Foundations for Growth: How infrastructure can increase productivity

Te Waihanga Research Insights series

February 2026

New Zealand Infrastructure Commission / Te Waihanga

Te Waihanga seeks to transform infrastructure for all New Zealanders. By doing so our goal is to lift the economic performance of Aotearoa and improve the wellbeing of all New Zealanders.

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Information on the Commission is available at www.tewaihanga.govt.nz/

How to cite this document

New Zealand Infrastructure Commission. (2026). *Foundations for Growth: How infrastructure can increase productivity*. Wellington: New Zealand Infrastructure Commission / Te Waihanga.

Research Insights series contact

Graham Campbell
Director, Economics and Research
E: graham.campbell@tewaihanga.govt.nz
Website: tewaihanga.govt.nz
Linkedin: tewaihanga

Acknowledgements

This research note was drafted by **Talosaga Talosaga** and **Danny Kwon**. We thank **Ezra Barson-McLean** and **Philip Stevens** for work on earlier versions of this report. We are grateful for comments and feedback from Arthur Grimes (Motu Research), Andrew Schoultz (Ministry of Transport), Mark Lea (MBIE) and Maryam Hasannasab (University of Auckland).

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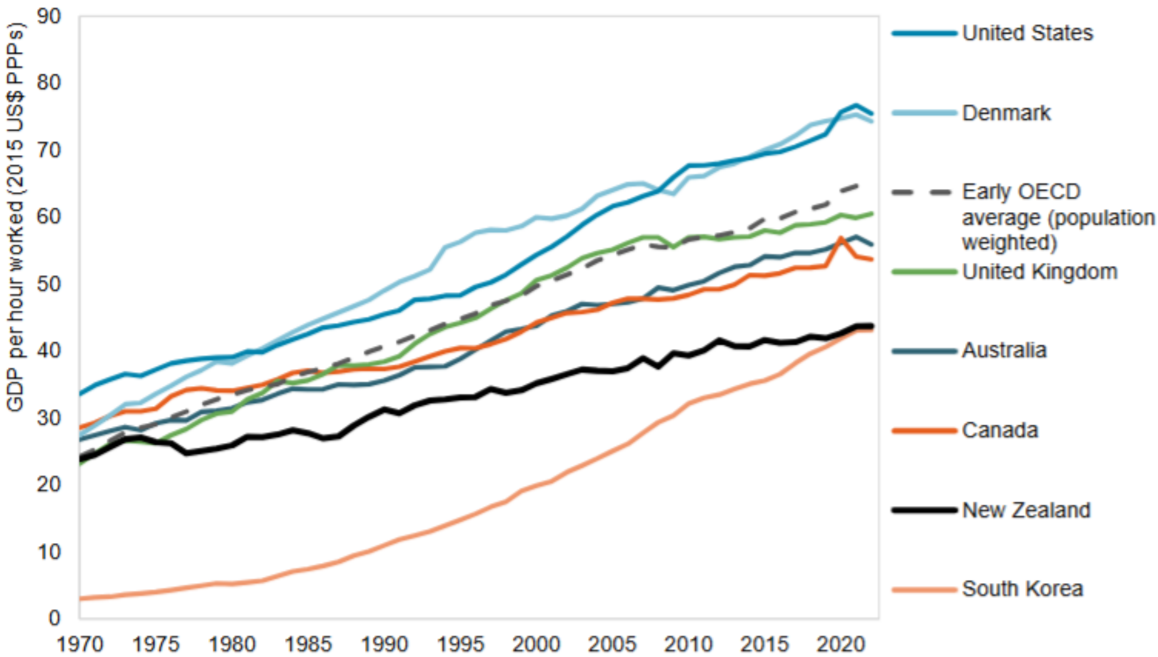
Cut to the chase

New Zealand – we have a productivity problem

> Productivity isn't everything, but, in the long run, it is almost everything. A country's ability to improve its standard of living over time depends almost entirely on its ability to raise its output per worker – **Paul Krugman**

New Zealand's productivity performance is poor compared to other advanced economies. As shown in Figure 1, we produce less per hour worked and our growth in productivity has been slower than other OECD countries.

Figure 1: New Zealand's labour productivity has lagged other developed countries, GDP per hour worked, 2015 US Dollars Purchasing Power Parity (PPP)



Source: Cook, Devine and Janssen (2024). Early OECD countries are those that joined the OECD prior to 1975.

This has contributed to a range of issues. Slow productivity growth means slower growth in the wages and salaries households need to afford basic necessities. Slow growth means a lower government tax take, making it harder for the government to balance the books and leaving less money available for public services. It makes it harder for us grapple with the challenging trade-offs needed to respond to climate change and live within our environmental limits. And being less productive than our closest neighbour has led to persistent flows of New Zealanders migrating to Australia.

Can infrastructure investment help?

Infrastructure is clearly important for an economy. But based upon our review of the body of literature on this topic, this is a nuanced relationship. Broadly speaking, infrastructure can affect economic output in three ways.

First, infrastructure is an output in and of itself, providing services to consumers like water, electricity and internet connectivity. This improves our wellbeing today but does not necessarily improve our ability to improve living standards tomorrow.

Second, infrastructure is an input to the production of other goods and services. This increases economic output today, which could either go towards more consumption or investment.

And finally, infrastructure can increase productivity, helping the economy to produce more given the same inputs. While increasing consumption and providing inputs to current production are important, long-term sustained economic growth is primarily driven by increases in productivity.

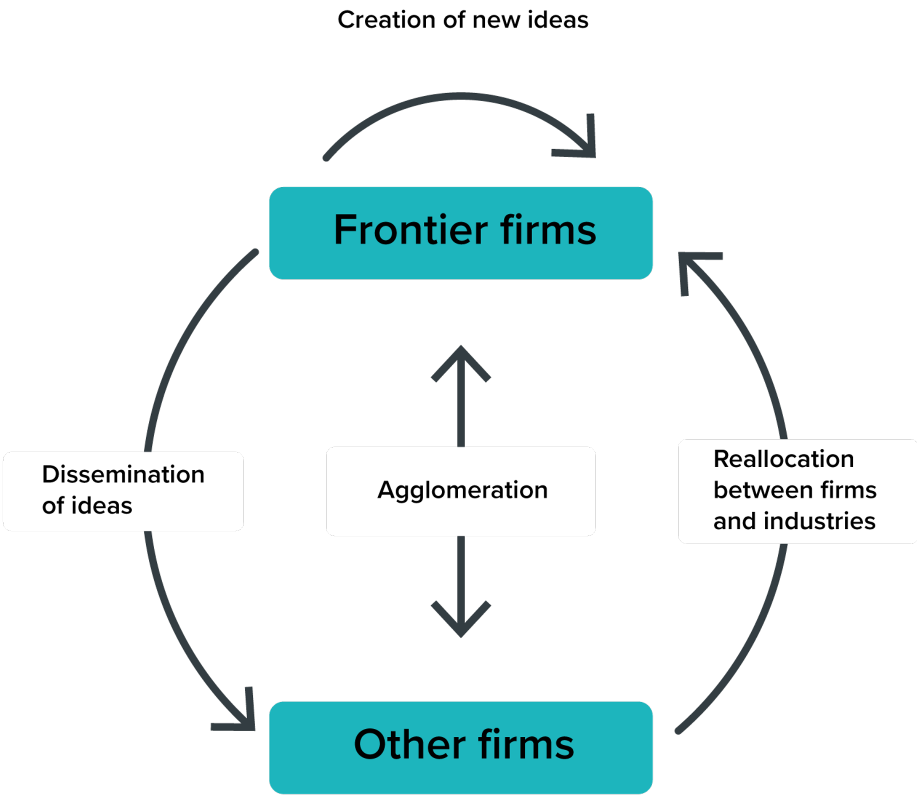
We can think of productivity as increasing through one of the following channels (Figure 2):

- creation and adoption of new ideas, innovations and products by frontier firms
- dissemination of new ideas throughout the economy
- reallocation of resources from lower productivity firms and industries to higher productivity firms and industries
- agglomeration: cities make the creation and spread of new ideas faster.

Infrastructure primarily plays an indirect, enabling role across these channels. Examples of where infrastructure can improve productivity include:

- Wide coverage of new telecommunication networks that can unlock access to entirely new technologies.
- Physically and digitally connecting consumers with a wide range of providers, spurring competition and helping more productive firms to expand.
- Enabling our cities to grow, allowing people and businesses to locate together at higher densities.

Figure 2: Factors contributing to productivity growth



Source: Adapted from OECD (2015).

When to invest can be just as important as what to invest in

Investing too early or too late both have costs. Invest too early and we lock-in capital that could be applied to other productive investments. Invest too late and we can constrain growth. In general, the Commission's previous work highlights that investment is most beneficial where there are bottlenecks, which have historically been driven by **significant technological change** or **rapid demographic shifts.**

The Commission's Forward Guidance in the National Infrastructure Plan projects that, for most sectors, demographic demand should be relatively stable on the whole and that bottlenecks will likely be highly localised in nature. However, there are some subsectors where rapid technological change could lead to bottlenecks such as AI datacentres increasing demand for electricity and water networks.

For infrastructure to improve productivity, investment needs to be efficient

Even if bottlenecks exist, infrastructure investment will best support economic growth if it is efficient – that is, if it delivers high outputs, such as electricity or connectivity, for a reasonable level of inputs. Every dollar spent on infrastructure investment comes at the expense of other activity in the economy and must be paid for with taxes, rates and user charges. Therefore, inefficient investments in infrastructure can hurt economic growth more than it helps.

In our international benchmarking work, and other research done by the Commission, we have identified that New Zealand has high levels of spending, but only average levels of infrastructure quality. In other words, we are not getting good bang for our buck.

Figure 3: International benchmarking of New Zealand's infrastructure networks

NZ difference from comparator country average
(based upon simple unweighted average of multiple measures)

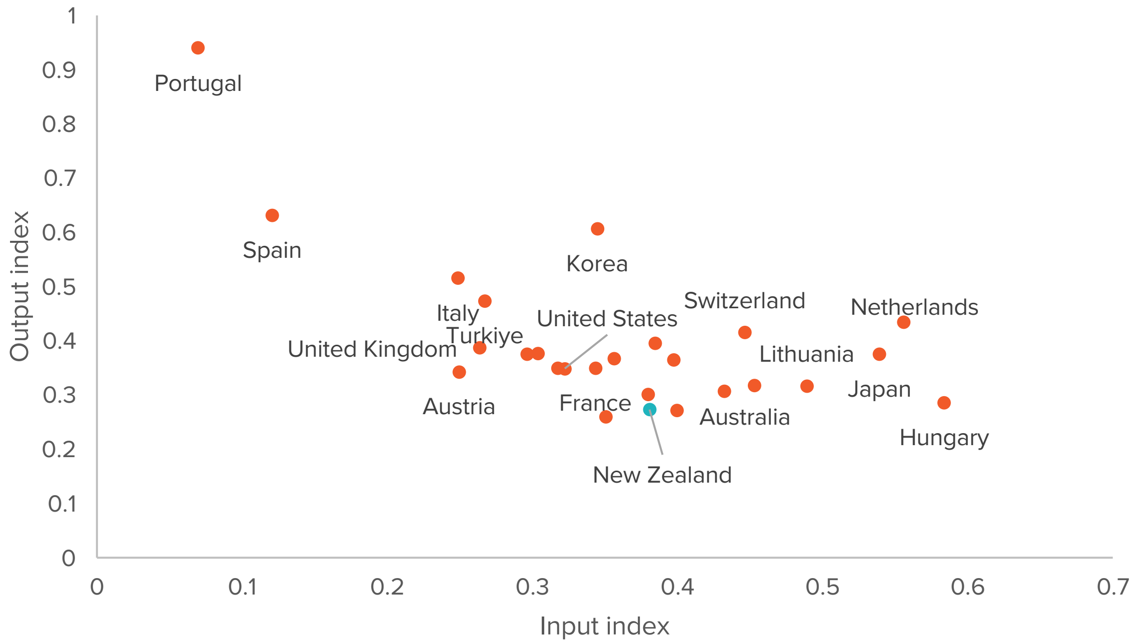
Network	Investment levels	Quantity of infrastructure	Usage	Quality	Comparator countries	Notes
Road	+34%	-13%	-33%	-13%	CZE, CAN, FIN, SWE, ISL, NOR	High investment levels, low usage, high amount of fatalities on the network
Rail	-64%	-43%	-23%	-90%	CHL, GRC, JPN, ESP, FIN, SWE, ISL, NOR	Low investment levels, low usage (both passenger and freight), high emissions
Electricity	-3%	+29%	-46%	-12%	COL, CRI, CHL, CAN, FIN, SWE, NOR, ISL	Large transmission network, relatively high frequency and length of outages
Health	-25%	-10%	-2%	-13%	UK, AUS, SWE, DEN, ISL, NOR	Low amounts of some medical equipment, some higher wait times, and older hospitals
Education	+1%	-10%	+6%	+4%	CHL, FIN, AUS, ISL, NOR, USA, IRL	No clear deficits or shortages
Telco	+28%	-12%	+3%	-4%	COL, CRI, CHI, CAN, FIN, SWE, ISL, NOR	High investment levels, developed fixed broadband but underdeveloped mobile broadband
Water	+70%	-3%	+99%	+9%	CHL, GRC, ESP, CZE, CAN, FIN, SWE, ISL, NOR	High levels of investment, very high usage, average levels of leakage

Notes: Comparator countries were chosen based upon different characteristics for each network, but often included measures of population, population density, land area, terrain ruggedness, and per-capita incomes. Differences from the comparator country average are composed of a simple average of various available metrics without weights. For instance, road network quality measures include metrics on congestion, road smoothness, travel speeds and safety, which are normalised and averaged to make a single measure. Source: International Benchmarking Technical Report, New Zealand Infrastructure Commission (2025).

In this paper, we explored this relationship more deeply for road networks and found:

- New Zealand has room to improve its efficiency of road networks, like many other countries (Figure 4). Across several different types of analysis, we rank towards the bottom third of countries at turning our roading inputs (spending, amount of roads) into outputs (usage levels, low levels of congestion, road safety, and access).
- Greater urbanisation and higher incomes are tailwinds in helping countries achieve greater efficiency, while things like terrain ruggedness and overall population density have less of an effect.

Figure 4: New Zealand has above average road inputs, but below average outputs



Source: New Zealand Infrastructure Commission analysis of international benchmarking data for road networks. See Benchmarking our infrastructure: technical report. New Zealand Infrastructure Commission 2025.

Moving in the right direction

If we want to ensure that our infrastructure is generating the highest value for users, and therefore, economic growth, the good news is we have a good evidence base about the steps we can take to ensure that. These include:

- *Focusing on project planning and robust economic appraisal.* This allows us to ensure that investments are focused on generating value.
- *Utilising strong pricing approaches to network infrastructure.* These prices signal to infrastructure providers where the future value and investment will be.
- *Applying a complementary approach to infrastructure*: We can do this by pulling policy levers to take advantage of opportunities for non-built solutions for current infrastructure issues.

These are all ideas that would result in more efficient infrastructure for the country, helping to stimulate long-term productivity and economic growth. At the same time, the area of infrastructure's contribution to economic growth is not settled science. For its part, the Commission will continue exploring how we can better use infrastructure to achieve higher living standards for New Zealanders.

1 Introduction

New Zealand – we have a productivity problem

New Zealand's productivity performance is poor compared to other advanced economies. We produce less per hour worked and our growth in productivity has been slower than other countries.

This has contributed to a range of issues. Slow productivity growth means slower growth in the wages and salaries households need to afford basic necessities. Slow growth means a lower government tax take, making it harder for the government to balance the books and leaving less money available for public services. Lower growth makes it harder for us to make the challenging trade-offs needed to respond to climate change and live within our environmental limits. And being less productive than our closest neighbour has led to persistent flows of New Zealanders migrating to Australia.

Infrastructure investment is sometimes seen as the answer to slow growth

Infrastructure has been deeply connected to significant shifts we've seen in the New Zealand economy. Electrification, urbanisation and digitisation have changed how New Zealanders live and work and would not be possible without investment in our infrastructure networks.

Infrastructure investment has also been used by Governments as a catalyst to drive economic growth. Historic infrastructure projects like the Clyde Dam and modern infrastructure programmes like the New Zealand Upgrade Programme (NZUP) and the Roads of National Significance have been motivated by the prospect of higher economic growth.

However, more investment isn't always better. New Zealand spends a higher share of GDP on public infrastructure than most countries in the OECD and has for at least the last decade. If spending money on infrastructure led directly to higher productivity, we wouldn't have a productivity problem. More investment also creates a legacy of maintenance and renewal needs, which, as we have seen, can be difficult to keep up with.

We provide a framework for the relationship between infrastructure and the economy...

In this paper, we provide an overview of macroeconomic and microeconomic relationships between infrastructure, the economy and productivity. We summarise the empirical literature on these relationships, and include additional analysis on the efficiency of New Zealand's roading network, using international infrastructure benchmarking data collected by the Commission.

In Section 2, we define exactly what we mean (and what we don't mean) by the term 'infrastructure'. In Section 3, we provide a framework for thinking about the macroeconomic relationships between infrastructure and the economy, the microeconomic channels that lead to productivity growth, and how infrastructure can impact these channels. In Section 4, we review some of the existing literature on infrastructure and productivity, and analyse the efficiency of the New Zealand roading network using frontier analysis. Finally, we conclude with high-level observations and suggestions for future research.

2 What is infrastructure?

A discussion of infrastructure and economic growth first requires a definition of what 'infrastructure' is. New Zealand Infrastructure Commission (2020) defines infrastructure broadly as:

> A system of inter-connected physical structures that employ capital to provide shared services to enhance wellbeing.

This definition highlights several key factors. First, the **purpose of infrastructure is to provide services**. It is a means to an end. We build bridges to enable transit, not just for their beauty. Because of this, we should consider their importance through the services they provide.

Second, the **infrastructure is a series of networks**. Horizontal infrastructure is networks that physically connect populations (like roads and water pipes). Vertical infrastructure is networks of individual physical structures that provide public services to the population (like schools or hospitals).

Third, infrastructure is typically **physical capital**. This means that we are explicitly excluding institutional infrastructure (like systems of laws and norms),[1] broader definitions of social infrastructure (such as the networks of connections and relationships in a community), knowledge infrastructure (the internet, the science system) and the environment (the natural world, biodiversity etc.). That is not to say these other types of infrastructure are not important, or indeed not related to physical infrastructure.

There is not a single definition of what constitutes infrastructure. Definitions often vary by how the infrastructure is used,[2] as seen in Table 1.

[1] The cultural, economic, legal, political, and social institutions are fundamentally important to the functioning of the economy and society (North, 1991; Stevens et al., 2023).
[2] See, for example, Bennett et al., 2021 for a discussion of the place of infrastructure in the National Accounts. For an overview and comparison of definitions see Buhr (2003) or Torrisi (2009).

Table 1: Classifications of infrastructure have changed over time

Hansen (1965)	Aschauer (1989a)	Sturm et al. (1995)	Di Palma et al. (1998)	Biehl (1986)
Economic	**Core**	**Basic**	**Material**	**Network**
Roads, highways, airports Naval transport Sewer networks Aqueducts, networks for water distribution, gas networks Electricity networks, irrigation plant, structures dedicated to commodities transfer	Roads, highways airports Public transport Electricity networks Gas networks, networks for water distribution, sewer networks	(main) railways, (main) roads, canals Harbours and docks Electromagnetic telegraph Drainage Dikes Land reclamation	Transport network Water system Energy network	Roads, railroads, 'water highways' Networks of communication Systems for energy and water provisioning
Social	**Not-core**	**Complementary**	**Immaterial**	**Nucleus**
Schools Structures for public safety, council flat, plant of waste disposal, Hospitals, sport structures, green areas	Residual component	Light railways Tramways Gas networks, electricity network, water supply, local telephone network	Structures dedicated to development, innovation and education	Schools Hospitals Museums

Source: Torrisi (2009).

In this paper, we primarily focus on horizontal infrastructure, like water, power, roads and telecommunications, and vertical infrastructure, like schools, courthouses and hospitals. These definitions align with the Commission's statutory purpose[3] and follow the Commission's approach in previous *Research Insights* pieces.[4]

2.1 Characteristics of infrastructure networks

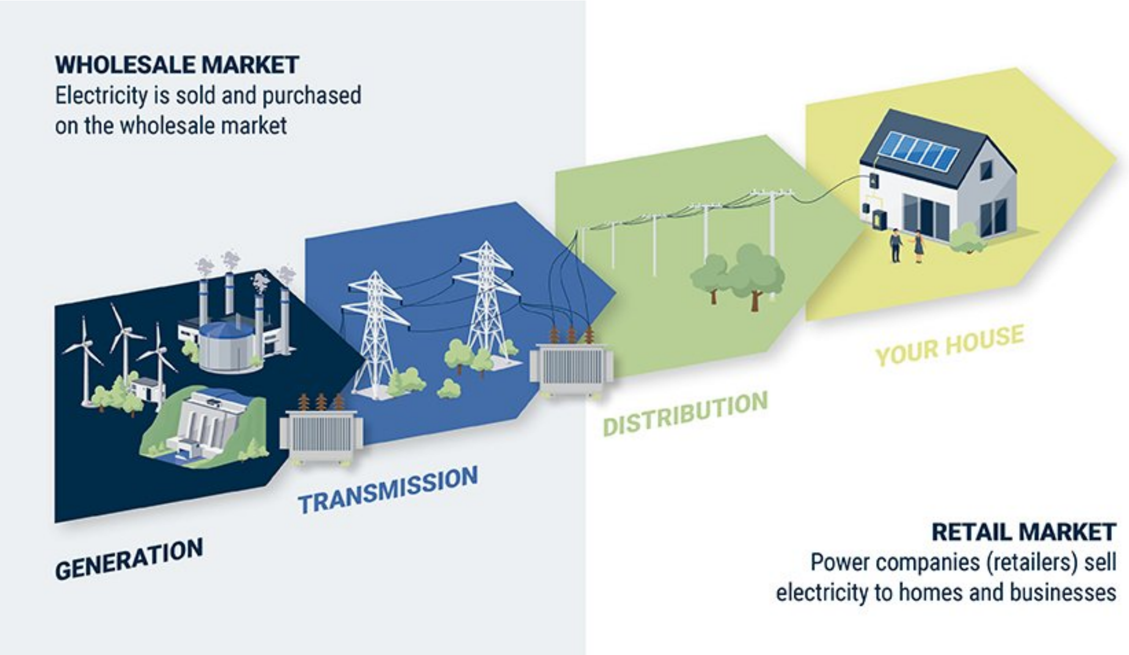
Infrastructure networks have a specific set of characteristics that are important when considering where they fit into an economic system. Understanding these unique characteristics can help us explain why some infrastructure is built and managed in a certain way.

Infrastructure is a series of connected networks

The first is that infrastructure networks are not homogenous. When we refer to 'electricity network infrastructure', we are referring to many different components of the electricity system.

[3] Part 1, Subsection 3 of the 2019 Te Waihanga Act, 2019.
[4] New Zealand Infrastructure Commission, 2024

Figure 5: Electricity flows from many generation sources, through transmission and distribution networks to millions of users



Source: Electricity Authority, How electricity works. https://www.ea.govt.nz/your-power/how-electricity-works/

The electricity system is generally considered to be made up of four parts: generation, transmission, distribution and end-users (see Figure 5). There are many *generators* distributed across the country – power stations, wind farms, hydroelectric dams etc. Electricity is *transmitted* across large distances at high voltage over a transmission network. It is then stepped down to a lower voltage and *distributed* locally to business premises and domestic *users'* houses.

These parts of the electricity network are different but they all play an important role in getting electricity to New Zealanders. For this reason, we consider generation, transmission, and distribution to be part of infrastructure.

Another consideration is that infrastructure networks overlap and are dependent on each other. This is particularly obvious in the telecommunications system. Telecommunications are made up of multiple networks often operating at the same time (Figure 6). In many areas, people will have access to ultrafast broadband, copper ADSL/VDSL and mobile networks at the same time. Each network can substitute for others, but has different characteristics in terms of speed, capacity, flexibility and cost.

Figure 6: Telecommunications. A series of overlapping networks

Source: MBIE, Briefing for the incoming Minister for Media and Communications 27 November 2023.[5]

Most telecommunications infrastructure is dependent on electricity infrastructure. Without electricity, cell phone towers can't function. This interdependence applies to other infrastructure too. Schools and hospitals can't operate without water and electricity, and it would be impossible to build and maintain electricity infrastructure without roads.

Infrastructure networks tend to be natural monopolies

Many infrastructure networks exhibit natural-monopoly characteristics. A natural monopoly is a market where one provider can supply the entire market's demand more efficiently than multiple competing providers.[6] The key characteristics of a natural monopoly are very high fixed costs to start up and relatively low marginal costs.

Infrastructure is expensive to build and benefits significantly from economies of scale. Therefore, it often makes economic sense for an infrastructure network in an area to be provided by a single provider. This is one of the reasons why the government becomes involved in infrastructure, either through regulation of the private sector, or through ownership and/or operation of infrastructure. It intervenes to protect consumers.

In some infrastructure sectors, it can be possible to isolate the part of the system that is subject to natural monopoly. This way, the benefits to consumers of competition can be enjoyed in the parts of the system where this is feasible, and the monopolistic parts are subject to a different regime. The classic example of this is the energy sector. It makes economic sense to only have a single transmission and distribution network. However, it is feasible to have a number of companies generating electricity and a number of companies selling power to end users. Because of this, national grids are kept operationally separate, and subject to different forms of regulation than generators and retailers.

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[5] https://www.mbie.govt.nz/dmsdocument/27989-briefing-for-the-incoming-minister-for-media-and-communications-proactiverelease-pdf
[6] Baumol, 1977

3 Infrastructure and productivity

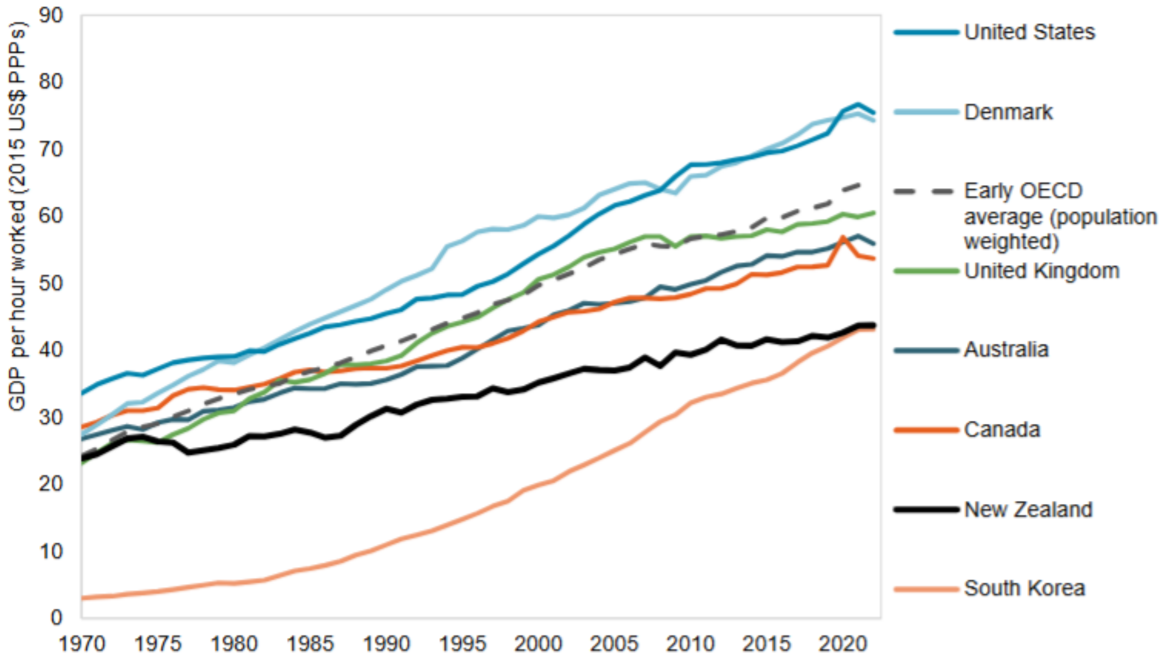
Productivity growth, being able to produce more with the same inputs, is the critical determinant of increasing living standards. This section describes the macroeconomic and microeconomic impacts of infrastructure, and the channels through which infrastructure can improve productivity.

3.1 New Zealand has a productivity challenge

New Zealand's productivity performance has been subject to significant policy analysis over multiple decades.[7] Overall, there are few key themes:

- New Zealand's level and growth of productivity, as measured by GDP per hour worked, is lower than comparable OECD countries (Figure 7).[8]

Figure 7: New Zealand's labour productivity has lagged other developed countries, GDP per hour worked, 2015 US Dollars Purchasing Power Parity (PPP)



Source: Treasury (2024). Early OECD countries are defined as those that joined the OECD prior to 1975.

- There are a wide range of factors that contribute to this lower productivity performance, but New Zealand's small population size and distance from major markets are likely key factors.[9]

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[7] See for example: Cook, Devine and Janssen (2024); Conway and Meehan (2013); Conway (2018).
[8] A notable exception to more negative assessments of New Zealand's productivity performance is Grimes and Wu (2022), who find New Zealand performs well based on per capita Real Adjusted Net National Income growth, which is a measure of sustainable consumption. New Zealand's better performance on a consumption measure versus a productivity measure appears to be driven by favourable terms of trade changes (New Zealand receiving better prices for our exports) and lower capital stocks which produce less depreciation and higher labour force participation rates.
[9] New Zealand Treasury, 2013

- Despite factors outside our control limiting our performance, in the long run productivity growth is still critical to increasing New Zealand living standards and gives us greater choices to further our social and environmental goals.[10]

3.2 Infrastructure and economic growth: the macro picture

Economists often use a simple production function to describe the economy, where the output (Y) of an economy depends on the amount of capital (K) and labour (L) inputs, and 'multifactor factor productivity' (A) – a residual term that captures all the factors other than labour and capital inputs that can increase output.[11] More capital increases output but with diminishing returns, represented by an α less than one.

$$Y = AK^{\alpha}L^{1-\alpha}$$

Capital includes a range of physical assets, including infrastructure, and intangible assets (e.g., software). An important feature of capital is that it depreciates or wears out over time. This requires investment in the maintenance and renewal of capital, which comes at the cost of reduced consumption. Therefore, the consumption (C) we can achieve is the amount we produce (Y) less the amount we invest to cover depreciation (δK) and the investments we make to increase the total capital stock (I).

$$C = Y - (I + \delta K)$$

This framework shows that more infrastructure isn't always better. Infrastructure helps to increase output but requires reducing consumption today and reducing consumption in the future to cover maintenance and renewals. Because infrastructure has diminishing returns, at some point the costs of extra infrastructure will exceed the benefits.[12] Beyond this framework, infrastructure investment often requires additional debt, taxes, rates and user charges, which can have indirect negative effects on the economy.

Therefore, infrastructure investment must produce a sufficient return to cover these costs. In contrast, increases in productivity, new ideas and innovations, do not depreciate and therefore reduce in consumption in the future.

This framework shows that infrastructure impacts on economic activity in three broad ways:

- **Infrastructure as an output in itself (Y):** Infrastructure provides services directly to consumers, such as water for household use, and data and electricity to use consumer electronics. Consumers pay directly for the production and delivery of these services, which directly leads to jobs in the utility sector. This channel leads

[10] Stevens, Sanderson, and Thakurta, 2023

[11] In other research (*Investment gap or efficiency gap? Benchmarking New Zealand's investment in infrastructure*, and *Nation Building: A Century and a Half of Infrastructure Investment in New Zealand*), the Commission has used models where infrastructure and other capital enter the production function separately, which can be used to more deeply investigate the impact of infrastructure on output. Here we present a simpler model to more cleanly illustrate higher level impacts.

[12] In a Solow model, this is referred to as the golden-rule savings rate, with savings being equal to investment in a closed economy model.

to our current living standards today but does not necessarily improve our ability to improve living standards tomorrow.

- **Infrastructure as an input to production of other goods and services (K):** Infrastructure, like other forms of capital, provides services to businesses which supports them to increase production. They need transport networks to move goods, electricity to power production, storefronts and offices, and digital infrastructure to coordinate with their suppliers and customers. This increases economic output today, which could either go towards more consumption or investment.
- **Increases in productivity (A):** In this simple framework, capital or infrastructure has no impact on productivity. The economic literature exploring economic growth and infrastructure often tests new models where productivity is directly linked to infrastructure. For this paper, we set aside the ideal modelling framework and instead focus on microeconomic channels driving productivity and how infrastructure could theoretically play a role. This is discussed in the next section.

While increasing consumption and providing inputs to current production are important, long-term sustained economic growth is primarily driven by increases in productivity.

3.3 Infrastructure and economic growth: the micro picture

To understand how infrastructure can increase productivity, we need to zoom in and look at infrastructure's impact at the micro level. Economic research has found that productivity growth is fundamentally driven by the creation of new ideas and innovations.[13] New ideas are introduced by individual firms competing to remain at the technological frontier. Therefore, we need a framework that connects this micro-level behaviour to economy-wide productivity growth.

The OECD, in its report 'The Future of Productivity', sets out a framework for how firm level dynamics contribute to aggregate productivity growth, and how policy can support this process. This framework draws a distinction between two types of firms. First, high productivity firms close to the 'frontier' who tend to develop and adopt new ideas, products and technologies. Second, other firms in the economy that are less productive and don't have the capacity or capability to develop entirely new products or technologies.

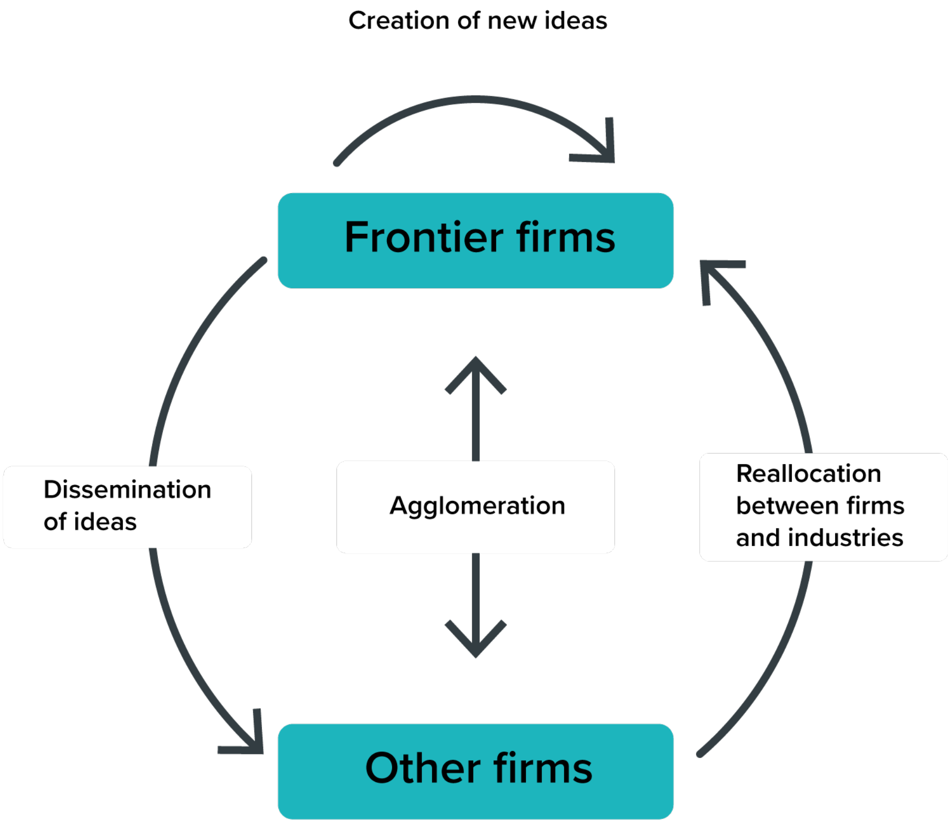
Within this framework, productivity can increase through the following channels (Figure 8):

- creation and adoption of new ideas, innovations and products by frontier firms
- dissemination of new ideas throughout the economy
- reallocation of resources from lower productivity firms and industries to higher productivity firms and industries

[13] Romer, 1990

- agglomeration: cities make the creation and spread of new ideas faster.

Figure 8: Factors contributing to productivity growth



Source: Adapted from OECD (2015).

In the following sections, we describe each of these channels and the role for infrastructure in each.

Creation and adoption of new ideas by frontier firms

Economic research has found that there are large and persistent productivity differences between firms, even within narrowly defined industries.[14] Firms that are highly productive compared to those in their industry are sometimes referred to in the literature as 'frontier firms'.

In New Zealand, frontier firms tend to employ more skilled workforces, particularly in Auckland, invest heavily in innovation, are more likely to export and are more likely to have up-to-date technology.[15]

International connections are particularly important for frontier firms. Frontier firms within a country can be less productive than firms at the 'global frontier'. International connections, such as exporting, foreign direct investment and migration can help New

[14] Bartelsman and Doms, 2000
[15] Fabling, 2021

Zealand firms adopt new technologies developed at the global frontier. Competition in international markets can also put pressure on frontier firms to improve their productivity to remain competitive.[16]

The creation of new ideas by frontier firms is a complex process that depends on many factors, including research and development, government investments in science and innovation, having a skilled and specialised workforce and strong international connections to gain access to innovations from the global frontier[17].

Infrastructure primarily plays an indirect, enabling role in this process, with examples including:

- *Investment in new telecommunications networks.* Frontier firms tend to quickly adopt new technologies, which are increasingly dependent on telecommunication networks. For example, research has found that frontier firms were more likely to adopt ultra-fast broadband[18] and that this resulted in increased in multi-factor productivity.[19]
- *Helping our cities grow.* Removing barriers to urban growth can support New Zealand frontier firms as they are more likely to operate in urban centres with thicker labour markets. The wider benefits of agglomeration are discussed further below.
- *Removing bottlenecks for exporters***.** Frontier firms are more likely to be exporters and engaging in international markets can help improve productivity.[20] Efficient provision of roads, ports and airports can help reduce New Zealand's 'effective distance' from international markets. Airports and telecommunication networks can also support digital and in-person connections internationally.
- *Removing barriers to the growth of new and emerging industries.* New technologies can rapidly increase demand for infrastructure and result in bottlenecks. In the past, technologies such as railways, automobiles and computers have radically changed our infrastructure needs. Predicting the next big technological shift is very difficult, but AI is one contender, which would significantly increase demand for electricity and water.
- *Increasing human capital.* A well-educated and skilled workforce is critical to the development of new ideas. Frontier firms are also more likely to employ more skilled and educated workers. If our education infrastructure, such as school and university facilities, are substandard, it can negatively impact learning outcomes and therefore the skills of the future workforce.

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[16] However, New Zealand research by Fabling and Sanderson (2010) suggests that higher productivity among exporting firms versus non-exporting firms is primarily a selection effect, rather than a causal impact of exporting on productivity.
[17] Syverson, 2011
[18] Fabling, 2021
[19] Fabling and Grimes, 2021
[20] Fabling, 2021

Dissemination of new ideas

While frontier firms are the engines that generate most new ideas and innovations, to increase productivity across the whole economy, these ideas need to disseminate to other firms. For example, Fabling (2021) finds that frontier firms (roughly 8% of all firms) make up around 27% of total output. While disproportionately high, due to their higher productivity and higher use of inputs, this implies that around 73% of output could be improved by disseminating new ideas to firms below the frontier.

Several factors can support the dissemination of ideas, including:

- Sharing ideas within 'industrial clusters' – groups of related firms and industries located in close proximity that benefit from shared infrastructure, labour pools and knowledge spillovers. For example, Silicon Valley is a large cluster of technology companies benefiting from movement of workers to and from high productivity firms. In other small, advanced countries, these clusters are more common and help to support industries to both create and spread new technologies.[21]
- Research and development can not only lead to development of new ideas, but it can also be used to search for and make use of other ideas and innovations developed elsewhere.[22]
- Management practices can also lead to the spread of ideas and innovations. International research has shown that firms with better management practices are more likely to adopt new technologies.[23]

Infrastructure can support dissemination of ideas primarily by indirectly enabling better connections between people and businesses, such as:

- *Enabling industrial clusters*. Industry specific infrastructure can help grow and build critical mass of these clusters. For example, Canterbury's aerospace industrial cluster has been supported by infrastructure such as the Tāwhaki National Aerospace Centre and the region's multiple airports.
- *Wide coverage of telecommunication networks***.** Wide network coverage helps to support more firms to adopt network-enabled technologies. Rural connectivity is particularly important given New Zealand's large food and fibre industry, as it enables producers to take up new productivity enhancing technologies, like 'smart collars' on cows that allow for virtual fencing and pasture management.

Reallocation of resources *between firms*

As noted above, there are large and persistent productivity differences between firms, even within narrowly defined industries. This suggests that there are large aggregate

[21] Ministry of Business, Innovation, and Employment & Ministry of Foreign Affairs and Trade, 2025
[22] Cohen and Levinthal, 1989
[23] Bloom et al., 2016

productivity improvements possible from reallocating resources from less productive firms to higher productivity firms.

New Zealand and international research have shown that the potential gains from reallocation are large. Meehan (2020) measured within-industry misallocation in New Zealand using firm-level data, estimating that, if resources were efficiently allocated across firms based on their productivity, value-add would increase by 83%.

One significant determinant of better resource allocation is competition. Research finds that greater competition (whether for customers, workers or capital) helps to improve productivity both by reallocating resources from less productive to more productive firms, but also by forcing lower productivity firms to improve business practices.[24] International research is still ongoing on the exact sources and determinants of productivity dispersion, and how policy might be able to improve the allocation of resources.[25]

Infrastructure is an important enabler of competition. Infrastructure such as transport and telecommunications helps to connect consumers with a wider set of providers. This is seen very clearly in developing economies as roads open local markets to regional, national and international competition. This increases choice, brings down prices and promotes innovation.[26] The introduction of mobile phones in developing countries, for example, has been important in reducing spatial producer price dispersion in agricultural product.[27]

However, while infrastructure overall is critical for enabling competition, the impact of marginal additions to infrastructure, particularly in mature networks, is not entirely clear. For example, a road connecting two previously disconnected regions could have a significant impact but improving that connection to reduce peak-hour travel times likely has a small marginal impact on competition.

Reallocation of resources *between industries*

Productivity can be improved by shifting resources from low to high productivity *industries*. The industry mix of an economy (i.e., what a country produces), can be an important determinant of economic growth.[28] Some industries and export products have greater potential for innovation, allowing countries to specialise in more complex and higher value products.[29]

Research recently released by Treasury staff investigated how changes in industry structure (i.e., reallocation between industries) have affected New Zealand's productivity performance.[30] Overall, reallocation between industries had a relatively small *negative* effect, suggesting that on average workers were moving to slightly *less* productive

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[24] Syverson 2004; Agarwal et al., 2020.
[25] Restuccia and Rogerson (2017) provide a summary what we know of the causes and consequences of misallocation.
[26] Eddington, 2006; Henckel & McKibbin, 2017; Lakshmanan & Anderson, 2007.
[27] Aker, 2010; Aker & Fafchamps, 2015; Foster, Gorgulu, Straub, et al., 2023b.
[28] Hausmann, Hwang and Rodrik, 2007
[29] Hidalgo et al., 2007
[30] Devine and Smith, 2025

industries. In comparison, industry reallocation in Australia and most OECD contributed a positively to productivity growth – that is, workers moved on average to *more* productive industries.

Infrastructure can affect the allocation of resources across industries if different industries consume different levels of infrastructure services. The most significant difference is likely from energy and electricity, as some industries are significantly more energy intensive than other industries. Improvements in energy infrastructure (gas, electricity generation, transmission and distribution) that increase the supply and reduce the price of energy would likely lead to reallocating resources across industries. As described above, infrastructure can also support new and rapidly growing industries, such as AI, space and advanced aviation.

Modelling by Sense Partners investigates this effect.[31] They have modelled the impact of a 30% increase in electricity prices in the years 2026 to 2030 on different industries, and have found that GDP would fall by 0.7% in 2030 and 0.5% in 2040. These impacts are concentrated in two energy intensive industries: primary metals production (such as aluminium and steel) and pulp and paper manufacturing industries.

The benefits of agglomeration

Agglomeration is when economic benefits arise from firms and workers being physically closer to each other in cities or industrial clusters. We can think of agglomeration as speeding up the process of creating and spreading ideas, helping the above mechanisms work more effectively.

The benefits of agglomeration can be split into three categories: *sharing*, *matching*, and *learning*.[32]

1. **Sharing.** Firms and households can share the costs of expensive, indivisible infrastructure and can share access to specialised services. This allows niche specialised services which boost productivity but wouldn't exist in smaller markets.
2. **Matching**
    - **Local skilled-labour pool.** For firms that need specialist staff, whether lawyers, computer programmers or sound designers, deeper local labour markets give access to more specialist skills at a lower reduce search costs.
    - **Suppliers and customers.** A larger pool of suppliers of inputs and services, as well as customers, increases the likelihood and decreases the costs of finding and contracting with a good match.
3. **Learning.** Collocation allows employees to share information between firms through formal and informal meetings allowing all to have a better understanding

[31] Sense Partners, 2025

[32] Duranton Puga, 2004

of the market they serve (e.g., the financial districts of the City of London, Wall Street or Tokyo).[33]

Infrastructure is a critical enabler of urban agglomeration. The high levels of density seen in modern cities wouldn't be possible without water and transportation networks. That said, infrastructure is only one enabler of agglomeration. To fully achieve the benefits of agglomeration from infrastructure, several factors need to happen simultaneously, such as:

- *Accommodative land-use regulations:* Agglomeration can only happen if people and firms are able to locate at higher densities in areas well-served by infrastructure. Land-use restrictions around our city centres and transport corridors can eliminate many of the benefits of urban infrastructure investment.
- *Investments are in high-demand locations:* Infrastructure investment will only lead to higher densities and agglomeration if there is sufficient demand to move to a location. Land-price indicators can provide an indication of where there is 'excess demand' for a location.[34]
- *Investments don't merely displace agglomeration benefits:* When a region or city grows, the additional population can either come from overseas (external migration) or from other areas in New Zealand (internal migration). Internal migration reduces the population of the source region, likely reducing the agglomeration benefits in that area. When considering how and whether infrastructure investment will lead to agglomeration, it is important to consider the overall impact on the country, rather than just a specific area.

3.4 When to invest in infrastructure for growth?

Up until this point, we have considered the question: *what* should we invest in for growth? A related question is: *when* should we invest? Investing too early or too late both have costs. Investing too early and we lock-in capital that could be applied to other productive investments. Investing early also involves greater risk, as the future demand for a piece of infrastructure is uncertain. Investing too late can constrain growth.

A critical feature of infrastructure investment is it provides capacity which only creates value and benefits when there is sufficient demand. When infrastructure capacity is below demand, increases in capacity are fully utilised, and can lead to agglomeration or better allocation of resources between firms and industries. However, if demand is already satisfied, further increases in capacity can have limited immediate impact.

In general, our previous work highlights investment is most beneficial where a bottleneck is starting to develop, or where a bottleneck could rapidly develop. Historically, bottlenecks are most likely to rapidly develop under two conditions: **significant technological change** there are **rapid demographic shifts.**[35] Electrification, the

[33] Marshall, 1890; McCann, 2001.
[34] Housing Technical Working Group et al., 2024
[35] New Zealand Infrastructure Commission, 2024

automobile and computers are examples of technologies that triggered waves of infrastructure investment and reshaped the New Zealand economy.

Across many infrastructure sectors, our Forward Guidance for infrastructure in the National Infrastructure Plan projects that at a macro level, overall demographic demand should be relatively stable and, outside highly localised areas, there is limited need to invest quickly to avoid future bottlenecks. In these areas, it is best to wait longer before investing and respond to bottlenecks as they develop.

However, there are some subsectors where rapid technological change could lead to bottlenecks which can be relieved by greater investment. For example, advancements in AI have led to significant investment in datacentre capacity, as seen in the US, which may put pressure on our electricity and water networks.

Even when there is a bottleneck, non-built solutions can be just as or more effective than infrastructure investment. For example, if a road is congested during peak times, time-of-use charging can help spread use over time, helping demand better match infrastructure capacity. By avoiding unnecessary capital investment and the taxes, rates, charges and debt to pay for that investment, non-build options can often help economic growth more than investment.

Infrastructure as a counter cyclical tool

Another determinant of when to invest is where the economy is in the business cycle. Infrastructure investment is sometimes used to provide stimulus during an economic downturn. In theory, infrastructure investment could stimulate aggregate demand at a time when there is spare capacity, helping to steady the economy during the downturn and reduce the crowding-out private economic activity.

However, economic research and recent experience have shown that infrastructure investment is a poor counter-cyclical tool. It takes time to plan, design and procure major infrastructure projects, meaning that investment often provides stimulus after the downturn has passed, which can increase inflationary pressures.[36] The desire to initiate 'shovel ready' projects can reduce the quality of projects selected and lead to inefficient rushing of project planning and delivery.

Instead, infrastructure investment can best assist economic stability by providing a steady, baseline of demand, regardless of the state of the economy. Getting the basics right, like long-term infrastructure planning, effective asset management and steady investment in maintenance and renewals, can provide a stable and predictable level of demand that provides support during an economic downturn.

[36] Ramey, 2021

4 What does the evidence say?

As we have discussed above, infrastructure affects our economy and our wellbeing in many ways. It provides important services for households, it is an important driver of productivity, and it helps create the conditions for growth and innovation.

In this section we review the empirical literature that examines the relationship between infrastructure and economic performance.

4.1 Different approaches to studying infrastructure and economic growth

The relationship between infrastructure and economic growth has been studied at length over the past 30 years. Researchers have traditionally approached the question from two different angles.

Macroeconomic studies look at the relationship between infrastructure and national economic growth. These studies use national-account level data such as GDP and public capital stock.

Microeconomic studies look at the costs and benefits to individuals and firms. These often use cost-benefit analysis to compare expected benefits against the cost of infrastructure investment.

Early work on the relationship between infrastructure and economic performance focused on the macro level, because that is where the data were most freely available. As project and organisation level data became more available, microeconomic analysis has increased in popularity. Improvements in data and increasing sophistication in modelling have led to increased focus on issues like agglomeration and competition.

4.2 Macroeconomic studies

There is a long history of economic analyses of the relationship between infrastructure and the growth of economies. The empirical literature received a kick start with Aschauer (1989a, 1989b). Aschauer examined the correlation between the jump in public investment after the Second World War and the long period of post-war productivity growth experienced in the US and other major economies. Aschauer concluded that public investment caused strong economic growth. However, his work has been severely criticised as not properly determining the direction of causality between investment and growth (i.e., does public investment cause growth, or does growth cause public investment?).[37]

When considering the New Zealand context, specific evidence linking economic output and infrastructure investment is lacking. Egert et al. (2009)[38] find strong positive returns

[37] Gramlich, 1994; Henckel & McKibbin, 2017
[38] Égert, Kozluk and Sutherland, 2009

for investment when funding roads and rail, but negative returns for investments in motorways, electricity generation, and telephone lines for the period between 1960 and 2005.

More recent literature appears to agree that careful studies examining the link between growth and infrastructure investments must control for this causality issue. However, there is continued debate on the best empirical approach to isolating this causal effect.

Calderón et al. (2015) is an example of newer estimates of returns to infrastructure that are more robust and address many of the methodological shortcomings of previous studies. Their estimates suggest a long-run infrastructure-output elasticity of 0.07 to 0.1, which implies that a 1% increase in infrastructure stocks increases GDP by 0.07% to 0.10% in the long run.

Over the years there have been papers which have reviewed the vast body of literature examining the relationship between public investment and economic growth. Bom & Ligthart, 2014 performed a meta-analysis of 68 different studies which found that a 1% increase in infrastructure stocks led to economic growth of 0.08% in the short run and 0.12% in the long run.

More recently, Foster et al. (2023a) looked at over a thousand estimates from over 200 papers. After accounting for publication bias and the impact of study design, across all studies they find a much lower average infrastructure-output elasticity around 0.02 to 0.04. However, there is significant variation in this estimate by method. Papers that looked across the whole economy using financial measures of infrastructure stocks (such as the value of assets) found elasticities between 0.09 to 0.19. On papers that consider individual sectors using physical, access, or usage measures, elasticities are much lower between 0-0.04.

The economic returns to infrastructure investment are affected by various factors. We will discuss the differences by level of development and differences by infrastructure sector, then we will look at some microeconomic analyses.

Differences by level of development

As discussed in previous sections, there are different returns to new infrastructure investment based on how economically and infrastructurally developed a place is. We would expect that initially, returns to infrastructure investment would be low, due to the network effect we discussed. But as the infrastructure networks mature, returns increase. Then we would expect returns to fall in well-developed countries with well-developed infrastructure.

Research has generally confirmed this. Lakshmanan & Anderson (2007) summarise results of the various studies as finding an inverted U-shape, with higher returns in middle-income countries and somewhat lower in the low and the high ends of the income distribution. High rates of return for paved roads are found in some middle-income developing countries (Chile, Colombia, South Korea and the Philippines). 'By contrast, low rates of return accrue for paved roads in affluent developed countries and in some developing countries' (pg. 32).

A major study for the UK government into investment in transport infrastructure concluded that:

> Today, in mature economies like the UK, with well-established networks and where connectivity between economic centres is already in place, the evidence suggests that there is considerably less scope for transport improvements to deliver the periods of rapid growth seen historically.

Eddington, (2006), pg. 1

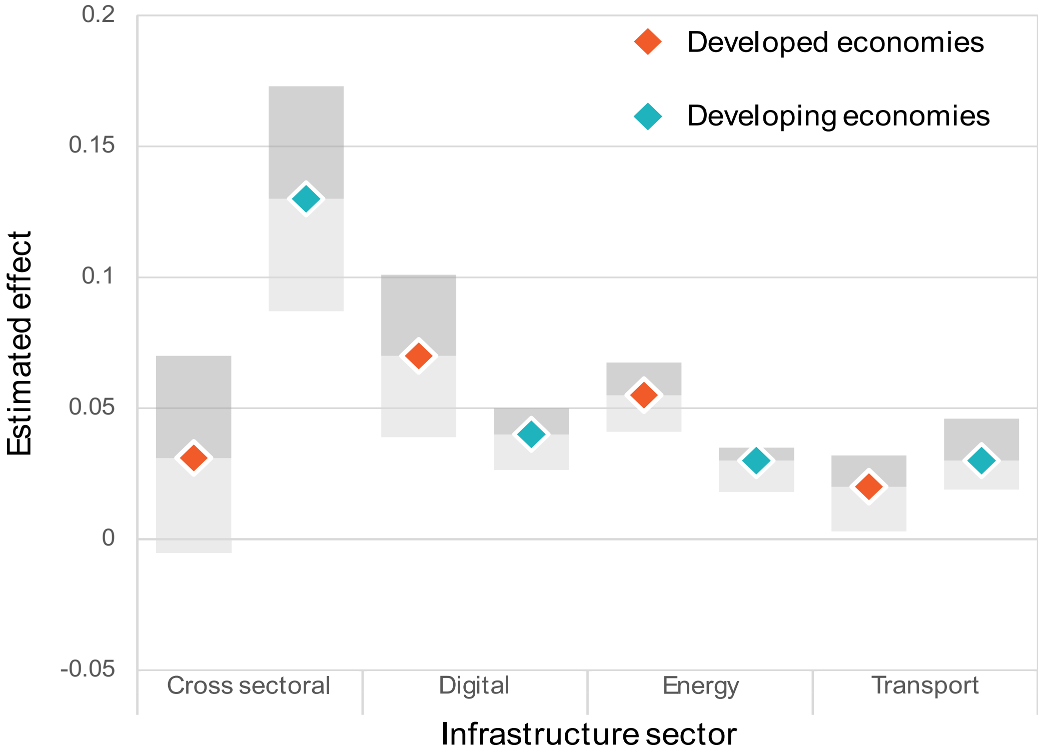
Differences by infrastructure type

The most common type of infrastructure considered in the empirical literature is transport, often roading. This isn't surprising given transport's theoretical importance to many of the economic phenomena we discussed above and given that transport is one of the oldest forms of infrastructure.[39]

In the Foster et al. (2023a) meta-analysis discussed above, they find that while effects appear larger in developed countries for digital and energy studies, those for transport studies are larger in developing countries (Figure 9). As noted above, the returns to investment in these countries will also depend on the level of development and the quality of individual investments.

[39] Fujita et al., 2001; Kelly, 1997; Lakshmanan and Anderson, 2002

Figure 9: Sectoral Estimates of the infrastructure elasticity by level of development



Notes: Diamonds represent point estimates and the boxes represent 95% confidence intervals. Cross sectoral includes studies covering data from multiple infrastructure and public capital; Digital covers fixed telephony, internet and mobile phones. *Source: Foster et al. (2023a) Figure 4, panel (a).*

What does this suggest about our investments?

Do empirical estimates suggest we are not investing 'enough' in infrastructure? To consider this, we convert these 'elasticities' into rates of return per dollar spent. In equilibrium, we should expect the marginal benefit of additional infrastructure to be equal to or greater than its return plus depreciation.[40] Mathematically, this can represented as:

$$MPK = \alpha\left(\frac{Y}{K}\right) = r + \delta$$

Where *MPK* is the marginal product (benefit) of infrastructure investment, α is the elasticity of output with respect to infrastructure, *Y* is economic output, *K* is the value of infrastructure stock, *r* is rate of return and δ is depreciation.

Rearranging, the rate of return is simply the elasticity of output with respect to infrastructure α multiplied by the capital/output ratio minus depreciation:

$$r = \alpha\left(\frac{Y}{K}\right) - \delta$$

Since 2016, the ratio of public capital stock to output in New Zealand has averaged 1.23.[41] Our *Build or maintain* research report found public capital had a depreciation rate of

[40] Jorgenson, 1963
[41] See Stats NZ series SNE055A.

approximately 4% in recent years.[42] To generate net-positive returns above depreciation and considering the cost of capital (proxied by Treasury's 8% discount rate for commercial investments), then for infrastructure to generate net positive benefit for the economy, we would need to see elasticities closer to Bom and Ligthart's (2014) estimate 0.1. A 0.1 elasticity would imply a rate of return of 8.3%, modestly above the 8% discount rate for commercial investments recommended by the Treasury.

In contrast, an elasticity of 0.03, roughly the average from Foster et al (2023a) would have a slightly negative rate of return – suggesting returns would not even be sufficient to cover depreciation, and well below the cost of capital.

4.3 Microeconomic analysis of infrastructure

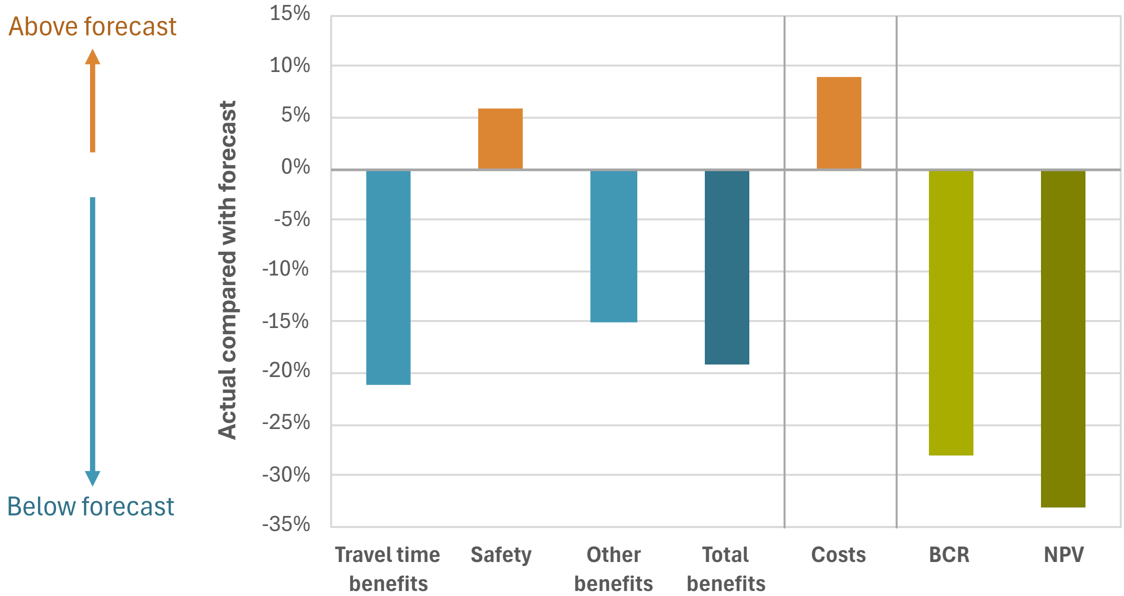
Microeconomic analysis looks at individual infrastructure investments, usually using cost-benefit analysis (CBA). CBA involves calculating the expected costs and the expected benefits and seeing whether an investment will deliver value for money. In practice, however, many investments do not perform as expected.

An extensive international literature exposes a consistent pattern of underestimated costs and overestimated benefits. Perhaps the largest and most well-known of these are those by Flyvbjerg and various co-authors.[43] Studies which draw on Flyvbjerg's database and studies by Flyvbjerg himself have found that infrastructure construction costs average 20-40% higher than predicted, while first-year benefits are almost always lower than predicted.[44]

In New Zealand, Wignall (2017) compares ex-post data with initial forecasts and estimates for 24 New Zealand transport investments, totalling $2.4b (in 2010 dollars).[45] The study suggests that total benefits are, on average, 19% lower than forecast. Travel time savings are particularly overestimated. Safety benefits, however, often turn out to be greater than originally forecast. On net, both the benefit to cost (BCR) ratio and the net present value (NPR) were lower than forecast. Another interesting result from the study is a suggestion that larger investments have more uncertainty both in the costs and the benefits of the investment.

[42] New Zealand Infrastructure Commission, 2024
[43] Flyvbjerg et al., 2002; Flyvbjerg & Bester, 2021; Flyvbjerg & Gardner, 2023a.
[44] Flyvbjerg & Bester, 2021.
[45] These investments vary in size, urban/rural area, State- vs non-State Highway etc.

Figure 10: Overall performance of NZ transport investments



Source: Wignall (2017).

While microeconomic analysis of infrastructure investments has its uses, they have limitations. The majority focus on direct, measurable benefits over relatively short time periods. These short periods are likely to miss the wider impacts that we discussed earlier, such as agglomeration and supporting the uptake of new technology.[46] There are also data challenges in this space.

4.4 Infrastructure inputs into economic growth: evidence of New Zealand's efficiency

Another way to consider the degree to which infrastructure investment produces long-run economic growth is by exploring how well infrastructure investments generate benefits for users.

The overall economy and infrastructure have complex linkages. At a high level, however, these connections can be thought of as follows:

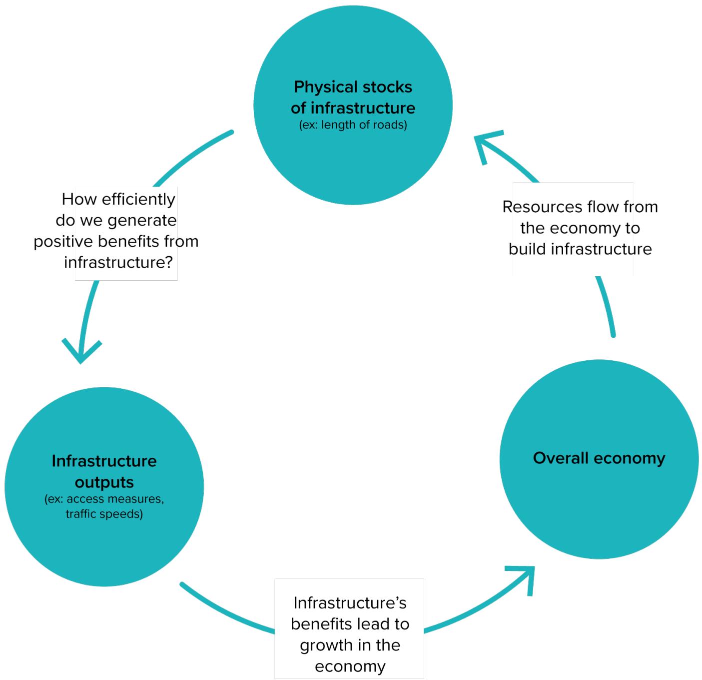
- The overall economy produces resources that can be used to produce capital goods and pay for goods and services. Some of these resources (money) can be used to build infrastructure, but doing so means these resources cannot be used for something else.
- That money produces infrastructure stocks (roads, schools, hospitals). That infrastructure will produce outputs and benefits for users and non-users. For instance, a new road will allow people to get places quicker.
- The overall benefit for the economy is a question of how efficiently the infrastructure stock produces benefits. For example, if we build a new road in an area, but the quality of the road is poor such that people cannot travel more

[46] Nicolaisen & Driscoll, 2016

efficiently, we shouldn't expect such a road to have any impact on the local economy.

Figure 11 lays out a schematic for this flow of resources.Figure 11

Figure 11: How infrastructure and the economy interact



Source: New Zealand Infrastructure Commission

If we want to understand how effectively infrastructure is contributing to the economy, we need to understand how efficient our current stock and level of investment in infrastructure is at creating benefits. Broadly speaking, this is an attempt to estimate technical efficiency of infrastructure at producing outputs, which leads to overall economic growth.[47]

The first step the Commission took to explore this question was our international benchmarking of infrastructure networks for the National Infrastructure Plan. As part of that process, the Commission worked to understand our networks relative to international peers. We compared across four measures:

- **Stocks:** How much infrastructure did we have? For example, the length of railway lines, the number of hospital beds, or the number of schools.
- **Investment:** How much did we spend over a length of time (10 years typically) building and renewing physical infrastructure networks?
- **Usage:** How many users do our networks have? For instance, the average class size, the number of passengers that travel our roads.

[47] Using the term 'efficiency' can result in some confusion, but for our purposes, we adopt the simplest definition: efficiency is when we can achieve more with less. As an example, if we are able to implement a better quality, longer roading network, that has a higher level of usage, while continuing to invest the same amount, we can assert that we have become more 'efficient'.

- **Quality:** Across several different network-specific quality measures, how did we compare? For roads, this might relate to congestion levels, safety, or access. For water networks, it would be drinking water quality and leakage levels.

We compared New Zealand to as many countries as we could find data for but focused in on countries that had similar characteristics to New Zealand. Our subset of control countries accounted for population size, density, income levels, and terrain ruggedness as well as other network-specific measures that might explain, at a high level, differences between country infrastructure building, usage, or quality measures.

What we found was that at a high level, across all infrastructure networks, the amount and quality of infrastructure we have measures up reasonably well. However, for most networks, we had relatively high investment levels (Figure 12). This implies that within the system, there is some degree of inefficiency.

Figure 12: International Benchmarking of New Zealand's infrastructure networks

NZ difference from comparator country average
(based upon simple unweighted average of multiple measures)

Network	Investment levels	Quantity of infrastructure	Usage	Quality	Comparator countries	Notes
Road	+34%	-13%	-33%	-13%	CZE, CAN, FIN, SWE, ISL, NOR	High investment levels, low usage, high amount of fatalities on the network
Rail	-64%	-43%	-23%	-90%	CHL, GRC, JPN, ESP, FIN, SWE, ISL, NOR	Low investment levels, low usage (both passenger and freight), high emissions
Electricity	-3%	+29%	-46%	-12%	COL, CRI, CHL, CAN, FIN, SWE, NOR, ISL	Large transmission network, relatively high frequency and length of outages
Health	-25%	-10%	-2%	-13%	UK, AUS, SWE, DEN, ISL, NOR	Low amounts of some medical equipment, some higher wait times, and older hospitals
Education	+1%	-10%	+6%	+4%	CHL, FIN, AUS, ISL, NOR, USA, IRL	No clear deficits or shortages
Telco	+28%	-12%	+3%	-4%	COL, CRI, CHI, CAN, FIN, SWE, ISL, NOR	High investment levels, developed fixed broadband but underdeveloped mobile broadband
Water	+70%	-3%	+99%	+9%	CHL, GRC, ESP, CZE, CAN, FIN, SWE, ISL, NOR	High levels of investment, very high usage, average levels of leakage

Notes: Comparator countries were chosen based upon different characteristics for each network, but often included measures of population, population density, land area, terrain ruggedness, and per-capita incomes. Differences from the comparator country average are composed of a simple average of various available metrics without weights. For instance, road network quality measures include metrics on congestion, road smoothness, travel speeds and safety, which are normalised and averaged to make a single measure. Source: International Benchmarking Technical Report, New Zealand Infrastructure Commission (2025).

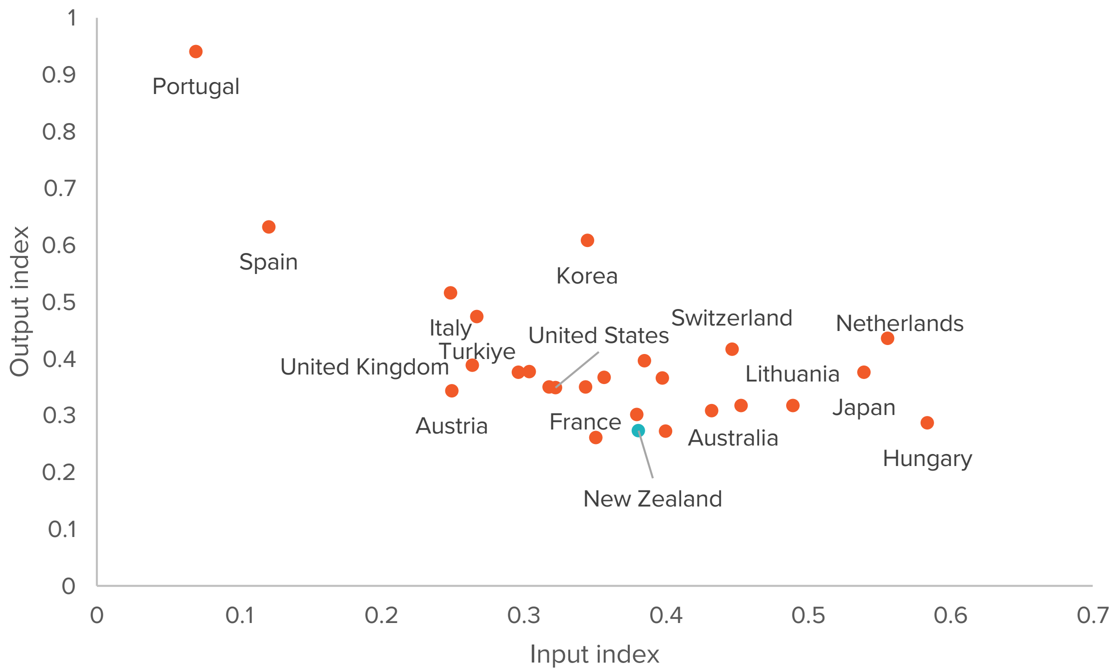
While this high-level international benchmarking provided us with a view of our network performance relative to other countries, it does not give us any immediate insight about the opportunities for New Zealand to become more efficient or inform advise us which countries have the 'ideal' mix of spending and outcomes.

To push our understanding of how New Zealand can achieve greater levels of efficiency, we undertook a deeper examination of the kinds of outcomes other countries receive for their infrastructure stocks and spending, focusing on roads, as it is our largest infrastructure network.

Figure 13 shows at a simple analytical level, the level of outputs countries receive from their inputs. These indices are derived by taking simple averages across several input and output measures.[48] Efficiency can be reflected in the 'bang-for-buck' countries realise. Greater efficiency corresponds to higher total output index values, while minimising input index values. Countries towards the upper left part of the chart are more efficient.

These results suggest that New Zealand has room to improve its efficiency. While our input index is roughly average, our output index is relatively low. Conversely, Portugal and Spain are highly effective, with high output index scores despite low index scores. The inverse is true for countries such as Lithuania and Hungary.

Figure 13: Roading input and output indices across countries



Source: New Zealand Infrastructure Commission analysis of international benchmarking data for road networks. See Benchmarking our infrastructure: technical report. New Zealand Infrastructure Commission 2025.

Using frontier analysis, we can get a better understanding of the countries who are most effectively generating positive outputs given a certain level of inputs.

Portugal and Spain present as hyper-efficient outliers, with both being able to achieve a relatively high output index while maintaining comparatively low inputs, both in terms of

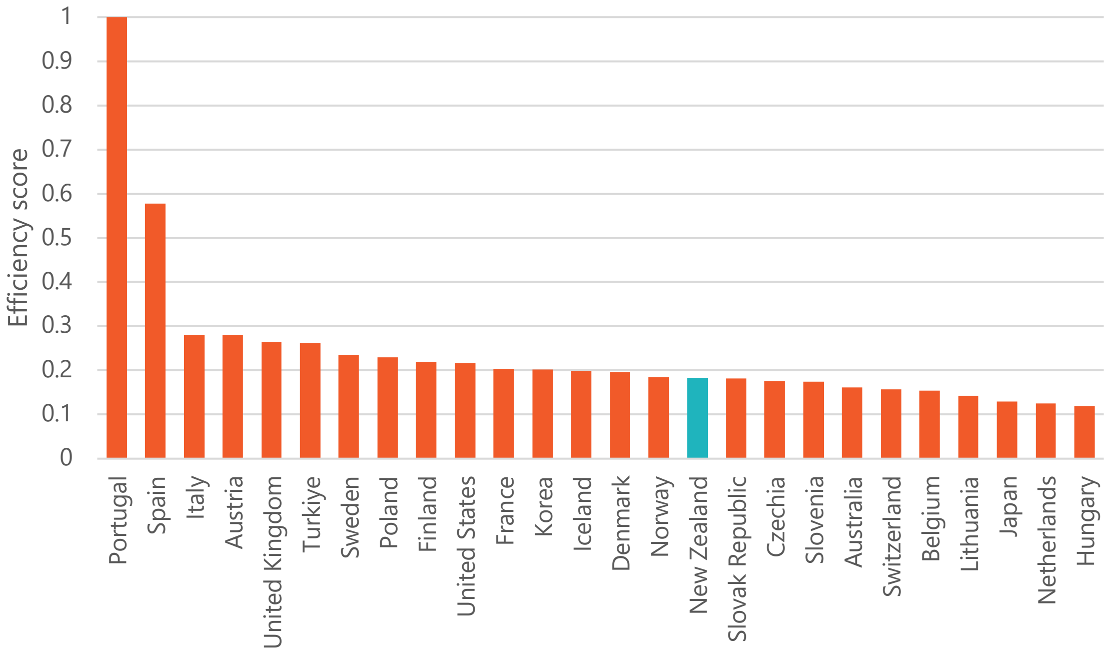
[48] These indexes are simple equal-weighed composite indexes, where the comprised variables were all normalised and ranked. The input index is comprised of investment as a share of GDP, roading km per capita, and roading km per sq. km. The output index is comprised of passenger density, freight density, and a Commission-developed quality index. More complex approaches to constructing input and output indices produce similar results.

total investment (which may reflect post-Global Financial Crisis consolidation), as well as the relatively lower level of roading network per capita and landmass.

Most countries exist in the middle cluster, with the general trend being that less efficient countries are further to the right. This spread is quite wide, and suggests that New Zealand is middle of the pack.

Figure 14 shows the results of our analysis, which suggests that most countries, including New Zealand (ranking 16 out of 26), are relatively inefficient with their roading networks.

Figure 14: Frontier analysis efficiency scores for select OECD countries, road infrastructure



Source: New Zealand Infrastructure Commission analysis. Note: certain countries were omitted due to missing data for various inputs or outputs.

This analysis also allows us to understand the potential levers countries could pull to improve their efficiency relative to international peers. For example, we estimate that if New Zealand were to lower its current roading network investment levels by 20%, while maintaining current utilisation and quality levels, our ranking would jump 5 places to 11th. This presents a valuable opportunity if the country were to realise more cost-effective ways of investing in the network.

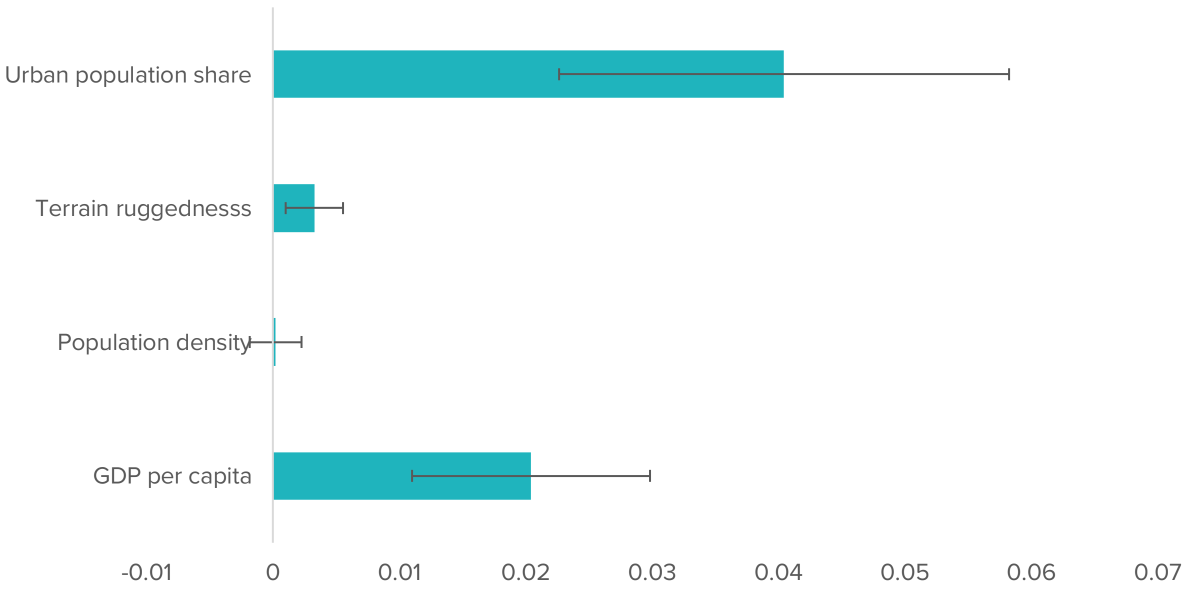
While these results come from simplified measures and metrics, the findings are corroborated by more comprehensive and detailed frontier analysis, which are discussed in the technical appendix.

Furthermore, we built on this technical exercise by also exploring the types of country characteristics associated with greater efficiency scores.[49] Across the different frontier

[49] This estimation was performed using the extended results from our order-M analysis, detailed in the technical appendix.

analyses we used, we find that countries with higher incomes and urban populations are associated with higher roading efficiency scores, while the ruggedness of a country's terrain or overall population density are not[50] (Figure 15). We estimate that a one standard deviation increase in urban population share or GDP per capita would lead to an efficiency score that is 0.05 higher.

Figure 15: Modelled impact of a 1% increase in country characteristics on efficiency scores



Source: New Zealand Infrastructure Commission analysis.

What all these analyses suggest is that there are opportunities for New Zealand to boost its overall economic output by improving the efficiency of its spending or improving the benefits from that spending. This finding reinforces other work by the Commission, including:

- Emphasising the importance of strong project planning and appraisal to ensure the investments that we are making are generating value.
- Utilising strong pricing approaches to network infrastructure as a way of signalling to infrastructure providers which investments and where value will be generated.
- Identifying opportunities for non-built solutions to infrastructure issues like congestion, to make better and more efficient use of existing infrastructure without significant new investment.

[50] Note that this reflects both the comparative greater impact of higher incomes and urban population, as well as their statistical significance.

5 Conclusion

Infrastructure can affect productivity and economic growth, but it's complicated

Infrastructure is foundational for our productivity and for our economy. Many of the great economic transformations have been driven by improvements in infrastructure. This might lead us to expect a positive and ongoing relationship between infrastructure and the performance of the economy. But it is important that we consider the channels through which infrastructure affects productivity and economic growth.

In this paper, we have looked at the macroeconomic impact of infrastructure on the economy. We have also looked at how infrastructure can support the microeconomic factors that contribute to productivity growth. Productivity growth is fundamentally about the creation and dissemination of new ideas. Infrastructure mainly plays an indirect enabling role in this process, particularly in helping our cities grow, providing telecommunication platforms that businesses adopt new digital technologies, and helping consumers connect with a wide range of providers.

Early academic literature did conclude that there was a strong relationship between infrastructure investment and economic growth, especially after the Second World War. However, more recent work has pointed out that rather than infrastructure investment *causing* economic growth, instead it may *accompany* it. As people become richer and economic activity increases, people and businesses demand more infrastructure.

More infrastructure isn't necessarily better

Over the past 20 years, our public investment in infrastructure has been one of the highest of all OECD countries as a share of GDP. If spending more on infrastructure meant greater GDP growth, we'd be leading the pack. However, New Zealand's recent productivity growth has been poor compared to other OECD countries. Clearly, the relationship between infrastructure investment and economic growth is more complex. We can't simply dial up infrastructure investment to boost economic growth. Not every infrastructure project will create economic growth and productivity.

Therefore, we must consider project quality and timing. Improving the quality of our infrastructure investment, rather than the quantity, is likely to have a greater impact on productivity and growth. Further, if those dollars are redirected from existing productive assets, it could worsen their condition. Infrastructure projects that deliver value-for-money and are aligned with the strategic objectives of the New Zealand Infrastructure Strategy will be more beneficial for New Zealanders.[51]

[51] The 2022 New Zealand Infrastructure Strategy, which the National Infrastructure Plan builds on, outlines a vision where our infrastructure drives higher living standards, contributes to a strong economy, enables our culture and society to thrive, and integrates into and supports te taiao, the natural world.

There is more to be explored

While there is a sizeable literature on the relationship between economic growth and infrastructure stocks, evidence for New Zealand is still somewhat light. This paper provides a framework for thinking about how infrastructure can improve productivity. The Commission plans to undertake more research in this area to help decision-makers better understand how the infrastructure system can best support productivity in New Zealand.

Key question to explore include:

- When does infrastructure increase the level of economic activity versus the growth of economic activity?
- Where are our infrastructure networks mature and facing diminishing returns, and where are marginal returns on investment high?
- When are the productivity benefits of urban agglomeration sufficient to justify investment in infrastructure to enable growth?
- How should the New Zealand infrastructure system respond to rapid technological change, such as the widespread use of AI?

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Appendix A: Frontier analysis of road network efficiency

This technical appendix lays out the methodology, results, and sensitivity tests of our analysis of road network efficiency using frontier analysis methods.

Overview of frontier methods

Frontier analysis methods are generally split between parametric and non-parametric methods. Across our analysis, we used four different frontier analysis methods. All of these are non-parametric deterministic methods, meaning they do not make any assumptions about the shape of the data, or the production function used to turn inputs into outputs.[52] In our analysis, we use different types of estimators as tests of efficiency.

These include a standard DEA estimator, using different assumptions about returns to scale, a free disposal hull (FDH) estimator, a super-DEA estimator and an order-m estimator proposed by Daraio & Simar (2007). What follows is a brief discussion of each.

DEA works by forming a frontier out of the countries that are the most efficient. Other countries are then compared to these countries to see how far they are from being as efficient as them. Figure 16 below shows an illustration of how DEA works. The DEA frontier assuming **variable returns to scale** (VRS) is represented by the orange line and comprises A, B, C, and D. These four points are efficient in this scenario. All other countries have room for improvement. For example, if we were to assume an input-oriented model, F should be able to keep its output the same but decrease its input to the point on the orange line close to B.

The **DEA** frontier assuming **constant returns to scale** (CRS) is shown by the purple. Assuming CRS requires that there are no economies or diseconomies of scale. Any increase or decrease in input should be accompanied by a proportional increase or decrease in output. Figure 16 displays how strong an assumption CRS is, as only B is efficient.

Super-DEA expands the standard DEA model, and removes the country being evaluated when forming the frontier. In Figure 16 below, the super-DEA is evaluating C, leaving the frontier to be formed by A, B, and D. C is evaluated against this frontier and will have an efficiency score greater than one. Super-DEA allows the ranking of both efficient and inefficient countries.

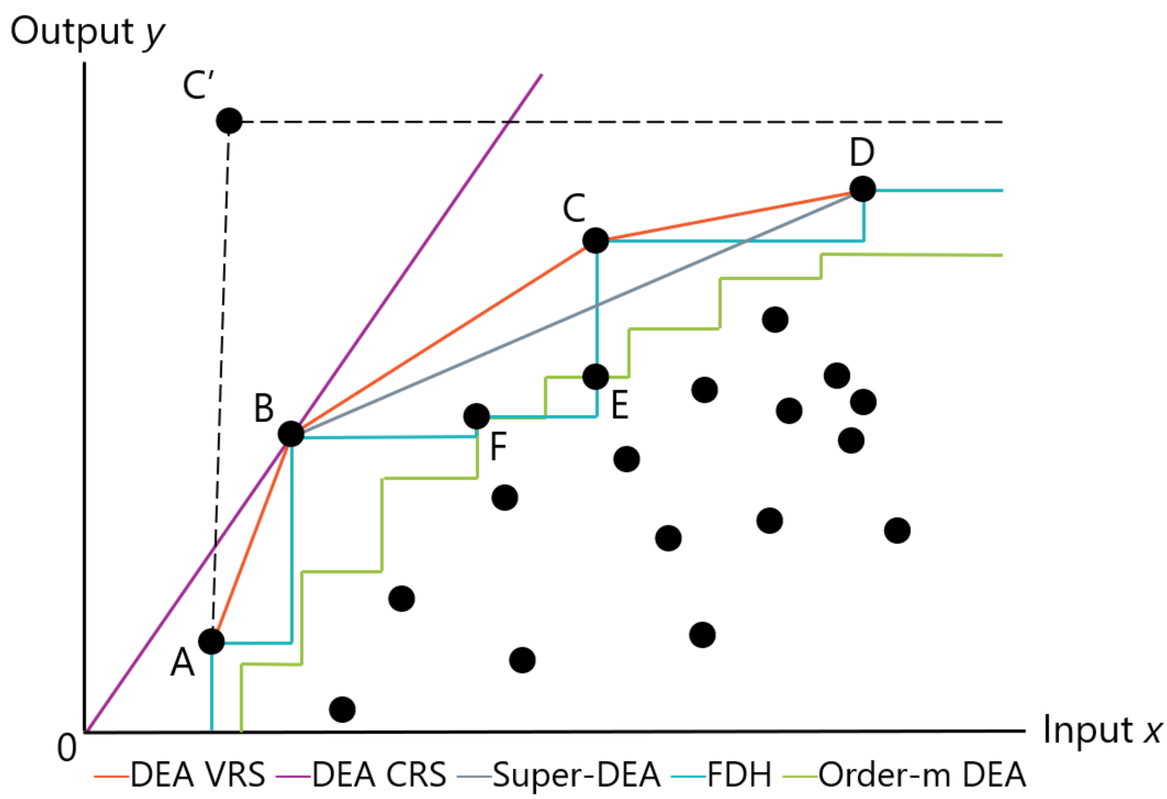
The **free disposal hull** (FDH) estimator is developed by Deprins, Simar, & Tulkens (2006). An illustration of the FDH frontier is shown in Figure 16 by the blue line. The FDH estimator creates a stepped frontier. In a FDH estimator, countries are compared to other

[52] This contrasts with parametric stochastic methods such as stochastic frontier analysis (SFA). There are benefits and drawbacks to using either type of method. See (Krüger, 2012) for a full discussion and analysis of these methods.

countries that are better in every way. In Figure 16, countries below the frontier will be compared to the blue line to their left in an input-orientated model. This is the amount of an input and efficient country should be using with its level of output.

The final estimator is the **order-m DEA** estimator proposed by Daraio & Simar (2007). Order-m further relaxes technology assumptions, which increases analytical flexibility. Imagine point C, rather than being where it is, is in the top left corner of Figure 16 as C′. This distorts the frontier severely as DEA and FDH methods don't have a way of detecting outliers. The super-DEA estimator can identify outliers as C′ would be removed when it is being evaluated, and it would have an efficiency score far above 1. The most robust estimator is the order-m however. Rather than using all countries at once to form the frontier, the order-m estimator chooses a random sample. It does this many times and averages the result. The frontier will look like the green line in Figure 16, but not exactly due to its random nature.

Figure 16: Illustration of how different frontier analysis methods work



Context

This section details both the foundational, and additional frontier analysis we performed to further support our conclusions regarding New Zealand's roading network efficiency.

Cross-country frontier analysis effectively seeks to provide answers to the question: which countries are most efficient at delivering a certain set of outputs for a certain amount of inputs. In infrastructure or other public services, this type of analysis is particularly useful because it helps policymakers understand whether they are allocating resources and money effectively.

We are trying to understand whether our spending and resulting infrastructure are doing an effective job of delivering benefits to their users in proportion to those inputs. If they are not, we suspect that overall economic performance could be improved by either reducing inputs (and keeping outputs constant) or increasing outputs (while keeping inputs constant).

Baseline analysis

For the 'simple', foundational analysis presented in the main body, we applied the DEA VRS process (as defined above) on two variables: one input, and one output.

Both these variables are equally weighted composite indexes of relevant factors, with the input index capturing investment (as a share of GDP), and the capital stock through roading km per capita, and roading km per square kilometre. The output index was comprised of passenger density, freight density, and a quality index comprised of a series of variables. This was done to reduce the curse of dimensionality: an issue that arises when we have a large number of explanatory variables, while having few countries. By using this composite index, we allow countries to be dominated, which generates rankings that offer more insight, rather than outputting rankings which assert equivalency between countries due to a lack of domination across variables.

Normalisation was performed by dividing the variable by the largest in the sample. This effectively translates the variables into some fraction of the largest, allowing both normalisation, and ranking.

We also tested alternative normalisation techniques to observe whether they generated materially different results. When applying min-max feature scaling normalisation to develop our indices, we still found that Portugal and Spain were the two outliers in terms of efficiency, with them having the highest, and other countries clustering with low scores. However, this normalisation process drastically deflated the scores of all non-Portugal countries. To derive better insight from our data, we chose to apply our simple normalisation technique, rather than min-max.

These variables are presented in Table 2.

Table 2: Quality index output variables

Variable	Input or output	Why is it included?	Source
Perceived rated quality of road infrastructure	Output	A measure of the quality of transport services provided by the road network.	World Economic Forum Executive Opinion Survey
Fatalities per passenger-KM	Negative output	A measure of quality of transport services on the road network. Higher values are a negative quality indicator.	OECD-ITF
Fatality rate per capita	Negative output	A measure of quality of transport services on the road network. Higher values are a negative quality indicator.	OECD-ITF, World Bank World Development Indicators
Rural access index	Output	A measure of quality of transport services on the road network. Higher values indicate greater connectivity.	Rural Access Index Measurement Tool, World Bank
Speed score	Output	A measure of quality of transport services on the road network. Higher values generally indicate a greater effectiveness of moving people and goods.	International Monetary Fund
Hours lost in traffic	Negative output	A measure of quality of transport services on the road network. Higher values are a negative quality for a network, as it indicates greater congestion.	INRIX
Quality index	Output	Equal-weighted index of the quality variables above.	Commission constructed measure

To reduce additional complexity, this baseline analysis did not interpolate missing data for countries. Rather, we limited our analysis to the countries which had complete datasets for each of the used variables. These countries, alongside their VRS efficiency scores are detailed in Table 3.

Table 3: VRS outputs for baseline analysis

Country	Efficiency score	Country	Efficiency score
Portugal	1.00	Denmark	0.20
Spain	0.58	Norway	0.18
Italy	0.28	New Zealand	0.18
Austria	0.28	Slovak Republic	0.18
United Kingdom	0.26	Czechia	0.18
Turkiye	0.26	Slovenia	0.17
Sweden	0.24	Australia	0.16
Poland	0.23	Switzerland	0.16
Finland	0.22	Belgium	0.15
United States	0.22	Lithuania	0.14
France	0.20	Japan	0.13
Korea	0.20	Netherlands	0.13
Iceland	0.20	Hungary	0.12

Pushing the frontier: order-M analysis.

In this section, we extend out our simple frontier analysis by using the order-M frontier estimator. Rather than comparing just two indices, we further increase complexity by now comparing three measures of inputs against nine different outcome measures, laid out in Table 4 below.

We collect these variables for 36 countries and compare New Zealand's relative scores. In our analysis, investment and the quantity of roads are considered inputs, while measures of quality, such as congestion, traffic injuries and fatalities, and usage are considered output measures. Where data is missing, we adopt an imputation process (as noted in Appendix C).

Table 4: Road infrastructure input and output variables for order-M estimation

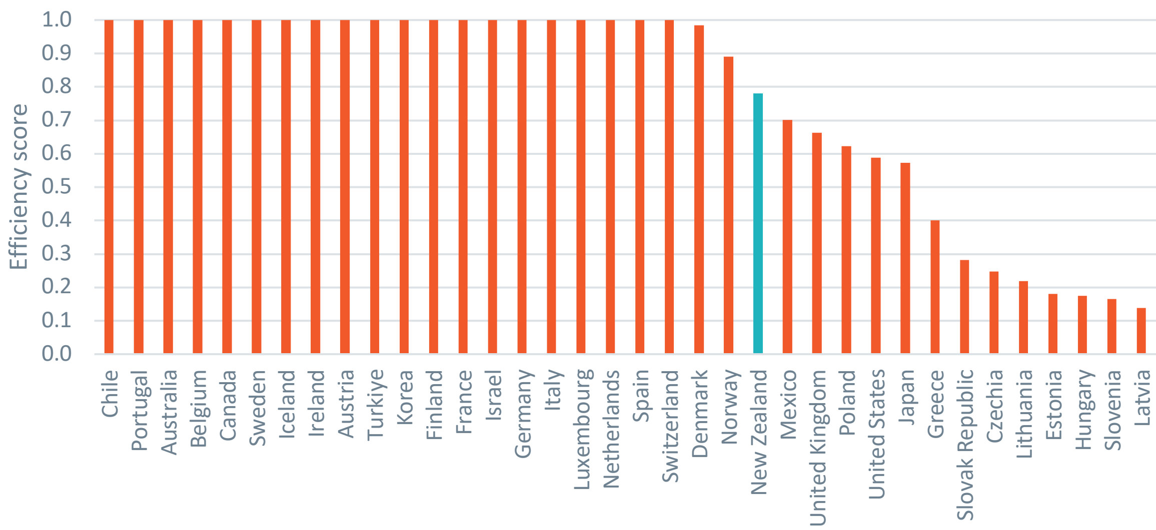
Variable	Input or output	Why is it included?	Source
Investment as a % of GDP over the last 10 years	Input	Investment generates growth in the stock of road infrastructure.	OECD-ITF
Road KM per capita	Input	Roads are an input into transport services. They are not the end in of themselves.	CIA World Factbook, OECD-ITF, UNECE, World Bank World Development Indicators
Road KM per KM^2	Input	Roads are an input into transport services. They are not the end in of themselves.	CIA World Factbook, OECD-ITF, UNECE, World Bank World Development Indicators
Passenger-KM per KM of road	Output	A measure of usage on the road network.	OECD-ITF, World Bank World Development Indicators
Freight tonne-KM per KM of road	Output	A measure of usage on the road network	OECD-ITF, World Bank World Development Indicators
Perceived rated quality of road infrastructure	Output	A measure of the quality of transport services provided by the road network.	World Economic Forum Executive Opinion Survey
Fatalities per passenger-KM	Negative output	A measure of quality of transport services on the road network. Higher values are a negative quality indicator.	OECD-ITF
Fatality rate per capita	Negative output	A measure of quality of transport services on the road network. Higher values are a negative quality indicator.	OECD-ITF, World Bank World Development Indicators
Rural access index	Output	A measure of quality of transport services on the road network. Higher values indicate greater connectivity.	Rural Access Index Measurement Tool, World Bank
Speed score	Output	A measure of quality of transport services on the road network. Higher values generally indicate a greater effectiveness of moving people and goods.	International Monetary Fund
Hours lost in traffic	Negative output	A measure of quality of transport services on the road network. Higher values are a negative quality for a network, as it indicates greater congestion.	INRIX
Quality index	Output	Equal-weighted index of the quality variables above.	Commission constructed measure

Using a more complex estimator has advantages and disadvantages. The order-M estimator can better account for outliers, but makes efficiency scores more difficult to interpret as 'outlier' countries can score above 1. Likewise, including more input and output variables has advantages and disadvantages. More variables gives a more nuanced picture of each country's performance. However, it can also make the estimator less discriminating due to the 'curse of dimensionality' – if a country performs best on at least one variable, it is automatically on the frontier. As the number of variables increases, more countries move up to the frontier.

When comparing order-M efficiency scores, we find that New Zealand's road technical efficiency score is 23rd out of 36 countries. This is largely due to the combination of the same factors found in the simplified analysis. First, New Zealand has relatively high investment levels. At the same time, however, we drive on our roads at a below average intensity, and the quality of our road network is only around average.

The technical efficiency scores for New Zealand and other OECD countries when using order-M efficiency scores are shown in Figure 17.

Figure 17: Frontier analysis efficiency scores for OECD countries using order-M efficiency



Source: Te Waihanga analysis. Note: Colombia and Costa Rica not included due to insufficient data. Error bars show 95% confidence intervals.

As expected, we find that many countries lie on the efficiency frontier. Compared to these efficient countries, New Zealand spends considerably more building and maintaining its roads, meaning that a greater level of inputs were required to deliver desired outputs.

If we aimed to get New Zealand to reach the efficiency frontier, the country would have to reduce investment, reduce our stock of roads, or some combination of the two. Alternatively, we would have to increase passenger and freight usage while maintaining the quality of our roads.

In our international benchmarking work, we identified seven peer countries that are similar to us in terms of income, overall population, terrain ruggedness, and population density.

These countries are shown in Table 5 below. Five of New Zealand's peers are fully technically efficient with an efficiency score of 1.0.

Table 5: DEA suggests New Zealand's peers are fully efficient

Peers	Investment	KM per capita	KM per KM2	Passenger density	Freight density	Quality index	Efficiency score
Canada	0.87%	2.99	12.68	0.83	0.22	0.66	1.00
Iceland	0.72%	3.46	12.80	0.59	0.08	0.52	1.00
Sweden	0.72%	1.91	49.14	0.51	0.22	0.75	1.00
Finland	0.84%	1.98	36.05	0.67	0.25	0.66	1.00
Spain	0.35%	0.35	33.20	2.10	1.49	0.74	1.00
Norway	1.18%	1.75	26.27	0.63	0.22	0.56	0.89
New Zealand	1.13%	1.86	36.93	0.53	0.27	0.49	0.78
Czechia	0.96%	1.23	169.43	0.69	0.41	0.64	0.25

What drives higher efficiency? Regression analysis using order-M results.

We also use the order-M results to derive how country characteristics are associated with efficiency scores. To do this, we perform a simple regression with the efficiency score as the explained variable, and various country characteristics as the explanatory variables.[53,54]

Our regression explores whether external factors like incomes (GDP per capita), population density, a measure of terrain ruggedness, and the percentage of the population that live in urban areas drive higher or lower efficiency. The results are shown in Table 6 below.

Table 6: Beta regression outputs of country characteristics on efficiency scores

Explained variable	Efficiency score	Efficiency score	Efficiency score	Efficiency score
Explanatory variables	(1)	(2)	(3)	(4)
Log of GDP per capita	2.053** (0.946)	2.115** (0.916)	2.116** (0.917)	2.428** (0.982)
Log of population density	0.022 (0.206)		0.042 (0.202)	0.003 (0.199)
Log of terrain ruggedness	0.330 (0.228)			0.333* (0.230)
Log of % of population urban	4.065** (1.789)			
Intercept	-19.916** (9.676)	-21.558** (9.770)	-21.755** (9.842)	-24.853** (10.368)
Log-likelihood	-20.68 on 7 Df	-25.24 on 4 Df	-25.21 on 5 Df	-24.17 on 6 Df

*Notes: All explanatory variables have had the natural logarithm taken. Statistical significance: * = statistically significant at the 10% level, ** = statistically significant at the 5% level, *** = statistically significant at the 1% level. Standard errors shown in brackets. GDP per capita is 2017 USD per person with purchasing power parity adjustment. Population density is people per square kilometre of land area. Terrain ruggedness is the average of the Terrain Ruggedness Index for the area of the country.[55] Percent of population urban is the share of the population living in urban areas as defined by national statistical offices. As the explained variable is distributed between 0 and 1, we have used a beta regression.*

The preferred regression with all our explanatory variables is shown in column 1. Increased GDP per capita and the share of the population who live in urban areas are statistically significantly associated with higher technical efficiency for road infrastructure.

Using this model, we also 'predict' what New Zealand's efficiency score would be if efficiency was largely explained by these four variables. It can also tell us whether, New Zealand is over- or under-performing given its characteristics. The regression predicts that New Zealand would have an efficiency score of 0.91. This is higher than our actual efficiency score of 0.78, suggesting that other factors might be leading to New Zealand being less efficient than peer countries.

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[53] We use a beta regression because the efficiency scores, which is our explained variable, takes values between 0 and 1. This means a linear regression would be unsuitable as it would predict values less than 0 and more than 1. The beta regression fixes this problem by assuming the efficiency scores follow a beta distribution which is bounded between 0 and 1.

[54] This is a method commonly used in DEA research referred to as two-stage DEA. For example, see ref: https://www.sciencedirect.com/science/article/pii/S2214716024000101#:~:text=In%20DEA%20research%2C%20it%20is,known%20as%20two%2Dstage%20DEA.

[55] https://diegopuga.org/data/rugged/ for more detail.

Sensitivity testing of different frontier analysis methods

Table 7 below shows New Zealand's efficiency scores across different frontier estimators. New Zealand performs best in the order-25 and the order-30 estimators. This is true for all countries on average. New Zealand performs poorly in traditional DEA, FDH, and in super-DEA. This suggests that New Zealand's efficiency score is being influenced by outlying countries who distort the frontier in the less robust estimators.

Table 7: New Zealand's efficiency score across estimators

Estimators	NZ score	95% confidence interval	Total average	NZ rank
Order-25	0.78	0.20 – 2.78	2,225.45	23
Order-30	0.63	0.20 – 2.55	1,404.57	23
DEA VRS	0.15	0.15 - 0.70	0.37	19
DEA CRS	0.08	0.08 - 0.42	0.18	12
FDH	0.20	0.20 - 0.88	0.44	21
Super-DEA	0.15	0.15 - 0.70	158.51	27

On average, the order-m estimator will provide higher efficiency scores than the basic DEA estimators due to its design. Even taking this into account, many countries in our results see large increases in efficiency using the order-m estimator. This could suggest the frontier in the DEA estimators are influenced by outlying countries and affirms our use of the robust order-m estimators.

Appendix B: Data imputations for frontier analysis

This technical appendix covers the methodology used to impute missing data for some of our frontier analysis estimates, particularly the order-M methods.

Raw data

Table 8: Full list of variables and sourcesTable 8 shows the variables that we used in our analysis. Table 9 below shows the raw data that we use for benchmarking road infrastructure. This data is from a variety of sources. We have 11 total variables. 6 of these variables are combined into the quality index. Colombia and Costa Rica are dropped from our analysis as they both are missing a significant amount of data.

When it comes to missing data, the variable Hours lost in traffic has the most missing data points with 11 missing, followed by passenger density with 10, and fatalities per road KM with 7. In total there are 30 missing data points. 20 out of 36 countries have no missing data. 8 countries have 1 missing data point, 3 have 2 missing, 4 have 3 missing, and 1 has 4 missing. The country with 4 missing data points is Chile. Colombia and Costa Rica, are both missing 6 data points.

Predictive mean matching

To fill in missing data points we use predictive mean matching (PMM). This method was first proposed by Rubin (1986) and Little (1988). First, PMM fits a regression model using the observed data. Then for each missing data point, the PMM forms a set of 'candidate donors' from all complete cases that have predicted values closest to the predicted value for the missing data point. One of the donors is then randomly selected and the observed data point is copied to the missing data point. This process is repeated, and the imputed values are averaged.

The strengths of PMM are that it preserves the original distribution of the data as all imputed values are copies of observed values. PMM is also robust to model misspecification as the regression results are only used to select donor candidates. Additionally, PMM preserves relationships between variables and handles both linear and non-linear relationships well.

The weakness of PMM is that it relies on having a suitable pool of donors. The donor pool can become weaker with smaller samples and when the missing data is systematic. The key assumption is that cases with similar predicted values are suitable donors for each other. The missing values in our dataset shows signs of being systematic. Despite this, PMM offers a robust and practical way of imputing missing values.

Imputed data and quality index

Table 9: Complete raw data

Country	Investment	KM per capita	KM per KM^2	Passenger density	Freight density	Perceived quality	Fatalities per KM	Fatalities per capita	Rural access index	Speed score	Hours lost in traffic
Australia	1.07%	3.52	11.41	0.34	0.24	4.93	0.09	10.36	86.44%	105	57.08
Austria	0.33%	1.42	155.09	0.62	0.15	6.01	0.27	12.84	93.76%	107	38.65
Belgium	0.23%	1.30	502.83	0.81	0.23	4.39	0.15	12.96	99.18%	98	55.89
Canada	0.87%	2.99	12.68		0.22	5.03	0.06	10.41	81.87%	119	50.11
Chile	0.85%	0.43	10.46			5.21		13.44	81.68%	101	
Colombia		0.40	18.58			3.38			37.55%	72	
Costa Rica		0.10	9.86			2.98			67.90%	66	
Czechia	0.96%	1.23	169.43	0.69	0.41	3.91	0.14	10.24	99.66%	109	55.03
Denmark	0.73%	1.26	187.37	0.90	0.18	5.57	0.08	8.39	97.90%	87	40.96
Estonia	1.02%	6.64	209.61		0.07	4.69		13.70	98.02%	85	
Finland	0.84%	1.98	36.05	0.67	0.25	5.26	0.07	8.09	86.72%	89	23.02
France	0.55%	1.62	201.22	0.75	0.15	5.43	0.12	12.48	99.19%	114	74.31
Germany	0.42%	0.99	237.56		0.37	5.30	0.09	8.43	98.85%	107	53.03
Greece	0.91%	1.09	90.77		0.25	4.64	0.62	13.78	93.86%	115	
Hungary	1.34%	2.26	239.22	0.38	0.17	4.02	0.18	12.12	92.02%	104	40.72
Iceland	0.72%	3.46	12.80	0.59	0.08	4.12	0.04	6.91	76.14%	97	
Ireland	0.24%	2.01	149.84		0.12	4.40		9.11	94.56%	95	66.66
Israel	0.62%	0.22	94.23		0.33	4.86		8.49	86.33%	99	
Italy	0.76%	0.40	79.95	3.10	0.56	4.41	0.10	10.28	99.16%	113	58.63
Japan	1.16%	0.96	334.37	0.72	0.20	6.09	0.12	7.29	94.96%	92	
Korea	1.10%	0.22	117.13	3.32	1.25	5.90	0.19	16.14	96.93%	100	
Latvia	1.43%	3.08	93.16		0.25	3.58		18.86	92.24%	82	
Lithuania	1.08%	2.97	134.52	0.35	0.62	4.77	0.14	16.96	93.20%	93	
Luxembourg	0.47%	0.45	112.99		2.24	5.54		13.61	99.98%		48.35
Mexico	0.37%	0.57	36.26		0.36	4.50		5.01	81.86%	99	83.28
Netherlands	1.02%	0.80	421.21	1.27	0.31	6.43	0.09	6.95	98.66%	98	59.85
New Zealand	1.13%	1.86	36.93	0.53	0.27	4.46	0.08	13.35	82.83%	95	48.43
Norway	1.18%	1.75	26.27	0.63	0.22	4.55	0.05	5.94	77.56%	88	31.26

Poland	0.66%	1.17	140.28	0.60	0.96	4.31	0.31	13.38	94.30%	98	57.21
Portugal	0.23%	0.14	15.65	7.52	2.15	5.99	0.37	16.36	98.86%	114	43.07
Slovak Republic	1.20%	0.85	95.61	0.76	0.71	3.99	0.17	9.13	95.21%	105	
Slovenia	0.77%	1.83	192.39	0.72	0.06	4.95	0.15	16.01	93.54%	100	
Spain	0.35%	0.35	33.20	2.10	1.49	5.70	0.18	10.56	89.75%	115	33.28
Sweden	0.72%	1.91	49.14	0.51	0.22	5.32	0.05	5.97	90.96%	102	38.39
Switzerland	1.10%	0.96	214.31	1.31	0.22	6.28	0.07	8.57	95.53%	97	47.28
Türkiye	0.99%	0.30	33.66	1.29	1.13	5.02	0.34	8.68	93.13%	109	73.63
United Kingdom	0.51%	0.62	173.74	1.59	0.37	4.86	0.06	6.06	97.41%	95	89.93
United States	0.74%	2.03	73.85	0.94	0.51	5.47	0.08	14.90	87.48%	114	95.88
Mean	0.80%	1.48	125.36	1.27	0.50	4.90	0.15	10.99	90.14%	99	54.56
Median	0.80%	1.20	94.92	0.74	0.25	4.90	0.12	10.38	93.65%	99	53.03
Min	0.23%	0.10	9.86	0.34	0.06	2.98	0.04	5.01	37.55%	66	23.02
Max	1.43%	6.64	502.83	7.52	2.24	6.43	0.62	18.86	99.98%	119	95.88
% missing	5.26%	0.00%	0.00%	31.58%	7.89%	21.05%	0.00%	23.68%	5.26%	0.00%	2.63%
% missing excl. COL and CRI	0.00%	0.00%	0.00%	27.78%	2.78%	22.22%	0.00%	19.44%	0.00%	0.00%	2.78%

Table 10 below shows the data when missing values have been imputed twenty times using PMM and averaged. When calculated the frontier estimators, the efficiency scores are calculated for all twenty imputations separately. This then allows us to calculate the standard error resulting from the data imputation. The quality index is calculated from this imputed data. To calculate the quality index, the quality variables are min-max adjusted so that the minimum is 0 and the maximum is 1 for each variable. Negative quality variables such as road fatalities are inversed. The quality index is then the simple average of the min-max adjusted quality variables.

Table 8: Full list of variables and sources

Variable	Definition	Source
Road investment as a share of GDP	Capital expenditure on new road infrastructure, including reconstruction, renewal and upgrades; and non-capital expenditure to maintain the condition and capacity of the existing road infrastructure, as a share of GDP.	OECD-ITF
Road km per 100 sq. km	Kilometres of all roads per 100 square kilometres of land area.	CIA World Factbook, OECD-ITF,

		UNECE, World Bank World Development Indicators
Road km per 100 people	Kilometres of all roads per 100 people.	CIA World Factbook, OECD-ITF, UNECE, World Bank World Development Indicators
Millions of freight tonne-km per km of road	Any movement of goods using a road vehicle on the road network. Tonne-kilometre: unit of measurement of goods transport which represents the transport of one tonne by road over one kilometre. Average annual road tonne-kilometres per kilometre of road.	CIA World Factbook, OECD-ITF, UNECE
Millions of passenger-kilometres per km of road	Any movement of passengers using a road vehicle on the road network. Drivers of passenger cars, excluding taxi drivers, are counted as passengers. Service staff assigned to buses, coaches, trolleybuses, trams and goods road vehicles are not included as passengers. Road passenger-kilometre: unit of measurement representing the transport of one passenger by road over one kilometre. Average annual passenger-kilometres per kilometre of road.	CIA World Factbook, OECD-ITF, UNECE
Perceived quality of road infrastructure	Response to the survey question 'In your country, what is the quality (extensiveness and condition) of road infrastructure?' (1 = extremely poor – among the worst in the world; 7 = extremely good – among the best in the world) 2018-19 weighted average or most recent period available.	World Economic Forum Executive Opinion Survey
Road fatalities per 100 million passenger-kilometres travelled	People killed immediately or dying within 30 days because of a road crash, excluding suicides, divided by average annual passenger-kilometres.	OECD-ITF
Road fatalities per 100,000 people	People killed immediately or dying within 30 days because of a road crash, excluding suicides, divided by total population.	OECD-ITF, World Bank World Development Indicators
Rural access index	The proportion of the rural population who live within two kilometres of an all-season road (a road which will not be closed for more than two	Rural Access Index Measurement

	consecutive days and not more than two weeks per year in total).	Tool, World Bank
Adjusted mean speed score	The sum of road distance between the largest city and other large cities divided by the travel time, both retrieved from Google Maps, adjusted for the geography of the country.[56]	International Monetary Fund
Hours lost in traffic per year	The total number of hours lost per person per year in congestion during peak commute periods compared to off-peak conditions.[57]	INRIX

[56] For more detail refer to https://www.elibrary.imf.org/view/journals/001/2022/095/article-A001-en.xml
[57] For more detail refer to https://inrix.com/scorecard/

Table 9: Complete raw data

Country	Investment	KM per capita	KM per KM^2	Passenger density	Freight density	Perceived quality	Fatalities per KM	Fatalities per capita	Rural access index	Speed score	Hours lost in traffic
Australia	1.07%	3.52	11.41	0.34	0.24	4.93	0.09	10.36	86.44%	105	57.08
Austria	0.33%	1.42	155.09	0.62	0.15	6.01	0.27	12.84	93.76%	107	38.65
Belgium	0.23%	1.30	502.83	0.81	0.23	4.39	0.15	12.96	99.18%	98	55.89
Canada	0.87%	2.99	12.68		0.22	5.03	0.06	10.41	81.87%	119	50.11
Chile	0.85%	0.43	10.46			5.21		13.44	81.68%	101	
Colombia		0.40	18.58			3.38			37.55%	72	
Costa Rica		0.10	9.86			2.98			67.90%	66	
Czechia	0.96%	1.23	169.43	0.69	0.41	3.91	0.14	10.24	99.66%	109	55.03
Denmark	0.73%	1.26	187.37	0.90	0.18	5.57	0.08	8.39	97.90%	87	40.96
Estonia	1.02%	6.64	209.61		0.07	4.69		13.70	98.02%	85	
Finland	0.84%	1.98	36.05	0.67	0.25	5.26	0.07	8.09	86.72%	89	23.02
France	0.55%	1.62	201.22	0.75	0.15	5.43	0.12	12.48	99.19%	114	74.31
Germany	0.42%	0.99	237.56		0.37	5.30	0.09	8.43	98.85%	107	53.03
Greece	0.91%	1.09	90.77		0.25	4.64	0.62	13.78	93.86%	115	
Hungary	1.34%	2.26	239.22	0.38	0.17	4.02	0.18	12.12	92.02%	104	40.72
Iceland	0.72%	3.46	12.80	0.59	0.08	4.12	0.04	6.91	76.14%	97	
Ireland	0.24%	2.01	149.84		0.12	4.40		9.11	94.56%	95	66.66
Israel	0.62%	0.22	94.23		0.33	4.86		8.49	86.33%	99	
Italy	0.76%	0.40	79.95	3.10	0.56	4.41	0.10	10.28	99.16%	113	58.63
Japan	1.16%	0.96	334.37	0.72	0.20	6.09	0.12	7.29	94.96%	92	
Korea	1.10%	0.22	117.13	3.32	1.25	5.90	0.19	16.14	96.93%	100	
Latvia	1.43%	3.08	93.16		0.25	3.58		18.86	92.24%	82	
Lithuania	1.08%	2.97	134.52	0.35	0.62	4.77	0.14	16.96	93.20%	93	
Luxembourg	0.47%	0.45	112.99		2.24	5.54		13.61	99.98%		48.35
Mexico	0.37%	0.57	36.26		0.36	4.50		5.01	81.86%	99	83.28
Netherlands	1.02%	0.80	421.21	1.27	0.31	6.43	0.09	6.95	98.66%	98	59.85
New Zealand	1.13%	1.86	36.93	0.53	0.27	4.46	0.08	13.35	82.83%	95	48.43
Norway	1.18%	1.75	26.27	0.63	0.22	4.55	0.05	5.94	77.56%	88	31.26
Poland	0.66%	1.17	140.28	0.60	0.96	4.31	0.31	13.38	94.30%	98	57.21
Portugal	0.23%	0.14	15.65	7.52	2.15	5.99	0.37	16.36	98.86%	114	43.07
Slovak Republic	1.20%	0.85	95.61	0.76	0.71	3.99	0.17	9.13	95.21%	105	
Slovenia	0.77%	1.83	192.39	0.72	0.06	4.95	0.15	16.01	93.54%	100	
Spain	0.35%	0.35	33.20	2.10	1.49	5.70	0.18	10.56	89.75%	115	33.28
Sweden	0.72%	1.91	49.14	0.51	0.22	5.32	0.05	5.97	90.96%	102	38.39

Switzerland	1.10%	0.96	214.31	1.31	0.22	6.28	0.07	8.57	95.53%	97	47.28
Türkiye	0.99%	0.30	33.66	1.29	1.13	5.02	0.34	8.68	93.13%	109	73.63
United Kingdom	0.51%	0.62	173.74	1.59	0.37	4.86	0.06	6.06	97.41%	95	89.93
United States	0.74%	2.03	73.85	0.94	0.51	5.47	0.08	14.90	87.48%	114	95.88
Mean	0.80%	1.48	125.36	1.27	0.50	4.90	0.15	10.99	90.14%	99	54.56
Median	0.80%	1.20	94.92	0.74	0.25	4.90	0.12	10.38	93.65%	99	53.03
Min	0.23%	0.10	9.86	0.34	0.06	2.98	0.04	5.01	37.55%	66	23.02
Max	1.43%	6.64	502.83	7.52	2.24	6.43	0.62	18.86	99.98%	119	95.88
% missing	5.26%	0.00%	0.00%	31.58%	7.89%	21.05%	0.00%	23.68%	5.26%	0.00%	2.63%
% missing excl. COL and CRI	0.00%	0.00%	0.00%	27.78%	2.78%	22.22%	0.00%	19.44%	0.00%	0.00%	2.78%

Table 10: Average of 100 missing data imputations using predictive mean matching (imputed values in bold and italics)

Country	Investment	KM per capita	KM per KM^2	Passenger density	Freight density	Perceived quality	Fatalities per KM	Fatalities per capita	Rural access index	Speed score	Hours lost in traffic	Quality index
Australia	1.07%	3.52	11.41	0.34	0.24	4.93	0.09	10.36	86.4%	105	57.08	0.60
Austria	0.33%	1.42	155.09	0.62	0.15	6.01	0.27	12.84	93.8%	107	38.65	0.68
Belgium	0.23%	1.30	502.83	0.81	0.23	4.39	0.15	12.96	99.2%	98	55.89	0.58
Canada	0.87%	2.99	12.68	***0.83***	0.22	5.03	0.06	10.41	81.9%	119	50.11	0.66
Chile	0.85%	0.43	10.46	***2.22***	***0.85***	5.21	***0.22***	13.44	81.7%	101	***55.33***	0.49
Czechia	0.96%	1.23	169.43	0.69	0.41	3.91	0.14	10.24	99.7%	109	55.03	0.64
Denmark	0.73%	1.26	187.37	0.90	0.18	5.57	0.08	8.39	97.9%	87	40.96	0.70
Estonia	1.02%	6.64	209.61	***1.06***	0.07	4.69	***0.08***	13.70	98.0%	85	***50.27***	0.55
Finland	0.84%	1.98	36.05	0.67	0.25	5.26	0.07	8.09	86.7%	89	23.02	0.66
France	0.55%	1.62	201.22	0.75	0.15	5.43	0.12	12.48	99.2%	114	74.31	0.68
Germany	0.42%	0.99	237.56	***1.10***	0.37	5.30	0.09	8.43	98.9%	107	53.03	0.75
Greece	0.91%	1.09	90.77	***1.23***	0.25	4.64	0.62	13.78	93.9%	115	***56.19***	0.49
Hungary	1.34%	2.26	239.22	0.38	0.17	4.02	0.18	12.12	92.0%	104	40.72	0.57
Iceland	0.72%	3.46	12.80	0.59	0.08	4.12	0.04	6.91	76.1%	97	***48.36***	0.52
Ireland	0.24%	2.01	149.84	***0.70***	0.12	4.40	***0.07***	9.11	94.6%	95	66.66	0.58
Israel	0.62%	0.22	94.23	***0.89***	0.33	4.86	***0.21***	8.49	86.3%	99	***54.51***	0.56
Italy	0.76%	0.40	79.95	3.10	0.56	4.41	0.10	10.28	99.2%	113	58.63	0.69
Japan	1.16%	0.96	334.37	0.72	0.20	6.09	0.12	7.29	95.0%	92	***40.64***	0.73
Korea	1.10%	0.22	117.12	3.32	1.25	5.90	0.19	16.14	96.9%	100	***43.81***	0.64

Latvia	1.43%	3.08	93.16	***1.02***	0.25	3.58	***0.12***	18.86	92.2%	82	***61.19***	0.33
Lithuania	1.08%	2.97	134.52	0.35	0.62	4.77	0.14	16.96	93.2%	93	***58.27***	0.48
Luxembourg	0.47%	0.45	112.99	***2.68***	2.24	5.54	***0.20***	13.61	100.0%	***104***	48.35	0.67
Mexico	0.37%	0.57	36.26	***1.69***	0.36	4.50	***0.24***	5.01	81.9%	99	83.28	0.48
Netherlands	1.02%	0.80	421.21	1.27	0.31	6.43	0.09	6.95	98.7%	98	59.85	0.77
New Zealand	**1.13%**	**1.86**	**36.93**	**0.53**	**0.27**	**4.46**	**0.08**	**13.35**	**82.8%**	**95**	**48.43**	**0.49**
Norway	1.18%	1.75	26.27	0.63	0.22	4.55	0.05	5.94	77.6%	88	31.26	0.56
Poland	0.66%	1.17	140.28	0.60	0.96	4.31	0.31	13.38	94.3%	98	57.21	0.49
Portugal	0.23%	0.14	15.65	7.52	2.15	5.99	0.37	16.36	98.9%	114	43.07	0.67
Slovak Republic	1.20%	0.85	95.61	0.76	0.71	3.99	0.17	9.13	95.2%	105	***57.45***	0.60
Slovenia	0.77%	1.83	192.39	0.72	0.06	4.95	0.15	16.01	93.5%	100	***60.08***	0.53
Spain	0.35%	0.35	33.20	2.10	1.49	5.70	0.18	10.56	89.7%	115	33.28	0.74
Sweden	0.72%	1.91	49.14	0.51	0.22	5.32	0.05	5.97	91.0%	102	38.39	0.75
Switzerland	1.10%	0.96	214.31	1.31	0.22	6.28	0.07	8.57	95.5%	97	47.28	0.76
Türkiye	0.99%	0.30	33.66	1.29	1.13	5.02	0.34	8.68	93.1%	109	73.63	0.58
United Kingdom	0.51%	0.62	173.74	1.59	0.37	4.86	0.06	6.06	97.4%	95	89.93	0.61
United States	0.74%	2.03	73.85	0.94	0.51	5.47	0.08	14.90	87.5%	114	95.88	0.54
Mean	**0.80%**	**1.55**	**131.53**	**1.29**	**0.51**	**5.00**	**0.16**	**10.99**	**92.2%**	**101**	**54.17**	**0.61**
Median	**0.80%**	**1.24**	**104.30**	**0.86**	**0.26**	**4.94**	**0.12**	**10.38**	**93.8%**	**100**	**54.77**	**0.60**
Min	**0.23%**	**0.14**	**10.46**	**0.34**	**0.06**	**3.58**	**0.04**	**5.01**	**76.1%**	**82**	**23.02**	**0.33**
Max	**1.43%**	**6.64**	**502.83**	**7.52**	**2.24**	**6.43**	**0.62**	**18.86**	**100.0%**	**119**	**95.88**	**0.77**

Appendix C: Additional information on frontier methods used

This technical appendix provides additional information about the construction of each frontier analysis method used in the previous appendices.

Standard DEA

An output orientated DEA model with variable returns to scale technology is constructed as follows:

$$\max\ e^{DEA} - \varepsilon\left(\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+\right) \text{ subject to}$$

$$\sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- = x_{i0}\,, i = 1, 2, \ldots, m$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} - s_r^+ = e^{DEA} y_{r0}\,, r = 1, 2, \ldots, s$$

$$\sum_{j=1}^{n} \lambda = 1, j = 1, 2, \ldots, n$$

$$s_i^- \geq 0;\ s_r^+ \geq 0, i = 1, 2, \ldots, m; r = 1, 2, \ldots, s$$

Where:

- e^{DEA} is the efficiency score which is being maximised.
- ε is a small positive number to ensure slacks are minimised.
- i is the index for m inputs.
- r is the index for s outputs.
- j is the index for n decision-making units.
- s_i^- is the slack for input i (capturing the inefficiencies associated with excess inputs).
- s_r^+ is the slack for output r (capturing the inefficiencies associated with an output shortfall).
- λ_j is the weight assigned to DMU j when constructing the frontier.
- x_{ij} is the amount of input i used by DMU j.
- x_{i0} is the amount of input i used by the DMU being evaluated.
- y_{rj} is the amount of output r used by DMU j.
- y_{r0} is the amount of input r used by the DMU being evaluated.

The constraints:

- $\sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- = x_{i0}$ ensures that the weighted combination of inputs from the sample, plus any input slack, equals the actual input used by the DMU being evaluated.
- $\sum_{j=1}^{n} \lambda_j y_{rj} - s_r^+ = e^{DEA} y_{r0}$ ensures that the weighted combination of outputs from the sample, minus output slack, equals the scaled-up output of the DMU being evaluated. This is the key constraint for output-orientated DEA: e^{DEA}=1 means the DMU is efficient, $e^{DEA} > 1$ means the country is inefficient.
- $\sum_{j=1}^{n} \lambda = 1$ is the convexity constraint which creates variable returns to scale by ensuring the weights sum to 1. Removing this constraint creates constant returns to scale.
- $s_i^- \geq 0;\ s_r^+ \geq 0$ are non-negativity constraints as you can't have negative excess.

The objective function:

- Maximises the efficiency score e^{DEA}.
- Secondarily, minimises slacks. ε is very small so it primarily serves as a tiebreaker for solutions with the same efficiency score. This formulation is a simplified representation of a two stage DEA model. In the first stage, the efficiency score is obtained by radially increasing the outputs to reach the frontier, and in the second stage, finding the minimum slacks while keeping the score the same as the first stage (Banker, Charnes, & Cooper, 1984).

The efficiency score is then calculated as $1/e^{DEA}$. If $e^{DEA} = 1$ then the efficiency score is 1.00, 100% efficient. If $e^{DEA} = 1.25$ then the efficiency score is 0.85, 85% efficient.

Standard data envelopment analysis' strength comes from its simplicity but can easily become unreliable with poor quality data.

The strengths of DEA include:

- Easily interpretable efficiency scores.
- Computationally efficient.
- Well established methodology with a large body of literature.
- Can separate technical efficiency from scale efficiency by using both VRS and CRS assumptions.

The weaknesses of DEA include:

- Highly sensitive to outliers and measurement errors.
- Frontier can be heavily influenced by a single extreme observation.
- Requires a relatively large sample size for reliable results.

Super-efficient DEA was developed by Anderson & Peterson (1993). It modifies standard DEA by excluding the unit being evaluated from the reference set when constructing the efficiency frontier. This is useful as it enables ranking of efficient units and identification of super-efficient DMUs.

Strengths of super-DEA include:

- Allows the ranking of efficient DMUs.
- Useful for identifying DMUs which are heavily influencing the frontier.
- Can identify DMUs with unique input-output combinations.

Weaknesses of super-DEA include:

- Computationally complex and prone to infeasibility problems.
- Results can be sensitive and unstable.
- Requires a relatively large sample size for reliable results.

Free disposal hull

The free disposal hull (FDH) estimator was developed by Banker, Charnes, & Cooper (1984). FDH compares each DMU k against all other DMUs $j = 1, 2, \dots, n$. This is done in two steps:

1. The peer set for DMU k is identified. The peer set for DMU k is $B_k = \{j: y_{rj} \geq y_{kj} \forall r\}$. The peer set is all DMUs that produce at least as much of every output compared to the DMU being evaluated.
2. Among the peer set, the one that uses the least inputs is the benchmark reference for DMU k. $\hat{e}_k^{FDH}$ is then calculated as:

$$\hat{e}_k^{FDH} = \min_{j \in B_k} \left\{ \max_{i=1,\dots,m} \left(\frac{x_{ij}}{x_{ik}} \right) \right\}$$

Strengths of FDH include:

- Doesn't require convexity of feasible production set.
- Flexible in accommodating different production processes.

Weaknesses of FDH include:

- Usually provides generous efficiency scores.
- Provides less discrimination and less useful peer groups among DMUs.
- A simplistic estimator.

Order-m data envelopment analysis

Order-m DEA compares the DMU being evaluated against a subset randomly drawn from the peer set B_k. Daraio & Simar (2007) outline four steps for order-m DEA:

- For DMU k being evaluated, draw from B_k a random sample of m DMUs with replacement.
- Calculate a pseudo-FDH efficiency score, $\hat{e}_{mi}^{\widetilde{FDH}_d}$, using the randomly drawn data.
- Repeat steps 1 and 2 D times.
- Order-m efficiency is calculated as the average of the pseudo-FDH scores:

$$\hat{e}_{mi}^{OM} = \frac{1}{D}\sum_{d=1}^{D} \hat{e}_{mi}^{\widetilde{FDH}_d}$$

Strengths of order-m DEA include:

- Robust to outliers and extreme observations.
- Less sensitive to measurement errors and data noise.
- Can identify super-efficient DMUs.

Weaknesses of order-m DEA include:

- Requires selection of m parameter which has a tangible impact on results.
- Computationally intensive.
- Newer methodology with less established best practices.