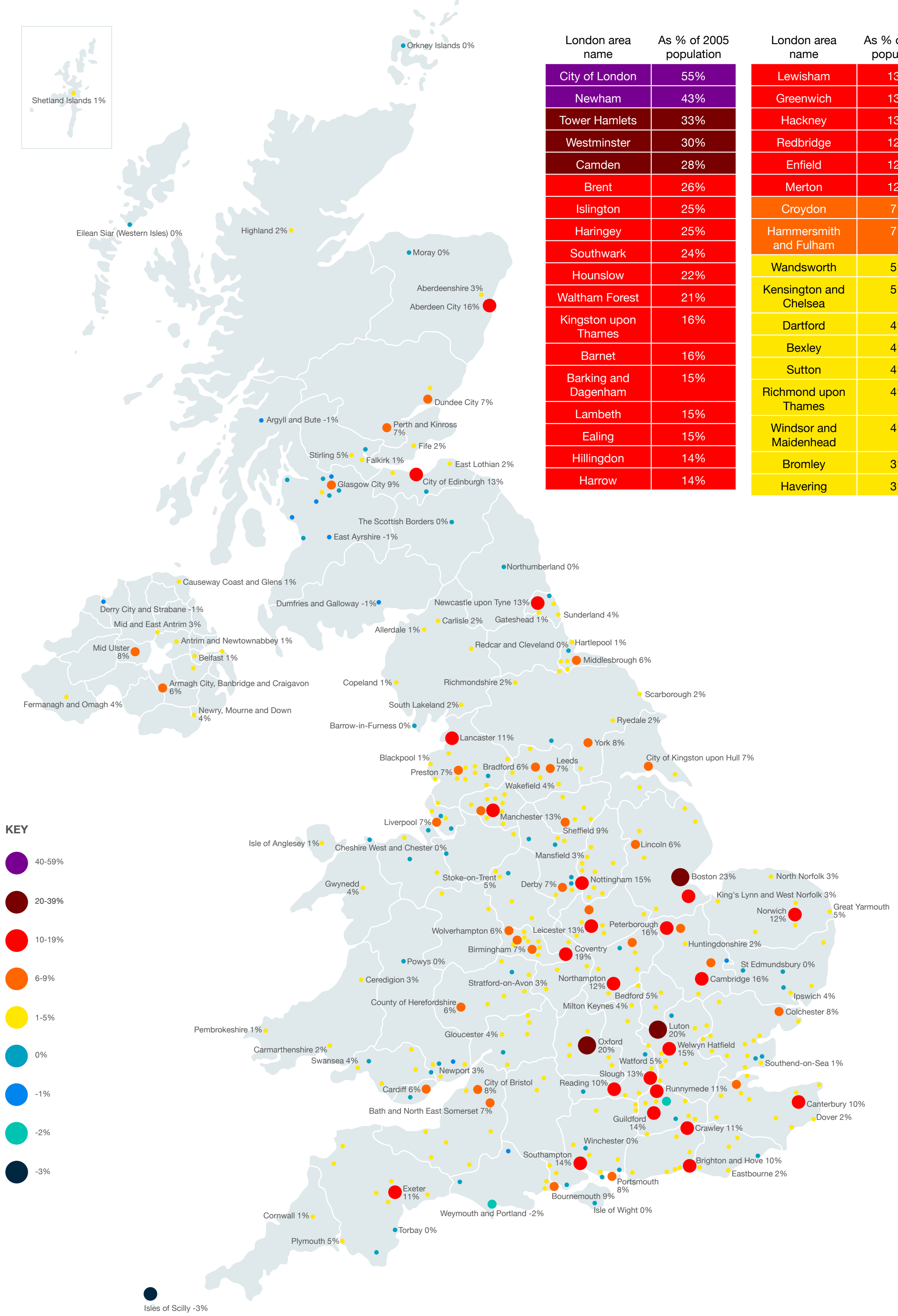


Figure 10: Net international migration by local authority as % of population (UK, 2005-2015)[39]

London area name	As % of 2005 population
City of London	55%
Newham	43%
Tower Hamlets	33%
Westminster	30%
Camden	28%
Brent	26%
Islington	25%
Haringey	25%
Southwark	24%
Hounslow	22%
Waltham Forest	21%
Kingston upon Thames	16%
Barnet	16%
Barking and Dagenham	15%
Lambeth	15%
Ealing	15%
Hillingdon	14%
Harrow	14%

London area name	As % of 2005 population
Lewisham	13%
Greenwich	13%
Hackney	13%
Redbridge	12%
Enfield	12%
Merton	12%
Croydon	7%
Hammersmith and Fulham	7%
Wandsworth	5%
Kensington and Chelsea	5%
Dartford	4%
Bexley	4%
Sutton	4%
Richmond upon Thames	4%
Windsor and Maidenhead	4%
Bromley	3%
Havering	3%



The decision to leave the European Union is likely to have an effect on future migration flows, but it is not currently possible to estimate what that might be. One simple benchmark is the level of migration in other advanced economies that are not members of the EU, although it is worth remembering that a wide range of factors will affect this. **Table 4** below shows the proportion of the population that were foreign born and the rate of long-term inward migration as a proportion of the total population in the UK and OECD member states that do not have free movement of labour with the EU, in 2014. The UK has much higher levels of migration, on either measure, than Mexico, Japan or South Korea. But lower rates than Canada, Australia and New Zealand.

Table 4: International migration comparisons (2014)[40]

Country	Proportion of foreign-born in the population, 2014 (%)	Long-term inward migration flow as a proportion of the population, 2014 (%)
Mexico	1	0.04
Japan	2	0.05
Turkey	2	n/a
South Korea	2	0.15
Chile	2	0.78
Iceland	11	1.33
UK	**13**	**0.49**
United States	13	0.32
Canada	20	0.74
Israel	23	0.30
New Zealand	28	1.21
Australia	29	1.00

Conclusion

The higher the population, the greater the demands placed on infrastructure will tend to be. So having an understanding of the possible paths for the future population is a key input into developing scenarios for possible future infrastructure demand.

The starting point is the ONS central population projection, the main official projection from the UK's independent statistical body. This would imply population growth of 0.51% per year, on average, to leave the population at 77.5 million in 2050, compared to 64.6 million in 2014.

However, the historical data show that population growth rates can vary significantly, both up and down, in ways that are hard to predict. It is therefore sensible to include variants on this central projection that reflect higher and lower possible growth rates.

Given the current uncertainty around the UK's migration policy, the ONS low migration variant is an obvious choice for a lower population projection. This would imply population growth of 0.37% per year, on average, to leave the population at 73.7 million in 2050. This would be similar to the growth rate from the mid-1980s to the early 2000s and below the long-term average since the 1850s.

The choice of a higher growth variant is less clear-cut. The ONS provide variants to 2050 with higher migration, higher fertility or higher life expectancy. Past experience suggests upward shocks to any of these variables could happen. These three variants have similar rates of implied population growth, on average, at 0.64%, 0.60% and 0.57% respectively, which would leave the population at 81.3 million, 80.1 million or 79.2 million in 2050. These growth rates are close to the long-run average since the 1850s and somewhat below the unusually high rates of recent years. They are also similar to the 1960s.

In terms of overall population, the three variants are sufficiently similar that the choice between them is unlikely to make any significant difference to forecasts of infrastructure service demand. Infrastructure service demand varies by age, as set out below. So the differing age structures would have some implications, with more working age people, children and older people respectively in the high migration, high fertility and high life expectancy variants. This variation in age structure is explored in more detail in chapter 4 (see **Table 6** page 19). In particular, peak demand for energy and transport would be lower in a scenario with more older people, providing less of a difference from the central projection.

Given these similar overall numbers, the Commission proposes to make a pragmatic choice. The ONS have produced sub-national projections for the high fertility variant up to 2039 as an experimental variant for England, but not for the high migration and high life expectancy variants. Sub-national projections allow the geographical implications of population growth to be analysed as well as the overall number of people. The Commission is therefore inclined to use the high fertility variant as a higher population variant.

3. WHERE WILL PEOPLE LIVE?

Infrastructure use varies across different locations. The recent geographical pattern of population growth reflects an urban recovery after a long period of relative decline. As **Table 5** below shows most of the UK's larger cities were in decline in the 1980s and 1990s. It is interesting to note that many major commentators at that time hypothesised the loss of economic rationale for cities.[41] These trends reversed from the 1990s: London's population has grown particularly strongly. In other major cities, the recovery from decline has been less pronounced and more variable, but in almost all cases population growth was stronger in the 2000s than in the 1990s.

Table 5: Population growth in the largest 10 cities (UK, 1981-2014)[42,43]

		Growth rate (%)				Growth 1981-2014
City	**Population 2014**	**1981-1991**	**1991-2001**	**2001-2011**	**2011-2014**	
London	9,752,000	0.3%	6.9%	11.5%	3.9%	24%
Birmingham	2,471,000	-2.1%	-2.1%	7.0%	2.0%	5%
Manchester	2,412,000	-2.7%	-1.5%	6.9%	1.9%	4%
Glasgow	973,000	-8.0%	-5.2%	1.5%	1.0%	-11%
Newcastle	842,000	-3.5%	-3.1%	3.3%	1.6%	-2%
Sheffield	824,000	-3.4%	-1.6%	6.3%	1.8%	3%
Leeds	766,000	-1.5%	1.3%	4.9%	2.1%	7%
Bristol	714,000	1.7%	3.5%	8.7%	3.3%	18%
Nottingham	656,000	1.7%	-1.1%	6.9%	2.5%	10%
Liverpool	620,000	-8.7%	-6.0%	3.1%	1.3%	-10%

These trends were partly driven by infrastructure – the rise of the car in the post-war period made it easier for people to move out of cities by lowering transport costs. In 1961, only 31% of households in England had access to a car/van, but by 1991 this had risen to 68%.[44] These trends were also influenced by changes in economic structure. The decline of manufacturing led to jobs and people moving out of large cities.[45] Policy was another important driver, with new towns built and slums cleared to encourage people to move out of cities.

Since the 1990s, however, a new pattern has been seen.[46] The benefits of firms in knowledge-based services clustering together in close proximity has made city centres attractive places for firms to locate, leading to a revival in many cities' fortunes. These "agglomeration" effects are discussed in more detail in the economy driver paper. Cities also became more attractive places to live as more highly skilled workers moved in, areas from the industrial past were regenerated and cultural and leisure amenities grew.[47] Significant increases in student numbers may also have played a role.[48] City centres in particular are growing quickly with population growth of 37% between 2001 and 2011.[49] This compares to 8% and 6% population growth for suburbs and hinterlands over the same period.

Alongside these trends in urbanisation, there has been a shift of population from the north to the south[50] of the country. From 1971-2011, the five regions of the south grew by almost 6 million or 81% of the total growth in this period.[51] In recent years internal migration from north to south has slowed. However, higher numbers of migrants and greater rates of natural change (births minus deaths) meant that population growth in the south has continued to outpace that seen in the north. Although the reasons are not yet clearly identified, explanations for the attenuation of north-south migration include more rapid growth in housing costs in the south.[52]

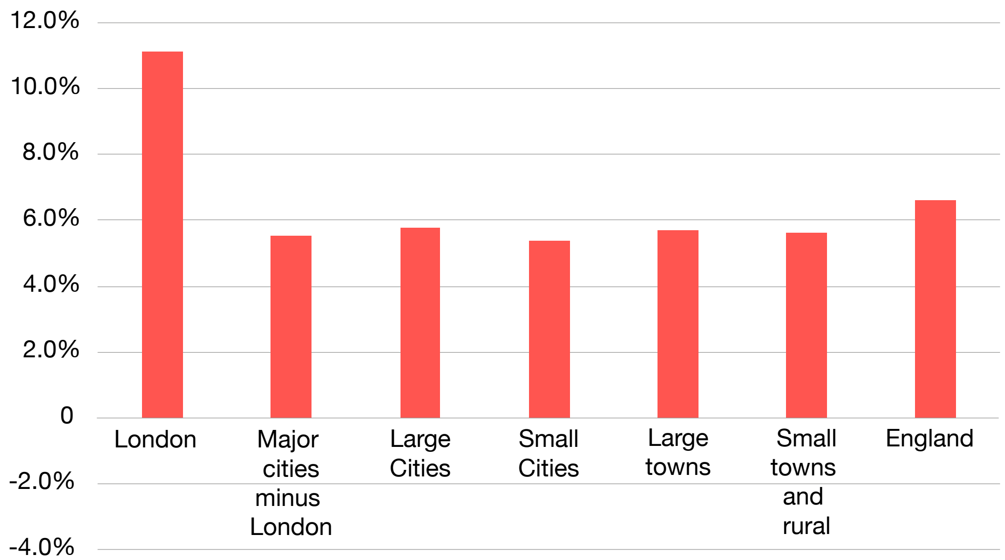
There is also a growing divide in demographics between the regions, particularly around age and education. In 2004 the population aged 16-64 with higher education in the south was 27.8% vs. 22.8% in the north. By 2015, the same figure was 40.0% and 31.5% in the south and north.[53]

Subnational projections

The ONS publish 25-year subnational projections using local authority census and estimates data, which are constrained to match the total population in the national projection. They take into account fertility, mortality, internal migration, and international migration trend data. They do not take into account factors such as housing, employment locations or Government policy, although local authorities must submit housing plans based on official household projections. The ONS also publish experimental variants for high fertility and zero net international migration of the 25-year subnational population projections for England.

The ONS central projection implies further significant increases in London's population from 9.8 million to 12.5 million by 2039.[54] This implies that London would take 30% of population growth in England,[55] although it only made up 18% of England's population in 2014. The remaining projected growth is spread across cities, towns and rural areas roughly in line with their current population shares, though projected growth for individual settlements within each category vary. In the ONS zero net migration projection, London's population would rise to 11.1 million by 2039 and in the ONS high fertility projection, it would rise to 12.7 million.[56]

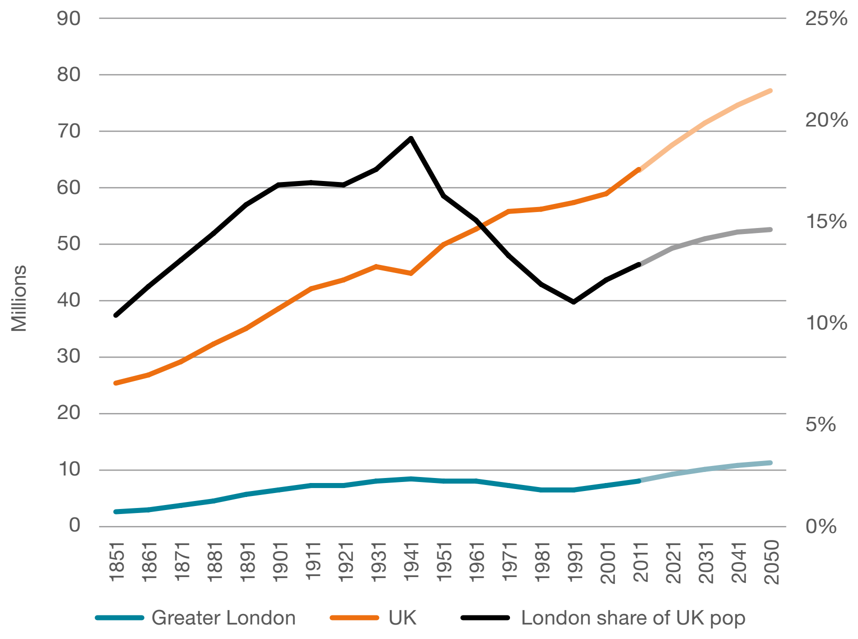
Figure 11: Average population growth rate per decade by settlement type (England, ONS central projection, 2014-2039)[57]



'Zipf's law' – an alternative perspective for where people will live

The very strong growth of London's population in the sub-national projections reflect London's pattern of strong growth in recent years. However, the relative growth of different cities tends to vary over longer time periods. For example, as shown in **Figure 12**, London's share of the total UK population rose in the years from the beginning of the twentieth century until World War 2 before falling until the early 1990s and rising since.[58] The projected share of London in the population keeps rising until the 2040s when it stabilises at about 15%.

Figure 12: London's population as a share of the UK population (GLA[59], UK[60] 1851 – 2050)



It is inevitably difficult to know what future shocks might arise. One possibility is that the economic forces that have driven a revival of cities, based on knowledge-based services and agglomeration effects, could attenuate or reverse. Alternatively, these forces may drive a continued urban revival with some of the UK's other major cities 'catching up' with London in population growth rates.

London's population growth may slow because of rising congestion, pollution and house prices or because of changes in net international migration. However there is uncertainty about how a slowdown of international net migration into London may impact on internal migration and therefore affect London's growth. Currently there is a significant internal migration away from London and other urban areas, but we don't know whether this trend would continue in case of lower international migration.

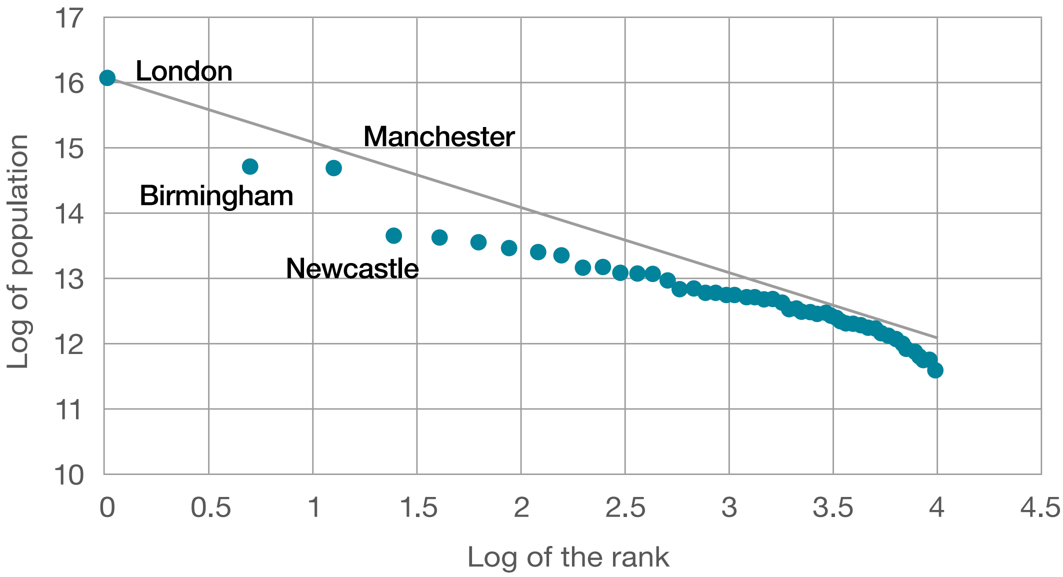
Certain statistical regularities emerge in the patterns of relative city sizes across time and between countries. While there are many different factors that contribute to the size of cities and their growth, two statistical relationships are often observed:

- 'Gibrat's law' states that the growth rates of cities are independent of a city's initial size;
- 'Zipf's law' is a statistical relationship between city size and rank. In its simplest form, it implies that the second largest city is half the size of the largest city, the third largest city a third the size of the largest city, and so on.

The two relationships can be shown to be consistent with each other.[61] A number of studies have shown that these relationships hold, at least approximately.[62] For example, Klein and Leunig show that Gibrat's law holds for cities in England and Wales throughout the nineteenth century, despite the very significant economic changes taking place.[63] Davis and Weinstein show that Zipf's law holds reasonably well for Japanese regions over 8,000 years of history, with the exception of the period in the eighteenth and nineteenth centuries when Japan was closed to external trade.[64]

Figure 13 shows Zipf's law for English cities in 2014. This demonstrates that England's major cities other than London are smaller than might be expected, compared both to London and to the long tail of medium-sized cities that roughly fit the line. Birmingham and Newcastle would have to grow by 2.4 and 1.6 million respectively to fit along the curve.[65]

Figure 13: Zipf's law for UK cities: Zipf plot, log of city population versus log of city population rank order (UK, 2014)[66]



However, it is unclear whether the relationship holds exactly as described.[67] The capital city is arguably different to other cities – indeed it is often an outlier for many countries when drawing the Zipf curve.[68] Acemoglu and Robinson argue that the size of the capital city is partly determined by the degree of political centralisation within a country.[69] England's long history as a centralised state within roughly continuous borders – dating back to Alfred the Great's grandson, Athelstan in the 10th century[70] – may have contributed to London's much larger size relative to other cities.

Conclusion

Infrastructure is inherently spatial. Demands placed on infrastructure will vary according to where people live. So having an understanding of the possible paths for where people will live is a key input into developing scenarios for possible future infrastructure demand.

The starting point is the ONS sub-national population projections, the main official projection from the UK's independent statistical body. This would imply a disproportionate level of growth in London, with growth fairly evenly spread elsewhere.

However, the historical data show that geographical patterns can vary significantly, with London and other cities having experienced periods of decline as well as growth. It is therefore sensible to include a variant on these projections.

A number of options could be chosen, for example a reversal of urbanisation or even stronger growth in London's population. However, the growth in London's population in recent years makes it an outlier within the UK. Long-term statistical regularities – Gibrat's and Zipf's laws – while certainly not definitive suggest this may not be sustained. A variant with lower growth in London, and correspondingly higher growth elsewhere in the country, would reflect this.

The Commission is therefore inclined to develop a set of sub-national projections that would be consistent with the ONS central projection for the total population, but would have slower growth in London and faster growth elsewhere. One possible way of calculating this would be to link growth rates across areas to trends in house building, since people can only live where there are properties for them to live in. Shortages of housing will bid up property prices and encourage people to move elsewhere. While this would inevitably be a simplified model of the complex interactions between housing and people's choice of where to live, it might capture a key driver of location choice.

4. AGE, HOUSEHOLD SIZE AND BEHAVIOUR CHANGE

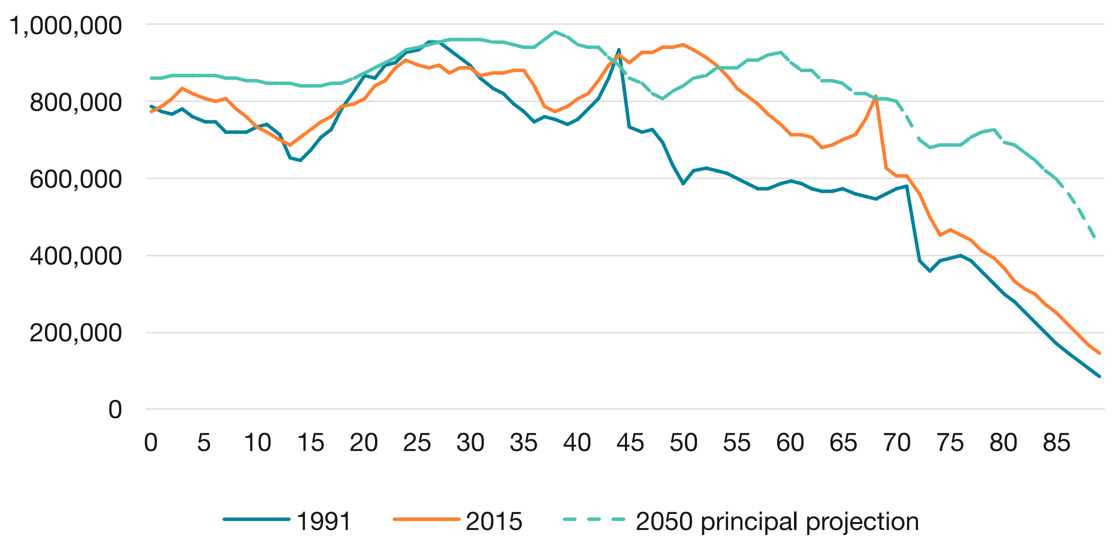
Section 1 above showed that infrastructure use varies across age groups and by household size. For example, older people currently travel less and are less likely to use transport and energy at peak times than younger people, both children and working age. These will therefore be factors which influence future infrastructure demand. ONS population projections provide detailed age breakdowns, and projections of household formation are published by the Department for Communities and Local Government (DCLG), allowing both to be taken into account to inform our forecasting and scenario planning.

Some differences in infrastructure use by age may reflect retirement ages rather than age itself. The Government has legislated to increase the state pension age to 68 by 2046. A review of the state pension age is currently underway and is due to report by May 2017. However, most of the increase in the older population is among the over 70s, so the impact of ageing on infrastructure service demand is likely to remain similar unless the state pension age exceeds 70 before 2050.

As shown in **Table 6** below, the ONS central projection shows population growth between 2015 and 2050 for the over 65s of 7.8 million compared to growth of 3.1 million for people of working age (16-64) and 1.5 million for those under 16.[71] The growth in the over 65 population remains fairly consistent across the ONS variants. In contrast, the working age and child populations are less certain as they are affected more by rates of migration and fertility. These have much larger impacts on population numbers in the variants than differences in life expectancy.

Figure 14 and **Table 6** show the population by age for 1991, 2015 and the projections for 2050. Whereas 59% of the increase in population over the last 25 years has been in the working age population, 63% of the projected increase for the next 35 years is in the over 65s. Even in the high migration variant this is still 50%.

Figure 14: Population by age, UK, 1991, 2015, and 2050 principal projection[72]



In the low net migration scenario, the total number of people of working age would be roughly constant. With zero net migration, the total number of people of working age would fall by 10%.

Table 6: Population and share of population by age group and projection variant (UK, 1991-2050)[73]

		Population (millions)				Share of population (%)		
		Under 16	16-64	65 and over	Total	Under 16	16-64	65 and over
1991		11.7	36.7	9.1	57.4	20%	64%	16%
2015		12.3	41.2	11.6	65.1	19%	63%	18%
2050	Principal Projection	13.7	44.4	19.4	77.5	18%	57%	25%
	High Migration	14.5	47.1	19.7	81.3	18%	58%	24%
	Low Migration	13.0	41.6	19.1	73.7	18%	56%	26%
	Zero Migration	11.3	37.2	19.0	67.4	17%	55%	28%
	High Fertility	15.3	45.4	19.4	80.1	19%	57%	24%
	Low Fertility	12.1	43.0	19.4	74.5	16%	58%	26%
	High life expectancy	13.7	44.5	20.9	79.2	17%	56%	26%
	Low life expectancy	13.8	44.2	17.8	75.7	18%	58%	23%

Households

As set out in Section 1, as the average size of households in the UK changes, this will have an impact on demand for infrastructure services. For example, bigger households use less energy and water per person than smaller households.

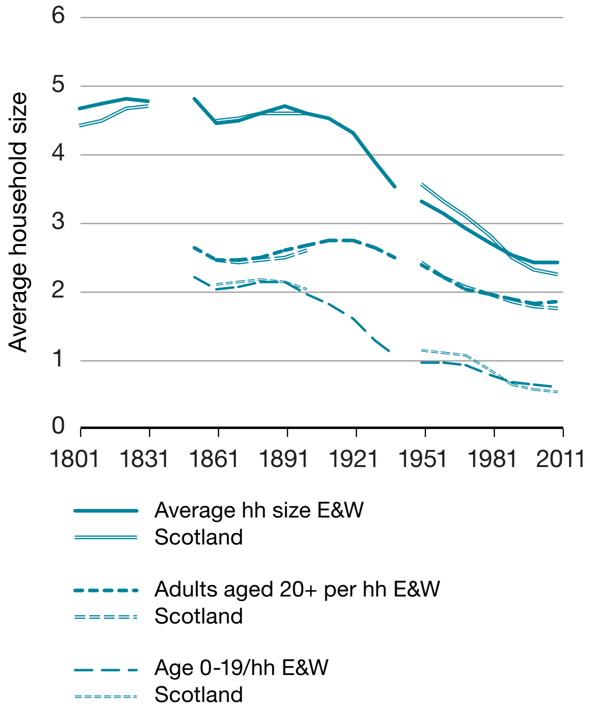
Figure 15 below shows that the average number of people living in each household in the UK fell through most of the 20th century. The average household size fell from 4.3 in 1921 to 2.4 in 2001.[74] This was mainly due to falls in the number of children per household over the course of the twentieth century, but changes in family structure and increases in the numbers of older people (who are more likely to live alone) also led to a reduction in the average number of adults in each household.

However, average household size has not continued on this declining trend in the 2000s. In England and Wales, household size remained roughly at 2.4 persons per household in both the 2001 and 2011 census. In some areas household sizes went up – for example, London and Birmingham increased by 3.4% and 1.3%, with even higher growth rates seen in some of their constituent local authorities.[75] **Figure 16** shows that there has been a steady rise in one and two-person households. However, the growth of 1-2 person households stalled in England and fell in London between 2001 and 2011. It is likely that this was driven in part by steep increases in the cost of housing.

DCLG's 2014-based household projections indicate that the number of households in England is projected to increase from 22.7 million in 2014 to 28.0 million in 2039, equivalent to an average annual household growth of 210,000 per year.[76] The average household size is projected to fall from 2.35 in 2014 to 2.21 in 2039, or by 6%. Although this varies by local authority, virtually all local authorities are projected to see a fall in household size, including those that have seen some increases in household size over the last decade. This is largely a result of the projections taking into account an ageing population and the tendency of older people to live in smaller households.

Figure 15 (left): Average household size (England and Wales, and Scotland, 1801-2011)[77]

Figure 16 (right): One and two person households, as % of all households (UK countries and London, 1961-2011)[78]



Behaviour change

People's demand for infrastructure services is not fixed, but can change over time. Most obviously it tends to increase with higher incomes, and this relationship is explored in the Commission's economy driver paper. Changes in behaviour, for example as a result of new technologies or new infrastructure services becoming available, can also have an impact, which is explored in the Commission's technology driver paper. Historically, a number of substantial behavioural changes of this kind have been seen:

- The invention of gas and kerosene lighting lengthened the working day and even led to changes in sleeping patterns[79]
- The shape of cities and the development of suburbs were driven by changes in transport technology, particularly the electric tram[80] and then the motor car[81]
- The telephone may have contributed to people living in smaller households, because they could remain in contact with their extended family without sharing a home[82]

Policy interventions can also lead to behavioural change, for example:

- recycling rates are generally found to be related to the availability of easy-to-use recycling services, such as kerbside recycling[83]
- the introduction of the London congestion charge reduced the number of cars, vans and trucks coming into central London by 27% between 2002 (before the charge) and 2003 (after). Bus passengers entering the charging zone increased by 38% (the charge was accompanied by increases in bus service provision).[84]

However, many behavioural changes are simply due to natural processes of social change. For example, successive cohorts of women, particularly older women, drive more than previous cohorts.[85] This is likely to reflect changing attitudes to women driving over time, particularly when these women became old enough to obtain a driving licence.

Conclusion

Along with the number and location of the population, some demographic factors affect the demands placed on infrastructure. Older people make different use of some services, such as transport, than younger people, and some services, such as heating, are more efficiently provided per person in larger households than smaller ones. These factors are therefore important to consider in developing scenarios for possible future infrastructure demand. Changes in behaviour can also have significant impacts on infrastructure demand.

The ONS population projections include detailed age breakdowns. The variants discussed above in sections 2 and 3 therefore already include variations in the age composition of the population. For instance the growth in the over 65 population is mainly affected by the life expectancy assumption and remains fairly consistent across the other ONS variants. However the proportion of older people in the total population depends on the comparative growth with respect to other segments of the population and it is higher in the low fertility and zero/low migration variants as well as the high life expectancy one. The Commission is therefore inclined to use this embedded variation in age composition in the different variants to account for possible changes in the age structure of the population in its scenarios.

Household size will have an impact on demand for infrastructure services, but for modelling purposes the Commission will assume that household size will evolve as per DCLG's projections across all scenarios.

Behaviour change is very hard to forecast. The Commission does not therefore propose to develop scenarios based explicitly on behavioural change. Instead, the Commission will consider the extent to which its scenario-based modelling is sensitive to key parameters that might change through behavioural change. In considering its recommendations, the Commission will draw upon this to ensure that it takes into account the possibilities for behavioural change and the consequences of this.

5. FEEDBACK FROM INFRASTRUCTURE TO THE POPULATION

The direction of causation between population and infrastructure demand is not necessarily one-way. Historically, the development of clean water and sewerage were significant causes of increased life expectancy.[86] Future infrastructure provision and usage is unlikely to have such significant effects on the overall population level, nor the age distribution, but it has potentially more significant effects on location decisions.

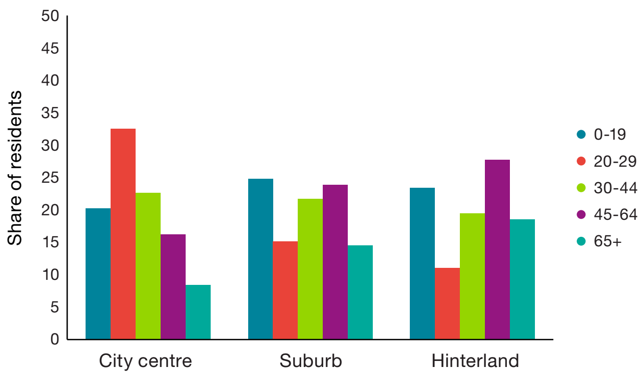
Infrastructure and location

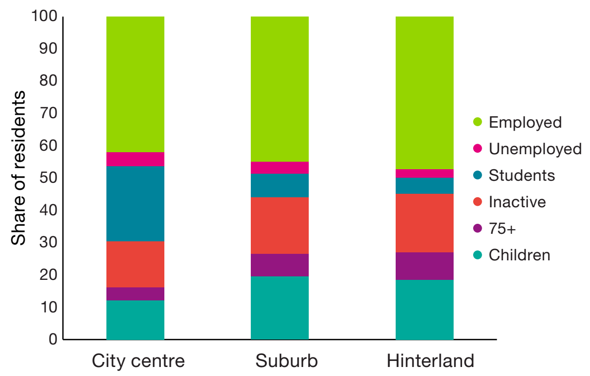
People's location choices are affected by a range of factors, especially access to jobs and house prices and availability.[87] High house prices are found to drive people to move to neighbouring areas while maintaining access to jobs.[88] Other important factors include access to amenities and facilities. People's location choices change with age. Those living in the centres of large cities are most likely to be young students or professionals who value the access they provide to leisure and cultural amenities/facilities, the workplace and public transport.[89] Smaller and medium sized cities are also home to families and to those working in non-professional occupations who may benefit from the availability of cheaper housing. In the suburbs, families are the dominant group as a result of the cost and type of housing, access to schools, and attractiveness of neighbourhoods. In rural hinterlands, those aged 55 and over make up the majority of the population and generally live there to be close to the countryside.

Infrastructure is most likely to affect location choices through its impact on the local economy and hence employment and wages. These issues are discussed in the economy driver paper.

Figure 17 (left): Share of residents by age and location (England and Wales, 2011)[90]

Figure 18 (right): Share of residents by economic activity and location (England and Wales, 2011)[91]





Access to transport infrastructure also makes areas more attractive. This can be observed by higher house prices in areas near major transport corridors.[92] One study found the Jubilee line and Docklands Light railway extensions in South East London in the late 1990s increased house prices in affected areas by 9.3%, and that people were willing to pay 1.5% more for a house for a 1km reduction in distance from a station on the line.[93] When asked why people have chosen to live where they do, availability of public transport and being close to the workplace commonly emerge as some of the most important factors.[94] However, people also value lower congestion[95] and lower levels of transport-related noise.[96]

Other infrastructure services may affect location choices. Data is increasingly available on broadband speeds and flood risk at postcode level. However, the Commission have not identified clear evidence on whether this has a substantial impact on location choices.

Housing

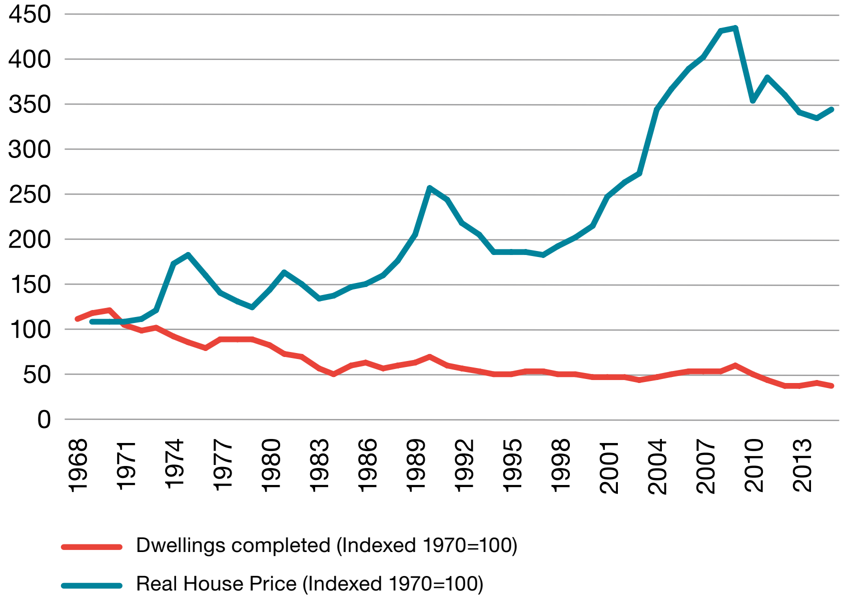
The most significant impacts of infrastructure on where people live are likely to be through the interaction between infrastructure and housing. Ultimately, people can only live where there is housing. Housing, in turn, requires infrastructure.

One example of new housing and infrastructure impacting the location of population are the New Towns built in the post-war decades. Government policy resulted in twenty-seven 'new towns' between 1946 and 1969.[97] The New Towns have seen some of the highest growth rates in the UK since the 1980s. The biggest of them, Milton Keynes, had a population of 260,000 people in 2014.[98]

Infrastructure, however, is just one factor in the growth of these New Towns, and infrastructure provision does not guarantee housing growth. Plans to build homes at Ebbsfleet since 1996 (in light of the major HS1 station that opened there in 2007) have not taken off for various reasons despite the area benefiting from fast and reliable rail services to central London via the High Speed One line.

The number of new houses built in England has averaged around 150,000 per year since the early 1980s, significantly below the numbers built in earlier decades.[99] As **Figure 19** shows, this reduction in house building has occurred despite significant increases in house prices.

Figure 19: Housing completions and real house prices (UK,)[100]



There is also a mismatch between where the houses are built within the country and where the population is growing fastest. **Table 7** below shows that the net increase in houses available compared to population growth in the area in all the regions of the south is lower than the average increase in the north and significantly lower compared to the north west and the north east. London in particular saw the greatest deficit of housing increases versus population growth. Other major cities are also seeing larger deficits compared to neighbouring areas.[101]

Table 7 – Net dwellings and population growth (England, 1991–2014)[102]

Region	Net dwellings (000s)	Population increase (000s)	Net dwellings over population growth
North East	48	53	0.90
North West	179	273	0.66
Yorkshire and Humber	165	298	0.55
West Midlands	141	317	0.45
East Midlands	175	334	0.52
East of England	209	455	0.46
London	268	875	0.31
South East	303	631	0.48
South West	182	360	0.51
England	1670	3595	0.46

Conclusion

Quantitative models of infrastructure demand tend to treat the population as a purely external driver of demand. This seems a reasonable assumption for the total population and its age structure in future, although historically infrastructure played a significant role in increases in life expectancy. However, location decisions are potentially more complex.

Transport infrastructure in particular is a determinant of where people choose to live, with people generally preferring to live near to transport hubs. Infrastructure is also necessary, but not sufficient, for house building and people can ultimately only live where there is housing.

Detailed modelling of these feedback loops is beyond the Commission's current modelling capabilities. Instead, as set out above, the Commission is inclined to develop a set of sub-national projections that would be consistent with the ONS central projection for the total population, but would have slower growth in London and faster growth elsewhere. One possible way of calculating this would be to link growth rates across areas to trends in house building. This would not fully capture the opportunity for new housing created by new transport infrastructure, so it will also be important to try to capture this in considering the case for proposed new investments.

There may be similar feedback loops with other infrastructure, such as digital and flood defence infrastructure. The Commission would be interested in any robust quantified estimates of the size of such effects that may be available.

6. CONCLUSION

Population is a key driver of infrastructure service demand. Over the National Infrastructure Assessment's horizon to 2050, significant changes in population can be expected. Understanding these will help the Commission to develop scenarios reflecting the range of possible futures. Both the number of people and the location of the population will affect demand. Demographic and behavioural changes also matter. Increases in demand can be met by a range of possible policies, including demand management and greater efficiency, as well as increases in supply.

An increase in the total population, driven by a large increase in the number of older people, is likely. The size of the working age population is harder to predict. It will vary more with the rate of migration, which is particularly uncertain.

Recent trends would imply a continued urban revival. London's population is projected to rise particularly strongly. But longer historical trends and comparisons with statistical regularities in city size distributions imply this is uncertain. Housing policy is likely to play a particularly strong role here, since people can only ultimately live where there are houses for them to live in. Under any of the variants considered here, it is unlikely that house prices will stabilise without a significant increase in rates of house building.

Infrastructure choices in turn can affect the population, especially location choices. There is a close link between transport and housing. This feedback loop will be considered by the Commission in deciding on policy options.

Based on the analysis in this paper, using the following population projections as inputs into scenario development should reflect the significant uncertainty around future population. These variants are not inherently more likely than others, but should rather span the range of plausible outcomes:

- The ONS central population projection – 77.5m in 2050
- The ONS low migration population variant – 73.7m in 2050
- The ONS high fertility population variant – 80.1m in 2050
- A projection based on the aggregate population in the ONS central projection, but with sub-national populations less skewed towards London, with the shift in population distribution motivated by trends in house building

Quantified scenarios allow consideration of the inherent uncertainty of future outcomes and enable modelling of policy options. The options above are intended to cover the range of realistic possible outcomes based on the analysis in this paper. Variants for the total population reflect uncertainty in the level of UK-wide demand, which will arise directly from people using infrastructure services themselves, and indirectly through those elements of business, government and third sector demand which relate to the size of the population. Variants for where people live reflect the uncertainty in location-specific demand. Scenarios using these inputs should ensure that potential infrastructure investments are tested against the range of plausible uncertainties in future demand arising from these key dimensions of population and demography. These variants also have different implications for the age structure of the population, so they should allow age-related factors to be taken into consideration.

The drivers also should not be thought of in isolation: the impact of changes in population and demography will need to be considered in context alongside other drivers of infrastructure demand and supply, notably technological, economic and environmental change.

The Commission would welcome comments on this discussion paper, including the proposed inputs set out above. In particular, references to further sources of evidence on these issues would be helpful. Please send any comments to **NICdiscussionpapers@nic.gsi.gov.uk** by 10th February 2017.

Further information on the overall scope and methodology of the National Infrastructure Assessment is available **here**.

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92. Cheshire and Shepperd (1995) *On the price of land and the value of amenities*, Economica, vol. 62, 247-67
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94. Ibid 89 – Centre for Cities (2015c)
95. Tang (2016) *Traffic externalities and housing prices: evidence from the London Congestion Charge*, Spatial Economics Research Centre discussion paper 205
96. Day, Bateman and Lake (2006) *Estimating the demand for peace and quiet using property market data*, CSERGE Working Paper EDM 06-03, UEA
97. Including the Commuter towns to London: **Stevenage**, **Crawley**, **Hemel Hempstead**, **Harlow**, **Hatfield**, **Basildon**, **Bracknell** and **Milton Keynes. Others including Newton, Aycliffe**, **Peterlee**, **Washington**, **Skelmersdale, Runcorn**, **Corby**, **Telford**, **Redditch, Cwmbran**, **East Kilbride, Glenrothes, Cumbernauld, Livingston and Irvine. Towns that were expanded under the new towns act were Peterborough, Northampton, Warrington, Ipswich, and Preston-Leyland-Chorley**
98. Centre for Cities Data Tool
99. DCLG housing statistics
100. DCLG housing statistics, and Land Registry UK House price index
101. Calculated from DCLG Housing Statistics
102. Calculated from DCLG Housing Statistics