ECONOMIC GROWTH AND DEMAND FOR INFRASTRUCTURE SERVICES

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

An important objective for the Commission's analysis of economic growth is to inform the inputs that the Commission will use in developing scenarios. The starting point for the economic growth inputs are Office for Budget Responsibility (OBR) long-term growth projections. The OBR provide 50-year economic and fiscal projections in their Fiscal Sustainability Report (FSR). The remit for the Commission requires the Commission to use the OBR's FSR projections for its 'fiscal remit', a limit set by Government on the level of public expenditure on infrastructure within which the Commission is required to make recommendations.[1]

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

- Long-term average growth of GDP per capita of 1.9% per year, based on the latest OBR long-term economic growth projections in the 2017 Fiscal Sustainability Report;
- More modest growth, of GDP per capita of 1.7% per year based on projecting forward the trend rate of productivity growth at the end of the five year forecast horizon of the OBR's November 2016 Economic and Fiscal Outlook;
- Much weaker growth, of GDP per capita of 0.7% per year, consistent with very weak productivity growth since 2008 and the arguments of 'techno-pessimists' (see section 2 below). This would also be consistent with projecting forward the OBR "weak productivity" scenario in the November 2016 Economic and Fiscal Outlook.

Table 1: Proposed annual average growth rate (%) inputs to scenarios for productivity, GDP and GDP per capita

	Productivity	GDP[1]	GDP per capita
OBR long-term	2.0	2.3	1.9
Modest growth	1.8	2.2	1.7
Weaker growth	0.8	1.2	0.7

[1]under the ONS 2014-based principal population projection, will vary in other population variants

Economic growth is important to understand because higher incomes tend to lead to higher demand on infrastructure services. Increases in demand can be met by a range of possible policies, including demand management and greater efficiency, as well as increases in supply. Structural changes in the economy may also affect the nature of demand, although these are very hard to predict. Infrastructure choices in turn can affect the rate of economic growth and this paper discusses both directions of causation. The Commission's objectives are wider than economic growth. The Charter for the National Infrastructure Commission sets out three objectives for the Commission:

- Support sustainable economic growth across all regions of the UK;
- Improve competitiveness; and
- Improve quality of life.

When considering infrastructure policy options, the Commission will consider the potential impact across these objectives and not simply the impact on growth. This paper, however, focuses on economic growth.

The paper includes a brief summary of the evidence on the growth impacts of past infrastructure investments. However, it does not consider the policy choices which the Commission will need to consider, nor how options should be appraised in reaching conclusions. A separate workstream within the National Infrastructure Assessment is considering appraisal methods.

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 31 March 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 economic growth; Section 2 assesses what the historic evidence and available forecasts suggest about the possible future paths of growth. Section 3 considers how infrastructure in turn might feed-back to affect growth. Section 4 concludes.

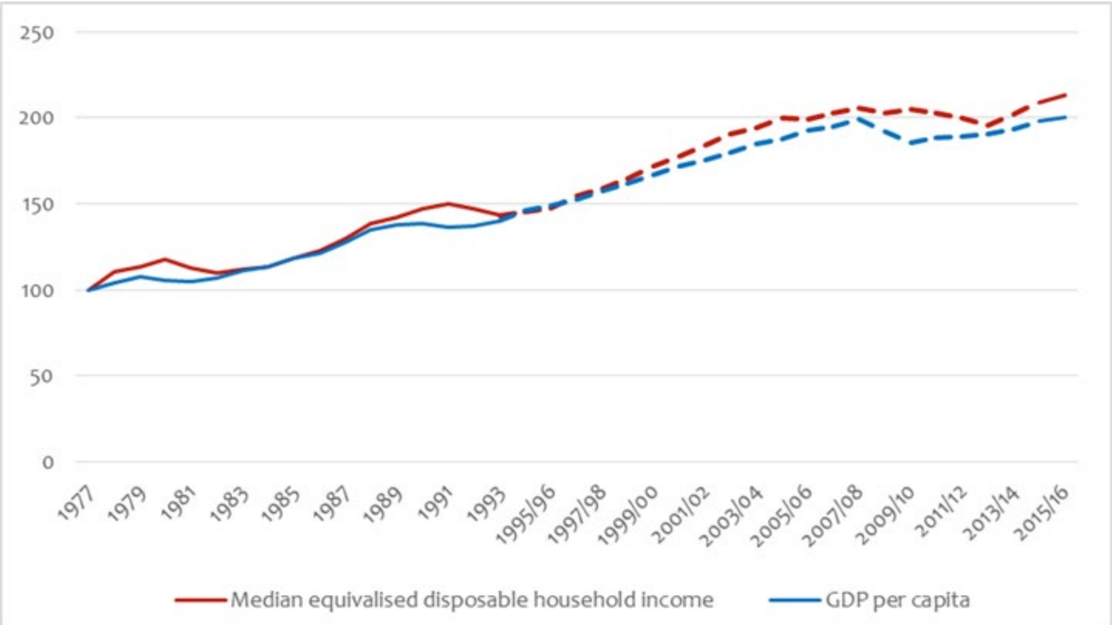
1. HOW DO TRENDS IN ECONOMIC GROWTH AFFECT DEMAND FOR INFRASTRUCTURE?

As people get richer, they generally demand more infrastructure services, consuming more energy and water, producing more waste and travelling more frequently and longer distances. Increased production will also tend to require more infrastructure services as inputs to the production process although the composition of demand will depend on which industry sectors grow most. Growth in services, for example, will affect demand for infrastructure differently to growth in manufacturing. This section considers how increases in growth feed into increases in demand. Section 3 below considers the reverse effect whereby increases in infrastructure provision can lead to increases in growth.

GDP and incomes

Forecasting infrastructure demand requires a consideration of income forecasts, because demand for infrastructure will be affected by income. Most long-term economic forecasts are for Gross Domestic Product (GDP) rather than household incomes. The two measures are closely related, but not identical. Figure 1 below shows the path of GDP per person and median household income for the UK from 1977 to 2015/16.

Figure 1: Growth of median household income and GDP per capita, UK - 1977 to 2015/16



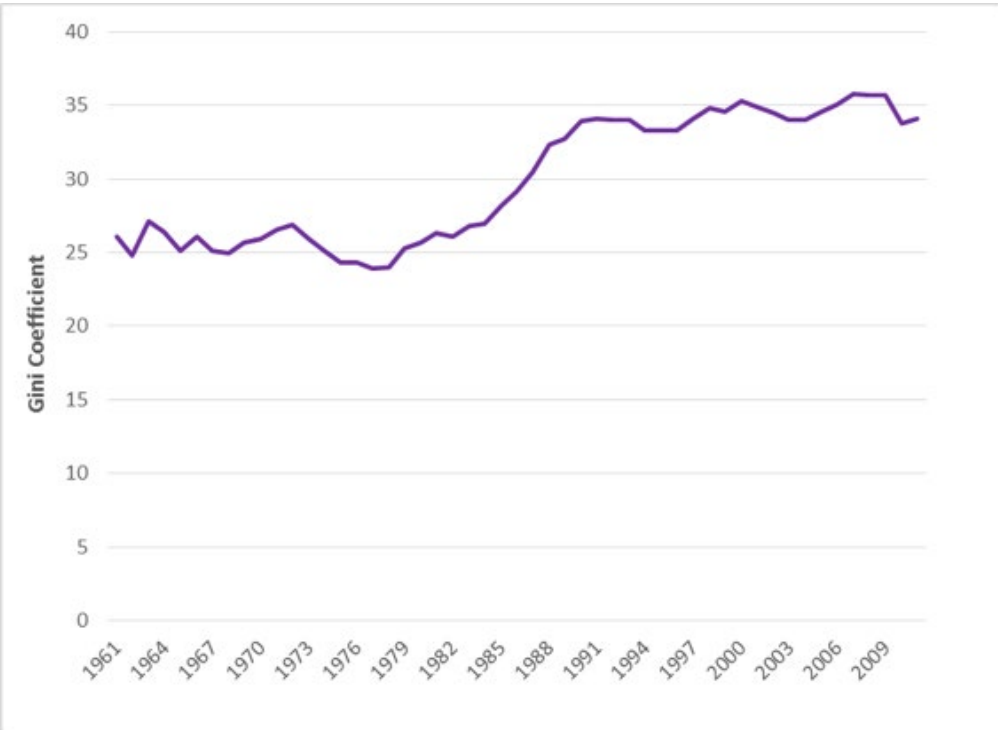
Source: Office for National Statistics[2] for median income and Thomas (2016)[3] for GDP per capita. Note: data on median income are recorded by financial year rather than calendar year from 1994 (indicated with dashes replacing continuous lines); data on GDP per capita have been adjusted accordingly.

Although there is some variation, particularly in the 2000s, the two data series are relatively well correlated, with the growth rates for GDP per capita and median household income averaging to 1.7 and 1.9% per year respectively for the past 30 years. Based on past data, using GDP per capita as a proxy for household income is unlikely to cause significant distortions given the inherent uncertainties already present in long-term forecasting.

A further consideration is whether a shift in the income distribution in the next 30 years could have an impact on demand for infrastructure services. For example, infrastructure service demand might grow less than expected if a greater proportion of GDP were captured by those at the top of the income distribution, who may save more of their income rather than consume it.

Figure 2 reports the Gini coefficient, a measure of inequality, for the period between 1961 and 2013 in the UK.[4] Inequality increased steeply in the early 1980s, after a period of stability in the 1960s and 1970s, and has broadly flattened out since the early 1990s. A future shock – either an increase or a decrease – cannot be ruled out. However, the lack of any trend in recent decades suggests a default assumption that inequality will remain broadly constant in future, unless some shock occurs. Hence, it is a reasonable starting assumption that the shape of the income distribution is not likely to have a significant impact on demand for infrastructure.

Figure 2: Gini coefficient (based on disposable income), UK 1961 - 2013



Source: Atkinson (2014).[5]

Incomes, prices and demand for infrastructure

The demand for infrastructure services reflects individuals' willingness and ability to pay and trade-offs they make between these and other goods and services they could buy. This demand depends on the characteristics and cost of services as well as individuals' income. We would expect demand to fall with higher prices and rise with higher incomes.

These relationships are described by "elasticities". Demand is said to be (income/price) "elastic" if it increases more than proportionately with income or falls more than proportionately with price. It is said to be "inelastic" if it increases less than proportionately with income or falls less than proportionately with price. Hence, if elasticities are low (inelastic), consumers are relatively unresponsive to changes in incomes or prices – their patterns of consumption of infrastructure services do not change by much – and vice versa.

Elasticities will vary within the population. For example, people on lower incomes are likely to be more responsive to changes in prices and incomes than people on higher incomes, who can adjust savings patterns more easily to maintain levels of consumption in the face of price and income changes. Some people have more flexibility in their patterns of infrastructure service usage: for example retired people may more easily be able to shift travel patterns to avoid peak periods than those going to work or school. They may therefore have more elastic responses to changes in intra-day pricing. The Commission has not been able to identify any robust sub-group elasticities that could be used for modelling purposes. However, in using aggregate elasticities, it is important to bear in mind that different parts of the population will have different responses to those implied by the average.

Although methodologies and assumptions vary, it is possible to draw some general conclusions on the characteristics of average demand for infrastructure services by sector. When choosing specific values, it is important to consider the details of relevant estimates: for example the measures of infrastructure services and prices, estimation techniques, and how other factors (such as changes in efficiency) are taken into account.

- Energy: recent estimates for households' income elasticities vary between 0.2 and 0.9 for the long run, suggesting that demand for energy increases less than proportionally to an increase in income. Estimates of households' price elasticities vary between -0.8 and -0.1, which implies that, as price increases, energy demand falls less than proportionately.[6] Estimates of industrial sector income elasticities vary between 0.5 and 0.7 with price elasticities between -0.2 and -0.6.[7] Estimates for whole economy elasticities are similar. The elasticity of demand for energy will depend upon which type of energy is being consumed, for example, energy for heating or energy for transportation. Demand for types of energy will also be affected by 'cross price' elasticities with other forms of energy, where it is possible to substitute between them. For example, if electricity became cheaper that might both directly increase demand from current uses of electricity, but also increase demand from people switching out of other energy sources into using electricity.
- Transport: evidence for UK road and rail travel points at income elasticities below or around 1. Estimates for road freight mostly sit within the same range as for passenger journeys. Measures of 'travel' vary between studies: for example tonne-kilometres or vehicle-kilometres for freight, and in whether they control for car ownership, which will tend to increase with higher incomes. Air transport exhibits an income elasticity of above one (estimates range between 1 and 2). This implies that, as income increases, demand for air travel increases more than proportionately, while demand for land

transport increases less than proportionately. Income growth in other countries, as well as in the UK, will affect aviation demand growth to and from the UK. Estimates for the long-run price elasticity of land transport vary between -0.1 and -0.8. Again, measures of price vary: for example £s per litre of fuel or £s per kilometre travelled, which treat changes in fuel efficiency differently. Estimates of the price elasticity for air transport are characterised by a higher variability, between -0.6 and -2.0.[8]

- Digital Communications: A recent study[9] found an income elasticity of demand for broadband of 0.8 and a price elasticity of -0.4. The Competition Commission[10] published price elasticities for mobile telecommunications for subscription, mobile calls and fixed to mobile calls of between -0.04 to -0.3. The Commission notes that elasticities will vary at different stages of network development and take up.
- Water: estimates for income elasticities of demand for residential water range between 0.2 and 0.3, suggesting demand for water rises less than proportionately with higher incomes. Estimates of price elasticities are between -0.2 and -0.3, suggesting demand falls less than proportionately with price increases.[11]
- Waste: The Commission has only identified estimates of income elasticities from international studies based on OECD countries. Estimated elasticities range between 0.2 and 0.7 suggesting demand rises less than proportionately with higher income. No estimates of price elasticities were found: households in the UK do not face a price of waste, which is instead paid for through taxation. However, businesses do pay.[12]

Table 2 sets out the range of elasticities below.

Table 2: Summary of estimates for income and price elasticities from the literature

Sector	Income elasticity	Price elasticity
Energy		
Residential	0.2 to 0.9	-0.1 to -0.8
Industrial	0.5 to 0.7	-0.2 to -0.6
Whole economy	0.2 to 0.8	-0.1 to -0.3
Land transport (passenger)	0.2 to 1.1	-0.1 to -0.8
Digital	0.8	-0.4 to -0.6
Air transport	1.3 to 2.4	-0.6 to -2.0
Water	0.2 to 0.3	-0.2 to -0.3
Waste	0.2 to 0.7	N/A

These estimates implicitly assume that infrastructure services are able to expand in response to increases in demand arising from economic growth. Rising demand for infrastructure services can be met in a number of ways, for example through increases in the efficiency of infrastructure asset use. However, if infrastructure services are unable to expand that may have a negative effect on future growth. Section 3 below considers whether increases in infrastructure provision can increase economic growth.

Other factors will affect demand besides incomes and prices, for example technological change. Such factors can have a one-off impact on the level of demand, or an on-going impact on the rate of change of demand or the relationship between demand and incomes or prices. In the short-term, these will look similar, but over time impacts on the rate of change of demand will cumulate and so are more important in the long-term.

Studies attempt to control for these in identifying income and price elasticities. A particular focus in a number of studies has been on energy efficiency and other shifts in underlying energy demand, which might offset or compound changes in energy demand due to changes in incomes or prices. For the UK, underlying energy demand appears to be on a downward trend, likely reflecting improved energy efficiency.[13] Improved efficiency may also lead to asymmetric responses to changes in price. An increase in price prompts the adoption of energy saving technology, lowering demand but subsequent falls in price do not lead to removal of the efficiencies and so have a smaller effect.[14]

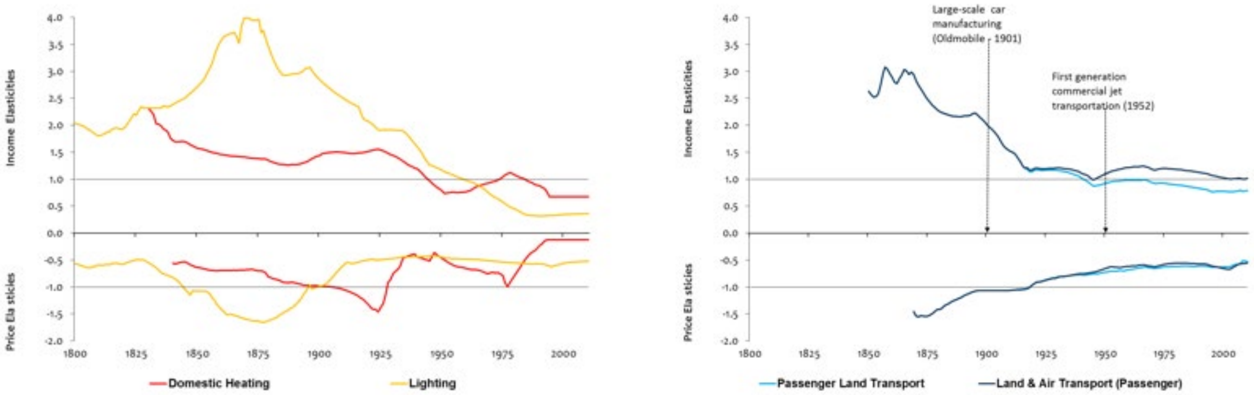
Historic patterns

Many studies are based on the implicit assumption that elasticities remain constant over time. One study, using long-run historic data, however, indicates that this may not be the case for transport and energy in the UK.[15]

Figure 3 shows estimates of the income elasticities for lighting and domestic heat (left hand panel) and transport services (right hand panel) from 1800-2010. Income elasticities varied widely between 1800 and 1980 for both lighting and domestic heat. Much of this variability originated from technological change, such as replacing gas and kerosene with electricity in lighting devices (early 1900s) or the introduction of central heating in households (1950-60). Lighting displayed high sensitivity to income changes until the 1960s, with an income elasticity that ranged between 1 and 4. More recently, evidence consistently points to an income elasticity below one, suggesting that demand for domestic lighting is becoming 'saturated': people are reaching the point where they have enough light regardless of its cost or their income.

Transport elasticities also vary over time, with the same general pattern of gradually declining elasticities interrupted by technological changes, particularly the mass production of cars and commercial jet transportation, with the rate of decline slowing or even temporarily reversing in response to these innovations.

Figure 3: Income and price elasticities of demand for energy and transport services, 1800-2010



Source: Fouquet (2014)[16]. Passenger transport measured as number of passenger-kilometres; lighting measured as lumen-hours; domestic heating measured as consumption of tonnes of oil equivalent.

Some studies argue that energy, transport (car usage and freight) and waste might have already peaked, which might imply that income elasticities are much closer to zero than those reported here.[17] However, the evidence is not conclusive. These studies do not typically estimate elasticities of zero, rather they point to a flattening of per capita demand over time. This combines the effects of any change in income elasticities with changes in behaviours (for example, greater recycling), technology (for example, more energy efficient appliances), or demographics (for example, more young people living in city centres where public transport is more available). These changes could reflect one-off shifts in the level of demand, or a permanent change in the rate of growth of demand. The latter would be much more important in the long-run, potentially offsetting the positive effect of rising incomes on demand. However, the evidence for a flattening of per capita demand over time in these studies is over too short a period to draw definitive conclusions on causes. Very low real income growth since the financial crisis also makes it hard to disentangle possible causes, although most 'peak' studies do point to trends that had started before the financial crisis.

Conclusion

Infrastructure demand generally increases with rising incomes and falls with rising prices. Understanding these patterns is therefore important for forecasting future demand. Household incomes are closely related to GDP, which is likely to provide a reliable proxy for incomes: long-term forecasts for GDP are discussed in the next section. However, a shock to inequality, such as the UK saw in the 1980s and early 1990s, might affect this relationship.

Estimates for digital, energy, land transport, water and waste suggest that demand rises less than proportionately with income and falls less than proportionately with prices. Demand for air transport appears to rise more than proportionately with income, while estimates for its price elasticity vary widely. There is also evidence for energy and transport that these elasticities have trended downwards over long time periods, with interruptions when significant new technologies are introduced.

Some studies have argued that demand in a number of infrastructure sectors has 'peaked', implying either that income elasticities are close to zero or that other factors are offsetting increases in demand. It is hard to draw firm conclusions yet from these studies, particularly since most do not disaggregate the various factors driving overall per capita demand. However, combined with the historical evidence of falling elasticities, there is clear scope for sensitivity analysis with income elasticities close to zero.

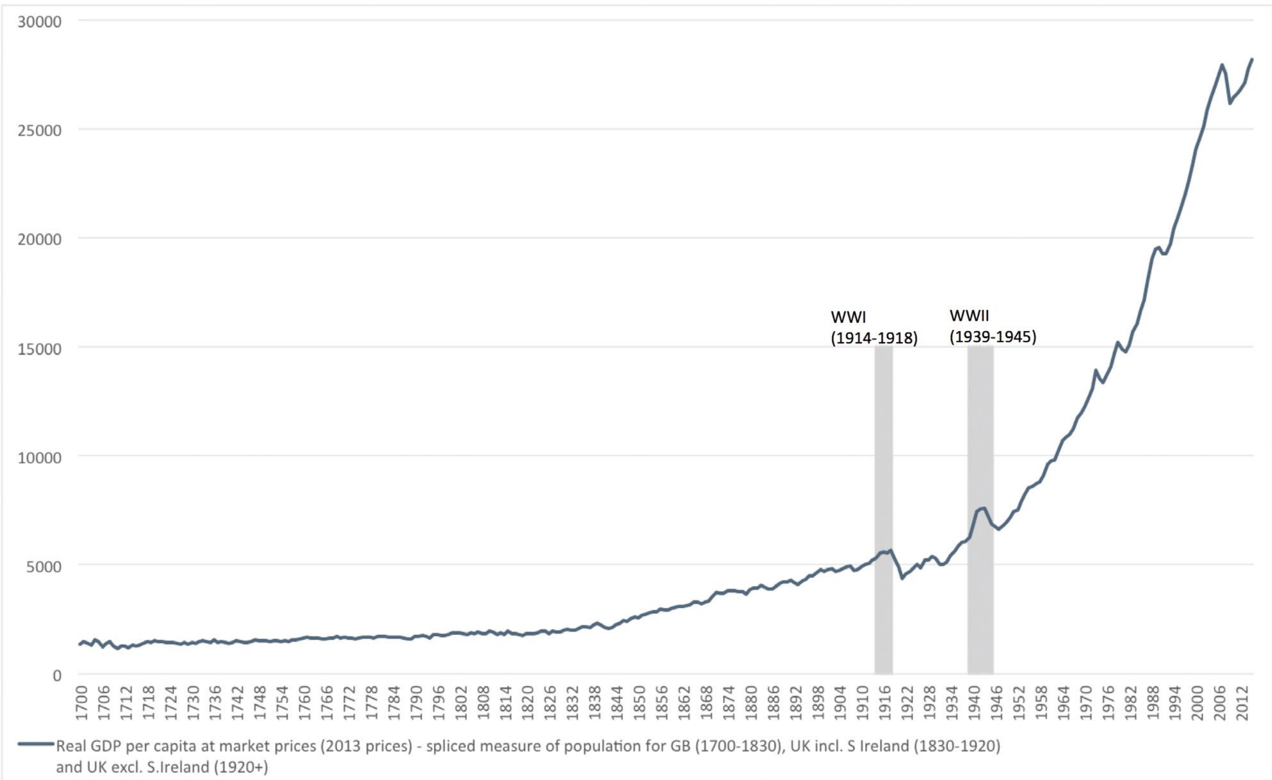
2. OUTLOOK FOR ECONOMIC GROWTH

Historic trends

Figure 4 below shows GDP per capita estimates for the past three centuries. The overall level of GDP and demand for infrastructure services are also affected by the size of the population and demographic factors such as ageing, which are analysed separately in the population driver paper. There has been a long-term upwards trend in GDP per capita punctuated by shocks such as the two world wars, the spike in oil prices in the early 1970s and the recent financial crisis, as well as smaller fluctuations from the business cycle.

The rate of economic growth is not constant across the three centuries. The annual average growth rate was below 1% until around 1840; around 1% until the late 1940s; around 3% between the late 1940s and 1973 (when the oil price shock set in) and around 2% since.

Figure 4: UK real GDP per capita (£), 2011 prices, 1700 - 2014

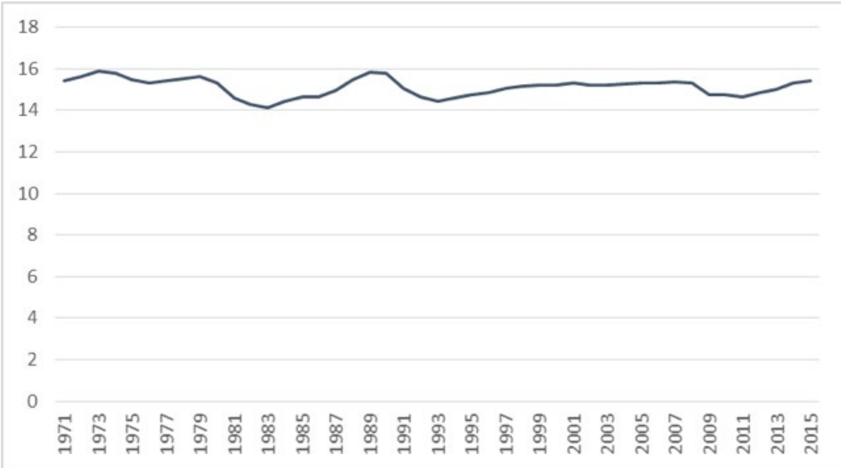


Source: Thomas et al (2016).[18]

GDP per capita is closely linked over the long-term to productivity.[19] In particular, if we measure productivity as output per hour (labour productivity), then GDP per capita is equal to productivity (output per hour) multiplied by the number of hours worked per capita.

As shown in Figure 5 below, aggregate hours worked per capita has been broadly constant since 1971. This is despite considerable change within the labour market, with female employment rising strongly and male employment falling and changes in the ratio of working age people to the total population. This may, of course, change in future as the population ages or if households choose to take part of future income growth in the form of more leisure time.

Figure 5: Total hours worked per week divided by population, UK, 1971-2014



Source: Office for National Statistics.[20]

Productivity enhancing technological progress is the main source of long-run economic growth and, as such, is behind the rise in growth rates seen in the past 200 years. Technological progress sustains growth by increasing the level and growth rate of productivity and facilitating the invention of new products and processes. The Industrial Revolution brought about the rise in the growth rate that started in the 1840s. Technologies such as the steam engine and the mechanisation of textile manufacture are historical examples of how innovation has had a long-term impact on economic growth and living standards. Electricity, scientific advances such as the discovery of antibiotics and, more recently, Information and Communication Technology (ICT) are more recent examples of innovations.

Not all of the benefits of innovation are captured within GDP. Increases in the quality of products, the variety of products available and differences between products from firms that go out of business and those that replace them are hard to measure or excluded from the measurement of GDP altogether.[21] Some valuable features of products are not priced at all: for example, some ICT services, such as Google or Facebook, are provided free to users. The replacement of horses with motor vehicles had significant positive public health impacts in urban areas, but these are not captured in GDP.[22] Similarly, GDP would not capture improvements to air quality and reductions in greenhouse gas emissions from replacing fossil fuel powered vehicles with low carbon vehicles or increases in leisure time from reductions in congestion.

Long-term forecasts

The Office for Budget Responsibility (OBR) produce long-term projections for UK economic growth over a 50 year horizon. The Directorate-General for Economic and Financial Affairs of the European Commission (EC) produce long-term projections for EU member states' economic growth to 2060.

The OBR long-term projections are published in its Fiscal Sustainability Report (FSR). Their main purpose is to assess long-term fiscal sustainability and the impact future government activities can have on it. The latest long-term projections are available from the Fiscal Sustainability Report (FSR) published in January 2017.[23] The OBR expect productivity growth to reach 1.8% by 2020 and to return to a long-term trend of 2.0% by 2026/27. This long-term trend rate translates into a growth rate for GDP per capita of 1.9% under the ONS 2014-based principal population projection and OBR projections for the employment rate.

The EC produce budgetary projections to evaluate the impact of an ageing population on potential economic growth and fiscal sustainability in the EU. The 2015 Ageing Report[24] is the latest published, with the next publication currently planned for autumn 2018.[25] The EC economic projections for the UK are based on ONS population projections from 2013. For the long-run projections, the EC assume that labour productivity growth in all EU member states converges toward the same value, 1.5% by 2060, with UK productivity growth reaching 1.5% by 2035. Within a 2050 horizon, this implies an average productivity growth for the UK of 1.1% per year and GDP per capita growth of 1.1% per year. A "risk scenario" is also included, to account for the stagnation in productivity growth, which for several EU countries started before the financial crisis. According to this "risk scenario" average productivity growth would be 1.0% per year, corresponding to 1.0% growth in GDP per capita.

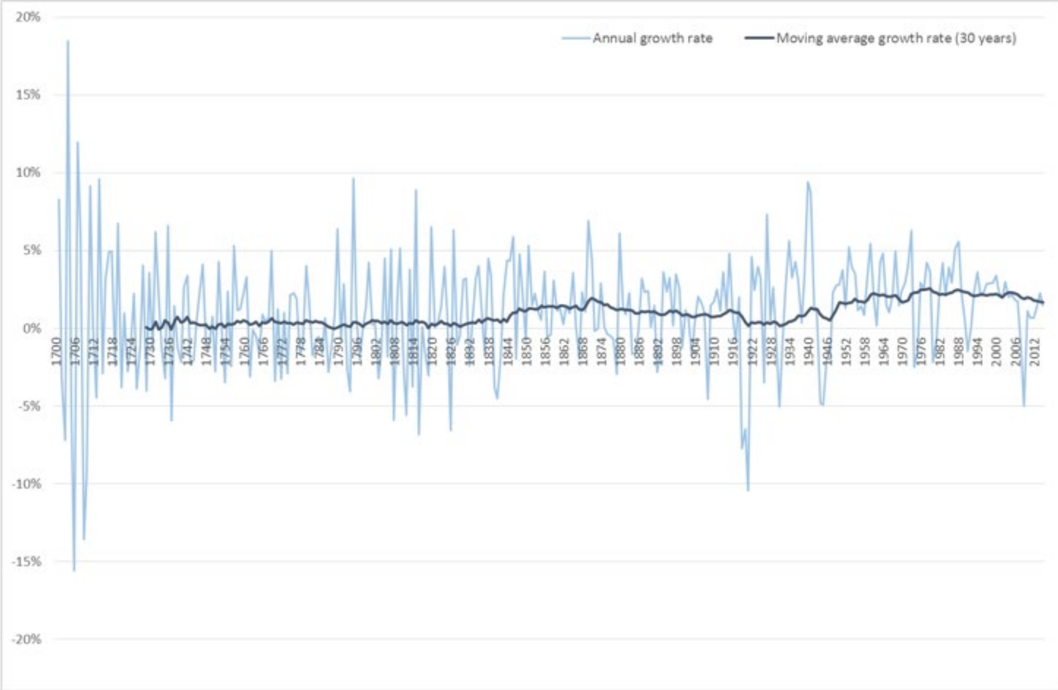
The accuracy of long-term GDP projections

Economic forecasts and projections are subject to considerable uncertainty. The OBR attempt to capture some of these uncertainties by doing sensitivity analysis on assumptions and contemplating alternative scenarios based on the different migration and age structure projections.

The accuracy of short-term forecasts is regularly appraised in the OBR's Forecast Evaluation Report. However, the validity of long-term projections has not been tested (the OBR was set up in 2010, therefore it is not yet meaningful to do so). As the OBR report, differences between forecasts and GDP outturn can be substantial in the short-term.[26]

However, long-term growth exhibits a more stable pattern. One way to see this is by calculating the annual average growth rate over the 30 year horizon of the NIA (the "30 year moving average"). As Figure 6 shows, the moving average of growth rate in GDP per capita for 30-year intervals has been relatively stable at around 2.1% since the late 1950s with a standard deviation (across all moving average values since 1955) of 0.22 percentage points. Even a small variation in the annual average growth rate will, however, compound to a significant change in the level of GDP over a 30 year period.

Figure 6: GDP per capita: annual growth rate and 30-year moving average, 1700-2015

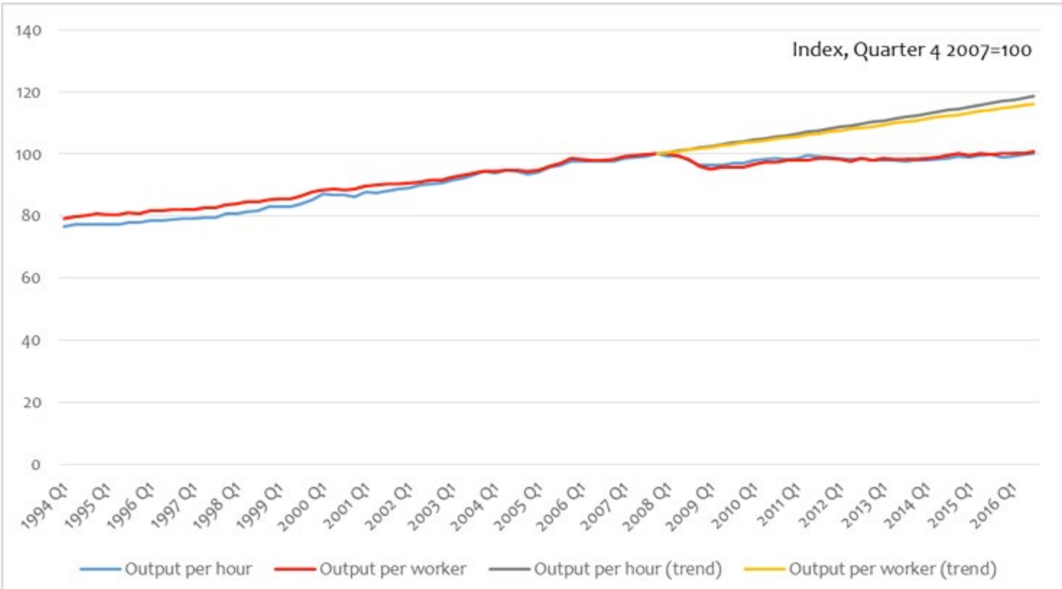


Source: Thomas et al (2016)[27] and Commission calculations.

Prospects for economic growth

Despite the relative stability of long-run average growth levels, there is considerable debate about future prospects. In part, this has been triggered by exceptionally low productivity growth in most advanced economies since the financial crisis. Productivity growth in the UK has been close to zero since 2008, as shown in Figure 7 below.

Figure 7: UK Productivity Growth (output per hour), 1994-2016



Source: Office for National Statistics[28]

Fundamental drivers of low productivity growth include a lack of responsiveness in labour, product and capital markets such that resources are not allocated efficiently. If markets do not respond to signals, due to rigidities and a lack of structural reform, productivity growth will necessarily be lower than it otherwise would be.

Low productivity is a typical feature of the aftermath of financial crises.[29] However, there is some evidence that productivity growth had already slowed ahead of the financial crisis. There are two main strands of thought, dubbed the "technology pessimists" and the "technology optimists".

Technology pessimists argue that the "low hanging fruit" of innovation has already been realised: the impact of technologies such as steam, electricity and the internal combustion engine had profound impacts on growth and living standards that will not be replicated in future:

> *"The audacious idea that economic growth was a one-time only event has no better illustration than transport speed. Until 1830 the speed of passenger and freight traffic was limited by that of 'the hoof and the sail' and increased steadily until the introduction of the Boeing 707 in 1958. Since then there has been no change in speed at all and in fact airplanes fly slower now than in 1958 because of the need to conserve fuel."*[30]

According to these authors, most notably Robert Gordon and Tyler Cowen, we have reached the point where diminishing marginal returns have set in and recent innovations have provided no significant economic boost.[31] In part this argument reflects the gains that have already been achieved from information technology.

In the case of the US, Gordon also argues that the economy has experienced a growth slowdown that started at least four decades ago. He argues that a series of US-specific headwinds, including ageing, lower achievements in education, inequality and repaying Government debt will reduce GDP and consumption in the US even if the current pace of technological change is maintained. He expects real GDP per capita growth in the US to fall by more than one percentage point between 2007 and 2077, from 2% down to 0.8%, with real disposable income for the bottom 99% lower still.

Cowen, though less pessimistic, takes the view that the changes we can expect from current innovations such as robots are likely to improve the living standards of the highly educated few while corroding those of the less skilled majority, who may find themselves displaced by automation of more jobs.[32]

Technology optimists, on the other hand, point to the substantial impacts that information and communications technology (ICT) has already had on the economy, compared for example to that of steam power or electricity and the very rapid rate of innovation in this sector, epitomised by "Moore's law", which states that the number of transistors per square inch in an integrated circuit doubles every two years.[33]

Among others, Brynjolfsson and McAfee believe that there is still a long way to go before we can exhaust the economic potential from ICT as we move from information to digital technology, with advancements in self-learning artificial intelligence and robotisation.[34] Mokyr points to the link between science and innovation and the availability of improved scientific tools, in particular computing power and genetic engineering, to posit that rates of technological innovation can be maintained:

> *"The interplay between science and technology creates a self-reinforcing or 'auto-catalytic' process that seems unbounded."*[35]

Technology optimists also take a less negative view on the scale of threat automation and robots represent for the future labour market: although robotisation may create job displacement in the short-run, it is expected to lead to shifts in demand for different types of work in the long-run. Optimists argue that emerging technologies such as industrial robotics, deep learning and DNA sequencing represent realistic transformational opportunities.[36]

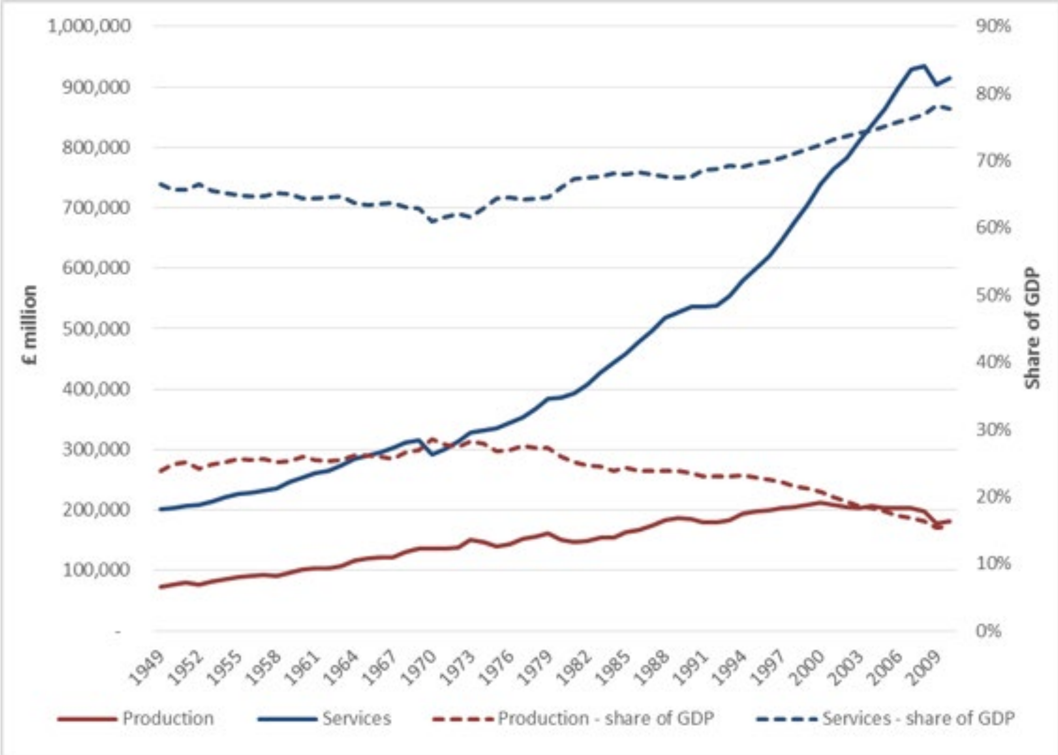
In contrast to the work by Gordon on the US, technology optimists have not made precise predictions on economic growth, other than asserting that the current productivity stagnation is only temporary. However, a reasonable conclusion would be that "technology optimism" was consistent with the long-run trend rate of growth in GDP per capita being maintained. The long-run trend already incorporates a series of transformational technologies, such as electricity, the internal combustion engine, antibiotics, broadcasting, the computer and the internet. Moreover, the growth rate is an average across the whole economy smoothing out differences across sectors that can benefit unevenly from technological progress. For example, from around 1780 to the end of the eighteenth century, output of cotton textiles increased by around 10 per cent a year but growth in GDP per capita across the whole economy was around 0.5 per cent a year.[37] Subsequent innovations have repeated the same pattern, where the directly affected sector grows rapidly but is only part of the overall, slower, growth rate.

Sectoral trends

Demand for infrastructure services will vary with the sectoral mix of economic activity. In particular, manufacturing is more energy intensive than services: for example, manufacturing and services use similar total amounts of electricity, but services make up around 80% of the economy.[38]

Figure 8 below shows the contribution to real GDP in absolute and relative terms for the production and services sectors from 1949-2010 (the data available do not distinguish between manufacturing and other sectors within production: mining and extraction; electricity and gas; and water and sewerage). Production output almost tripled between 1949 and 2000 (from £77bn to £211bn), but subsequently flattened out. Production's share of GDP has steadily declined since the 1980s, falling to 15% in 2010. The share of GDP for the services sector increased from around 65% in the early 1980s to 78% in 2010. The increasing share of services in the economy is not a new phenomenon. Services are estimated to have been the largest sector of the economy as early as 1801. By 1841, services made up more than 40% of GDP.[39]

Figure 8: Services and production sectors: contribution to real GDP and its share, 1949 – 2010



Source: Office for National Statistics (2012).[40]
Note: due to changes in the Standard Industrial Classification (from SIC2003 to SIC2007), these values are only available until 2010 and for production (rather than manufacturing) only.

Conclusion

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

The starting point is the OBR's central long-term economic projection, the main official projection from the UK's independent economic and fiscal forecaster. This would imply long-run GDP growth per capita of 1.9% per year, on average. However, in the OBR's projection, productivity growth does not reach its long-run level until 2026/27, so growth in GDP per capita until then is somewhat lower. Overall, the OBR's projection would leave GDP per capita in 2050 74% larger than in 2020.

However, the historical data show that economic growth rates can vary. Partly driven by concerns about very low productivity growth since 2008, there is a considerable debate about potential future growth prospects. This has been captured in sensitivity analysis for the OBR's short-term forecasts and in the EC's "risk scenario". It is therefore sensible to include variants to the central projection that reflect lower possible growth rates.

A 'modest growth' variant assumes an average long-term growth rate of GDP per capita of 1.7% per year. This is based on an extension of the OBR's central 5 year forecast, with productivity growth remaining at 1.8% per year (as assumed at the end of the EFO forecasting period), rather than returning to 2.0% as the OBR assume in their central long-term projection. It thus weights the more recent period of very low productivity more heavily. This would imply that GDP per capita in 2050 would be 67% larger than in 2020.

A 'weak growth' variant assumes long-term productivity growth (output per hour) of 0.8% per year, with GDP per capita growth of 0.7%. This is in line with the arguments made by economists such as Bob Gordon and Tyler Cowen and the recent trend of very weak productivity growth since 2008. This figure is similar to values of GDP growth per capita in the 19th century, reflecting the argument that the great inventions of the 20th century will not be repeated. It is also consistent with an extension to the OBR "weak productivity" scenario (that only covers the period 2016/17 to 2021/22) across the full period. This would imply that GDP per capita in 2050 would be 23% larger than in 2020.

The Commission has considered whether a more optimistic variant would also be useful. However, the central variant is already based on productivity growth over a period which included significant innovation, including the internet, and broader technological change. The historical data do not point to the likelihood of a significant period of growth above this trend rate even if further significant innovations are developed. While growth was somewhat higher in the immediate post-war period, this partly reflected 'catch-up' following the Second World War.

Table 1: Proposed annual average growth rate (%) inputs to scenarios for productivity, GDP and GDP per capita

	Productivity	GDP[1]	GDP per capita
OBR long-term	2.0	2.3	1.9
Modest growth	1.8	2.2	1.7
Weaker growth	0.8	1.2	0.7

[1]under the ONS 2014-based principal population projection, will vary in other population variants

Structural changes in the economy could also lead to changes in the quantity, nature or location of demand for infrastructure services. Some of these will arise from technological or demographic changes, which are discussed in separate discussion papers. Others may reflect changes in economic policy, such as approaches to free trade or protectionism. These are extremely difficult to predict and hence to model. However, when considering policy options it will be important to consider the extent to which they may be robust to such changes.

3. HOW DO INFRASTRUCTURE SERVICES AFFECT ECONOMIC GROWTH?

As well as economic growth impacting on the demand for infrastructure services, as set out above, the provision of infrastructure impacts on the rate of economic growth. This section considers these effects. Whilst growth is the focus of this paper, the Commission has a wider set of objectives:

- Support sustainable economic growth across all regions of the UK;
- Improve competitiveness; and
- Improve quality of life.

The potential impact of policy options will be considered across these three objectives. For example, reductions in congestion may lead to increases in leisure or family time rather than economic growth, which would contribute to improvements in quality of life. Similarly, infrastructure investments may lead to improvements in health (eg through improved air quality) or the environment (eg through reduced greenhouse gas emissions), which would not directly be captured in GDP, although there may be indirect positive effects (eg healthier workers may be more productive).

Economic growth is also only one of the key drivers of infrastructure services which the Commission has identified, along with population and demography, climate and environment, and technology. Separate discussion papers consider these issues.

Economic growth is a complex process. As described above in section 1, most long-term growth comes from productivity growth, driven by technological progress: new inventions and better ways of doing things.

Infrastructure comes into this process in several ways. Firstly, improving the quantity and quality of infrastructure services can lower costs for firms. For example, a more efficient transport network will reduce the cost of distribution, increasing the amount of output that firms can produce for a given level of inputs (fuel, lorry driver time etc).

Secondly, infrastructure can directly enable productivity enhancing technological change. For example, broadband enables customers and suppliers to find one another, and interact, at very low cost improving the efficiency of a wide range of services, such as travel agency, retail and banking. It also enables the creation of entirely new services, such as social media.

Thirdly, infrastructure is essential to the efficient working of the housing and labour markets. Without infrastructure, housing cannot be built where people want to live, and people cannot move between where they want to live and where jobs are located. In particular, infrastructure enables cities and other population centres to form. Water and wastewater, waste removal, flood risk management, energy and transport have always been essential for cities to function. Rome developed a series of aqueducts, bringing clean water into the city, from 312BC.[41] The energy demands of London led to the development of the British coal industry, which in turn was a key enabler of the industrial revolution.[42] Modern society increasingly requires digital communications.

Cities allow large numbers of people to interact, which makes economic activity more productive, a process known as "agglomeration".[43] This is one of the reasons why cities such as London, Hong Kong and New York have employment densities of around 150,000 workers per square kilometre.[44] These agglomeration effects operate through learning, knowledge sharing, specialisation and access to deeper labour markets.[45]

One estimate gives the elasticity of productivity with regard to agglomeration for the UK at around 0.04, with the elasticity of manufacturing at 0.02 and for services at 0.08.[46] This implies that doubling the population of a city would increase the productivity of its services sector by around 8%; a relatively large effect given the variation in the size of UK cities. However, these effects dissipate over relatively short distances, with proximity more important for services than manufacturing.[47] One study suggests that agglomeration effects in the advertising industry dissipate beyond around 1km.[48]

Increased population density, however, can be costly if it leads to congestion, generating economic costs by slowing travel speeds and reducing the connectivity between places. Congestion does not just affect transport networks. Any factors that are in scarce supply within city centres will become congested: most obviously land, which leads to high housing and commercial property prices.

Infrastructure can play a key role in enabling agglomeration benefits to be realised. Additional infrastructure investments can ease congestion and increase the density of employment in highly productive city centres. However, as the density of employment increases, induced increases in traffic offset the initial reduction in congestion.[49] At some point, the costs of further capacity might outweigh the benefits of further agglomeration.

How big are the growth effects of infrastructure?

While there is broad consensus over the need for functioning infrastructure services, the size of the growth effects has been the subject of extensive debate.

Most studies find a substantial positive impact on economic growth when new forms of infrastructure networks are first built. Although clearly rare, an investment that represents a step change in the quantity and quality of available infrastructure and is undertaken in fertile conditions appears to have significant effects on productivity and growth. For example:

- The UK's railways contributed about one sixth of productivity improvements in the mid-nineteenth century, before allowing for agglomeration effects.[50] Including both trains and electric trams, and capturing agglomeration effects, by 1906 transport innovations increased GDP by around 8%.[51] Similarly large effects are found for railways in Sweden[52] and colonial India.[53]
- Road building in the US between 1951 and 1973 (which included the building of the interstate highway network) is estimated to have increased aggregate yearly productivity growth by 1.4 percentage points in that period[54] (although this may be an overestimate[55]). However, this impact on productivity slowed down over time and vanished after 1973, when the interstate network was complete.
- The roll-out of broadband infrastructure in OECD countries from 1997 to 2007 increased per capita growth by 0.9 to 1.5 percentage points for a 10 percentage point increase in broadband penetration.[56]

The timing of these benefits can vary. Gains from the UK's railway network increased sharply after train operators, prompted in part by the Government, introduced cheaper third class fares making the rail network more accessible. Conversely, the gains from broadband have arisen rapidly, alongside the extension of the infrastructure – perhaps because computers were already widely and cheaply available by this point.

Infrastructure networks, once established, may also be important enablers of future economic growth. For example, productivity in the retail and logistics sectors has increased significantly due to ICT, which has enabled 'just-in-time' delivery. However, these ICT-enabled productivity gains relied on the existence of previous infrastructure investments, in motorways and container ports.

Infrastructure is not unique in this 'enabling' ability for future productivity growth. Institutions, such as property rights, the rule of law and independent central banks and some ideas, such as scientific method, can continually enable growth, long after their initial impact. However, these effects are hard to measure once the original investment is achieved, since it is rarely practical to compare the economy with a counterfactual that lacks for example electricity or clean water.[57] The estimates of the growth effects of existing networks may therefore be underestimated.

Most UK infrastructure networks are well beyond this initial, step change, point, though digital communications may be an exception. The growth effects of enhancements to mature infrastructure networks have proven harder to pin down, with a range of studies giving differing answers. However, recent surveys of the evidence point to an overall positive impact of infrastructure investment – typically a measure of capital stock of public infrastructure – on GDP.[58] A recent 'meta-analysis' of 578 estimates from 68 studies concludes that the long-run elasticity of GDP with regard to public capital stock is around 0.1.[59]

These estimates imply that, once networks are mature, the impact on growth from further investments are more in line with the general returns you might expect from additional capital investment of any sort. Some studies explicitly compare the returns from infrastructure with those from general capital investment, finding them to be similar on average, although this varies somewhat between countries.[60]

Once infrastructure is in place, maintenance is important and likely to have high returns.[61] Maintenance ensures infrastructure can continue to provide the infrastructure services that support economic growth. A lack of maintenance can also lead to unpredictability in the services that infrastructure is able to provide, for example electricity outages or road delays. These incur both direct costs, such as delays, but also 'precautionary' costs, such as allowing longer for journeys in case of delays or investing in back-up electricity generation. More significant failures of infrastructure networks, although rare, could have major impacts on the economy. For example, the '3 day week' when electricity supplies had to be rationed, led to a significant fall in GDP.

The impacts of specific schemes

As well as national and regional studies on the impacts of infrastructure as a whole, there are a number of studies of specific transport and digital schemes. This evidence is more relevant to making choices between potential new investments and understanding the impact of infrastructure at a local level. However, the number of robust evaluations is fairly small. More evidence would be very valuable.

In the UK, positive effects would generally be expected to impact on measures of productivity or wages, rather than employment. Whilst infrastructure may increase employment within a local area, the UK labour market as a whole operates close to full employment, and increases in one place will generally involve a shift in jobs from one place to another, rather than an increase in total UK employment. However, these jobs may be more productive – including because of agglomeration effects – which is an important benefit. Increases in productivity will, in turn, typically be reflected in higher wages.

There is some evidence that road projects can have positive impacts on wages and productivity in the local area. For example, a study of improvements to the UK road network between 1998 and 2007 found that increased accessibility increased wages by 0.2% and productivity (gross value added) per worker by around 0.4%, for firms within 20km of the improvements.[62] However, one study in the US found that highways increased the demand for higher skilled workers in areas that started off with higher skills and reduced it elsewhere.[63]

There appear to be very few robust studies on rail and none at all for trams, buses, cycling or walking.[64] Two studies consider the impact of high speed rail. One looks at small towns which received a connection to the Cologne-Frankfurt high speed line.[65] The effects are positive and relatively large, with output in the counties affected 8.5% higher. However, the small size of the towns concerned makes it hard to generalise the findings: high speed rail is generally used to connect large cities. The other paper finds positive impacts on sales among input-intensive firms following the extension of the Shinkansen high speed network in southern Japan, which cut journey times to key centres very significantly.[66]

Studies on digital communications show that extending or improving broadband connections in an area can have a positive economic impact on local firm productivity, employment and wages. However these effects are not uniform, with urban areas, skilled workers and the services sector usually benefitting more than rural areas, unskilled workers and manufacturing.[67]

Can infrastructure regenerate struggling places?

Infrastructure projects are often proposed as a way of regenerating places that are struggling economically.[68] The evidence for this is not compelling.

The factors that make local areas succeed or struggle economically are complex and not fully understood. Skills are central. There is also evidence that fragmented local governance leads to lower economic growth.[69] There are almost certainly other factors that matter. It is clear, however, that there are powerful virtuous or vicious cycles of success and decline. Places with strong growth have desirable feedback loops: they attract skilled workers because wages are high (interactions between skilled workers boost productivity) and the presence of other skilled workers makes them nice places to live (shops and amenities are geared to the desires of skilled workers).[70] Firms locate there because they can attract skilled employees. The reverse is true in places with weak growth. These forces can be very powerful, although congestion and rising house prices push back the other way.

Infrastructure can support the virtuous cycle in successful places, by easing the constraints of congestion. A classic example of a project building on success is the extension of the Jubilee Line and associated enhancements to the Docklands Light Railway at the end of the 1990s. Evidence shows large positive impacts.[71] Conditions for this project were strongly supportive: London was already successful; the investments brought a substantial, but poorly linked, area of land close to the centre of the city into the main transport network; and Docklands benefited from governance reform (the development corporation), structural economic reform (the 'Big Bang') and structural shifts in the economy (the rise of knowledge intensive business services from the early 1990s).

It is much less clear that infrastructure alone can reverse, or even significantly mitigate, the vicious cycle in struggling places. Infrastructure is necessary for growth, but not sufficient. Probably the most notorious example of the failure of infrastructure in struggling areas is the 'People Mover', a monorail in Detroit. Built in the 1980s with the purpose of regenerating the declining city, in 2008 only 7,500 people (2.5% of its capacity) used it daily.[72] These problems are not unique to the US. Some UK local transport schemes have suffered from low passenger numbers and limited, if any, observable impacts on local economic growth;[73] for example, the Humber Bridge has done little to support the regeneration of the region.

Many of the UK's major cities are neither straightforwardly successful nor struggling. Productivity in most of the UK's major cities, other than London and Bristol, is below the national average.[74] However, population declines seen in the 1980s and 1990s have reversed and major cities are undergoing something of a revival, partly driven by changes in economic structure that increase the importance of agglomeration economies and rising numbers of students, who tend to live in city centres.[75]

There is a general lack of high quality evidence for the UK on specific interventions at local and regional level, and in particular for infrastructure investments in cities and towns that are neither straightforwardly successful nor struggling. This makes it hard to draw conclusions on the likely impact of proposed new schemes in these places.

Spillovers and displacement

One additional complexity encountered when assessing the aggregate economic impact of local projects is to understand whether the gains and losses are isolated within the area studied or whether they spill over into other places. These 'spillover' effects could be positive or negative.

Positive spillovers might occur if improvements in productivity for firms directly benefiting from infrastructure also benefit other, more distant, firms. Gains to education, for example, appear to be larger at the level of cities than simply the sum of individual gains.[76] The same effects may be true across the country for infrastructure networks but would be hard to measure with existing techniques.

Negative spillovers may occur if impacts derive from simply moving activity from one place to another, which is termed 'displacement'. For example, a study of the impact of interstate highways on rural counties in the US found earnings grew in those counties that received the infrastructure but fell by an equivalent amount in adjacent counties, implying economic activity had simply shifted from one place to another with no net gain.[77] The study looked only at interstates built after 1969, when much of the network was already in place, so estimates the impact of additions to a relatively mature network.

Shifting economic activity from relatively successful to relatively unsuccessful areas might be worthwhile even if there is no net gain. However, evidence from economic regeneration policies shows that displacement instead often shifts activity from one struggling area to another.[78] This should not be surprising: firms are already paying substantial premia to locate in successful areas – higher rents and wages – in order to access the skilled labour and interactions between firms and workers available in those places. So they are not easily going to move to places that lack those benefits.

Conclusion

Overall, the literature implies that infrastructure can have positive effects on economic growth. The effects are large when completely new infrastructure networks are developed. Once networks are mature, effects are more in line with the benefits of greater capital investment in general.

Scheme specific studies support these findings, but results are inevitably context specific. There are very few robust studies for UK infrastructure investments. More research here would be very valuable, especially in understanding how the impact of investments varies depending on the economic circumstances of the location.

Including the possible effects of future infrastructure investment on economic growth in scenario modelling is very hard. The existing national infrastructure models that the Commission is aware of are not set up to treat the rate of growth within the model ('endogenous'). Rather it is taken as an external driver ('exogenous'). This is clearly an approximation. However, as set out in section 2, the central growth variant already includes the positive growth effects of substantial infrastructure developments over the period from which the historic trend of productivity growth has been estimated. It can thus be seen as consistent with a future in which wise infrastructure investments are made.

In the time available for the first NIA, it is not practical to develop new models. Treating the growth rate as endogenous within a model would also be far from straightforward in modelling and computational terms. The Commission therefore proposes to address the feedback from infrastructure to growth in other ways. In particular, cost-benefit analysis of potential packages of investments allows for analysis of the impacts on growth and will feed into the evidence base for the NIA's recommendations. The Commission recognises the limits of standard cost-benefit analysis approaches, and will also be exploring improvements that can be made to current methodologies. A further option would be to make 'off-model' adjustments to growth. This would involve estimating the impact of packages of investment on growth outside the model, and then modelling 'policy on' and 'policy off' (baseline) scenarios using different growth rates.

4. CONCLUSION

Economic growth is a key driver of infrastructure service demand. In addition, investment in infrastructure has positive effects on economic growth. Over the National Infrastructure Assessment's horizon to 2050, significant changes in household incomes can be expected. Understanding these will help the Commission to develop scenarios reflecting the range of possible futures. Increases in demand can be met by a range of possible policies, including demand management and greater efficiency, as well as increases in supply.

There is inherent uncertainty in forecasting long term growth rates. Relatively small differences in annual growth rates compound to substantial differences in incomes by 2050. Even though demand for most infrastructure services appears to rise less than proportionately with income, there will be a material impact on demand in many sectors. Where – as with air travel – demand appears to rise more than proportionately with income, the effect is larger still and hence more sensitive to the possible path of future incomes.

Infrastructure choices in turn can affect the rate of economic growth. This feedback loop will be considered by the Commission in deciding on policy options, although the Commission will consider the potential impact across all three of its objectives and not simply the impact on growth.

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

- Long-term average growth of GDP per capita of 1.9% per year, based on the latest OBR long-term economic growth projections in the 2017 Fiscal Sustainability Report;
- More modest growth, of GDP per capita of 1.7% per year based on projecting forward the trend rate of productivity growth at the end of the five year forecast horizon of the OBR's November 2016 Economic and Fiscal Outlook;
- Much weaker growth, of GDP per capita of 0.7% per year, consistent with very weak productivity growth since 2008 and the arguments of 'techno-pessimists'. This would also be consistent with projecting forward the OBR "weak productivity" scenario in the November 2016 Economic and Fiscal Outlook.

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. Scenarios using these inputs should ensure that potential infrastructure investments are tested against the range of plausible uncertainties in future demand.

The drivers also should not be thought of in isolation: the impact of changes in economic growth will need to be considered in context alongside other drivers of infrastructure demand and supply, notably technological, population 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 31 March 2017.

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

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