NEW ZEALAND
INFRASTRUCTURE
COMMISSION
Te Waihanga

Investment gap or efficiency gap? Benchmarking New Zealand's investment in infrastructure

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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.

We are an autonomous Crown entity, listed under the Crown Entities Act 2004, with an independent board. We were established by the New Zealand Infrastructure Commission/Te Waihanga Act 2019 on 25 September 2019.

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Contents

Cut to the chase

New Zealand faces many infrastructure-related challenges. There is a gap between the infrastructure we have and the infrastructure we need to address climate change, population growth and demographic change, and the need to lift economic productivity.

A common response is to call for increased infrastructure investment to close the gap. However, spending more money does not necessarily lead to useful, high-quality infrastructure if project selection processes do not prioritise value for money, or if delivery agencies have poor incentives to control delivery costs.

This raises the question: If New Zealand's infrastructure challenges are going unmet, is it because we are not investing enough… or because we are not investing efficiently enough?

We are already making significant investments in infrastructure

In recent years, we have invested around 4.5% of gross domestic product (GDP) in network infrastructure (electricity, telecommunications, transport, and water) and social infrastructure (education and health). Our largest investments are in education infrastructure (almost 1% of GDP), transport infrastructure (0.9%), and telecommunications (0.8%).

Our investment levels are in line with other developed countries

In recent decades, we have spent a similar share of GDP on network infrastructure as the average high-income country (*Figure 1*). Our local and central government investment is slightly higher than average.

However, some high-income countries do spend substantially more. This includes Australia, which significantly ramped up spending in most infrastructure sectors starting in 2014.

Infrastructure performance lags behind our spending

While our spending measures up, New Zealand ranks 46th overall, and 43rd out of the 54 high-income countries, on the World Economic Forum's infrastructure quality index. A simple benchmarking analysis suggests that New Zealand is among the least efficient high-income countries at delivering infrastructure (*Figure 2*).

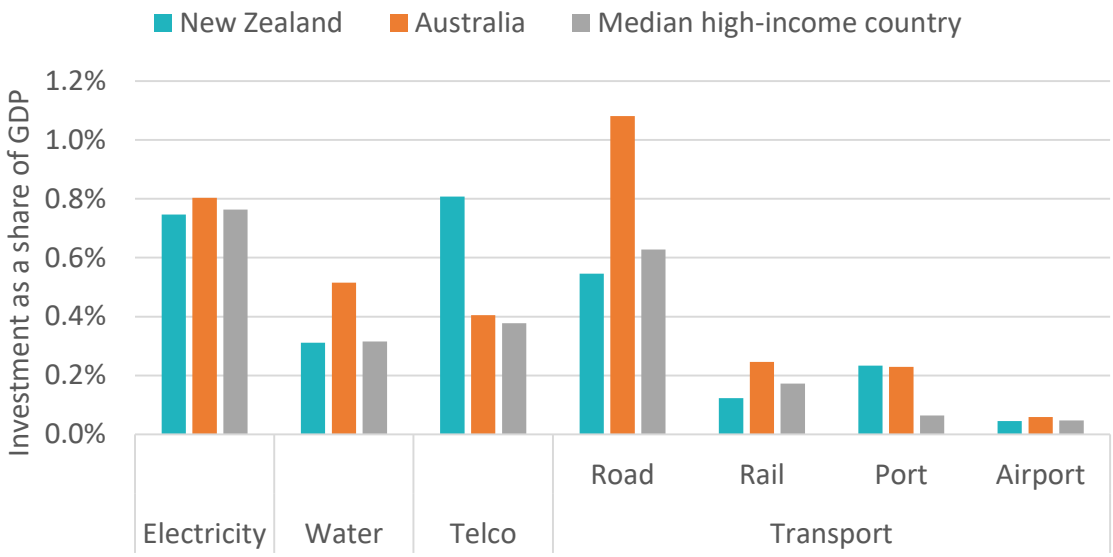
The efficiency of infrastructure investment is determined partly by geography – larger, more densely populated countries tend to be more efficient – and partly by the quality of our infrastructure investment decision-making. We face a penalty due to our small population size and challenging terrain. However, countries like Chile and Switzerland show that it is possible to overcome this with a focus on good institutions, robust investment decision-making processes, and a credible pipeline of future investment intentions.

So how much *should* we be investing?

Macroeconomic models suggest a 'golden rule' for infrastructure investment: the amount of money we should spend on infrastructure depends upon how efficiently we can build infrastructure and the value that we get from what we build. We have both an investment gap and an efficiency gap. We need to deliver infrastructure more cost-effectively, ensure good value for money from new infrastructure, *and* ramp up our investment.

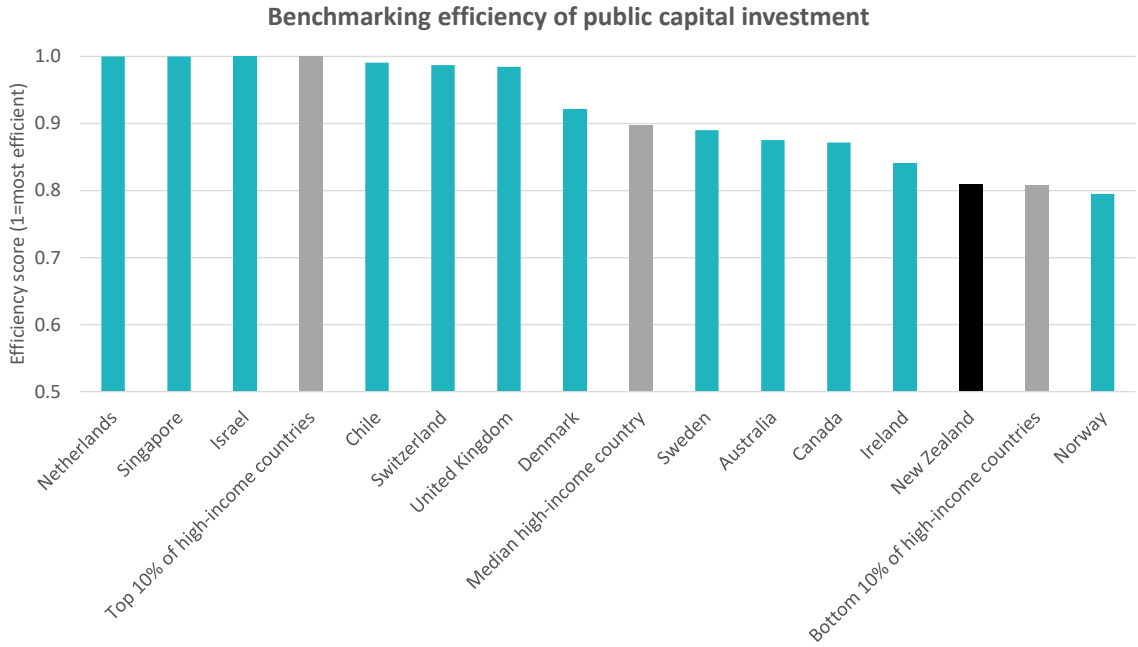
When the cost to deliver infrastructure is too high, we should look for other solutions instead. Sometimes, non-infrastructure alternatives, ranging from rooftop solar and rainwater harvesting to congestion pricing, are a better alternative. Our focus should be on providing people with the services they need, rather than building physical networks.

Figure 1: Comparing investment in different in different infrastructure networks, 2007-2020



Source: Te Waihanga analysis; Global Infrastructure Hub data

Figure 2: Comparing the efficiency of infrastructure investment in high-income countries



Source: Te Waihanga analysis

Introduction

Infrastructure needs are going unmet

Infrastructure is a foundation for our living standards. In the words of economist Robert Gordon (2016), the development and extension of electricity, water, telecommunication, and transport networks between the mid-1800s and mid-1900s transformed everyday life "from dark and isolated to bright and networked". This in turn fostered a period of rapid productivity growth that raised living standards in many countries.

Today, there is a widespread perception that New Zealand is under-investing in infrastructure, and hence achieving poor outcomes in a range of areas, from urban growth to water quality.

Research undertaken for Te Waihanga's draft *Infrastructure Strategy* suggests that there is a gap between the infrastructure we have and the infrastructure we would need to address the challenges facing us at present and over the next generation (Sense Partners, 2021). Other analysis has documented potentially significant investment requirements in areas like water and renewable electricity (Department for Internal Affairs, 2021; Transpower, 2020).

Our infrastructure challenges are part of a broader global picture. International organisations have documented an 'infrastructure gap' that is potentially worth trillions of dollars (Global Infrastructure Hub, 2018; Woestzel et al, 2016).

Spending money doesn't always solve infrastructure problems

Spending more money on infrastructure does not necessarily lead to useful, high-quality infrastructure. Public investment can be inefficient if project selection processes do not prioritise value for money and if public sector agencies have poor incentives to control delivery costs.

Systematic reviews show that infrastructure projects often cost more and deliver less value than originally expected (Flyvbjerg, 2009; Flyvbjerg and Bester, 2021). In extreme cases, billions of dollars can be spent without delivering a useful outcome. Country-level studies have found that a significant share of public investment is spent inefficiently, especially in low-income countries with weak institutions (Pritchett, 2000; Olken, 2007; Albino-War et al, 2014).[1]

Even in high-income countries, there is evidence that value for money is routinely disregarded in public infrastructure investment decision-making in favour of other considerations, like rewarding supporters or attracting voter support in key electorates. This happens even in countries that we perceive as having sound investment processes, like the United Kingdom, Sweden, and the Netherlands (Coyle and Sensier, 2020; Eliasson et al, 2015; Mouter, 2017). In Australia, several recent infrastructure decisions appear to have been made on political grounds, rather to maximise the benefits of investment (Alizadeh and Farid, 2017; Australian National Audit Office, 2021; Jacks, Le Grand, and Sakkal, 2021).

It is often difficult to understand whether infrastructure projects are being delivered in a cost-effective way, because good benchmarking data on delivery costs is rare (Australian Productivity

[1] Contrary to narratives about efficient authoritarians, Pritchett (2000) finds that non-democratic or politically repressive countries are more likely to mis-invest, as they still have interest-group politics but lack public transparency and accountability for public spending. Democracy is more likely to be the solution to the problem, rather than its cause. See Acemoglu and Robinson (2012) for a discussion of this issue.

Commission, 2014). Several recent research initiatives shed some light on this issue, but without better benchmarking data it is hard to know whether infrastructure spending is addressing problems at an affordable cost.[2]

Do we have an investment gap or an efficiency gap?

New Zealand faces a lot of infrastructure-related challenges. If we are failing to rise to that challenge, is it because we are not investing enough, as implied by discussions of 'infrastructure gaps', or is it because we are not investing efficiently enough, as implied by research on poor project selection and cost performance?

In this Research Insights piece, we consider this issue from three different directions:

1. **Benchmarking investment levels**: How much does New Zealand spend on infrastructure, and how does this compare with other high-income countries?
2. **Benchmarking efficiency**: Does New Zealand achieve good outcomes for what it invests, relative to other high-income countries?
3. **Optimal investment**: How much money *should* we invest in public infrastructure, relative to what we have spent in the past?

This analysis is undertaken at an aggregate level, looking at country-level or sector-level metrics. Aggregate analysis can be useful for highlighting broad issues facing the infrastructure sector, but it is limited. To properly understand problems and solutions it is necessary to study decisions and outcomes at a more detailed level, for instance by examining investment and performance at the organisational or project level. We therefore conclude by discussing some areas where further research is needed.

[2] Relevant research includes a Brookings Institute's study on US highway construction cost trends (Brooks and Liscow, 2019), an Asian Infrastructure Investment Bank study on road and water infrastructure costs (Economist Intelligence Unit, 2020), the Eno Center for Transportation's study of rail cost and delivery timeframes (Aevaz et al, 2021), and a current NYU Marron Institute research project on rail tunnelling costs (Goldwyn, Levy, and Ensari, 2021). Benchmarking project delivery costs can be difficult as major infrastructure projects are often 'bespoke' in some way.

Benchmarking investment levels

How does our spending stack up?

To begin, we benchmark New Zealand's infrastructure investment levels against other high-income countries.3 Regardless of which data source we use to measure investment, we find that:

- There are signs that New Zealand under-invested in the early 1990s, but investment levels recovered to their long-term trend by the early 2000s.[4]
- Over the last 20 years, infrastructure investment has been roughly constant as a share of GDP, although individual sectors have seen increases or decreases.
- New Zealand's current investment levels are average, or even above average, relative to other high-income countries. At the sector level, our investment levels are near the average or above average.

Definitions and data sources

Infrastructure investment is difficult to benchmark because the role of central government, local government, and the private sector in infrastructure provision varies between countries. For instance, water utilities are mostly privately owned in France and the United Kingdom but are mostly owned by local or state governments in New Zealand and Australia, and the United States. By contrast, hospitals are mostly privately-owned in the United States but are publicly owned in New Zealand and the United Kingdom.

We therefore use two data sources to benchmark our investment levels.[5] As shown in *Figure 3*, we use the International Monetary Fund (IMF)'s *Investment and Capital Stock Dataset* to benchmark total investment by central and local governments and the Global Infrastructure Hub (GI Hub)'s *Infrastructure Monitor* to benchmark both public and private investment in four network infrastructure sectors – electricity, water, telecommunications, and transport. In the New Zealand context, the IMF data captures most investment in health, education, transport, and water.[6]

The measure of investment used in this analysis is 'gross fixed capital formation'. This covers capital investment in new infrastructure and major renewals of existing infrastructure. It excludes routine maintenance costs and other operating costs, like public transport operating costs or the cost to buy fuel for power stations.

This approach to benchmarking differs from Sense Partners' (2021) analysis, which was focused

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[3] We focus on high-income countries because lower-income countries systematically spend a higher share of GDP on infrastructure and other public capital. Lower-income countries typically need to build and expand infrastructure networks where they did not previously exist, and the costs of doing so are higher relative to their income levels (Cubas, 2020). We use the World Bank's 2020 definition of high-income countries as countries with per-capita GDP is greater than US$12,536. New Zealand's per-capita GDP was US$42,450 at this point. See the Appendix for a list of high-income countries.

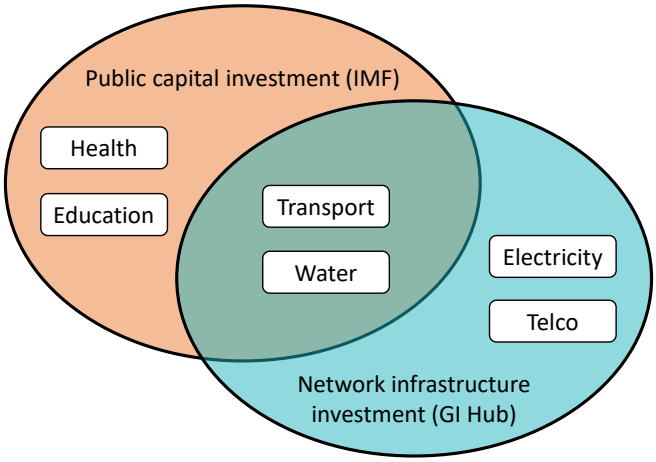
[4] There are some signs that low investment in the 1990s resulted in an ongoing 'deficit' (Sense Partners, 2021).

[5] Previous comparisons (eg Sense Partners, 2021) have focused more narrowly on transport infrastructure investment, drawing on data published by the International Transport Forum. The comparisons in this research note are more comprehensive.

[6] Some private investment in health, education, transport, and water infrastructure is not captured in the IMF data. For instance, some ports and airports are partly or fully privately owned and hence investment by these businesses would not be covered by the public capital investment data.

on how New Zealand's accumulated stock of public and private capital has evolved over time. The Appendix presents some comparisons of public and private capital stock in high-income countries.

Figure 3: Coverage of datasets used in analysis



What are we building? Our investment in different infrastructure sectors.

Figure 4 shows how much we have been investing in different infrastructure sectors over the last two decades.[7] Between 2015 and 2019, we invested an average of around 4.5% of GDP in infrastructure every year.

Our largest investment categories are:

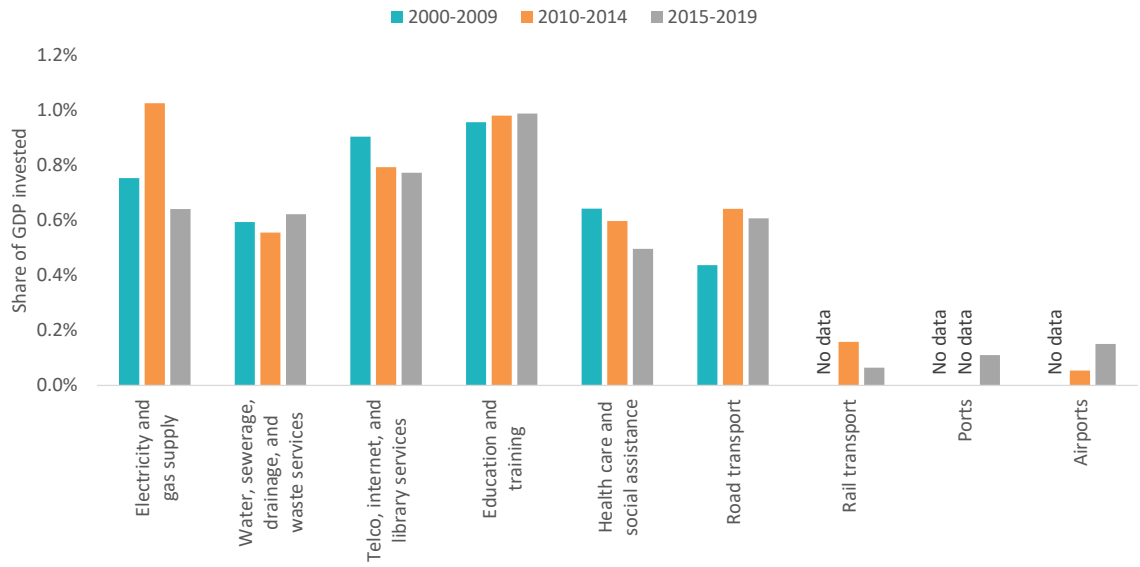
- Education infrastructure (almost 1% of GDP). This mostly comprises investment in school and university buildings.
- Transport infrastructure (around 0.9% of GDP). This mostly reflects road transport investment, with smaller investments in port, airport, and rail infrastructure.
- Telecommunication and information services infrastructure (around 0.8% of GDP). This includes building networks and buying the equipment and software needed to operate them.
- Electricity and gas infrastructure (around 0.7% of GDP). This mostly comprises building networks and buying the equipment needed to operate them.

Overall investment levels have remained roughly the same over the last two decades, although there have been some shifts at the sector level. Investment in health infrastructure has declined, as a share of GDP, since the 2000s. By contrast, road transport investment rose substantially over the same period. Electricity and gas investment rose in the early 2010s and fell in the second half of the decade.

Figure 4: What are we building? New Zealand's investment in different infrastructure sectors as a

[7] This chart is based on data from Statistics New Zealand's (2020a) National Accounts and International Transport Forum (2021). National accounts data on gross fixed capital formation at the industry level is used to measure investment in electricity/gas supply (ANZSIC industries D26, D27), water, sewerage, drainage, and waste (ANZSIC D28, D29), telco, internet, and library services (ANZSIC J58, J59, J60), education and training (ANZSIC P), and health and social assistance (ANZSIC Q). International Transport Forum data is used to measure investment in road, rail, port, and airport infrastructure. National Accounts data covers the period from 1987 to 2019 while ITF data covers a shorter period.
These data sources are also the underlying source of information for the IMF and GI Hub investment datasets, but there are likely to be minor differences due to currency conversions.

share of GDP

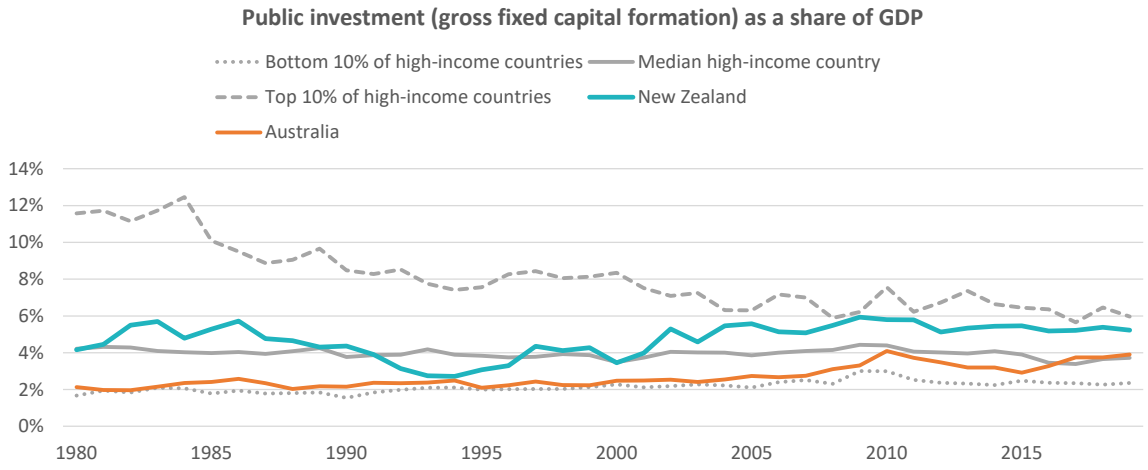


How do we measure up? The public capital investment picture.

Figure 5, based on the IMF's *Investment and Capital Stock Dataset*, compares New Zealand's public investment as a share of GDP with public investment in 55 other high-income countries.[8]

Except for several years of low investment in the early 1990s, New Zealand's public investment levels have consistently been above the high-income country average. Public investment increased significantly during the late 1990s and early 2000s. Over the last decade, New Zealand has ranked in the top 20% of high-income countries on this metric.[9]

Figure 5: Public investment trends in New Zealand and other high-income countries, 1980-2019



[8] There is a positive correlation between population growth rates and public capital investments. New Zealand has experienced higher-than-average population growth in recent decades. However, restricting the analysis to high-income countries with comparable or faster population growth results in the same conclusion that New Zealand is currently investing an above-average share of GDP in public capital.

[9] New Zealand's public capital investment has averaged around 5.4% of GDP over the last decade. This figure includes non-infrastructure investments like office buildings, community facilities, social housing, defense equipment, vehicles, and so on and so forth.

How do we measure up? Investment in network infrastructure.

Figure 6, based on data from GI Hub's *Infrastructure Monitor*, compares New Zealand's network infrastructure investment as a share of GDP with investment in 17 other high-income countries.[10] In contrast to the IMF data, this includes investment by the private sector as well as the public sector (see *Figure 3*). However, it covers fewer countries and a shorter timeframe (2007 to 2020), which means that it may not fully capture all relevant investment in long-lived infrastructure.

Between 2008 and 2012, New Zealand network infrastructure investment levels were like Australian investment levels and above the high-income country average. Since 2013, New Zealand's investment levels have closely tracked the high-income country average, while Australian investment levels have increased substantially.

Australia is seen as a close comparator to New Zealand and hence Australia's recent increase in investment in most types of network infrastructure may have contributed to perceptions of under-investment in New Zealand.

Figure 6: Network infrastructure investment trends in New Zealand and other high-income countries, 2007-2020

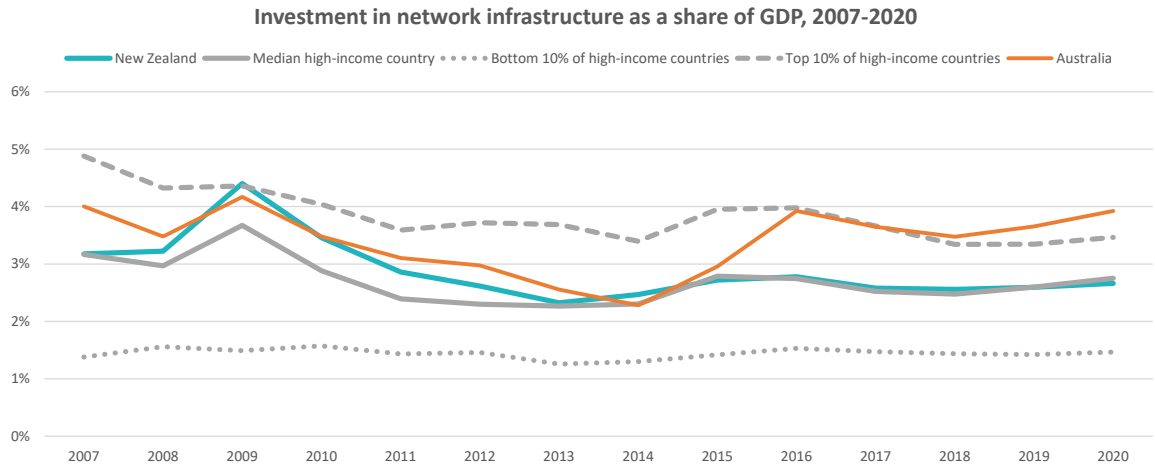
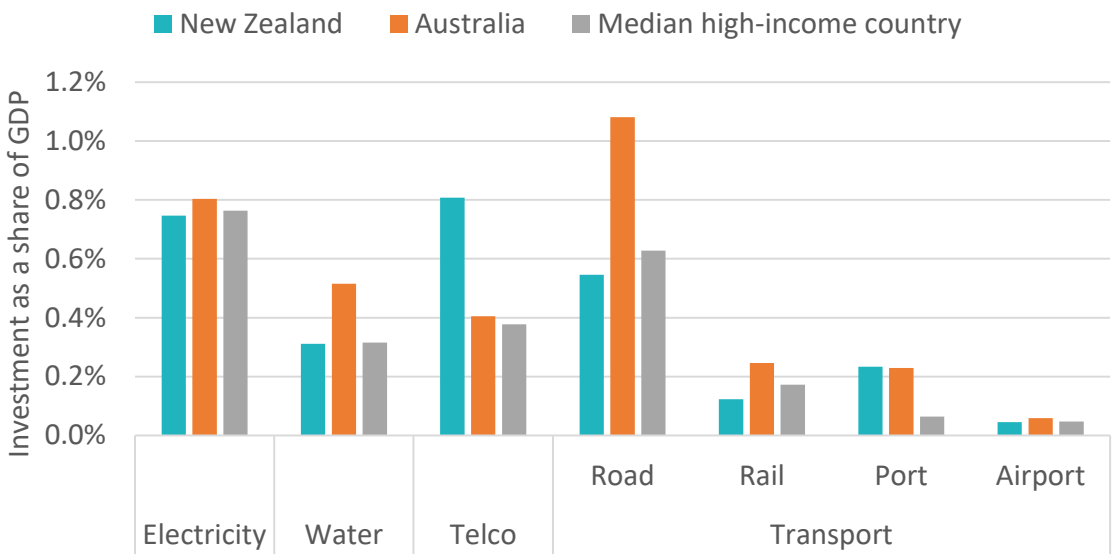


Figure 7 compares investment levels in different types of networks. Our investment in transport and water infrastructure is similar to the high-income average but significantly lower than Australia. Our investment in telecommunications infrastructure is higher than other high-income countries, reflecting significant investments in broadband and mobile networks.

[10] New Zealand has experienced higher-than-average population growth in recent decades, which may drive greater investment need. However, restricting the analysis to high-income countries with comparable or faster population growth results in the same conclusion that New Zealand is currently investing an average share of GDP in network infrastructure.

Figure 7: Comparing investment in different in different infrastructure networks, 2007-2020



Benchmarking efficiency

Does more investment lead to better infrastructure?

The analysis in the previous section shows that New Zealand invests an above-average share of GDP in public capital and an average share of GDP in network infrastructure compared with other high-income countries.

However, our infrastructure performance does not appear to measure up with our spending. According to the World Economic Forum (WEF)'s *Global Competitiveness Index*, New Zealand ranks 46th overall, and 43rd out of the 54 high-income countries, on infrastructure quality.

This suggests that we might have an efficiency gap, rather than an investment gap. In this section, we use data on infrastructure investment along with the WEF's infrastructure index to benchmark how efficiently New Zealand provides infrastructure relative to other high-income countries at an aggregate level.

Measuring relative performance

We use a technique called data envelopment analysis to benchmark the productive efficiency of infrastructure investment. This means identifying the relationship between cumulative infrastructure investment and infrastructure quality, identifying a 'frontier' comprising the countries that have the best outcomes for any given level of spending, and identifying how far other countries are from the frontier.[11]

Data envelopment analysis is commonly used for benchmarking infrastructure performance (Botasso and Conti, 2011; Pisu, Hoeller, and Joumard, 2012) and benchmarking the performance of public sector entities (Productivity Commission, 2018). Our work updates and extends a previous International Monetary Fund analysis of public investment efficiency that used this approach (IMF, 2015).

We measure cumulative infrastructure spending using the IMF's estimate of public capital stock per capita.[12] The Appendix presents an alternative version of this analysis that uses GI Hub data as an alternative measure of infrastructure investment. We measure infrastructure quality using WEF's Infrastructure Index, which is a quantitative measure of relative infrastructure quality that ranges from 0 to 100.[13] Higher scores indicate greater coverage and quality of infrastructure

[11] Analysis was conducted using the 'deaR' library in R (Benítez, Coll-Serrano, and Bolós, 2021). We used an output-oriented data envelopment analysis model with variable returns to scale.
We considered alternative techniques, such as stochastic frontier benchmarking, which does not assume a 'hard' frontier at the level of the most efficient country. Different benchmarking techniques can produce different results, especially when they measure different combinations of inputs or outputs (Estruch-Juan et al, 2020). As this analysis only includes a single input (accumulated investment) and a single output (infrastructure quality), different benchmarking methods are likely to produce similar rankings of efficiency.

[12] The IMF calculates public capital stock by adding up cumulative investment in infrastructure and subtracting off the value of depreciation. This approach is commonly used to compare the value of investment assets. For New Zealand, this approach leads to a similar estimated ratio of public capital stock to GDP as the approach used by Statistics New Zealand.
Countries that invest a higher share of GDP in public capital tend to have a larger stock of public capital. The IMF data suggests that lifting public investment by 1% of GDP on an ongoing basis leads to a roughly 13% increase in the ratio of public capital stock to GDP.

[13] The WEF's Infrastructure Index is based on 12 measures of the coverage and performance of transport infrastructure, electricity, and water supply. These are a mix of 'objective' measures, like the share of the population with access to electricity and clean drinking water, and 'subjective' measures, like perceived

networks. The lowest-ranked country (Haiti) has a score of 26.8, the highest-ranked country (Singapore) has a score of 95.4, and scores follow an (approximately) normal distribution.

Who's on the frontier?

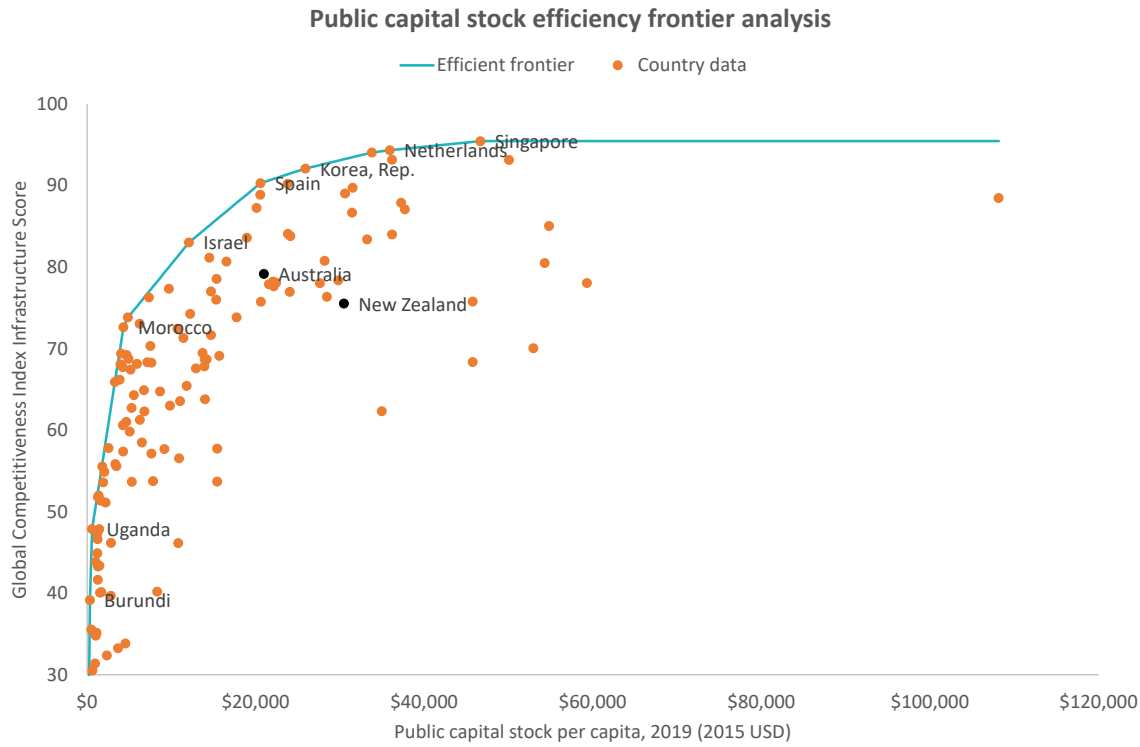
Figure 8 shows the relationship between public infrastructure investment and infrastructure quality for the 129 countries that are included in both datasets.

The blue line shows the 'frontier' of efficient countries. These are the countries that have achieved the best-quality infrastructure for a given level of spending. For instance, the Netherlands has three times as much infrastructure per capita as Israel (US$36,000 versus US$12,000), as well as a higher infrastructure index (94.3 versus 83.0). Both countries are on the frontier as no other country has achieved better infrastructure quality while spending less than them.

The slope of the frontier is steep at low levels of investment but flattens out as investment increases. This indicates that there are diminishing returns from infrastructure investment – past a certain point, spending more money to upgrade infrastructure will lead to smaller improvements in infrastructure quality.

Dots indicate the position of individual countries. Countries that are closer to the frontier (in terms of vertical distance) are comparatively more efficient. New Zealand and Australia are highlighted as black dots.

Figure 8: Infrastructure investment efficiency based on IMF public investment data, 2019

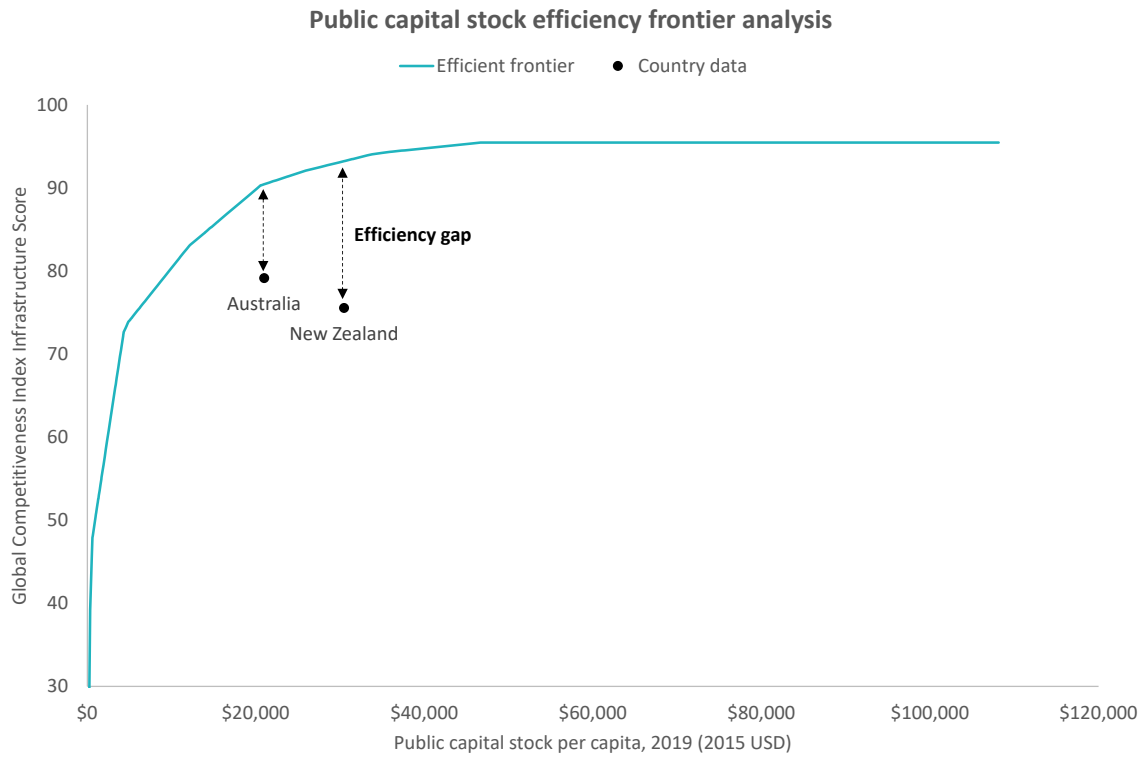


quality of road infrastructure and train services from a survey of business executives. An aggregate index is constructed by assigning 50% weight to transport metrics and 50% weight to electricity and water metrics, and, within each sub-category, assigning equal weight to each metric. These measures can suffer from bias, but the WEF index is the only infrastructure index with sufficient coverage for this analysis.

Figure 9 shows how this analysis can be used to measure how efficient different countries are. The vertical lines indicate the outcomes that could have been achieved if we had spent the same amount of money on infrastructure but spent it as efficiently as the leading countries.

This analysis suggests that both New Zealand and Australia are far from the frontier. Other high-income countries that have invested a similar amount per capita have better infrastructure. For instance, we have invested about the same amount of money in infrastructure as France, but WEF's infrastructure index suggests that infrastructure quality is around 23% higher in France.

Figure 9: Calculating efficiency gap measures based on IMF public investment data, 2019



How do we measure up relative to other high-income countries?

To measure our infrastructure investment performance, we convert the above analysis into efficiency scores that reflect how well different countries have converted money into quality infrastructure.[14] A score of 1 indicates a country that is on the frontier, while lower scores indicate less efficient countries. The least efficient countries in the dataset have scores of around 0.5.[15]

Figure 10 compares New Zealand with 49 other high-income countries for which we can calculate efficiency scores.[16] New Zealand's efficiency score is 0.81, meaning that we are one of the least

[14] This is calculated by dividing countries' observed infrastructure quality scores by the score that they could have achieved if they had spent the same amount of money and achieved frontier levels of efficiency. For instance, New Zealand's actual infrastructure index was 75.3 but it could have achieved an index of 93.2 if it was on the frontier. Our efficiency score is therefore 75.3/93.2=0.81.

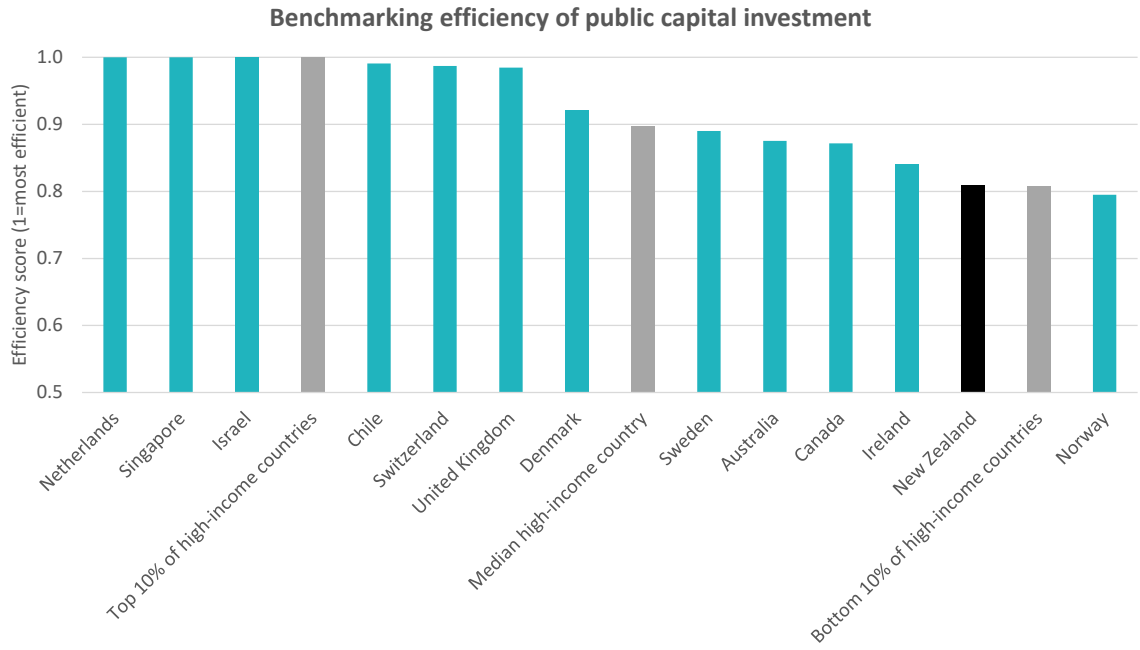
[15] Haiti and Yemen are estimated to be the least efficient countries.

[16] We use the World Bank's 2020 definition of high-income countries as countries with per-capita GDP is greater than US$12,536. New Zealand's per-capita GDP was US$42,450 at this point. See the Appendix for a list of high-income countries.

efficient high-income countries.

Our trans-Tasman neighbours do not impress, either. Australia's efficiency score of 0.88 is below average for high-income countries. Because Australia is nearby and English-speaking, New Zealanders tend to look there for lessons about how to deliver infrastructure efficiently. This analysis suggests that we would be better off looking for best practices in the Netherlands, Singapore, Israel, Chile, or Switzerland, which are small countries that seem to be highly efficient in terms of infrastructure investment.

Figure 10: Comparing the efficiency of infrastructure investment in high-income countries



Why are some countries more efficient than others?

If we are less efficient at infrastructure investment than other countries, what can we do about it? To answer that question, we first need to understand what factors influence efficiency.

Table 1 summarises a brief econometric analysis to identify factors that are correlated with efficiency scores. It reports three models that use different measures of institutional quality (models 1 and 2) or different measures of investment efficiency (model 3).[17] We found that:

[17] This analysis uses ordinary least squares (OLS) regression with heteroskedasticity-robust standard errors. An alternative would be to use a Tobit model to account for the fact that efficiency scores are constrained to fall between 0 and 1 (Botasso and Conti, 2011). Both Tobit and OLS models produced very similar results, so we reported OLS results as they are easier to interpret. We also investigated three other variables – GDP per capita, population growth rates (from 2000 to 2019), and natural resource rents (eg oil exports) – that are hypothesised to influence efficiency. There are statistically significant bivariate correlations between each of these variables and efficiency, but these correlations become smaller and statistically insignificant after controlling for other factors. This suggests that:

- Better institutions are an underlying factor that can improve both incomes and public investment performance (Acemoglu, Johnson, and Robinson, 2001; Andrews, Pritchett, and Woolcock, 2017)
- Faster-growing countries may need to 'over-build' networks to provide for future growth, but this does not seem to have a large impact on the overall efficiency measure
- The previously-measured negative impact of 'windfall' revenues from natural resource exports (Albino-War et al, 2014) becomes smaller and less statistically significant after controlling for

- **Population size matters**: Countries with larger populations tend to have higher efficiency scores. Larger countries may obtain better outcomes from investment because they can sustain specialised expertise in delivering and managing infrastructure networks.
- **Geography matters**: Countries with higher average population density tend to have higher efficiency scores. This reflects the fact that density lowers the per-person cost of providing quality infrastructure (MRCagney, 2019). It is possible that urbanisation may also influence efficiency, although we have not tested this.
- **Institutional quality matters**: Countries with better institutions tend to have higher efficiency scores. Models 1 and 3 measure institutional quality using the institutions index from the WEF's *Global Competitiveness Index*, while Model 2 uses the Public Investment Management Index (PIMI) developed by Dabla-Norris et al (2012) for a subset of low- and medium-income countries. Both measures are positively correlated with efficiency scores.
- **Volatility is bad**: Countries that experience year-to-year swings in public investment tend to be less efficient.[18] Stop-start investment patterns make it difficult to build capability and capacity to deliver efficiently (IMF, 2015).

Table 1: Econometric analysis of factors that are correlated with efficiency scores

Model	Model 1	Model 2	Model 3
Outcome measure	Efficiency score (calculated with public investment data)	Efficiency score (calculated with public investment data)	Efficiency score (calculated with infrastructure investment data)
Population size (natural log)	0.020*** (0.005)	0.012 (0.010)	0.009 (0.008)
Population density (natural log)	0.022*** (0.006)	0.029* (0.015)	0.019*** (0.006)
WEF Institutions Index	0.004*** (0.001)		0.004*** (0.001)
PIMI score		0.035 (0.028)	
Standard deviation of public investment as a share of GDP	-2.346*** (0.770)	-3.068 (2.034)	-2.695* (1.431)
Constant	0.229** (0.098)	0.481*** (0.179)	0.412*** (0.158)
Number of observations	129	54	55
R^2	0.538	0.344	0.380

Statistical significance codes: *p<0.1; **p<0.05; ***p<0.01

The first and second factors are difficult to change, but the third and fourth can be improved through better infrastructure investment decision-making. As a small country with a low average population density and challenging terrain, New Zealand faces some intrinsic challenges for investment efficiency.[19] To offset the penalty imposed by size and geography, we need high-

institutional quality and volatility in public investment. This suggests that oil revenues create incentives for weak public investment management (including to enable corruption, in some cases) and uncertainty about future investment pipelines.

[18] We measure this using the standard deviation of public investment as a share of GDP over the 1980 to 2019 period. By high-income country standards New Zealand has experienced average levels of volatility over this period (standard deviation of 0.9%), while Australia had lower volatility (0.6%). The least volatile countries were Switzerland (0.3%) and the Netherlands (0.3%), while oil exporting countries like Oman (5.4%), Kuwait (4.0%), and Saudi Arabia (3.7%) were the most volatile.

[19] We used coefficients from Model 1 in *Table 1* to adjust New Zealand's efficiency score to the level that would be expected if it had the same population and population density as the median high-income country. This closed roughly one-quarter of the distance to the frontier. This suggests that other factors, including the quality of infrastructure investment decision-making, are likely to be important.

performing infrastructure institutions, robust investment decision-making processes, and a stable pipeline of future investment intentions.

Even though New Zealand has generally good institutions, there are signs that our public investment processes are not performing as well as they could be. The Organization for Economic Co-operation and Development (2021) is currently developing infrastructure governance indicators for high-income countries. New Zealand is ranked in the bottom quarter of the OECD on the first three indicators that have been developed.[20] This raises questions about whether our public investment system is performing as well as it needs to be.

[20] These indicators are: long-term strategic vision; fiscal sustainability, affordability, and value for money; and efficient and effective public procurement. New Zealand's low score on the fiscal sustainability, affordability, and value for money index reflects the fact that, although we have a sustainable budgeting process at the macroeconomic level, affordability and value for money are not always as carefully guarded at the project level.

Optimal investment

How much should we spend on infrastructure?

Analysis in previous sections suggests that, while our investment in public capital and network infrastructure is typical for high-income countries, the outcomes we achieve from infrastructure investment are not ideal due to our comparatively low efficiency. As a result, we are not meeting our perceived needs for infrastructure.

What should we do about this? Do we need to spend even more money on infrastructure to offset the fact that we invest inefficiently? Or should we put a lid on spending to try to drive greater efficiency?

This section addresses these questions, drawing on insights from the economic growth literature. The answer is simple: If we can deliver infrastructure efficiently and achieve strong benefits from using it, we should ramp up investment – and if we can't, we should spend less on infrastructure, focusing on a smaller number of high-value projects.

The economic benefits of public infrastructure

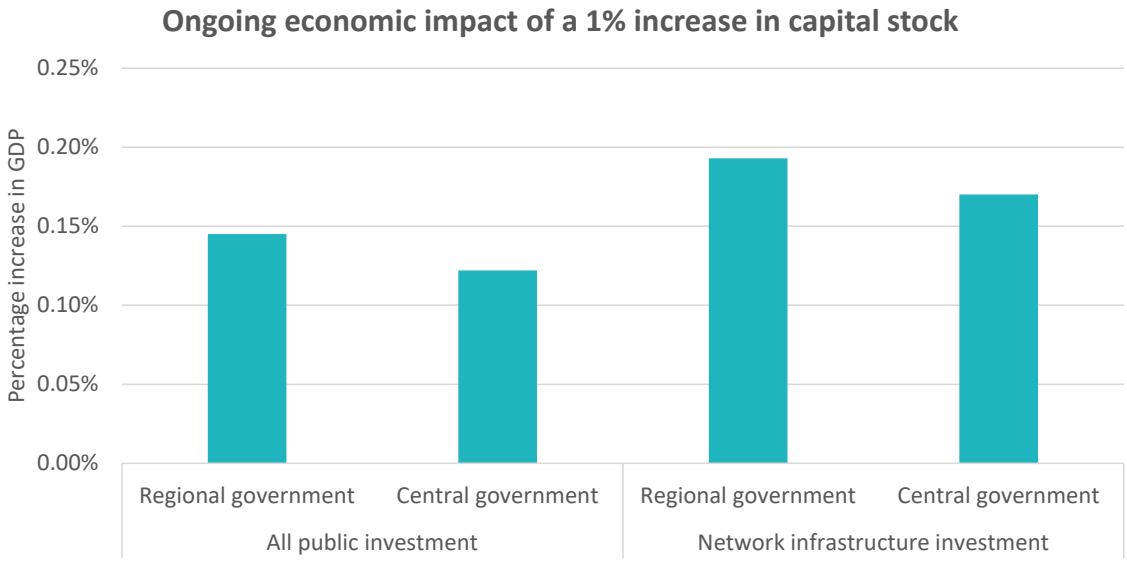
Thus far, we've focused on the costs of providing infrastructure and the challenges to delivering it efficiently. However, good infrastructure investment also has a lot of economic, social, and environmental benefits.

Better infrastructure can reduce transport and transaction costs, allowing people to do existing activities more efficiently and develop new business models. For instance, when the original Lord of the Rings films were made in the early 2000s, the fastest way to transmit footage from Wellington to Los Angeles for review was by airplane (Holson, 2003). Since then, improvements to broadband networks and international cable capacity have made it possible to transmit large amounts of data at a much lower cost. As a result, the value of information and communication technology exports has quadrupled over the last decade (Statistics New Zealand, 2020b).

International research shows that investment in public infrastructure tends to lift economic productivity. *Figure 11* summarises Bom and Ligthart's (2014) estimates of the output elasticity of infrastructure investment, which reflects the degree to which increased investment raises GDP, based on a systematic review of empirical studies. They estimate that a 1% increase in the total value of public infrastructure provided by central government will increase GDP by around 0.12% per annum in the long run. Investment by regional governments and investment that is focused on network infrastructure tend to have higher impacts.

Other studies obtain higher or lower results, but most conclude that infrastructure has a positive impact. For instance, another systematic review by Melo, Graham, and Brage-Radio (2013) suggests that transport investment may have a lower impact. They estimate that a 1% increase in the value of transport infrastructure is estimated to lift GDP by around 0.5%. These estimates provide reasonable upper and lower bounds on the output elasticity of infrastructure.

Figure 11: Estimated output elasticities of public infrastructure investment



Source: Bom and Ligthart (2014); Table 4

Infrastructure is not free – somebody must pay for it

While infrastructure provides a variety of benefits, the benefits of supplying more infrastructure need to be weighed up against the cost to build, maintain, and operate it. If infrastructure was free, then we would supply as much as possible to ensure that nobody ever had to wait at a queue at a traffic light, limit water use during dry months, or pay higher electricity prices during periods of high demand. In reality, infrastructure is costly to supply and hence over-building it to this degree would impose excessive financial burdens on users or taxpayers.

Lessons from economic growth models

Because infrastructure contributes to economic growth, macroeconomists have considered how to incorporate infrastructure into economic growth models. These models can in turn be used to identify how much infrastructure we should have to maximise wellbeing.

Cockburn et al (2013) provide a recent overview of these models, with a focus on foundational models outlined by Barro (1990) and Futagami, Morita, and Shibata (1993). Cubas (2020) is a more recent effort. While the details and dynamics of these models vary, the basic implication is that optimal infrastructure investment should balance the benefits that we derive from infrastructure with the cost to provide it.

Equation 1 brings these elements together into a simple expression for the optimal stock of public infrastructure relative to GDP.[21] Optimal infrastructure supply is a function of four parameters:

- **The output elasticity of infrastructure**: This parameter reflects the degree to which infrastructure increases economic productivity, or, potentially, the degree to which it provides other social or environmental benefits like climate change abatement. If the

[21] This equation draws upon Cubas (2020), Bom and Ligthart (2014), and Pritchett (2000). It is based on an aggregate production function that includes labour, private capital, and public infrastructure as a factor that affects the productivity of both labour and private capital. See the Appendix for derivation of this equation. Achieving an optimal stock of infrastructure would require an ongoing increase in the share of GDP invested in infrastructure.

output elasticity is larger, reflecting infrastructure that is more useful and hence more successful in lifting wellbeing, then it is optimal to invest more in infrastructure.

- **Delivery efficiency**: This parameter, which is related to the efficiency scores estimated in the previous section, reflects the degree to which infrastructure investment is delivered in a cost-effective way. All else equal, higher values mean that it is optimal to invest more in infrastructure.
- **Cost of capital**: This reflects the opportunity cost of infrastructure investment – ie the cost of diverting funds away from other priorities. This is often measured through the public sector discount rate (Treasury, 2020). If the cost of capital is higher, it is optimal to invest less in infrastructure.
- **Depreciation rate**: Once infrastructure is built, there are ongoing costs to maintain and renew it. The depreciation rate reflects how rapidly infrastructure wears out and needs replacing. Higher depreciation rates mean that it is optimal to invest less in infrastructure.

Equation 1: The optimal stock of public infrastructure relative to GDP

$$\text{Optimal infrastructure (Value of infrastructure/GDP)} = \frac{\left(\text{Output elasticity of infrastructure } (\varepsilon)\right) \times \left(\text{Delivery efficiency } (\gamma)\right)}{\left(\text{Cost of capital } (r)\right) + \left(\text{Depreciation rate } (\delta)\right)}$$

Equation 1 identifies the optimal ratio of infrastructure to GDP, meaning that the total quantity of public infrastructure will also depend upon the size of the economy. If the economy increases in size, for instance due to population or productivity growth, then we will need more infrastructure, but should not require us to spend a larger share of GDP on infrastructure in the long run.

The 'golden rule' for optimal infrastructure investment

This model suggests a 'golden rule' for optimal infrastructure investment: **the amount of money we should spend on infrastructure depends upon the quality of our spending**. If we can deliver infrastructure cost-effectively and achieve good value for money from new infrastructure, then we should spend more on infrastructure. But if we cannot achieve efficiency and value for money, we should consider spending less instead.

Spending less on physical infrastructure does not necessarily mean a lack of service. In some cases, there are viable 'off-grid' solutions that can provide similar services in a more cost-effective way. This includes things like rooftop solar and batteries for homes that are too expensive to connect to electricity lines, rainwater harvesting and septic tanks for homes that are too expensive to service with piped water and sewage, or telehealth to provide medical services to people who cannot easily travel to clinics.

This is common in some sectors. For instance, electricity lines companies have an obligation to continue serving customers that are currently connected to the network (Electricity Industry Act 2010). When rural lines that serve small numbers of people go down, it can be extremely expensive to restore them, and hence lines companies will often negotiate with customers to install off-grid electricity solutions instead. When this happens, it results in a decrease in the value of New Zealand's infrastructure stock – even though nobody has lost power.

So how much infrastructure should we have, anyway?

We can use *Equation 1*, plus some best guess estimates of the key parameters in the model, to get a sense of whether New Zealand should lift its infrastructure investment.

Our 'baseline' estimates of model parameters are as follows:

- Output elasticity of infrastructure: 0.1, in line with Bom and Ligthart's (2014) estimates. We also test a lower value of 0.05 (following Melo, Graham, and Brage-Ardao, 2013) and a higher value of 0.15 (nearer the upper end of Bom and Ligthart, 2014).
- Delivery efficiency: 0.81, as estimated above. This is in the range that Pritchett (2000) estimates for developed countries (0.7 to 1.0).
- Cost of capital: 0.05, which reflects the Treasury's most recent estimates of the real discount rate for public investment (Treasury, 2020). Discount rates have fallen significantly since the late 2000s, reflecting falling interest rates on government bonds. In 2008 Treasury estimated the discount rate to be 0.08 (Treasury, 2008).
- Depreciation rate: Sense Partners (2021) estimate a depreciation rate of 0.046 for public investments, in line with rates observed in other developed countries (Cubas, 2020).

Figure 12 plugs these figures into *Equation 1* and calculates optimal levels of public infrastructure under alternative parameter estimates. The grey bar shows the current value of public infrastructure, which is equal to 74% of GDP, while the blue bars show the estimated optimal level of public infrastructure under different parameter estimates.

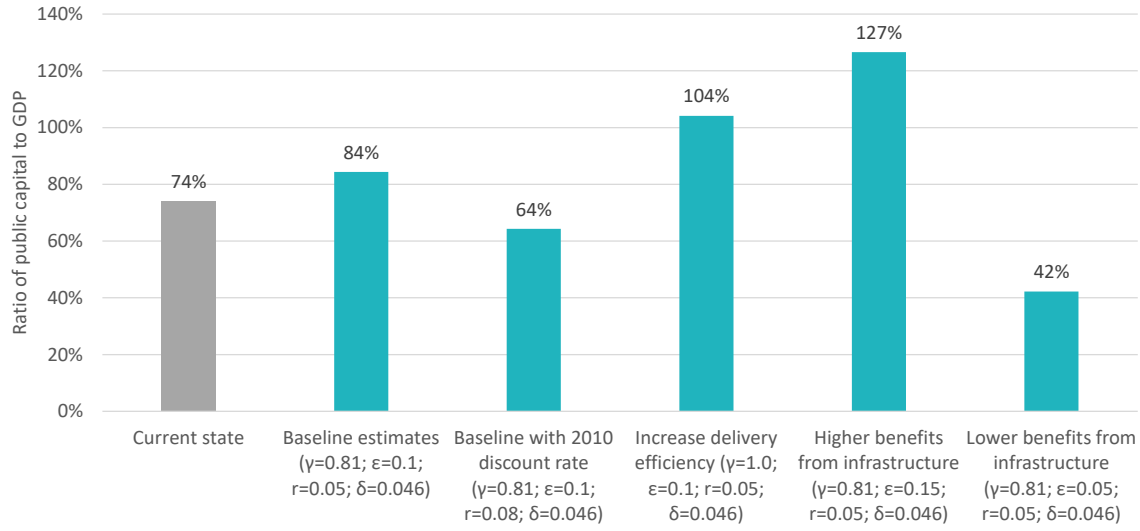
Our baseline parameter estimates suggest that our infrastructure networks may be slightly undercapitalised. Lifting our stock of infrastructure from 74% of GDP (their current level) to 84% might deliver net benefits.[22] However, a decade ago, the opposite may have been true because the cost of capital was substantially higher. If we expect low interest rates to persist, then it would be desirable to respond by increasing investment.

The other blue bars show that:

- If we lift delivery efficiency to a similar level as the leading high-income countries, then it would be optimal to lift public infrastructure to over 100% of GDP
- If we lift the value we achieve from infrastructure investment by 50%, then it would be optimal to lift public investment even further
- Conversely, if value for money from infrastructure projects slips substantially from its current levels, then we should respond by reducing investment and spending money elsewhere.

[22] This is consistent with Sense Partners' (2021) conclusion that additional infrastructure investment would be desirable.

Figure 12: How much public infrastructure should we have? It depends on your assumptions.



Areas for further work

In this research note, we have found that:

- We spend more on infrastructure than we might assume – our rates of investment are in line with other high-income countries, or even a bit above-average
- The quality of our infrastructure does not match the quantity of our spending, suggesting that we are comparatively inefficient in delivering infrastructure relative to other high-income countries
- There is a case to lift investment in infrastructure – but only if we can deliver cost-effectively and achieve good value for money from our spending.

This raises an important question: How can we do better? To address *that* question, we need to drill into the detail about how our investments are performing, in terms of cost-effectiveness and value for money, and what we would need to do differently to achieve better outcomes.

Getting the evidence base right

We can only learn so much from benchmarking investment rates and infrastructure quality at the country level. While our analysis has highlighted potential issues with the efficiency of our infrastructure investments, further evidence and research is needed.

Te Waihanga's draft *Infrastructure Strategy* calls for more benchmarking of infrastructure sector performance and infrastructure delivery costs against outcomes in more efficient countries. This will provide a more nuanced picture of our performance and improve our ability to identify problems and solutions.

Better evidence is also needed to guide investment decisions. This includes more consistent use of cost benefit analysis and post-implementation reviews to ensure that we are choosing investments that deliver economic, social, and environmental benefits at an acceptable cost, and independent advice on infrastructure project prioritisation.

Getting the system right

Efficient infrastructure delivery is underpinned by good decision-making and sound planning and investment management processes. To lift efficiency, and hence build the case for higher levels of investment, we need to lift the quality of the infrastructure investment system.

Te Waihanga's draft *Infrastructure Strategy* outlines the key components of a high-quality infrastructure system. These include good decision-making, supported by the right information on the performance of infrastructure networks and projects, an enabling planning system that makes it possible to consent infrastructure projects, appropriate funding and financing tools, workforce capacity and capability, and use of technology to improve infrastructure.

To make progress, we need good evidence that links infrastructure institutions and practices with outcomes for infrastructure projects and networks – and a willingness to reform when what we're doing is not working well.

Appendix

Summary of public investment and infrastructure investment data

The following data sources were used in this analysis:

- Public investment data: International Monetary Fund *Investment and Capital Stock Dataset*, May 2021 update: https://infrastructuregovern.imf.org/content/dam/PIMA/Knowledge-Hub/dataset/WhatsNewinIMFInvestmentandCapitalStockDatabase_May2021.pdf
- Network infrastructure investment data: Global Infrastructure Hub *Infrastructure Monitor*, 2021 update: https://www.gihub.org/infrastructure-monitor/
- Infrastructure index: World Economic Forum, *Global Competitiveness Report*, 2019 update: http://reports.weforum.org/global-competitiveness-report-2019/downloads/
- Institutional quality indices: World Economic Forum, *Global Competitiveness Report*, 2019 update; Dabla-Norris et al (2012), "Investing in public investment: An index of public investment efficiency"; Organization for Economic Co-Operation and Development, *OECD Infrastructure Governance Indicators* (draft)
- Population, population density, and natural resource rent data: World Bank *World Development Indicators*: https://data.worldbank.org/

Table 2 summarises key data for 56 high-income countries that are included in this analysis, including the infrastructure quality index, the public investment share of GDP over the 2000-2019 period, the network infrastructure investment share of GDP over the 2007-2019 period, and the estimated efficiency of infrastructure investment using the infrastructure index and two different measures of investment.

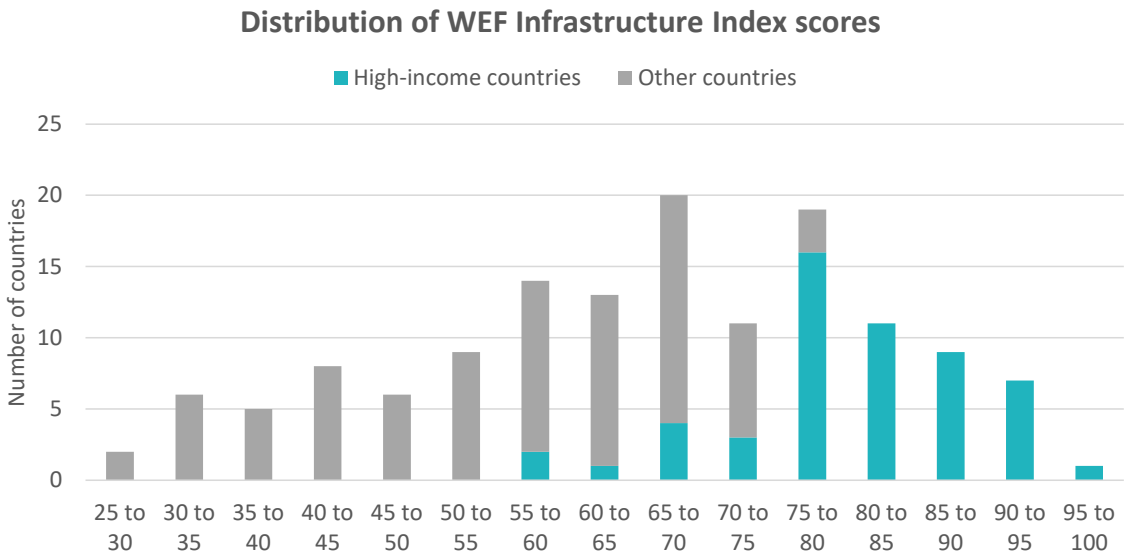
Table 2: Summary of data for high-income countries

Country	OECD member	GCI Infrastructure index (value), 2019	Public investment share of GDP, 2000-2019	Network infrastructure investment share of GDP, 2007-2019	Efficiency measure based on public investment	Efficiency measure based on network infrastructure investment
Antigua and Barbuda			8.1%			
Australia	**Yes**	**79.2**	**3.1%**	**3.3%**	**0.88**	**0.83**
Austria	Yes	89.0	2.9%		0.95	
Bahamas, The			1.8%			
Bahrain		78.4	5.0%		0.84	
Barbados		57.7	6.8%		0.67	
Belgium	Yes	87.3	2.2%		0.97	
Brunei Darussalam		70.1	4.4%		0.73	
Canada	Yes	80.8	3.9%	2.3%	0.87	0.85
Chile	Yes	76.3	2.5%	2.9%	0.99	0.89
Croatia		78.2	4.7%	4.0%	0.86	0.82
Cyprus		74.9	4.7%			
Czech Republic	Yes	83.8	4.5%		0.92	
Denmark	Yes	87.1	3.2%		0.92	
Estonia	Yes	75.8	4.6%		0.84	
Finland	Yes	83.4	3.9%		0.89	
France	Yes	89.7	3.9%	2.1%	0.96	0.94
Germany	Yes	90.2	2.2%	1.3%	0.99	0.95
Greece	Yes	77.7	4.0%		0.86	
Hong Kong SAR, China		94.0	5.2%		1.00	
Hungary	Yes	80.7	4.2%		0.93	
Iceland	Yes	76.4	3.6%		0.82	
Ireland	Yes	77.0	3.0%		0.84	
Israel	Yes	83.0	2.2%		1.00	

Italy	Yes	84.1	2.8%	1.8%	0.92	0.88
Japan	Yes	93.2	5.8%	2.4%	0.98	0.98
Korea, Rep.	Yes	92.1	5.2%	3.0%	1.00	0.96
Kuwait		68.4	4.9%		0.72	
Latvia	Yes	76.0	4.0%		0.89	
Lithuania	Yes	77.0	3.4%		0.90	
Luxembourg	Yes	85.0	3.8%		0.89	
Macao SAR, China			3.2%			
Malta		75.0	4.4%			
Mauritius		68.7	4.4%		0.81	
Netherlands	Yes	94.3	3.8%		1.00	
New Zealand	**Yes**	**75.5**	**5.2%**	**2.8%**	**0.81**	**0.79**
Norway	Yes	75.8	4.6%		0.79	
Oman		80.5	14.3%		0.84	
Panama		69.5	3.8%		0.82	
Poland	Yes	81.2	3.7%	3.6%	0.95	0.89
Portugal	Yes	83.6	3.1%		0.94	
Romania		71.7	3.9%	4.0%	0.84	0.82
Saudi Arabia		78.1	9.1%	2.8%	0.82	0.84
Seychelles		62.3	9.3%		0.66	
Singapore		95.4	4.8%	1.1%	1.00	1.00
Slovak Republic	Yes	78.6	3.6%		0.92	
Slovenia	Yes	78.1	4.2%		0.86	
Spain	Yes	90.3	3.2%	2.8%	1.00	0.95
St. Kitts and Nevis			6.7%			
Sweden	Yes	84.0	4.1%		0.89	
Switzerland	Yes	93.2	3.0%		0.99	
Taiwan		86.7	5.1%		0.93	
United Arab Emirates		88.5	12.5%		0.93	
United Kingdom	Yes	88.9	2.5%	1.8%	0.98	0.93
United States	Yes	87.9	3.9%	1.5%	0.93	0.92
Uruguay		68.7	3.8%	2.9%	0.81	0.78
High-income country median		**80.6**	**4.0%**	**2.8%**	**0.90**	**0.89**
OECD country median		**83.5**	**3.8%**	**2.4%**	**0.92**	**0.92**

Figure 13 shows the distribution of Infrastructure Index scores for high-income countries and other countries. While high income countries tend to have higher scores, on average, there is no 'massing' of scores near the maximum value. This suggests that this metric captures variations in infrastructure coverage and quality among high-income countries.

Figure 13: Distribution of WEF Infrastructure Index scores



Comparisons of public and private capital stock

Table 3 summarises IMF estimates of public and private capital stock, relative to GDP, for the high-income countries included in this analysis. The IMF calculates capital stock by adding up cumulative investment and subtracting off the estimated value of depreciation. This data shows that New Zealand has:

- A larger stock of public capital than the average high-income country
- A smaller stock of private capital than the average high-income country
- A higher ratio of public to private capital than the average high-income country.

Table 3: Public and private capital stock relative to GDP for high-income countries, 2019 or most recent available year

Country	OECD member?	Public capital stock as share of GDP	Private capital stock as share of GDP	Total capital stock as share of GDP	Ratio of public to private capital
Antigua and Barbuda		111%	232%	343%	48%
Australia	**Yes**	**42%**	**218%**	**260%**	**19%**
Austria	Yes	55%	234%	289%	23%
Bahamas, The		25%	313%	338%	8%
Bahrain		64%	186%	250%	35%
Barbados		132%	355%	487%	37%
Belgium	Yes	39%	230%	269%	17%
Brunei Darussalam		81%	247%	328%	33%
Canada	Yes	58%	212%	270%	27%
Chile	Yes	31%	189%	220%	17%
Croatia		80%	176%	256%	46%
Cyprus		78%	274%	353%	29%
Czech Republic	Yes	59%	229%	288%	26%
Denmark	Yes	65%	186%	251%	35%
Estonia	Yes	56%	182%	239%	31%
Finland	Yes	68%	227%	295%	30%
France	Yes	69%	218%	286%	31%
Germany	Yes	44%	215%	259%	21%
Greece	Yes	75%	167%	242%	45%
Hong Kong SAR, China		68%	214%	282%	32%
Hungary	Yes	51%	177%	228%	29%
Iceland	Yes	51%	170%	221%	30%
Ireland	Yes	27%	172%	199%	16%
Israel	Yes	30%	165%	196%	18%
Italy	Yes	56%	220%	277%	26%
Japan	Yes	121%	236%	357%	51%
Korea, Rep.	Yes	61%	234%	295%	26%
Kuwait		83%	161%	244%	52%
Latvia	Yes	50%	181%	231%	27%
Lithuania	Yes	40%	146%	186%	27%
Luxembourg	Yes	48%	141%	189%	34%
Macao SAR, China					
Malta		45%	186%	232%	24%
Mauritius		59%	121%	180%	49%
Netherlands	Yes	63%	186%	250%	34%
New Zealand	**Yes**	**72%**	**161%**	**233%**	**45%**
Norway	Yes	71%	215%	286%	33%
Oman		186%	116%	302%	161%
Panama		45%	190%	235%	24%
Poland	Yes	44%	131%	174%	34%
Portugal	Yes	55%	193%	247%	28%
Romania		49%	202%	252%	24%
Saudi Arabia		123%	125%	248%	99%
Seychelles		140%	277%	417%	51%
Singapore		55%	187%	242%	29%
Slovak Republic	Yes	48%	184%	233%	26%
Slovenia	Yes	58%	190%	248%	30%
Spain	Yes	50%	199%	249%	25%

St. Kitts and Nevis		89%	309%	398%	29%
Sweden	Yes	69%	210%	279%	33%
Switzerland	Yes	51%	252%	303%	20%
Taiwan, China		66%	146%	212%	45%
United Arab Emirates		163%	151%	314%	108%
United Kingdom	Yes	44%	172%	216%	26%
United States	Yes	59%	172%	231%	35%
Uruguay		67%	139%	206%	48%
High-income country median		**59%**	**189%**	**250%**	**30%**
OECD median		**55%**	**190%**	**249%**	**28%**

Alternative estimates of infrastructure investment efficiency

This section presents an alternative estimate of infrastructure investment efficiency. This uses the same infrastructure quality index and an alternative measure of investment based on GI Hub network infrastructure investment data rather than IMF public investment data. This analysis includes a smaller number of countries. *Figure 14* presents the result of this analysis.

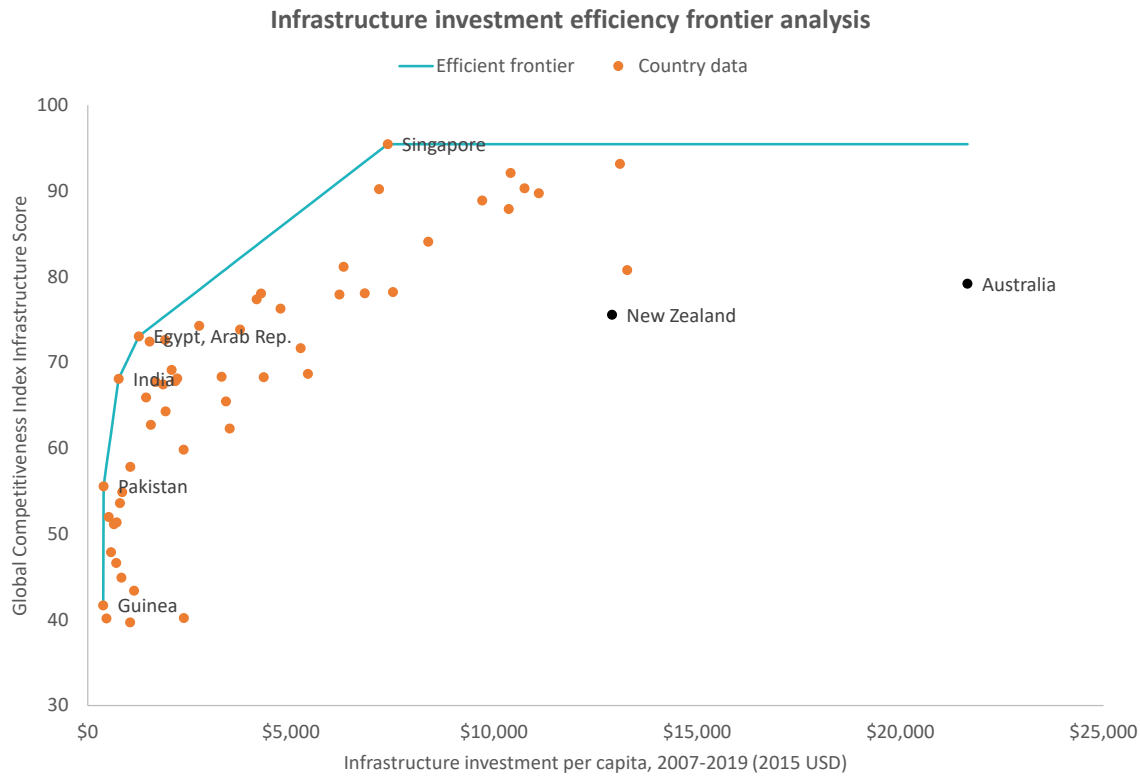
There is a strong positive correlation between both measures.[23] Countries that are estimated to be less efficient based on public investment data are *also* estimated to be less efficient based on network infrastructure investment data, despite the different coverage of the two datasets. New Zealand has a similar efficiency score of 0.79 using this measure, while Australia's efficiency score is slightly lower at 0.83.

We do not test alternative measures of infrastructure quality, although this is likely to be an interesting area for further research. For instance, benchmarking of investment versus infrastructure quality could be done at a sector level rather than an aggregate level. We note that IMF (2015) analysis shows that conclusions about the relative efficiency of different countries are similar regardless of whether the analysis uses 'objective' measures of infrastructure quality and coverage, 'subjective' measures, or a combination of the two as in the WEF infrastructure index.

Figure 14: Infrastructure investment efficiency based on GI Hub network infrastructure investment

[23] There is a correlation coefficient of 0.71 for all 55 countries included in both datasets, and a stronger correlation coefficient of 0.92 for the 18 high-income countries included in both datasets.

data, 2019



Deriving an expression for optimal public infrastructure stock

Equation 1 sets out a simple expression for the optimal provision of public capital derived from an economic growth model. This appendix briefly explains how this expression is derived, drawing upon a larger discussion in Bom and Ligthart (2014) and Pritchett (2000).

Equation 2 sets out a standard Cobb-Douglas production function augmented with public infrastructure. In this model, Y is total economic output (GDP), which is a function of private sector capital stock (K), labour input (L), public sector capital stock (K_G), and total factor productivity (A), which shifts the productivity of all other inputs.

Equation 2: Cobb-Douglas production function with public infrastructure

$$Y = AK^{\alpha}L^{\beta}K_G^{\varepsilon}$$

The marginal productivity of one additional unit of public capital can be obtained by differentiating *Equation 2* with respect to K_G. This gives *Equation 3*. Note that $\frac{Y}{K_G}$ is the inverse of the public capital to GDP ratio.

Equation 3: Marginal productivity of public capital investment

$$\frac{\partial Y}{\partial K_G} = \varepsilon \frac{Y}{K_G}$$

Equation 4 defines the cost to supply one additional unit of public capital (P_{K_G}). This cost reflects the opportunity cost of additional public spending (r, the real discount rate) plus the depreciation rate on public capital (δ). The term γ reflects the efficiency with which public infrastructure is

delivered – lower values indicate that more money is 'wasted' in the process of building infrastructure.

Equation 4: Cost to supply additional public capital

$$P_{K_G} = \frac{r + \delta}{\gamma}$$

The first-order condition for maximising the net economic value of public infrastructure is that the marginal productivity of public capital investment is equal to the cost of investment. Setting $\frac{\partial Y}{\partial K_G} = P_{K_G}$ and rearranging the equation results in the following expression for optimal public capital stock as a share of GDP.

Equation 5: First order condition for maximising the net economic value of public infrastructure

$$K^* = \frac{K_G}{Y} = \frac{\varepsilon * \gamma}{\delta + r}$$

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