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INFRASTRUCTURE COMMISSION
Te Waihanga

The lay of the land: Benchmarking New Zealand's infrastructure delivery costs

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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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Contents

Cut to the chase

Rautaki Hanganga o Aotearoa, the New Zealand Infrastructure Strategy finds that our current approach to infrastructure is not keeping up with the challenges facing us. There is a need to improve the efficiency of our infrastructure sector, rather than only focusing on broadening the funding and financing options available to it. Simply put, we cannot address our infrastructure challenges unless we can build good infrastructure at a more affordable price.

This *Research Insights* piece examines the cost to deliver infrastructure in New Zealand. We draw on local and international data to analyse how costs to deliver transport, electricity, and social infrastructure in New Zealand compare with costs in other high-income countries, and to identify factors that might cause infrastructure costs to differ between countries.

A nuanced picture of cost performance

Figure 1 shows how cost distributions for eight types of infrastructure projects in New Zealand compare with costs in other high-income countries. This is a high-level comparison – projects in each category are broadly similar, but the details of the projects and the context in which they are being built will differ. And in several cases, we have few New Zealand projects to compare with projects elsewhere in the world.

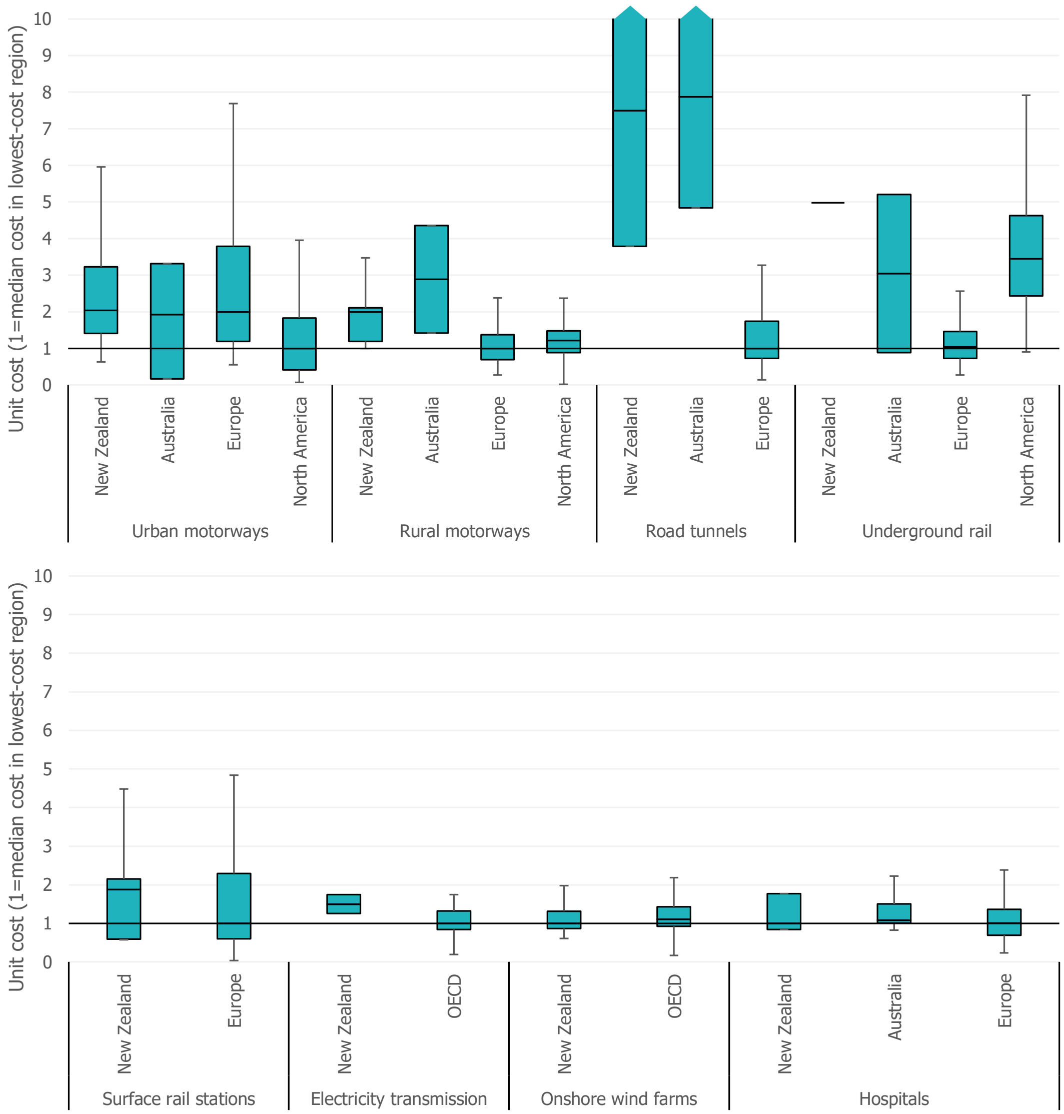
However, some patterns emerge from this data.

Relative to other high-income countries, New Zealand does not appear to have high infrastructure construction costs across the board. If we face a cost premium for infrastructure projects, it primarily relates to complex, large-scale infrastructure projects rather than smaller or more standardised infrastructure projects.

Statistical analysis suggests that we have statistically significant cost premiums for four types of complex, large-scale projects: urban and rural motorways, road tunnels, and underground rail projects. Examples like the Christchurch Stadium, which is one of the most expensive rugby stadiums in the world on a cost per seat basis, suggest that our challenges with complex, large-scale projects go beyond transport.

However, statistical analysis suggests that we have similar costs for four types of infrastructure projects: surface rail stations, electricity transmission lines, onshore wind farms, and hospitals. This is a positive sign, although past performance is no guarantee of future success in the current environment of cost inflation.

Figure 1: Distribution of unit costs for eight infrastructure project types



Source: Te Waihanga analysis of data from Oxford Global Projects (2022) and Goldwyn et al. (2022). The shaded 'box' shows the 25th percentile value (lower end of box), 50th percentile/median value (black line in middle of box), and 75th percentile value (top end of box), while the 'whiskers' show the minimum and maximum values, excluding outliers. Costs are scaled relative to median costs in the lowest-cost country grouping.

Many factors can drive cost differences

Why do some countries build infrastructure more cheaply than others? We identify four broad reasons why the cost of similar infrastructure projects might vary between countries:

- First, input costs – labour, materials, equipment, and land – might be higher in some places.
- Second, construction productivity may be higher in some places, allowing them to build more infrastructure using the same quantity of inputs.
- Third, differences in physical context – factors like geology, climate, and built environment – can increase the cost to build infrastructure in some places.

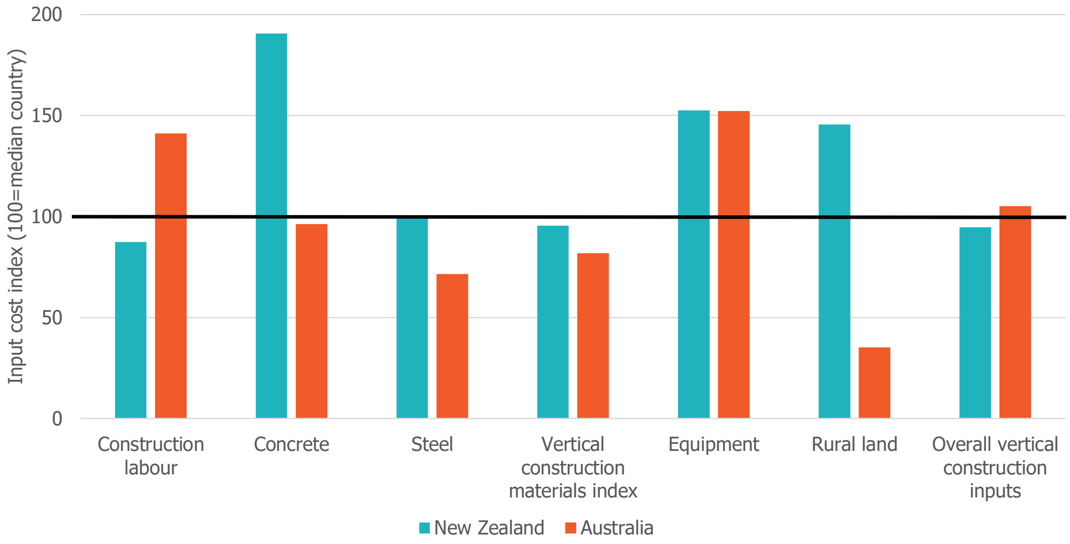
- Fourth, policy and institutions – factors like project sponsor decision-making, infrastructure design standards, planning and consenting systems, and procurement and contract models – can increase scope requirements and thus increase costs.

We have similar input costs to other high-income countries

Figure 2 shows how New Zealand's construction input costs compare with costs in ten other high-income countries. We face lower construction wages but higher costs for equipment, bare land, and some infrastructure construction materials, especially concrete. Our overall input costs for vertical construction are similar to other high-income countries. However, projects that need to buy a lot of concrete, machinery, or land may cost more in New Zealand.

Land prices can significantly increase the cost to build infrastructure in urban or suburban locations with valuable land. Based on current New Zealand land values, buying land in a rural location may account for around 5% of project cost, while buying a similar amount of land in a suburban or urban context could account for half of the project cost.

Figure 2: New Zealand's construction input costs relative to ten other high-income countries



Source: Te Waihanga analysis of data from Turner and Townsend (2022) and Savills (2020).

Our construction productivity is keeping up

New Zealand's productivity levels for building construction appear to be similar to the average high-income country. Our overall construction productivity is growing at a similar rate to the average OECD country and may be catching up with some comparator countries.

However, construction productivity can be very project specific. We find that different types of infrastructure projects experience different productivity trends:

- Renewable electricity generation projects such as wind farms have experienced steady cost reductions in recent decades. These projects 'learn' at a global level. Wind turbine technology is improving due to investments in research and development and economies of scale in turbine manufacturing, and these improvements diffuse rapidly to New Zealand.
- Complex horizontal infrastructure projects such as rail tunnels do not appear to get cheaper over time, at least not at the global level. However, these projects can 'learn' at a

local level as cities and countries gain experience in planning, designing, and building them. There are benefits from building local experience and capability in delivering complex projects.

New Zealand’s geology is challenging for infrastructure

The physical context for infrastructure projects can have a significant impact on project costs.

In urban areas, the availability of at-grade infrastructure corridors has a large impact on project costs. If corridors are not available, transport infrastructure must be put in tunnels, increasing costs by a factor of two to ten. At present, we rarely protect infrastructure corridors well in advance of growth, meaning that this is likely to pose ongoing challenges for infrastructure costs.

When infrastructure requires tunnelling, geotechnical conditions can have large impacts on project costs. Tunnelling in difficult conditions can be as much as three times as expensive as tunnelling in favourable conditions.

New Zealand’s geology is likely to increase infrastructure delivery costs. We are a seismically and volcanically active country due to our position on the Ring of Fire, with a range of natural hazards and challenging ground conditions.

Policy choices and institutional factors can drive costs up

When policy and institutional factors increase infrastructure project costs, it is often because they have added scope or design requirements. It can sometimes be difficult to determine whether added scope has increased the value of the project, or simply ‘over-engineered’ it.

In general, over-engineering is more common when infrastructure planning and decision-making processes create opportunities for well-organised or influential groups to delay projects or secure benefits for themselves at the expense of the project’s funders.

International examples highlight some straightforward cases of over-engineering, such as road projects funded by the European Union that are over-built relative to traffic volumes, and some cases that are more complex, such as increases in US highway construction costs that are linked to better community and environmental mitigation efforts.

To build infrastructure at a reasonable cost, project sponsors need to understand what they are building and the costs and benefits of their scope and design decisions. While good planning and design processes can take time at the start of a project, they save significantly more time and money later on.

We can lift our game

Our research highlights five key opportunities to improve our ability to build good infrastructure at a lower cost.

First, to deliver good infrastructure at an affordable cost, the New Zealand government needs to act as a **sophisticated client of infrastructure**. This means taking the time to understand what we are building before we set out to build it, establishing good processes and principles for making decisions about project scope and design, and investing in the right capability to plan, procure, and manage infrastructure.

Second, **strengthening independent advice for infrastructure prioritisation** and **establishing a pipeline of future investment** can help to lift productivity and reduce costs. Our analysis of underground rail projects shows that cities and countries can drive down costs by learning and repeating projects. These measures can help to achieve that.

Third, **openness to new technologies and methods** also lifts productivity and reduces costs. New Zealand's success in delivering wind farms at a similar cost to other high-income countries and ability to rapidly benefit from global improvements to wind turbine design highlights the value of adopting new technology.

Fourth, **efficient planning and consenting systems** can make it easier to develop cost-effective infrastructure solutions and avoid costs arising from delays or scope uncertainty.

Fifth, **ongoing infrastructure delivery cost benchmarking** can help us to improve. Knowing what projects *should* cost to build and maintain, based on both local and international data, can guide us towards better infrastructure decisions. Sometimes, we have no choice but to build an expensive piece of infrastructure – but if we have robustly tested that choice, we can be confident that we are addressing our infrastructure challenges as affordably as possible.

Introduction

Infrastructure construction costs are important

We cannot address our infrastructure challenges unless we can build good infrastructure at a more affordable price.

We know that our current approach is not keeping up with the challenges facing us. New Zealand currently spends around 5.5% of gross domestic product (GDP) building new public infrastructure and renewing or replacing existing infrastructure (Sense Partners, 2021).[1] If we attempted to build our way out of our challenges without addressing infrastructure delivery costs, it would cost around 9.6% of GDP every year for the next three decades. Even setting aside workforce capacity constraints, this is unlikely to be financially sustainable.

Rautaki Hanganga o Aotearoa, the New Zealand Infrastructure Strategy 2022– 2052 therefore identifies the need to improve the efficiency of our infrastructure sector, as well as broadening funding and financing options.

We have significant room to improve efficiency. In previous research, we found that New Zealand ranks in the bottom 10% of high-income countries when it comes to the efficiency of infrastructure delivery (New Zealand Infrastructure Commission, 2021b). Lifting efficiency will require us to make better use of existing infrastructure, improve project selection to choose the projects with the greatest impact, and streamline planning and delivery of infrastructure to reduce costs.

Some places build more affordably than others

There is evidence that the cost to build infrastructure can vary significantly between countries, even for very similar projects.

Here's one example: Between 2000 and 2006, Germany and the Czech Republic worked together to build a new motorway from Dresden to Prague. When the two countries' audit offices reviewed the project, they found that long bridges that were built on the Czech side were around 30% more expensive than similar German bridges, and tunnels were twice as expensive (Bundesrechnungshof & Nejvyšší kontrolní úřad, 2006). Terrain and road design standards were the same on either side of the border – which suggests that the cost differences were caused by other factors, such as differences in project management and procurement between the two countries.

Here's another example: In 2022, Christchurch City Council committed to build a new 30,000 seat stadium in the city centre. After significant cost escalation through the design process, the project is expected to cost NZ$683 million. By international standards, it is an expensive stadium. Figure 3 shows that Christchurch Stadium will be the second most expensive rugby stadium built in recent decades – assuming costs increase no further. On a per-seat basis, it is twice as expensive as the average rugby stadium. It is also three times as costly as Dunedin's Forsyth Barr Stadium, another 30,000-seat stadium with a roof that was built only a decade prior.

There might be good reasons for these differences – but they require an explanation.

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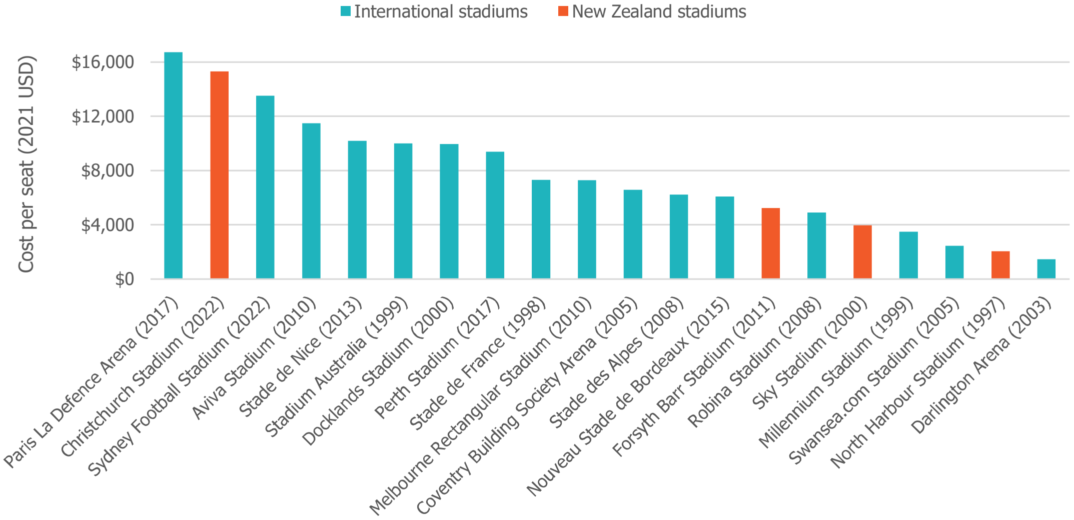
[1] This includes our transport, water, hospital, education, and defence facilities and excludes privately provided infrastructure like electricity generation and telecommunications.

Figure 3: The cost to build rugby stadiums in high-income countries



Source: Te Waihanga analysis of publicly-available cost and capacity data for rugby/multi-purpose stadiums with capacity over 20,000 seats built in the last 25 years in high-income rugby-playing countries. Costs are converted to US dollars using purchasing power parity exchange rates and inflated to 2021 values.

The aim of this research

This *Research Insights* piece examines the cost to deliver infrastructure in New Zealand. It addresses two main research questions, drawing upon a companion report by Oxford Global Projects (2022) and a range of other data sources:

1. **Where do we stand:** How does the cost to deliver infrastructure in New Zealand compare with costs in other high-income countries?
2. **Why do costs differ:** What factors could potentially cause infrastructure delivery costs to be higher in some places than others?

This research is primarily comparative – it focuses on describing differences in costs. Where New Zealand's costs differ from international comparisons, it outlines potential drivers of differences, rather than identifying specific factors that cause differences in costs.

Analysis of infrastructure project cost overruns, or drivers of cost overruns, is out of scope for this *Research Insights* piece. However, the companion report by Oxford Global Projects (2022) provides some international benchmarking data on cost and schedule overruns.

What's been done previously

Many countries are concerned about high infrastructure delivery costs (McKinsey, 2013), and there has been increasing interest in national and international cost benchmarking in recent years.

The United Kingdom's 2010 *Infrastructure Cost Review* provides a useful introduction to this topic (HM Treasury & Infrastructure UK, 2010). This report concludes that UK infrastructure delivery costs are higher than in other European countries, and that costs could be reduced by around 15% on average, saving £2-3 billion per annum. It recommends a set of actions that could be taken to achieve these cost reductions.

The Australian Productivity Commission considered infrastructure delivery costs in its *Public Infrastructure Inquiry* (Productivity Commission, 2014). It finds that infrastructure cost benchmarking information is "disappointingly limited" in Australia, making it difficult to understand whether Australian infrastructure delivery costs are high relative to international benchmarks. The Commission recommended implementing a cost benchmarking framework for major infrastructure projects. Following this recommendation, the Bureau of Infrastructure, Transport, and Regional Economics (2018) has compiled state-level cost benchmarks for transport projects.

In recent years, there have been various attempts at international benchmarking of infrastructure construction costs.[2] Benchmarking efforts mainly focus on transport infrastructure, although some studies include projects from other sectors. Most have been undertaken as one-off studies rather than ongoing programmes of benchmarking.

Pan-European agencies are particularly active in benchmarking. Relevant studies include:

- Benchmarking costs of road projects that are co-funded by the European Union (European Court of Auditors, 2013; PwC, 2021; RGL Forensics et al., 2009) or co-funded by EU member states (Bundesrechnungshof & Nejvyšší kontrolní úřad, 2006).
- Benchmarking of electricity and gas transmission project costs in European countries by the European Union Agency for the Cooperation of Energy Regulators (2015).
- A European Commission study on rail construction costs (PwC, 2018).
- An ongoing project by the UN Economic Commission for Europe to benchmark transport infrastructure costs in Europe (Group of Experts on Transport Infrastructure Construction Costs, 2020, 2022).

Other international agencies also play a role in benchmarking, including:

- The Asian Infrastructure Investment Bank (2020), which published a study of road and water infrastructure construction costs in 15 cities with varying income levels.[3]
- The International Energy Agency and Nuclear Energy Agency (2020), which published research and comparative data on electricity generation plant costs.

Independent research centres occasionally engage in cost benchmarking, often focusing on tunnelling or urban rail projects as international datasets on these projects are comparatively easy to gather. These studies also examine factors that cause costs to differ between countries, using a mix of quantitative and qualitative evidence. Relevant studies include:

- Efron and Read's (2010) benchmarking study of transport and utility tunnel costs that draws out lessons for Australia and New Zealand.
- An Eno Center for Transportation study on urban rail infrastructure costs that compares costs in North America and Europe and uses comparative case studies to identify why costs are higher in North America (Aevaz et al., 2021).
- The NYU Marron Institute's *Transit Costs Project*, which develops a large international database of underground rail project costs and develops a set of comparative case studies to identify underlying causes of cost differences between countries (Chitti et al., 2022; Ensari et al., 2022; Goldwyn et al., 2020, 2022; Levy et al., 2022).

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[2] Some countries also undertake within-country benchmarking or publish project cost datasets. Relevant examples include Washington State Department of Transport (2002); Australian Bureau of Infrastructure, Transport, and Regional Economics (2018); and a public transport project cost database published by the US Federal Transit Administration (2016).

[3] This study controlled for project scope by costing standard designs and controlled for purchasing power parity differences using the method developed by Langston (2013).

Quantity surveying and cost estimation firms frequently benchmark costs for specific construction and infrastructure projects (Royal Institution of Chartered Surveyors, 2013). Some firms, such as Turner & Townsend (2022), also publish international comparisons of construction costs for 'typical' projects, which focus mainly on buildings rather than horizontal infrastructure.

At the country level, competition regulators and utility regulators often seek to benchmark the efficiency of regulated infrastructure providers for the purpose of setting price caps, quality standards, or efficiency targets (Botasso & Conti, 2011). This analysis typically focuses on analysing overall costs to provide networks, rather than assessing costs for individual investments. In New Zealand, benchmarking against international comparators has been used to inform regulation of monopoly telecommunication infrastructure (Commerce Commission, 2007) and electricity transmission (Synergies Economic Consulting & GHD, 2018).[4]

In addition, a number of recent studies have examined how infrastructure project costs have changed over time. Some types of projects are getting cheaper over time, while others are getting more expensive. These studies highlight the role of technology adoption, productivity growth, and changing community expectations in causing cost differences.

In transport, Brooks and Liscow (2019) find that US highway construction costs are rising over time, due to increased demand for environmental and community mitigation rather than increased input costs. In energy, Kavlak et al (2018) and Elia et al (2020) find that solar photovoltaic cells and wind turbines are getting cheaper, due to a combination of R&D investment, economies of scale in manufacturing, and learning by doing. By contrast, nuclear power plants are getting more expensive due to increased safety requirements and declining construction productivity (Eash-Gates et al., 2020).

Key finding: The existing evidence base for benchmarking infrastructure costs between countries is limited and does not usually cover New Zealand.

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[4] However, Section 53P(10) of the Commerce Act prohibits New Zealand's Commerce Commission from using efficiency benchmarking to set prices for electricity distribution businesses subject to default price paths: "*The Commission may not, for the purposes of this section, use comparative benchmarking on efficiency in order to set starting prices, rates of change, quality standards, or incentives to improve quality of supply.*"

Comparing New Zealand with the world

To address the first research question, we commissioned a high-level cost benchmarking analysis of selected infrastructure project types (Oxford Global Projects, 2022) and supplemented this with additional analysis of the Transit Costs Project's underground rail project cost dataset (Goldwyn et al., 2022), which is described in Appendix 1.

Approach to comparisons

We examined eight categories of infrastructure projects

We were able to develop high-level cost benchmarks for eight categories of infrastructure projects in three different sectors.

These included five types of transport projects (urban motorways, rural motorways, road tunnels, underground rail, and surface rail stations), two types of electricity projects (onshore wind farms and high-voltage electricity transmission lines), and one type of social infrastructure project (hospitals). Projects in each category provide broadly similar services, but we did not attempt to control for project design and scope in a detailed way.

In each project category, we were able to compile cost data for most completed or in-progress New Zealand projects, largely from public sources. New Zealand project cost data was based on information that was publicly available in mid to late 2022. Oxford Global Project's international project database is extensive, including around 17,000 projects, but country coverage varies for each specific project category. We also draw on other information to validate these comparisons.

We focus on comparisons with other high-income countries

The international infrastructure project datasets that were used for comparisons include projects from both high-income and low-income countries. We focus primarily on comparisons with high-income countries, as labour and material input costs, environmental standards, and health and safety rules are more likely to be broadly similar in these countries.

We compared unit cost to build projects

Projects in each category can differ in scale. For instance, we may be trying to compare the cost of a wind farm with 20 turbines with the cost of a wind farm with 100 turbines. We therefore calculate unit cost metrics for each project by dividing total delivery cost by a measure of project size, such as electricity generating capacity in megawatts.

Project costs were stated as 'overnight' construction costs, which means that they exclude financing costs for the project. Project costs were originally stated in nominal local currency units (eg 2010 New Zealand dollars or 2014 Euros). They were then inflated to a common comparison year (2021) using country-specific implicit price deflators and converted to US dollars using economy-wide purchasing power parity (PPP) exchange rates published by the World Bank.[5] This approach is pragmatic but has several limitations:

- Infrastructure construction prices tend to rise slightly faster than economy-wide prices (New Zealand Infrastructure Commission, 2022). Using economy-wide price deflators is

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[5] PPP exchange rates are calculated by comparing the overall cost to purchase a similar basket of consumption goods in different countries.

likely to under-estimate the cost of projects that were built earlier. However, as the majority of New Zealand and international projects included in this analysis were undertaken in the last two decades, the magnitude of bias is likely to be small – no more than 10-20%.

- Economy-wide PPP exchange rates are preferable to market exchange rates as they place more weight on 'non-tradable' goods like construction and personal services. A better approach would be to use an infrastructure-specific PPP exchange rate (Productivity Commission, 2014). In Appendix 3, we show that economy-wide PPP exchange rates are strongly correlated with construction-specific PPP exchange rates, and that using economy-wide PPP exchange rates is unlikely to lead to errors of more than +/-20%.

In short, issues with price deflators and exchange rates could explain small differences in infrastructure delivery costs between countries – on the order of 20% - but that they are unlikely to explain larger differences.

We compared distributions of costs and tested the statistical significance of differences

For each infrastructure project category, we used two main approaches to compare infrastructure costs between countries.

First, we plotted the range of costs observed in each country using 'box and whisker' charts. These charts show average costs in each country as well as the distribution of costs at a project level. These charts can be used to check whether different countries have a similar distribution of costs, or whether some countries' projects are systematically more expensive.

Second, we tested whether there were statistically significant differences in costs between countries using several simple statistical techniques. These include non-parametric tests of whether distributions of project costs were similar in different countries and regression-based statistical tests that controlled for other project characteristics that could affect costs. These statistical tests are described in Oxford Global Projects (2022) and in Appendix 1 to this report.

Additional statistics, including average (mean and median) unit costs for each project type and country group, are available in Oxford Global Projects (2022) and in Appendix 1 to this report.

Caveats apply

These infrastructure cost comparisons are high-level and should be interpreted subject to four important caveats.

First, while infrastructure projects in each category provide broadly similar infrastructure services, limited effort has been applied to ensure that we are making exact 'like for like' comparisons. Observed differences in costs may reflect unmeasured differences in scope or design – an issue we discuss in more depth in the next section – or differences in how project costs have been recorded.[6]

Previous research highlights that exact 'like for like' comparison is hard. For instance, the UK Infrastructure and Projects Authority (2018) gathered data on 169 international tunnelling projects but ultimately found that it could ensure like for like comparisons for only 16 UK projects. They concluded that:

> *Subject matter expertise and direct project knowledge is required to enable sensible decisions about which projects can provide valid benchmark data, about how to adjust for inflation and economic factors, and how to allow for differences between the benchmark projects and the project in hand.*

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[6] On this point, we note that New Zealand data was compiled separately from international data.

However, there is still value in comparing similar projects, even if they are not exactly identical. Inexact comparisons can be timelier and can draw on larger datasets, which can help to identify areas where more in-depth analysis is needed. Moreover, decision-makers sometimes make choices about scope and design that drive up costs, and these types of comparisons can help to understand the impact of those choices.

Second, there are relatively few New Zealand projects in some categories (Table 1). For instance, New Zealand only has one in-progress underground rail project and two recently completed above-ground transmission line projects. It may be difficult to generalise from this data, as the next project that New Zealand builds may have a different cost structure than the previous one.[7]

Third, coverage of international projects is variable (Table 1). For instance, most road tunnel projects in the Oxford Global Projects dataset are from Europe, while most electricity transmission projects are from the United States. This data provides a more comprehensive picture of typical costs in some countries than in others. There is no guarantee that these benchmarks are perfectly representative of international costs. However, in Appendix 2 we show that our findings are consistent with evidence from other cost benchmarking studies.

Fourth, these comparisons are backward-looking rather than forward-looking. Costs are likely to change in the future. Even if New Zealand has historically had similar infrastructure construction costs to other high-income countries, costs may change in the future.

Table 1: Number of infrastructure projects included in benchmarking analysis

Project category	Number of NZ projects	Number of international projects
Transport infrastructure		
Urban motorways	25	Australia (3); Europe (27); North America (16)
Rural motorways	8	Australia (2); Europe (137); North America (14)
Road tunnels	4	Australia (4); Europe (87); North America (1)
Underground rail	1	Australia (2); Europe (76); North America (17)
Surface rail stations	5	Europe (36)
Electricity infrastructure		
Transmission lines	2	North America (45)
Onshore wind farms	15	OECD (12)
Social infrastructure		
Hospitals	4	Australia (10); Europe (69)

Source: Oxford Global Projects (2022); Te Waihanga analysis of data from Goldwyn et al. (2022). As there is only one North American road tunnel project, we omit this from subsequent charts.

Key comparisons

Ranges for infrastructure project costs in different countries

Figure 4 shows box and whisker plots for eight categories of infrastructure projects. These charts illustrate average (median) costs in each country as well as the distribution of costs at a project level. The blue 'boxes' show the range from the 25th percentile of unit costs to the 75th percentile, while the 'whiskers' show minimum and maximum values, excluding any outliers.

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[7] For instance, public hospitals that are currently in planning appear to be costlier than the past four hospital projects.

To make it easier to see trends and patterns in the data, we have normalised unit costs relative to median costs in the lowest-cost country group. For instance, urban motorway projects are cheapest to build in North America, which has a median cost of around US$3.2 million per lane-kilometre, so a value of 1 indicates costs of US$3.2m/lane-km, a value of 2 indicates costs of US$6.4m/lane-km, and so on and so forth.

Three key insights emerge from these charts.

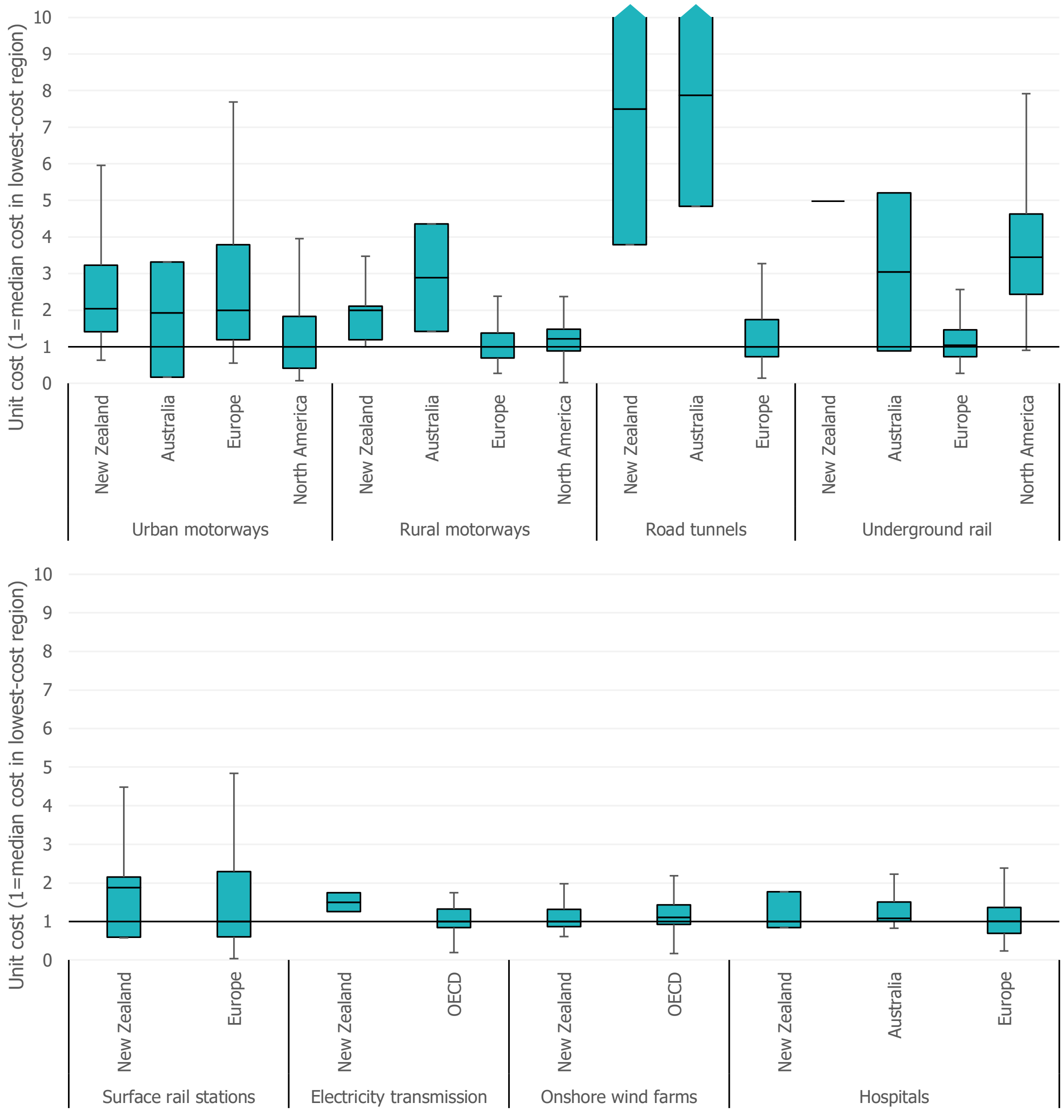
First, **there is much greater variation in unit costs for large-scale 'horizontal' infrastructure projects** – motorways and tunnels – than for 'vertical' infrastructure projects – surface rail stations, transmission lines, wind farms, and hospitals. Costs for large-scale horizontal projects vary more between and within countries, whereas costs for vertical projects are much more consistent, with the exception of a few outliers.

Second, **New Zealand appears to have higher infrastructure project costs for some (but not all) project types, relative to some countries**. In particular, our distribution of unit costs appears to be higher in the following cases:

- Urban motorway costs tend to be higher in New Zealand than in North America
- Rural motorway costs tend to be higher in New Zealand than in Europe or North America
- Road tunnel costs tend to be higher in New Zealand than in Europe
- While we only have one underground rail project, it would be a high outlier in Europe.

Third, **best practice is not always found in the same place for all types of projects**. Europe appears to build underground rail more affordably than North America, but the opposite appears to be true for urban motorways.

Figure 4: Distribution of unit costs for eight infrastructure project types



Source: Te Waihanga analysis of data from Oxford Global Projects (2022) and Goldwyn et al. (2022). The shaded 'box' shows the 25th percentile value (lower end of box), 50th percentile/median value (black line in middle of box), and 75th percentile value (top end of box), while the 'whiskers' show the minimum and maximum values, excluding outliers.

Testing the statistical significance of cost differences

Data shown in Figure 4 suggests that in some cases New Zealand's infrastructure delivery costs are higher, on average, than costs in other high-income countries. However, differences in average costs could reflect random chance – for instance, we may have built a small number of unusually complex projects that were still within the range of costs observed in other countries.

We use two types of statistical tests to assess whether differences in costs are statistically significant, ie unlikely to have arisen solely by chance. First, we use the Wilcoxon rank-sum test to compare New Zealand's distribution of unit costs with distributions observed in other countries. This is a non-parametric test that tests the hypothesis that two countries' unit costs are drawn from the same underlying distribution of costs. Second, we use ordinary least squares (OLS) regression to test whether New Zealand's average unit costs differ from other countries' costs after controlling for basic project characteristics like project size.

Table 2 summarises the results of these statistical tests. It highlights cases where there are statistically significant differences at the 10%, 5%, or 1% significance level. Lower significance levels indicate that it is less likely that differences have arisen by chance. More information on these statistical tests is available in

This analysis suggests that New Zealand's cost differences for motorway projects, road tunnels and underground rail are statistically significant, at least relative to some other country groups. However, cost differences for surface rail stations, transmission lines, wind farms, and hospitals are not statistically significant.

Table 2: Statistically significant differences in unit costs between countries

Project category	**Statistical significance on Wilcoxon rank-sum test**	**Statistical significance in OLS regression with basic project characteristics**
Transport infrastructure		
Urban motorways	Yes, with North America (10% significance level)	Yes, with OECD in general (1% significance level)
Rural motorways	Yes, with Europe (5% significance level)	Yes, with OECD in general (1% significance level)
Road tunnels	Yes, with Europe (5% significance level)	Yes, with Europe (5% significance level)
Underground rail	Not applicable	Yes, with Europe and OECD in general (1% significance level)
Surface rail stations	No	No
Electricity infrastructure		
Transmission lines	No	No
Onshore wind farms	No	No
Social infrastructure		
Hospitals	No	No

Source: Te Waihanga summary of data in Oxford Global Projects (2022) and analysis of NYU Marron Institute (2022) rail tunnel cost data in Appendix 1.

Key finding: Relative to other high-income countries, New Zealand does not appear to have high infrastructure construction costs across the board. If we face a cost premium for infrastructure projects, it primarily relates to complex, large-scale infrastructure projects rather than smaller or more standardised infrastructure projects.

Digging deeper: The case of the City Rail Link

New Zealand only has one in-progress underground rail project – Auckland's City Rail Link. On a per-kilometre basis, this is a high-cost project relative to underground rail projects in other high-income countries. It would be a high outlier in Europe, and it would be among the 25% most expensive projects undertaken in North America.

However, **international evidence also suggests that we would expect higher costs for a project like City Rail Link**. Statistical analysis reported in Table 4 and Table 5 in Appendix 1 indicates that the project has several characteristics that are associated with higher costs.

First, City Rail Link is a comparatively short tunnel (3km, compared with an OECD-wide average of over 8km) with a high density of new stations (three new stations). Our statistical analysis suggests that both of these factors raise the cost of underground rail projects. This is exacerbated by the fact that it was necessary to use two different tunnelling techniques along the route, raising the fixed costs of setting up tunnelling processes.

Second, City Rail Link faces challenging geotechnical conditions as it is located in a city in the 'Ring of Fire' around the Pacific tectonic plate boundaries. Our statistical analysis suggests that other underground rail projects in Ring of Fire locations cost more than projects in less seismically and volcanically active locations.

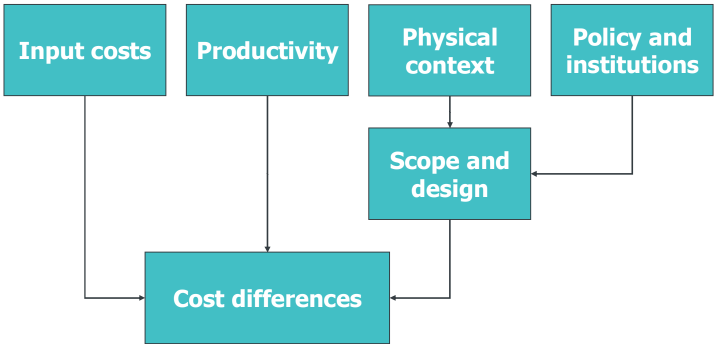
Third, City Rail Link is the first project of this nature built in New Zealand. Our statistical analysis suggests that cities and countries that have gained more experience building these projects tend to learn how to build them more cheaply as a result. The City Rail Link project appears to be paying some of the fixed costs to set up systems and develop the expertise required to successfully plan and deliver these projects.

Capturing lessons from planning and delivery of City Rail Link and retaining workforce capability for future projects can help us to deliver these projects at a lower cost.

Why might costs vary?

Figure 5 identifies four broad reasons why infrastructure projects that provide similar services might cost different amounts in different places.[8]

Figure 5: Drivers of cost differences



First, **input costs** might be different. A variety of inputs – labour, materials, equipment, and land – are needed to build infrastructure. Costs for tradable inputs, like construction machinery and building materials, should in theory be similar across countries. However, costs for non-tradable inputs, like construction labour, land, and bulky materials like aggregate, may differ significantly between countries. This may drive differences in the cost of completed infrastructure.

Second, **construction productivity** and the efficiency of resource use may be different. Lower productivity means that more inputs are needed to build the same amount of infrastructure. For instance, if poor project management creates a need for re-work, it will increase the amount of labour, material, and equipment needed to build infrastructure. Productivity differences may therefore drive differences in the cost of completed infrastructure.

Third, the **physical context** for the project might be different. Physical context includes factors like geology, climate, and existing built environments and infrastructure networks. Physical context can affect project costs by increasing project scope and design requirements. For instance, hospitals in earthquake-prone countries may incur more costs for seismic strengthening.[9]

Fourth, **policy and institutions** can have significant impacts on costs. Factors like design standards, planning and consenting requirements, procurement practices, and project sponsor decision-making can affect the scope and hence cost of infrastructure projects. For instance, rail projects that choose to build bespoke 'iconic' stations rather than simpler, more standardised designs tend to be more expensive as a result.[10] Similarly, countries that set stronger wastewater discharge standards may need to pay more to build wastewater treatment plants to achieve better environmental quality. These examples highlight how scope decisions often have complex costs and benefits.

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[8] These factors are not always easy to separate in practice. For instance, in countries with weak institutions, corruption can significantly increase infrastructure delivery costs (Chitti et al., 2022; Fazekas & Tóth, 2018; Pritchett, 2000). Corruption can manifest as excess input costs, low productivity (due to hiring too many workers for the job and having them stand around), excess scope (over-building to benefit the contractor), or a combination of all three.

[9] The services provided by these hospitals – providing medical services without risk of falling down – are similar, but costs to provide these services are higher due to geological factors.

[10] One of the most extreme examples is the new underground rail station at the World Trade Centre site in New York, which took over a decade to deliver and ultimately cost US$4 billion due to the desire to deliver an iconic, architecturally designed station (Dunlap, 2014).

Differences in input costs

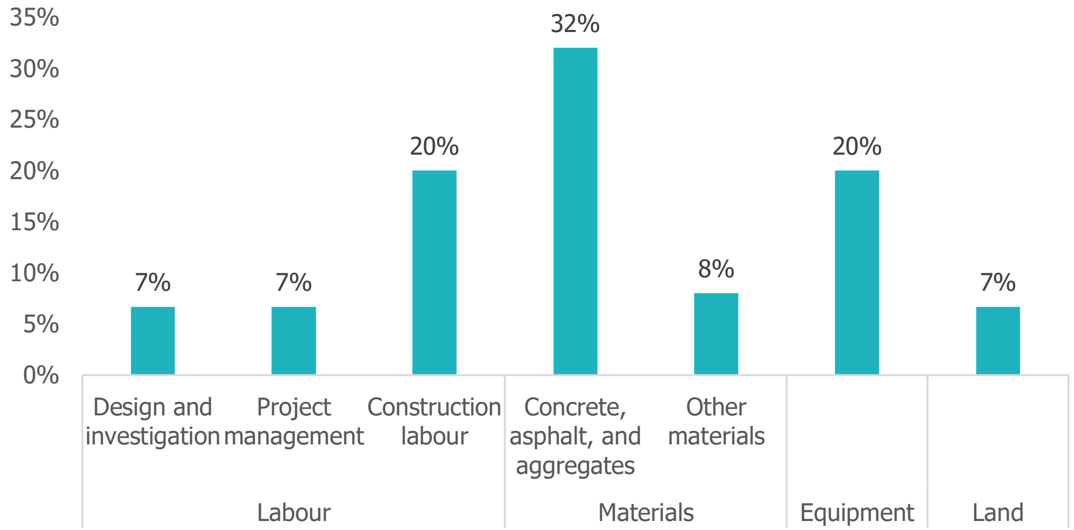
Building an infrastructure project requires inputs of labour, materials, equipment and machinery, and land. Labour inputs can be further broken down by skill level and occupation, while materials inputs can be broken down into bulk commodities that are costly to move long distances, like aggregates, and tradable inputs, like structural steel.

Key inputs to infrastructure projects

Figure 6 summarises Australian data on the composition of project cost for road projects and other transport projects. For the average major road project:

- Labour costs make up roughly one-third of total project cost. This is broken down into 13% of total costs for planning/design and project management labour, and 20% for construction labour.
- Material costs contribute roughly 40% of total project cost. This is broken down into 32% for bulk commodities (concrete, asphalt, and aggregates) and 8% for other materials.
- Equipment costs make up roughly one-fifth of total project cost.
- Land costs make up around 7% of total project cost, although this can vary substantially depending on the context, and in some cases exceed 20% of total project costs.

Figure 6: Composition of input costs for an average major road project in Australia



Source: Te Waihanga estimates based on a breakdown of construction costs for freeways / tollways from Figure 9.9 in Australian Productivity Commission (2014) and a breakdown of total project costs for Class 6 roads from Figure R.2 in BITRE (2018). Numbers do not sum to 100% due to rounding.

Comparing New Zealand's construction input costs

We use data from Turner & Townsend's (2022) *International Construction Market Survey* to benchmark New Zealand's input costs against other high-income countries covered in the survey.[11] Appendix 3 provides further information on this data and explains how we compiled an overall index for vertical construction input costs based on Langston (2013).

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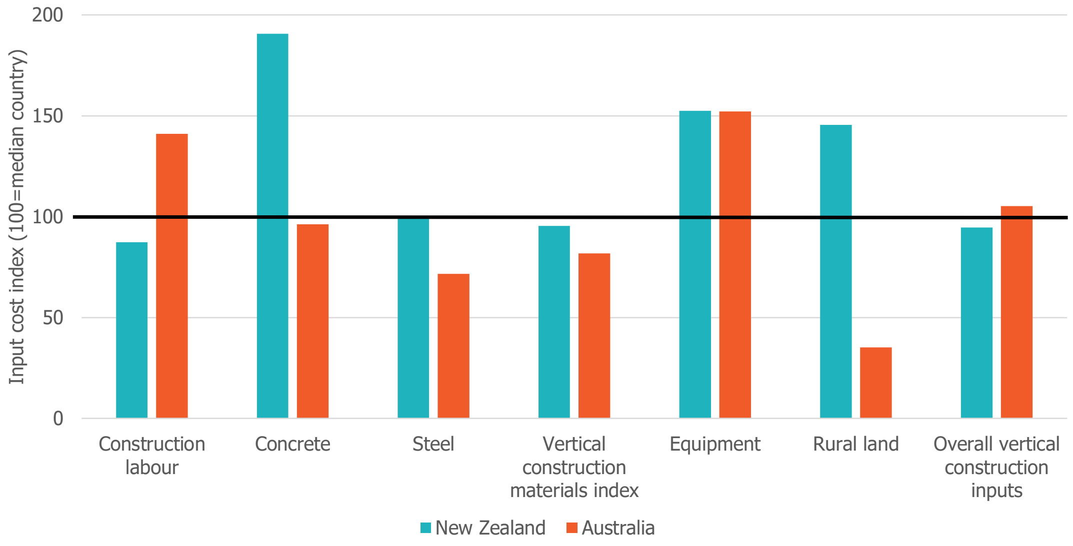
[11] Turner and Townsend (2022) provide data for 22 cities in 11 high-income countries, including Auckland. We average city-level costs within each country.

Figure 7 shows how New Zealand's construction input costs measure up to other high-income countries. We find that:

- New Zealand has below-average construction labour costs, and average construction wages in New Zealand are around 35% lower than construction wages in Australia.[12]
- New Zealand has higher concrete costs than other high-income countries, but average costs for structural steel beams.[13] Concrete is 50% cheaper in Australia and steel is almost 30% cheaper. Previous research shows that New Zealand's cost of aggregate (excluding transport costs) is comparable to the United States and lower than Sydney (New Zealand Infrastructure Commission, 2021a).
- On the whole, New Zealand has average costs for materials used in vertical construction (structural steel, concrete, timber, and 'finish' materials).
- New Zealand has high construction equipment costs – around 50% higher than the median high-income country, and similar to Australia.
- New Zealand has comparatively high agricultural land prices, likely reflecting the fact that we have comparatively productive agricultural land.

'Soft costs' for planning, design, and consenting are harder to compare across countries. There is some evidence that soft costs for transport projects vary significantly between countries and that they are increasing over time (Aevaz et al., 2021). There is also some evidence that infrastructure consenting costs are comparatively high in New Zealand, although consenting costs are hard to compare between countries (Moore et al., 2021).

Figure 7: New Zealand's construction input costs relative to ten other high-income countries



Source: Te Waihanga analysis of data from Turner and Townsend (2022) and Savills (2020).

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[12] However, given trans-Tasman competition for labour, hiring or retaining workers may require New Zealand firms to pay comparable wages to Australia. This is likely to push infrastructure delivery costs up to varying degrees, depending upon labour-intensiveness of different projects.

[13] The Commerce Commission (2022) is currently undertaking a market study into residential building supplies, which includes a case study of concrete and cement. The Commerce Commission's preliminary view is that "there appears to be a reasonable level of competition occurring for both materials, particularly at the RMX level. However, there are elements of markets for both materials which may be causing competition to not work as well as it could."

Key finding: New Zealand's overall input costs for construction are similar to the average high-income country. We face lower construction wages but higher costs for equipment, bare land, and some infrastructure construction materials, such as concrete.

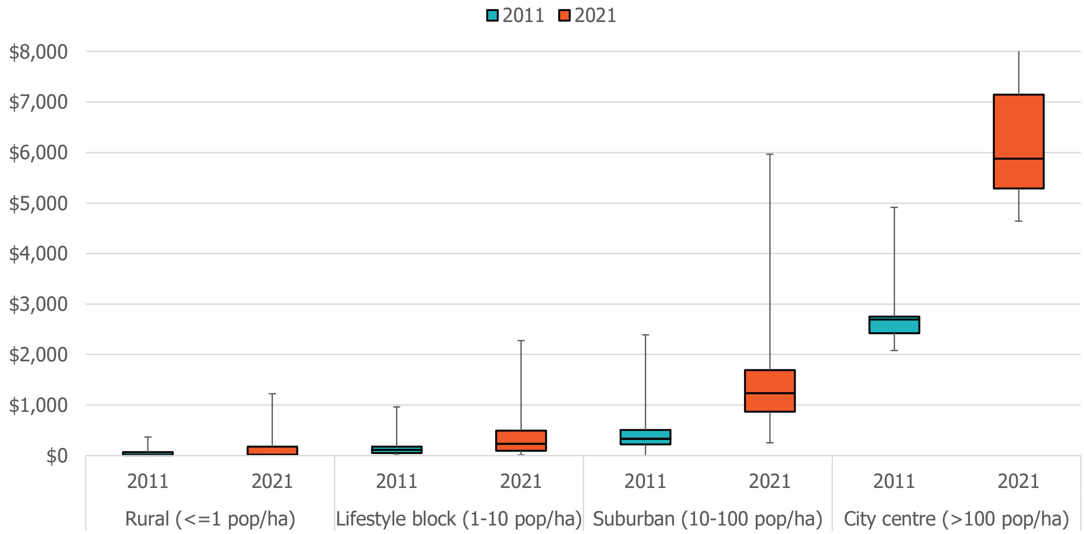
The impact of land prices on infrastructure delivery costs

International variations in rural land prices are small relative to differences between urban and rural land values within countries. Because infrastructure projects often require significant amounts of land, the cost to build similar infrastructure can be considerably higher in places where land is expensive.

To illustrate this point, Figure 8 shows that land values rise with population density in the Auckland region, and that urban land values have increased significantly in recent years.

In 2021, land is valued at around $20/m^2 in a typical rural area with population density less than one person per hectare. Land values are around ten times higher (around $200/m2) in lifestyle block areas with density of 1-10 people per hectare, and over fifty times higher (around $1200/m^2) in suburban areas with density of 10-100 people per hectare. They are even higher in city centres.

Figure 8: Distribution of land values in Auckland region, 2011-2021



Source: Te Waihanga analysis of land valuation data at the SA2 level. The shaded 'box' shows the 25th percentile value (lower end of box), 50th percentile/median value (black line in middle of box), and 75th percentile value (top end of box), while the 'whiskers' show the minimum and maximum values, excluding outliers.

When it is necessary to buy land or purchase easements to build an infrastructure project, the project will typically be much cheaper to build in a lower-density environment.

For instance, a major transport corridor may require up to 10 hectares of land per kilometre.[14] If the project is being built in a rural area in Auckland with land values of around $20/m^2, it will be necessary to spend roughly $2 million per kilometre to buy land for the project.[15] This is likely to be around 5% of the total cost of the project, in line with the Australian average shown in Figure 6.

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[14] Based on a maximum corridor width of around 100 metres (Douglass & Dryden, 2012).

[15] Calculated as 10 ha land/km * $23/m^2 land * 10000m^2/ha.

However, building a similar project in a built-up suburban area will be much more expensive. Even in the suburban areas with the lowest land values, land still costs around $600/m^2, meaning that it would be necessary to spend roughly $60 million per kilometre to buy land for the project.[16] In this scenario, land costs could be comparable to direct construction costs – doubling the cost of the project.

Key finding: Land prices can have significant impacts on infrastructure delivery costs. Based on current New Zealand land values, buying land in a rural location may account for around 5% of project cost, while buying a similar amount of land in a suburban or urban context could potentially account for half of the total project cost.

Differences in construction productivity

Construction productivity affects how many inputs are needed to build a given quantity of infrastructure.[17] For instance, reducing rework and schedule delays can reduce the amount of labour, equipment, and materials needed to complete a project.

Construction does not occur in a controlled factory environment where tasks can easily be tracked, optimised, and automated. Construction productivity growth mainly relies upon standardisation of designs and components and 'learning by doing', which occurs when firms and workers repeat tasks or projects and learn to do them more efficiently.

In our September 2022 *Research Insights* paper, we compared construction labour productivity *growth* between different OECD countries and between different parts of the New Zealand construction sector (New Zealand Infrastructure Commission, 2022). New Zealand's overall construction productivity is growing slightly faster than the OECD average. Within New Zealand, infrastructure construction productivity is growing more slowly than building construction productivity.

Construction productivity levels

The relative *level* of construction productivity in different countries is harder to measure and compare. Here, we provide new evidence on the subject.

Figure 9 presents our estimates of multifactor productivity levels in vertical construction in 11 high-income countries.[18] Appendix 3 explains how we derived these estimates using Langston's (2013) methodology for international comparisons of construction productivity and data from Turner and Townsend (2022). Our estimates reflect how many units of construction output (in this case, square metres of high-rise office gross floor area) can be constructed using one standard 'bundle' of

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[16] Calculated as 10 ha land/km * $600/m^2 land * 10000m^2/ha.

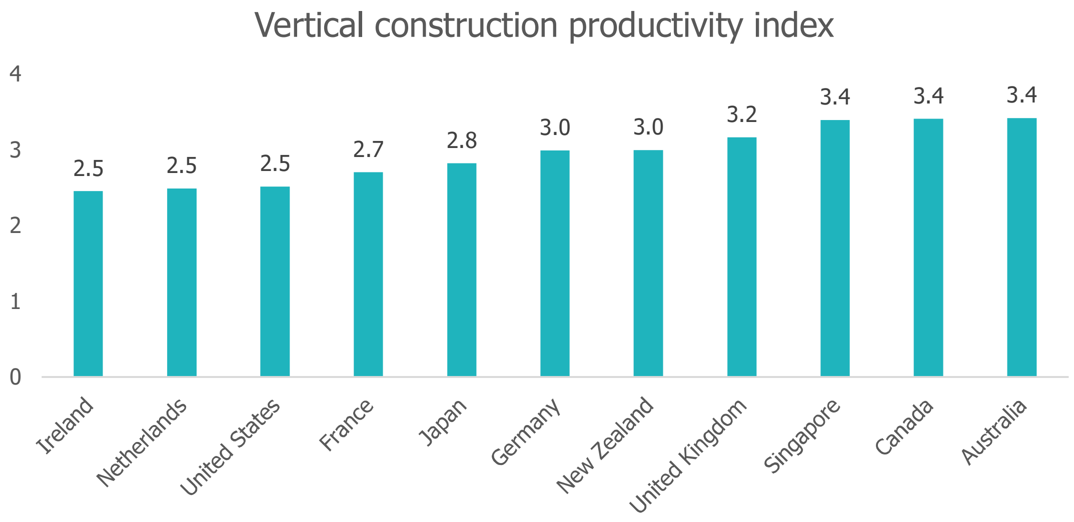
[17] Productivity can be measured in several ways. Partial productivity measures, like labour productivity, reflect the amount of output produced by each worker on the job. Labour productivity comparisons tend to be more straightforward, but they don't account for other inputs used in production, such as equipment. Multifactor productivity measures address this by accounting for all inputs used in production, including labour, capital goods, and (sometimes) materials.

[18] Asian Infrastructure Investment Bank (2020) used a similar method to benchmark productivity in road and water infrastructure projects in selected countries. The available data was not sufficient to replicate that analysis for New Zealand and other high-income countries, and hence we focus on vertical construction.

construction inputs (ie the labour, material, and equipment inputs described above).[19] Higher numbers indicate higher productivity levels.

In vertical construction, New Zealand has average productivity for a high-income country. We are roughly 12% less productive than Australia, which almost exactly offsets our lower input costs.[20]

Figure 9: A multifactor productivity index for vertical construction in urban areas of 11 high-income countries



Source: Te Waihanga analysis of Turner and Townsend (2022) data based on Langston (2013).

Key finding: New Zealand's productivity levels for vertical construction appear to be similar to the average high-income country. Our overall construction productivity growth is middling relative to other OECD countries.

Wind farm construction: Lifting productivity through global learning

The cost to build wind farms has declined significantly over time (IRENA, 2021). Elia et al (2020) estimate that unit costs to install wind turbines declined by an average of 2.8% per annum between 2005 and 2017 (Elia et al., 2020). These cost reductions reflect ongoing research and development to improve turbine designs and improved productivity in turbine manufacture and installation.

These cost trends can be summarised into a 'learning rate' that measures the relationship between total global installed capacity and unit costs for new wind farm projects.[21] Previous research

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[19] There are some important caveats to this approach. In particular, it does not consider the fact that different cities/countries may use different combinations of inputs. For instance, cities with high labour costs may substitute equipment for labour. This makes it more challenging to use this approach to compare productivity levels between high-income and low-income countries.

[20] We also estimate that the US is comparatively unproductive in vertical construction. This reflects the fact that the US data is weighted towards several large cities with stringent land use regulations that drive up the cost of high-rise construction (Albouy & Ehrlich, 2018; Glaeser et al., 2005). However, the US appears to be relatively more productive at building single-family housing (Baily & Solow, 2001).

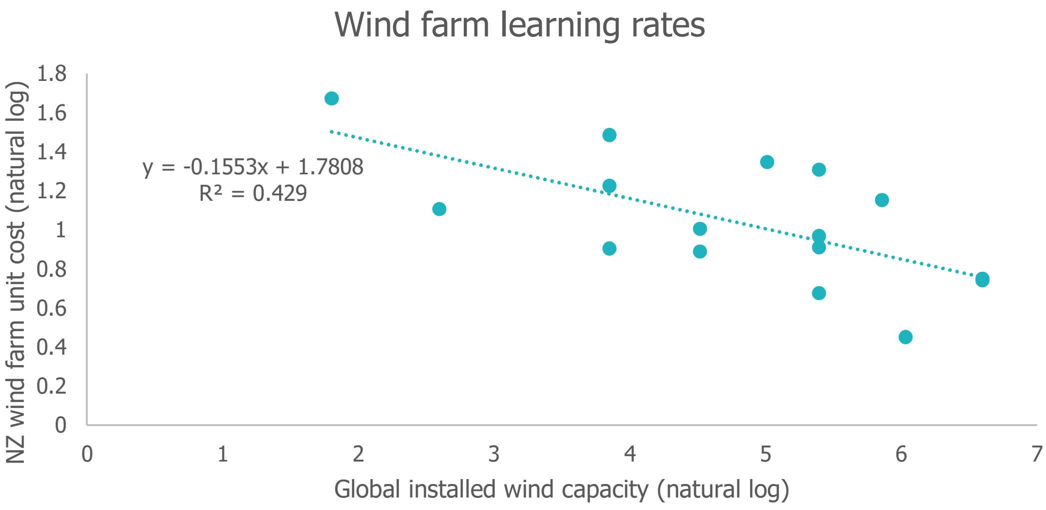
[21] Specifically, we test whether Wright's law, which posits that costs decrease as a power law of cumulative production, holds for each type of project (Nagy et al., 2013). To do this, we regress the natural log of unit costs on the natural log of cumulative installed capacity.

estimates a learning rate of around 15%, meaning that doubling the total installed capacity of wind farms reduces unit costs by around 15% (Bolinger et al., 2022).

Figure 10 shows that New Zealand's wind energy sector has 'learned' as the global industry scales up. Based on data for 16 large New Zealand wind farms completed between 1996 and 2020, we estimate that the cost to build wind farms in New Zealand has fallen by around 15% every time global installed capacity has doubled.[22]

Wind farm construction highlights the importance of openness to innovation and use of standardised technologies and designs. New Zealand has reduced the cost of wind farms by actively adopting new technologies. While local factors, like our planning and consenting system and the productivity of our civil construction sector, also influence the cost to develop wind farms, they do not increase overall project costs relative to other high-income countries.

Figure 10: Wind farm learning rates in New Zealand



Source: Te Waihanga analysis.

Rail tunnel construction: Lifting productivity by gaining local experience

While wind farms cost about the same to build everywhere, there are large differences in the cost to build underground rail in different countries. This suggests that local factors, rather than global factors, determine cost and productivity trends.

We use Transit Costs Project data (Goldwyn et al., 2022) to estimate learning rates for underground rail projects in OECD countries, controlling for some other factors that may affect project cost. We examine learning effects at the city level and the global level. See Appendix 1 for more information on our econometric analysis.

Figure 11 shows estimated learning rates at different geographical scales. Unlike for wind farms, we find no evidence of learning at a global level. Controlling for other factors, rail tunnel costs have

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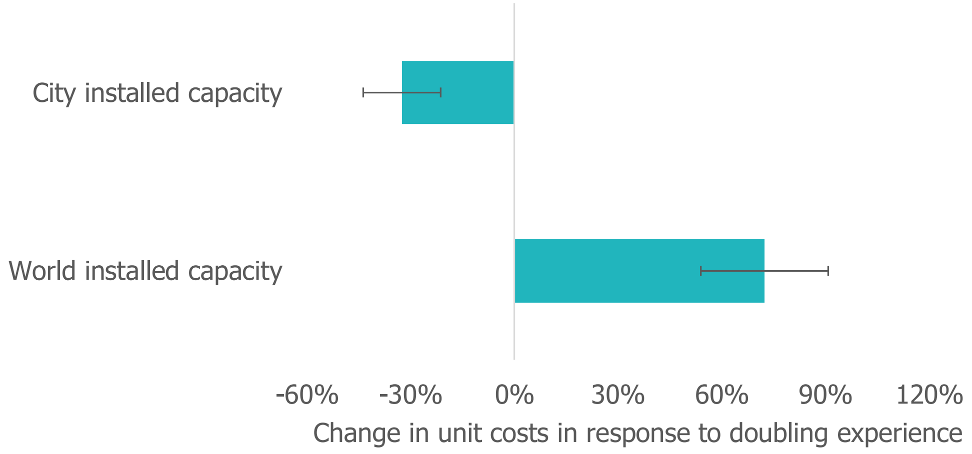
[22] This is the slope of the regression line in Figure 10. In a multivariate analysis, we find that global installed capacity has a stronger impact on New Zealand wind farm costs than local installed capacity. When we compared models with variables for local installed capacity, global installed capacity, or both, we found that the model variant that only included global installed capacity resulted in the best combination of model information and model complexity (measured using Akaike's Information Criterion).

increased as global installed capacity increases. This does not necessarily mean that rail tunnelling has become less productive – it could be driven by design changes to improve safety, resilience, or customer amenity.

However, underground rail costs decline significantly, relative to the underlying trend, when cities gain more experience building them. We estimate a local learning rate of 33%, meaning that doubling the length of a city's rail network is expected to bring down unit costs by around 33%.

Figure 11: Underground rail learning rates at local and global levels



Source: Te Waihanga analysis in Appendix 1 (Table 5). Error bars indicate one standard error around the point estimate.

Case studies show that some cities and countries have leveraged rail tunnel construction programmes to lift productivity and drive down costs, while others have not (Aevaz et al., 2021; Chitti et al., 2022; Ensari et al., 2022; Flyvbjerg, 2021). Ongoing programmes create opportunities to reduce costs by standardising designs, building planning and procurement expertise, and developing and retaining skilled project teams. Flyvbjerg (2021) describes how Madrid used this approach to build a major underground rail expansion at half the cost of similar projects:

> *[...] the tunnel boring teams began to compete against each other, accelerating speed further. They'd meet in Madrid's tapas bars at night and compare notes on daily progress, making sure their team was ahead, transferring learning in the process. And by having many machines and teams operating at once, Melis [the project director] could also systematically study which machines and teams performed best and hire those the next time around. More positive learning.*

Key finding: Some infrastructure projects, such as wind farms, 'learn' at a global level. This example shows the benefits of openness to innovation and the use of standard technology and designs. Other infrastructure projects, such as underground rail, 'learn' at a local level but not a global level. This highlights the benefits of building local experience and capability in delivering complex projects.

Physical context

A complex set of physical factors can affect the scope or design of infrastructure projects, including:

- Geology – factors like ground conditions, terrain, and seismic risk affect the cost to build many types of infrastructure projects, for instance by requiring costlier foundation works
- Climate – factors like weather-related risks, service standards, and the need to design for different climates
- Built environment – factors like interactions with existing infrastructure networks and the need to design around other land uses or mitigate impacts on archaeology or heritage
- Remoteness – projects in remote locations may need to spend more to transport labour and materials to the site.

These physical factors are typically outside the control of infrastructure providers – unless they choose not to build infrastructure in excessively challenging locations.[23] Addressing them can increase project scope or add design requirements. For instance, retaining walls may be needed to protect a hilly road from weather-related slips, adding cost without increasing the capacity of the road for moving people and goods.

Built environment, geology, and tunnelling costs

Figure 12 shows how physical context can affect the scope and cost of urban transport projects. If an at-grade corridor has been reserved in advance through corridor protection, urban rail projects can be built relatively cheaply. However, if an at-grade corridor is not available, then the project must be built in an elevated structure (increasing costs by a factor of 1.5 to 2.5) or in a tunnel (increasing costs by a factor of 2 to 10, depending on conditions).

If the tunnel is being built under an existing road with sufficient width, cut and cover methods can be used. Cut and cover is 2 to 3 times as expensive as at-grade construction in favourable geotechnical conditions, and 3 to 6 times as costly in difficult conditions. If cut and cover is not possible, or if it is seen as too disruptive, the tunnel must be bored.[24] Bored tunnels are 3 to 6 times as expensive as at-grade construction in favourable geotechnical conditions, and 6 to 10 times as costly in difficult conditions.

Geotechnical conditions can have large impacts on tunnelling costs. Tunnelling in difficult conditions can be as much as three times as expensive as tunnelling in favourable conditions.

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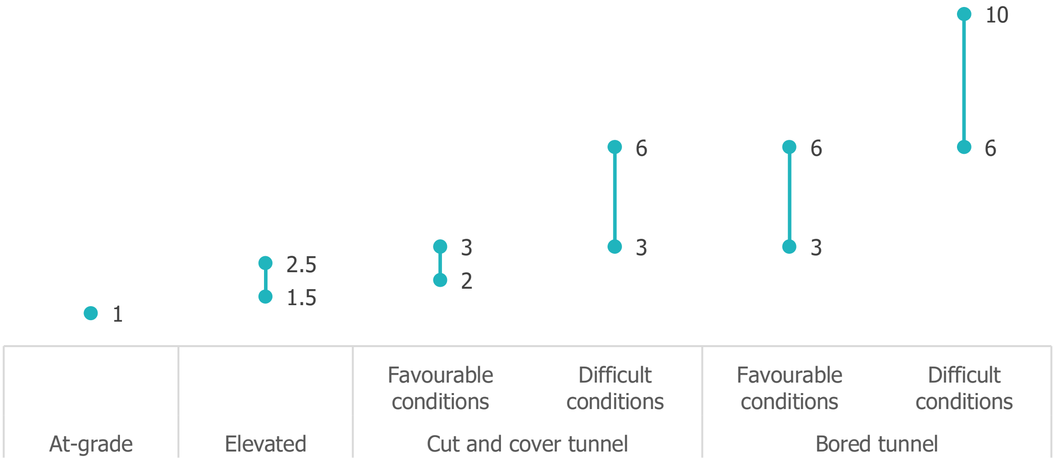
[23] If infrastructure providers consistently apply 'hurdle' criteria to projects, such as only funding projects that meet a minimum return on investment or benefit cost ratio threshold, we would expect them to avoid excessively difficult sites unless they delivered exceptionally high benefits.

[24] Alternative tunnelling methods, such as drill-and-blast or tunnel boring machines, vary in costs and are better suited for different types of projects and different ground conditions (Zare et al., 2016).

Figure 12: Relative cost of urban rail projects in different physical contexts



Source: Godard and Hugonnard (1989).

New Zealand has many geological challenges

Prebble (2001) observes that "New Zealand is well endowed with hazardous terrain." We are a seismically and volcanically active country due to our position on the Ring of Fire. Geological challenges include the Taupo Volcanic Zone, weak rock in the Southern Alps and throughout the North Island, liquefaction-prone soils in coastal areas, and variable ground conditions throughout the Auckland Volcanic Field.

Geological challenges can raise the cost to build infrastructure. In Appendix 1, we show that the cost to build underground rail is systematically higher in other cities that are on the Ring of Fire.[25] This reflects more challenging ground conditions and increased seismic requirements.

Tunnelling in Auckland can be complex due to the heterogeneity of the underlying rocks (Boyd & Macklin, 2017). Although the City Rail Link was only three kilometres long, it traversed several different geological formations, including younger sedimentary rocks (Tauranga Group) and reclaimed land at the north end of the route, East Coast Bays Formation rocks through the middle of the route, and volcanic materials from the Auckland Volcanic Field at the south end of the route (Kirk et al., 2021). Varying ground conditions required two different tunnelling methods to be used along the route, which increased construction costs.

Key finding: The physical context for infrastructure projects can have a significant impact on project costs. One issue is that the availability of at-grade infrastructure corridors in urban areas has a large impact on project costs. Another issue is that New Zealand's geology is likely to increase infrastructure delivery costs in some locations.

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[25] See Model 3 in Table 4. The difference between the coefficients for Ring of Fire cities (-0.951) and non-Ring of Fire cities (-1.550) indicates that underground rail project costs are around 82% higher, on average, in Ring of Fire cities [estimated as exp(1.550-0.951)-1].

Policy and institutions

Infrastructure delivery costs can be influenced by a complex set of policy and institutional factors. Chitti et al (2022) observe that costs can rise and fall "by constraints and scope changes that appear to be minimal to observers but have a dramatic effect on costs".

Relevant policy and institutional factors include, but are not necessarily limited to:

- Project sponsor decision-making processes
- Infrastructure design standards
- Planning and consenting requirements for environmental or community mitigation
- Health and safety requirements
- Procurement and contract models.

These factors change over time, meaning that projects' scope and design can change as well.

Over-engineering is in the eye of the beholder

When policy and institutional factors increase infrastructure project costs, it is often because they have added scope or design requirements. It is often difficult to determine whether added scope has increased the value of the project, or simply over-engineered it.

This is because large infrastructure projects often have a complex mix of positive and negative impacts. They may provide regional or national benefits while having large, localised costs. There is usually a need to mitigate localised costs, but if this is done in a poorly coordinated way, it can create opportunities for well-organised or influential groups to delay the project or secure benefits for themselves at the expense of the project's funders (Donahue, 2022; Pritchett, 2000).

Over-engineering of infrastructure projects appears to be more common in countries with planning and consenting processes that are adversarial in nature and make it easy to oppose projects (Axelrad & Kagan, 2000; Brooks & Liscow, 2019; Goldwyn et al., 2020) and in contexts where there are few checks and balances on investment decisions or influential actors that can oppose over-building (Crescenzi et al., 2016; Henisz & Zelner, 2006; International Monetary Fund, 2015).

There is no simple test to determine whether costs related to additional project scope represent added value or over-engineering. Economists have traditionally suggested using social cost benefit analysis to evaluate the costs and benefits of scope choices (Glaeser & Poterba, 2021), but this recommendation is rarely adopted in practice.

European Union cohesion funds: A case of over-engineering?

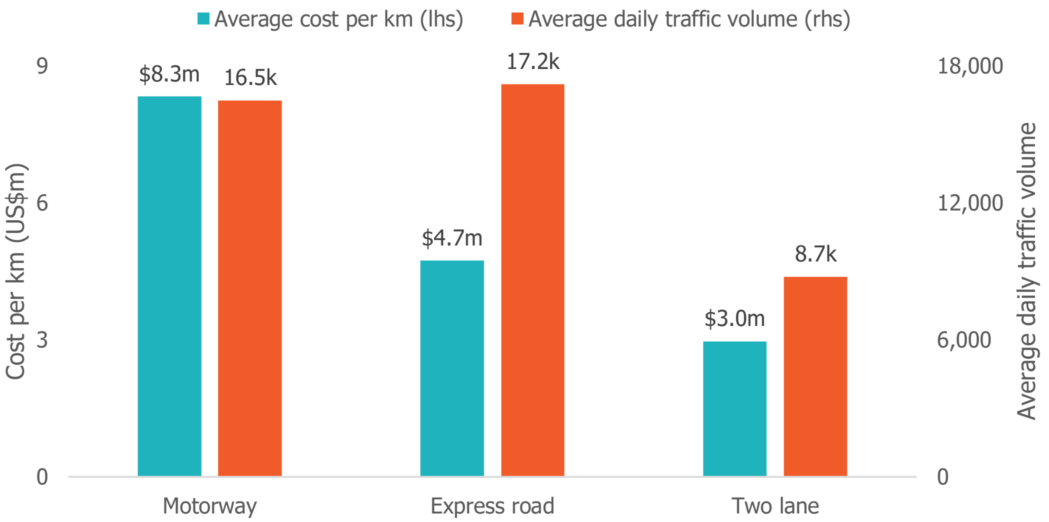
The European Union allocates 'cohesion funds' to build infrastructure in regions with below-average incomes. The European Court of Auditors (2013) reviewed 24 road projects that were built using cohesion funds to understand how well these funds were invested.

Member states have choices about what to build using cohesion funds. They can choose 'basic' projects, such as new two-lane roads in rural areas or four-lane, divided express roads with a design speed of 110km/hr, or higher-quality projects, such as four-lane motorways with higher design speeds and higher traffic capacity.

The higher capacity offered by motorways comes at a cost, as they require new, wider road alignments. Figure 13 shows that motorway projects were typically 76% more expensive than express roads. However, higher costs were not justified by higher traffic volumes – on average, express roads and motorways carried similar volumes of traffic.

Spending more to build motorways might be justified if they offer other benefits, for instance if faster travel speeds enabled faster regional economic growth. However, there is little evidence of wider benefits. Crescenzi, Cataldo, and Rodriguez-Pose (2016) show that motorway investment has failed to improve regional economic performance in Europe.[26] This suggests that some countries may have used cohesion funds to inefficiently over-build their road networks.

Figure 13: The cost of and traffic volumes on European Union cohesion fund roads



Source: Te Waihanga analysis of data from European Court of Auditors (2013). Currency converted to USD using purchasing power parity exchange rates.

American highways: The role of changing community expectations

Brooks and Liscow (2019) show how changing demands for environmental and community mitigation can affect the scope and cost of infrastructure projects.

Panel A in Figure 14 shows that highway construction costs rose faster than construction labour and material costs between the 1960s and 1990s. This divergence appears to have started in the mid-1960s (indicated with the black arrow). Rising highway construction costs cannot be explained by the need to build in more challenging locations.

Brooks and Liscow link rising project costs to changing environmental and community mitigation requirements.[27] Panel B in Figure 14 shows that regulation of transport infrastructure projects started change rapidly in the mid-1960s (indicated with the black arrow). Between 1965 and 2001, an average of 1.4 new environmental laws and executive orders were enacted every year. These new requirements resulted in changes to project scope to mitigate negative impacts, such as noise barriers, overbridges to reduce community severance, putting highways in tunnels or trenches, and deviating routes to avoid sensitive areas.

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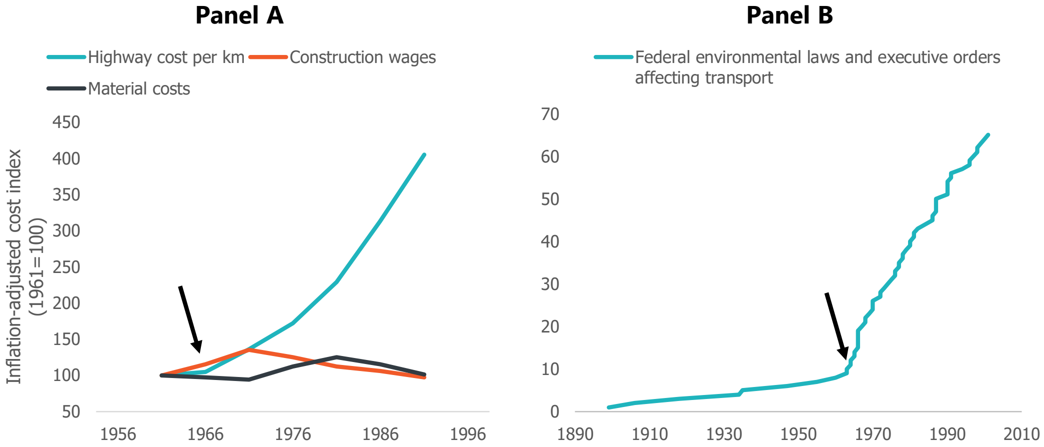
[26] However, investment in other types of roads only improves economic performance in areas with good institutions.

[27] Specifically, they show that highway construction costs increased faster in places with rising incomes and house prices, which tend to increase demand for mitigation measures, and in places and time periods where regulation of infrastructure projects was increasing.

Added mitigation costs are not necessarily an example of inefficient or excessive scope. Early US interstate highway construction often resulted in large-scale urban displacement and community severance (Brinkman & Lin, 2019). There are benefits from reducing the negative impact of highways on nearby communities and on the natural environment, as well as costs.

However, a constantly changing regulatory environment causes challenges for infrastructure project delivery. It can take several years to plan and design a major transport project. During that time, regulations and design requirements may have changed, potentially resulting in added costs and delays to redesign the project around new requirements. This can also make it difficult to repeat standard designs and learn how to build them more productively.

Figure 14: Interstate highway spending per kilometre relative to input costs in the United States



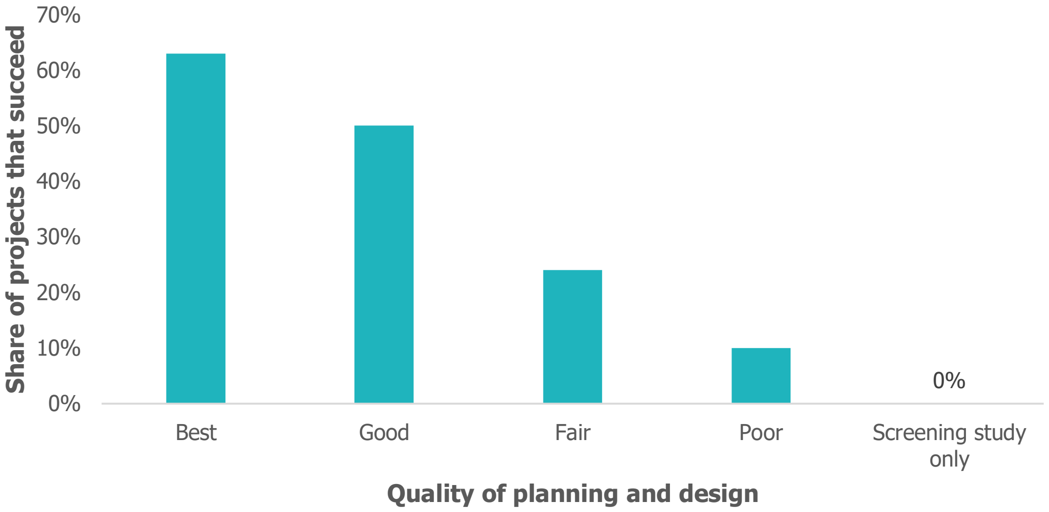
Source: Brooks and Liscow (2019); New York State Department of Transport (2012).

Know what you're building before you commit to building it

To build infrastructure at a reasonable cost, project sponsors need to understand what they are building and the consequences of their scope and design decisions. Premature commitments to projects tend to lead to solutions that are more expensive than they need to be. For instance, the Grattan Institute finds that 79% of cost overruns on major infrastructure projects in Australia occur in the 35% of projects that were announced before completion of a business case (Terrill et al., 2021).

Good planning and design processes take time at the start of the project, but they save time and money later on. Figure 15 shows that projects with better planning and design were significantly more likely to succeed than projects that were built without good processes. Appropriate in-house capability is necessary to achieve this (Chitti et al., 2022; Merrow, 2011).

Figure 15: High-quality planning and design increases project success



Source: Adapted from Figure 10.10 in Merrow (2011). Projects were considered to succeed if they had cost and schedule overruns of no more than 25%, if they were no more than 25% more expensive than similar projects, if they took no more than 50% longer to build than similar projects, and if they did not experience significant reductions in production after their first year.

Procurement methods are no substitute for client capability. Infrastructure project sponsors, rather than their contractors, are ultimately responsible for the scope and design of projects. While it is common to transfer scope and design risk to contractors through fixed-price contracts, this can have unintended consequences (Makovšek & Bridge, 2021). As Merrow (2011) observes, "no sponsor has ever paid *less* than the value of a lump-sum contract, but many, many a sponsor has paid much more."

Bajari et al (2014) illustrate this point in an analysis of contract prices for small road projects in California. They find that bid costs were systematically higher for contracts that subsequently experienced scope variations. Contractors marked up their bids in anticipation of future disruption and cost to renegotiate these contracts. As a result, the client paid twice for poor scoping – first, when contractors marked up their bids to reflect uncertainty, and second, when the ultimately paid out for contract variations.

Key finding: Policy and institutional factors can add scope and thus cost to projects. It can be difficult to determine whether added scope has increased the value of the project or whether it reflects unnecessary over-engineering. To guard against excessive cost, project sponsors need to understand what they are building and the consequences of their scope and design decisions.

Conclusion

This *Research Insights* piece examines the cost to deliver infrastructure in New Zealand. It addresses two main research questions, drawing upon local and international data for various types of infrastructure projects:

1. **Where do we stand:** How does the cost to deliver infrastructure in New Zealand compare with costs in other high-income countries?
2. **Why do costs differ:** What factors could potentially cause infrastructure delivery costs to be higher in some places than others?

Our analysis highlights opportunities to improve the efficiency and cost performance of the New Zealand infrastructure sector. It reinforces analysis in *Rautaki Hanganga o Aotearoa, the New Zealand Infrastructure Strategy 2022-2052*, that finds that attempting to build our way out of our challenges without tackling costs is unlikely to be financially sustainable.

Our key findings

A nuanced picture of cost performance

New Zealand does not appear to have high infrastructure construction costs across the board. Rather, we have high costs for some types of projects, but not all, relative to some other high-income countries. We find that:

- New Zealand has statistically significant cost premiums for motorways, road tunnels, and underground rail projects
- New Zealand has similar costs for surface rail stations, electricity transmission lines, onshore wind farms, and hospitals.

These comparisons, as well as other examples like the Christchurch Stadium, suggest that New Zealand's cost premium for infrastructure performance primarily relates to complex, large-scale infrastructure projects rather than smaller or more standardised infrastructure projects.

Many factors can drive cost differences

There are four broad reasons why the cost of similar infrastructure projects might vary between locations:

- First, input costs – labour, materials, equipment, and land – might be higher in some places.
- Second, construction productivity may be higher in some places, allowing them to build more infrastructure using the same quantity of inputs.
- Third, differences in physical context – factors like geology, climate, and built environment – can increase the cost to build infrastructure in some places.
- Fourth, policy and institutions – factors like project sponsor decision-making, infrastructure design standards, planning and consenting systems, and procurement and contract models – can increase scope requirements and thus increase costs.

Our construction input costs are generally in line with other high-income countries

We compare New Zealand's construction input costs to costs in ten other high-income countries. We face lower construction wages but higher costs for equipment, bare land, and some infrastructure construction materials, especially concrete. Our overall input costs for vertical construction are similar to other high-income countries.

Land prices can significantly increase the cost to build infrastructure in urban or suburban locations with valuable land. Based on current New Zealand land values, buying land in a rural location may account for around 5% of project cost, while buying a similar amount of land in a suburban or urban context could account for half of the project cost.

Our construction productivity is similar to other high-income countries

New Zealand’s productivity levels for vertical construction appear to be similar to the average high-income country. New Zealand’s overall construction productivity is growing at a similar rate to the average OECD country and may be catching up with some comparator countries.

However, different types of infrastructure projects experience different productivity trends:

- Renewable electricity generation projects such as wind farms have experienced steady cost reductions in recent decades. These projects ‘learn’ at a global level. Wind turbine technology is improving due to investments in research and development and economies of scale in turbine manufacturing, and these improvements diffuse rapidly to New Zealand.
- Complex horizontal infrastructure projects such as rail tunnels do not appear to get cheaper over time, at least not at the global level. However, these projects can ‘learn’ at a local level as cities and countries gain experience in planning, designing, and building them. There are benefits from building local experience and capability in delivering complex projects.

New Zealand’s geology creates challenges for infrastructure projects

The physical context for infrastructure projects can have a significant impact on project costs.

In urban areas, the availability of at-grade infrastructure corridors has a large impact on project costs. If corridors are not available, transport infrastructure must be put in tunnels, increasing costs by a factor of two to ten. At present, we rarely protect infrastructure corridors well in advance of growth, meaning that this is likely to pose ongoing challenges for infrastructure costs.

When we have to build infrastructure in tunnels, geotechnical conditions can have large impacts on project costs. Tunnelling in difficult conditions can be as much as three times as expensive as tunnelling in favourable conditions.

New Zealand’s geology is likely to increase infrastructure delivery costs. We are a seismically and volcanically active country due to our position on the Ring of Fire, with a range of natural hazards and challenging ground conditions. Further work is needed to quantify the degree to which our geological challenges raise infrastructure costs relative to other high-income countries.

Policy choices and institutional factors can drive costs up

When policy and institutional factors increase infrastructure project costs, it is often because they have added scope or design requirements. Large infrastructure projects often have a complex mix of positive and negative impacts. It can be difficult to determine whether added scope has increased the value of the project, or simply ‘over-engineered’ it.

In general, over-engineering is more common when infrastructure planning and decision-making processes create opportunities for well-organised or influential groups to delay projects or secure benefits for themselves at the expense of the project's funders.

International examples highlight some straightforward cases of over-engineering, such as road projects funded by the European Union that are over-built relative to traffic volumes, and some cases that are more complex, such as increases in US highway construction costs that are linked to better community and environmental mitigation efforts.

To build infrastructure at a reasonable cost, project sponsors need to understand what they are building and the consequences of their scope and design decisions. While good planning and design processes take time, they improve project success and affordability.

We can lift our game

International cost benchmarking can help us to identify where we have opportunities to improve the affordability of infrastructure delivery. International evidence and best practice guidance also highlights some things that we can do to lift our game (Aevaz et al., 2021; Goldwyn et al., 2022; HM Treasury & Infrastructure UK, 2010; Productivity Commission, 2014).

First, to deliver good infrastructure at an affordable cost, the New Zealand government needs to act as a **sophisticated client of infrastructure** (*Infrastructure Strategy* Recommendation 38). This means taking the time to understand what we are building before we set out to build it, establishing good processes and principles for making decisions about project scope and design, and investing in the right capability to plan, procure, and manage infrastructure.

Second, **strengthening independent advice for infrastructure prioritisation** (*Infrastructure Strategy* Recommendation 40) and **establishing a pipeline of future investment** (Recommendation 64) can help to lift productivity and reduce costs. Our analysis of underground rail project costs shows that cities and countries can drive down costs by learning and repeating projects. These measures can help to achieve that.

Third, **openness to new technologies and methods** (*Infrastructure Strategy* Recommendation 61) also lifts productivity and reduces costs. New Zealand's success in delivering wind farms at a similar cost to other high-income countries and ability to rapidly benefit from global improvements to wind turbine design highlights the value of adopting new technology.

Fourth, **efficient planning and consenting systems** (*Infrastructure Strategy* Recommendations 57-60) can make it easier to develop cost-effective infrastructure solutions and avoid costs arising from delays or scope uncertainty.

Fifth, **ongoing infrastructure delivery cost benchmarking** (*Infrastructure Strategy* Recommendation 46) can help us to improve. Knowing what projects *should* cost to build and maintain, based on both local and international data, can guide us towards better infrastructure decisions. It can help us to ask the right questions about projects: When they are more expensive than average, is it because project sponsors have chosen an unusually challenging site? Or have they chosen an unusually costly design? Are there opportunities to reduce cost by making different choices? Sometimes, we have no choice but to build an expensive piece of infrastructure – but if we have robustly tested that choice, we can be confident that we are addressing our infrastructure challenges as affordably as possible.

Appendix 1: Underground rail construction costs

Description of data

Our analysis of international underground rail project costs is based on data compiled and published by the NYU Marron Institute's *Transit Costs Project* (Goldwyn et al., 2022). We use Version 1.4 of this dataset, which includes roughly 900 rail projects completed, underway, or in planning in 187 cities in 59 countries.

This dataset includes all construction and construction-related expenditures, excluding rolling stock purchases and sales taxes. Costs are converted to US dollars using purchasing power parity exchange rates for the midpoint year of the project, and then adjusted to 2021 USD using US implicit price deflators published by the World Bank.[28] The dataset also includes some information on project characteristics, such as start and end year of construction, project length, number of stations, and length tunnelled, elevated, or at grade.

We cleaned the data to exclude projects that were less than 80% tunnelled, exclude projects with no stations, and exclude projects with starting dates before 1980 or after 2021. This resulted in a final comparative dataset with 360 completed or underway projects in 111 cities in 46 countries. There was only one New Zealand project in the dataset (Auckland's City Rail Link).

To enrich the analysis, we also join up data from several other sources, including World Bank data on GDP per capita (at a country level), UN-Habitat data on urban agglomeration population, and the Institute for Transportation and Development Policy's Rapid Transit database, which provides information on the length of cities' metro rail, light rail, and busway networks over time.[29]

Summary statistics

Table 3 summarises average costs per kilometre for underground rail projects in New Zealand and different country groupings. These costs include all project elements, including tunnelling, stations, tracks, and signalling, but exclude rolling stock costs. Some key findings from these comparisons:

- North America has higher average rail tunnel costs than Asia and Europe
- Average costs are slightly higher in OECD countries than non-OECD countries
- Average costs are higher in Ring of Fire locations (ie Pacific Rim countries/cities like New Zealand that sit on tectonic plate boundaries) than non-Ring of Fire locations
- New Zealand's one in-progress rail tunnel project is higher than averages for all country groupings except North America.

Figure 16, Figure 17, and Figure 18 show the distribution of costs in different country groupings (regions of the world, OECD/non-OECD countries, and Ring of Fire / non-Ring of Fire countries, respectively) using box and whisker plots. These provide a simple visual indication of overlaps and differences between the distribution of unit cost in different countries and country groupings.

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[28] https://data.worldbank.org/indicator/PA.NUS.PPP
https://data.worldbank.org/indicator/NY.GDP.DEFL.ZS

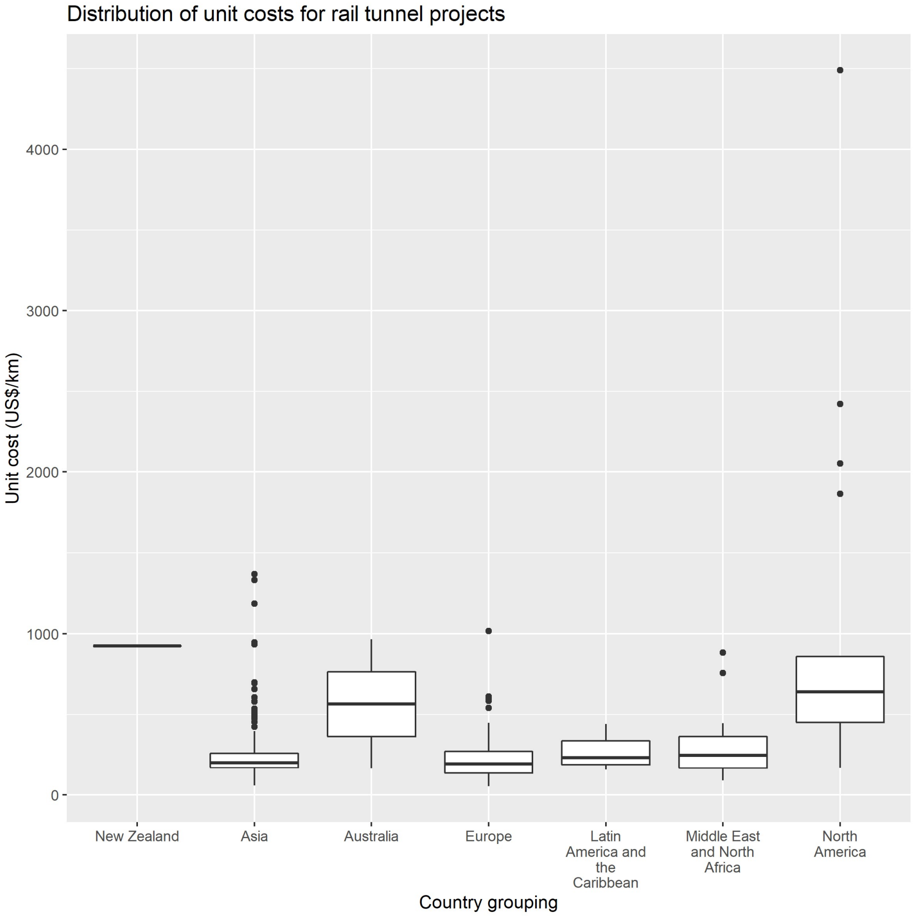
[29] https://data.worldbank.org/indicator/NY.GDP.PCAP.KD
https://population.un.org/wup/Download/
https://www.itdp.org/rapid-transit-database/

Table 3: Average unit costs (US$/km) for underground rail projects in different countries

Region	Mean	Std dev	Min	p25	Median	p75	Max	Count
New Zealand	922.4				922.4			1
Australia	563.9	567.0	162.9		563.9		964.8	2
Asia	248.2	179.2	56.8	167.8	200.7	259.8	1370.1	223
Europe	234.1	165.9	51.5	134.8	194.2	271.0	1015.8	76
Latin America and the Caribbean	262.8	98.5	155.6	188.3	232.3	335.8	441.8	9
Middle East and North Africa	287.8	178.8	89.0	166.2	246.0	364.1	881.2	32
North America	1040.3	1101.8	166.5	450.0	639.2	857.1	4491.3	17
OECD	311.6	463.4	51.5	125.4	186.5	331.4	4491.3	154
Non-OECD	268.1	184.3	55.7	183.3	210.8	271.3	1370.1	203
Ring of Fire	447.9	180.6	155.6	328.0	428.2	579.7	857.1	24
Non-Ring of Fire	275.2	340.4	51.5	157.3	201.0	268.3	4491.3	333

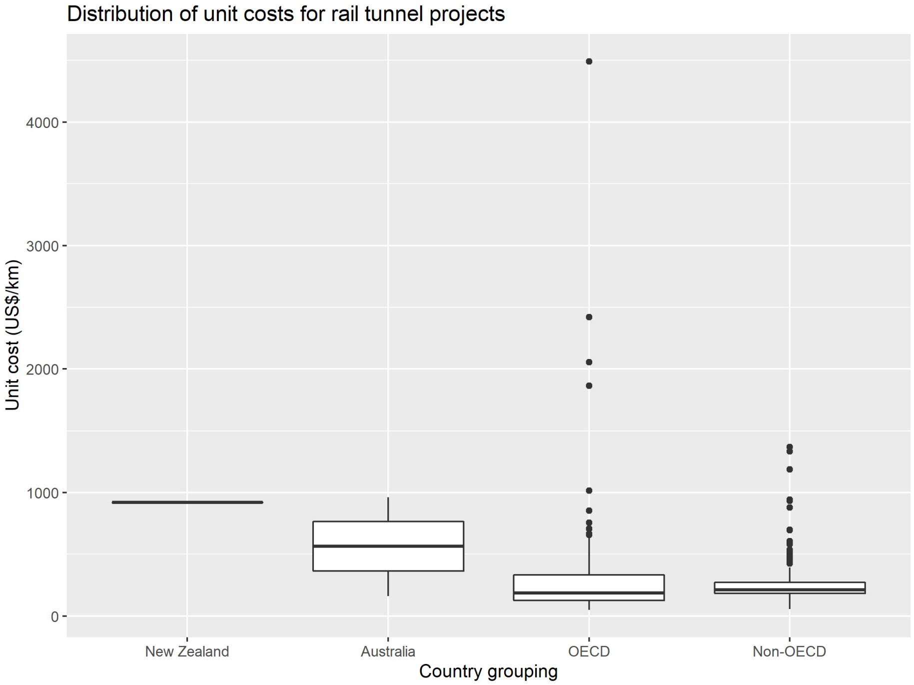
Source: Te Waihanga analysis of data from Goldwyn et al (2022). New Zealand and Australia are excluded from other categories.

Figure 16: Distribution of underground rail costs per kilometre, by region (USD, 2021)



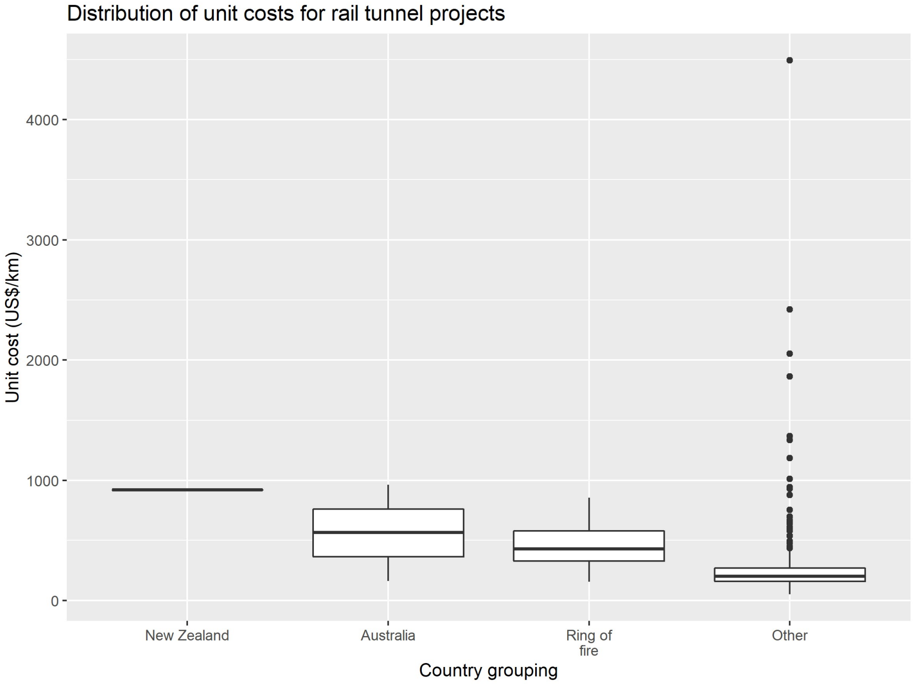
Note: Box and whisker plots visually display how data is distributed. The grey-shaded box shows the 25th percentile value (lower end of box), 50th percentile/median value (black line in middle of box), and 75th percentile value (top end of box). Whiskers show the minimum and maximum values, *excluding any outliers. Dots above and below the ends of the whiskers show outlier values. Outliers are defined as outside 1.5 times the interquartile range (size of the grey-shaded box) above the upper quartile and below the lower quartile.*

Figure 17: Distribution of underground rail costs per kilometre, by OECD status (USD, 2021)



Note: Box and whisker plots visually display how data is distributed.

Figure 18: Distribution of underground rail costs per kilometre, by Ring of Fire status (USD, 2021)



Note: Box and whisker plots visually display how data is distributed.

Statistical tests

We now examine whether differences in average costs are statistically significant. Because New Zealand only has one project in the dataset, the non-parametric tests used by Oxford Global Projects (2022) cannot be used. We therefore use ordinary least squares regression (OLS) to test the statistical significance of differences between New Zealand and other country groupings, controlling for basic project characteristics, including route length, station density (stations per kilometre), and project duration (years between start and end of construction), and background trends in rail construction costs (using year fixed effects).

Table 4 summarises this analysis. We find statistically significant differences (at the 1% significance level) between New Zealand and the following country groupings: Asia, Europe, other OECD countries in general, and other locations in the Ring of Fire. Cost differences with Australia and North America are not statistically significant.

Table 4: Testing statistical significance of cost differences between New Zealand and other countries

	Model 1	**Model 2**	**Model 3**
Outcome variable	**Unit cost (natural log, US$/km)**	**Unit cost (natural log, US$/km)**	**Unit cost (natural log, US$/km)**
Control variables			
Project length (natural log, km)	-0.001 (0.042)	-0.161*** (0.041)	-0.017 (0.034)
Station density (natural log, stations/km)	0.068 (0.076)	-0.010 (0.086)	0.012 (0.091)
Project duration (natural log, years)	0.173* (0.094)	0.505*** (0.11)	0.223** (0.101)
Country group variables (base level: New Zealand)			
Australia	-0.896 (0.598)	-0.624 (0.569)	-0.960 (0.596)
Asia	-1.502*** (0.180)		
Europe	-1.685*** (0.162)		
Latin America and the Caribbean	-1.371*** (0.188)		
Middle East and North Africa	-1.425*** (0.161)		
North America	-0.299 (0.216)		
OECD countries		-1.442*** (0.144)	
Non-OECD countries		-0.923*** (0.182)	
Ring of Fire countries			-0.951*** (0.161)
Non-Ring of Fire Countries			-1.550*** (0.158)
Year fixed effects	Yes	Yes	Yes
Number of observations	360	360	360
R2	0.326	0.239	0.211

*Source: Te Waihanga analysis of data from Goldwyn et al (2022). Heteroskedasticity-robust standard errors. Statistical significance indicators: *p<0.1; **p<0.05; ***p<0.01.*

Learning rates

We now examine learning rates in underground rail projects. In construction, multifactor productivity growth in mainly relies upon standardisation of designs and components and 'learning by doing', which occurs when firms and workers repeat similar tasks or projects and work out how to do those tasks more efficiently over time. Case studies of cost-effective rail tunnel delivery in cities like Madrid and Istanbul suggest that these mechanisms are also important for rail tunnels (Aevaz et al., 2021; Ensari et al., 2022).

We use the Transit Costs Project dataset, plus data on the length of cities' metro rail, light rail, and busway networks over time from the Institute for Transportation and Development Policy, to estimate learning rates for underground rail projects in OECD countries. Our estimates reflect the degree to which rail tunnel construction gets cheaper – or more expensive – as people gain experience in building them at either a global or local level.[30]

Table 5 summarises the results of our analysis, which employs ordinary least squares regression and builds upon the regression models presented in Table 4. All models include:

- Controls for project characteristics (route length, station density, and project duration)
- Controls for country-level GDP per capita, which may affect construction wages and potentially other input costs, and urban area population, which may be correlated with project complexity as larger cities tend to be denser and thus more expensive to build in.
- City fixed effects to control for time-invariant factors that affect project cost, such as geology, archaeological heritage, and planning legislation.

The six models in the table include different combinations of global and local experience variables. Model 1 is our preferred model as it optimises the tradeoff between model fit and model complexity (as measured by Akaike's Information Criterion). It includes variables for global experience and city-level experience in building metro rail systems, excluding projects happening in cities without previous experience of building metro rail projects. We find that:

- There is no evidence that underground rail projects 'learn' at a global level. On average, global rail tunnel costs have risen as the length of total installed capacity increases.
- Underground rail projects *do* 'learn' at a local level. Cities that build more rail tunnels tend to experience smaller cost reductions than cities that build less. Local 'learning' can offset global trends towards increasing costs.

Other models in the table act as sensitivity tests. Model 2 includes both city-level and country-level experience. Model 3 replaces the global experience variable with year fixed effects. Model 4 uses a slightly different measure of experience – total rapid transit system length (metro rail, light rail, and busway kilometres) – instead. Model 5 adjusts the city-level experience variable to include projects happening in cities without previous experience of building metro rail.[31] Model 6 drops variables related to project characteristics (length, station density, and project duration) as these could in principle be optimized with experience.

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[30] We test whether Wright's law, which posits that costs decrease as a power law of cumulative production, holds true by regressing the natural log of unit costs on the natural log of cumulative installed capacity (Nagy et al., 2013).

[31] Specifically, we add a small constant (0.001km) to cities' metro rail network length before log-transforming this variable and include an indicator variable for cities with no existing metro rail network. This avoids dropping 19 project observations from the regression model.

Table 5: Global and local learning rates for underground rail projects

	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
Outcome variable	**Unit cost (natural log, US$/km)**	**Unit cost (natural log, US$/km)**	**Unit cost (natural log, US$/km)**	**Unit cost (natural log, US$/km)**	**Unit cost (natural log, US$/km)**	**Unit cost (natural log, US$/km)**
Control variables						
Project length (natural log, km)	-0.033 (0.046)	-0.034 (0.047)	-0.056 (0.048)	-0.027 (0.047)	-0.050 (0.048)	
Station density (natural log, stations/km)	-0.050 (0.08)	-0.051 (0.080)	-0.107 (0.079)	-0.044 (0.081)	-0.022 (0.083)	
Project duration (natural log, years)	0.344*** (0.08)	0.347*** (0.082)	0.281*** (0.091)	0.348*** (0.081)	0.395*** (0.083)	
GDP per capita (natural log, constant price PPP)	-0.456 (0.446)	-0.468 (0.451)	-1.251** (0.561)	-0.697 (0.430)	-0.370 (0.377)	-0.851* (0.486)
Urban area population (natural log)	-0.018 (0.070)	-0.021 (0.071)	0.006 (0.043)	-0.032 (0.072)	-0.018 (0.072)	-0.005 (0.097)
Global experience variables						
Global length of metro rail systems (natural log)	0.723*** (0.184)	0.720*** (0.183)			0.689*** (0.164)	0.837*** (0.194)
Global length of urban rapid transit systems (natural log)				0.684*** (0.170)		
Local experience variables						
City length of metro rail systems (natural log)	-0.325*** (0.112)	-0.378* (0.225)	-0.260* (0.153)		-0.322*** (0.111)	-0.376*** (0.126)
City length of urban rapid transit systems (natural log)				-0.288* (0.148)		
Country length of metro rail systems (natural log)		0.056 (0.173)				
City fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects			Yes			
Number of observations	135	135	135	142	154	135
R2	0.894	0.894	0.924	0.897	0.893	0.872

*Source: Te Waihanga analysis of data from Goldwyn et al (2022). Heteroskedasticity-robust standard errors. Statistical significance indicators: *p<0.1; **p<0.05; ***p<0.01.*

Appendix 2: Validating our infrastructure cost benchmarks

We draw upon other benchmarking studies to validate the international cost comparisons reported here – in effect, benchmarking our benchmarking. Other studies generally support Oxford Global Projects' (2022) findings.

Urban and rural motorways

In Australia, BITRE (2018) finds that the average cost to build urban motorways (class 6 roads) in Australia is A$6.8m/lane-kilometre, including property acquisition costs. This is similar to Oxford Global Project's median costs of US$6.2m/lane-km for urban motorways and US$65.m/lane-km for rural motorways in Australia.

In Europe, UNECE's Group of Experts on Transport Infrastructure Construction Costs (2022) finds that the average cost of motorway projects in nine European countries is US$2.2m/lane-km.[32] The highest-cost country was Sweden (average cost of US$4.0m/lane-km). It is unclear whether this is for urban or rural motorways. It is lower than the median cost of US$6.4m/lane-km for European urban motorways in the Oxford data but similar to the median cost of US$2.3m/lane-km for European rural motorways.

In the United States, the Washington State Department of Transport (2002) surveyed motorway construction costs in 25 US states, finding an average cost of US$1.5m/lane-km (in 2003 USD; converted from cost per lane-mile by dividing by 1.6) for both urban and rural motorways. The three highest-cost states had costs on the order of US$3m-5.3m/lane-km. Updated for inflation, these figures are similar to Oxford Global Project's median costs of US$3.2m/lane-km for urban motorways and US$2.8m/lane-km for rural motorways in North America.

Road tunnels

Efron and Read (2010) compare Australian tunnelling costs with costs in other countries, finding that average costs for completed transport tunnels tended to be higher in Australia and the Americas than in Europe. This is consistent with Oxford Global Projects' (2022) finding of higher road tunnel costs in Australia and New Zealand than in Europe. However, these comparisons were based on a limited number of cases and are not generally statistically significant. This study provides relative costs, but not absolute costs.

Underground rail

Rail tunnel costs have been analysed in previous studies by the Eno Center for Transportation (Aevaz et al., 2021) and the Transit Costs Project (Goldwyn et al., 2022). As we use data published by the Transit Costs Project, our findings about relative costs in different countries are similar.

Surface rail stations

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[32] Surveyed countries were Austria, Bulgaria, Croatia, Cyprus, Finland, Italy, Russian Federation, Sweden, and Turkey. The Oxford data is likely to be more consistent with western European countries (Austria, Sweden, Italy). Data is from country-level averages in Table XI.1 from Group of Experts on Transport Infrastructure Construction Costs (Group of Experts on Transport Infrastructure Construction Costs, 2022)

There have been few attempts to benchmark rapid transit stations as standalone products. Flyvbjerg, Bruzelius, and van Wee (2008) cite past data on rail station costs in the United States. In the 1980s, underground stations average US$40m in cost, elevated stations average US$23m, and at-grade stations average US$10m, all in 1985 US dollars. Adjusted for inflation, this equates to a cost of around US$27m for at-grade stations in 2021.

Goldwyn et al. (2022) compile data and case studies that suggest that underground rail station costs are now considerably higher in the United States than in European countries.

Transmission lines

In the United States, Black & Veatch (2012) estimate capital cost benchmarks for new transmission lines in western states. In normal terrain and conditions and excluding land costs, they estimate costs of US$0.9m/km for 2-circuit 230kV AC transmission lines and costs of US$1.9m/km for 2-circuit 500kV AC transmission lines. These equate to around US$3900/kV-km, which is slightly higher than the median cost of US$3430/kV-km cited by Oxford Global Projects (2022). However, Black & Veatch note that costs are higher in forested, hilly, or urban areas. In midwestern and southern states, MISO (2019) provides unit cost estimates that are roughly twice as high; however, they include land costs and assume a mix of easy and difficult terrain.

In Europe, which was not covered by the Oxford Global Projects (2022) dataset, ACER (2015) finds mean costs of EUR0.4m/km for 2-circuit 220-225kV AC transmission lines and mean costs of EUR1.1m/km for 2-circuit 380-400kV AC transmission lines. After currency conversions, these are comparable to North American transmission line costs.

The Commerce Commission's (2015) decision on amending Transpower's allowance and outputs for the North Island Grid Upgrade Project found that unit costs for two New Zealand transmission line projects were roughly comparable with costs for one recent Australian project.

Wind farms

The International Energy Agency and Nuclear Energy Agency (2020) provide data on electricity generation plant costs, including wind farm costs completed in 18 countries in 2020, excluding New Zealand. The mean unit cost for large wind farm projects was US$1.4m/MW, with a range of $0.9m-3.0m/MW. This cost range is similar to the international cost range in Oxford's data, albeit slightly lower. It is likely that lower costs in the IEA data reflect the fact that wind farm costs are reducing over time.

Hospitals

Turner & Townsend (2022) provide cost benchmarks for general hospital construction in 22 cities in 11 high-income countries. These indicate that New Zealand's costs are similar to, or slightly lower than, Australian costs (US$4600/m^2 compared with an average of US$5100/m^2). They are also similar to the average for the 9 European cities (US$4900/m^2), but lower than the average for 7 North American cities (US$8500/m^2). These costs are lower than the averages cited by Oxford, but the relativities are comparable.

A study of United States hospital costs cites figures of around US$6500/m^2 (Sharma et al., 2021), while an Italian study cites figures of around EUR1900/m^2, or around US$2900/m^2 (Sdino et al., 2021).

Appendix 3: Comparing construction input costs and productivity levels

This Appendix summarises our approach for comparing construction input costs and relative multifactor productivity levels for vertical construction.

We replicated Langston's (2013) methodology for calculating a purchasing power parity index for construction inputs and using this to compare vertical construction productivity in different cities.[33] The Australian Productivity Commission (2014) noted that this method is relevant for international construction price comparisons, and the Asian Infrastructure Investment Bank (2020) subsequently extended it for international comparisons of road and water project costs. We update Langston's original analysis of input costs and productivity for high-rise office construction as all the necessary source data is available from Turner & Townsend's (2022) *International Construction Market Survey*.

Langston's approach includes the following steps:

1. Identify a standard 'bundle' of material, labour, and equipment inputs used to construct a given type of project. Langston describes this as a 'basket of locally obtained commodities', or BLOC.
2. Estimate the cost of each input (eg the cost of a tonne of concrete or the cost of an hour of skilled labour) in each city or country
3. Multiply the cost of each input by the quantity included in the BLOC and average across all inputs to obtain an overall input cost index for each city or country
4. To obtain an estimate of relative construction productivity levels in each city or country, divide the total cost of the BLOC by the cost of one unit of output (for instance, one square metre of high-rise office construction). This is a multifactor productivity index as it considers all types of inputs to construction.

Langston's approach differs from conventional purchasing power parity exchange rates in some important ways. In particular, the composition of the BLOC is held constant across all cities / countries, even though people may choose different input mixes in response to relative price differences.[34] This could make it difficult to use this approach to compare between high- and low-income cities.

Calculating the cost of a BLOC

Table 6 summarises key inputs for calculating the cost of a BLOC for vertical construction. Langston (2013) identifies ten representative commodities that are used in high-rise building construction and uses Australian data to estimate their share of total input costs. The BLOC consists of five types of construction materials, four different types of construction labour, and one type of construction equipment.

Table 6 presents data on unit costs for each individual input for Auckland (in both NZD and USD), Melbourne, Sydney, and the highest- and lowest-cost high-income cities in the dataset.[35] It also calculates the cost of a single BLOC in Auckland, Melbourne, Sydney, and the lowest- and highest-cost cities.

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[33] Langston's approach in turn builds upon work by Best (2010).

[34] For instance, if concrete is expensive, people may respond by using more steel or wood in construction, and if labour is expensive, people may substitute equipment for labour.

[35] Turner & Townsend provide data in local currency units and USD, converted using market exchange rates.

Table 6: Calculating the cost of a BLOC for vertical construction

Input	Unit	BLOC quantity	Auckland (NZD)	Auckland (USD)	Melbourne (USD)	Sydney (USD)	All cities minimum (USD)	All cities maximum (USD)
Materials								
Concrete (30 Mpa,1500m3 job)	$/m3	45	$460	$319	$128	$195	$89	$319
Structural steel beams (100 tonne +job)	$/tonne	6.8	$4,900	$3,402	$1,874	$2,999	$1,874	$5,287
Glass pane (10mm, tempered)	$/m2	44	$313	$217	$187	$255	$103	$409
13 mm plasterboard	$/m2	1300	$13.0	$9.0	$7.5	$9.7	$4.6	$14.5
Softwood framing timber (100mm x 50mm)	$/m	2750	$5.5	$3.8	$4.8	$5.8	$3.5	$15.7
Labour								
Group 1 Tradesman e.g. plumber / electrician	$/hour	150	$85	$59	$98	$83	$29	$153
Group 2 Tradesman e.g. carpenter / bricklayer	$/hour	185	$70	$49	$88	$75	$21	$115
Group 3 Tradesman e.g. carpet layer / tiler / plasterer	$/hour	200	$70	$49	$83	$71	$26	$113
General labourer	$/hour	275	$55	$38	$68	$60	$22	$90
Equipment								
50t mobile crane and operator	$/day	5	$3,850	$2,673	$2,339	$2,999	$1,315	$4,943
Input cost index	**$/BLOC**		**$17,389**	**$12,065**	**$12,729**	**$14,092**	**$9,021**	**$19,962**

Source: Te Waihanga analysis of data from Langston (2013) and Turner & Townsend (2022).

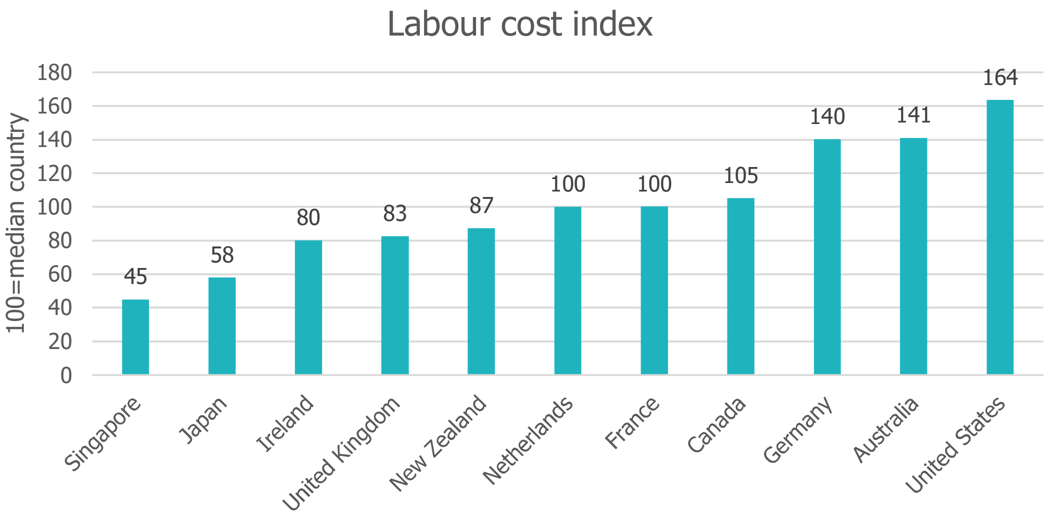
Input cost comparisons

We use this data to compare New Zealand's input costs with input costs in other high-income countries by taking the unweighted average across all cities in each country. These averages are more likely to be representative of conditions in large urban areas than the countries as a whole. Results of this analysis are summarised in Figure 7 in the body of the report.

Labour costs

Figure 19 presents a construction labour cost index that includes a mix of skilled construction trades and general construction labour. This data suggests that labour costs vary significantly between high-income countries. Labour costs in the highest-cost country (the United States) are roughly 3.5 times higher than labour costs in the lowest-cost country (Singapore).

Figure 19: Construction labour cost index in urban areas of 11 high-income countries

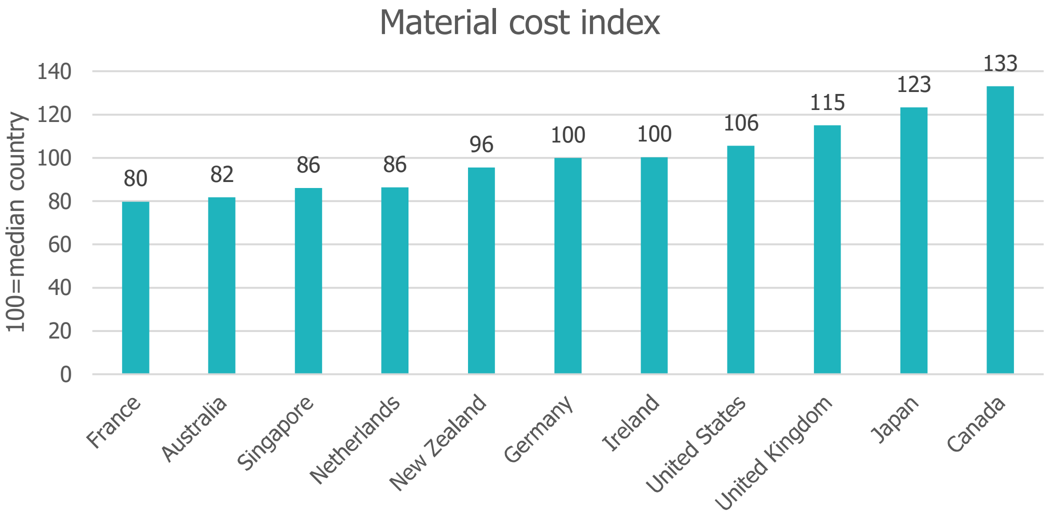


Source: Te Waihanga analysis of Turner and Townsend (2022) data.

Material costs

Figure 20 presents a construction material cost index that includes structural steel, concrete, timber, and 'finish' materials. Costs for construction materials vary less than labour costs. Material costs in the highest-cost country (Canada) are roughly two-thirds higher than material costs in the lowest-cost country (France).

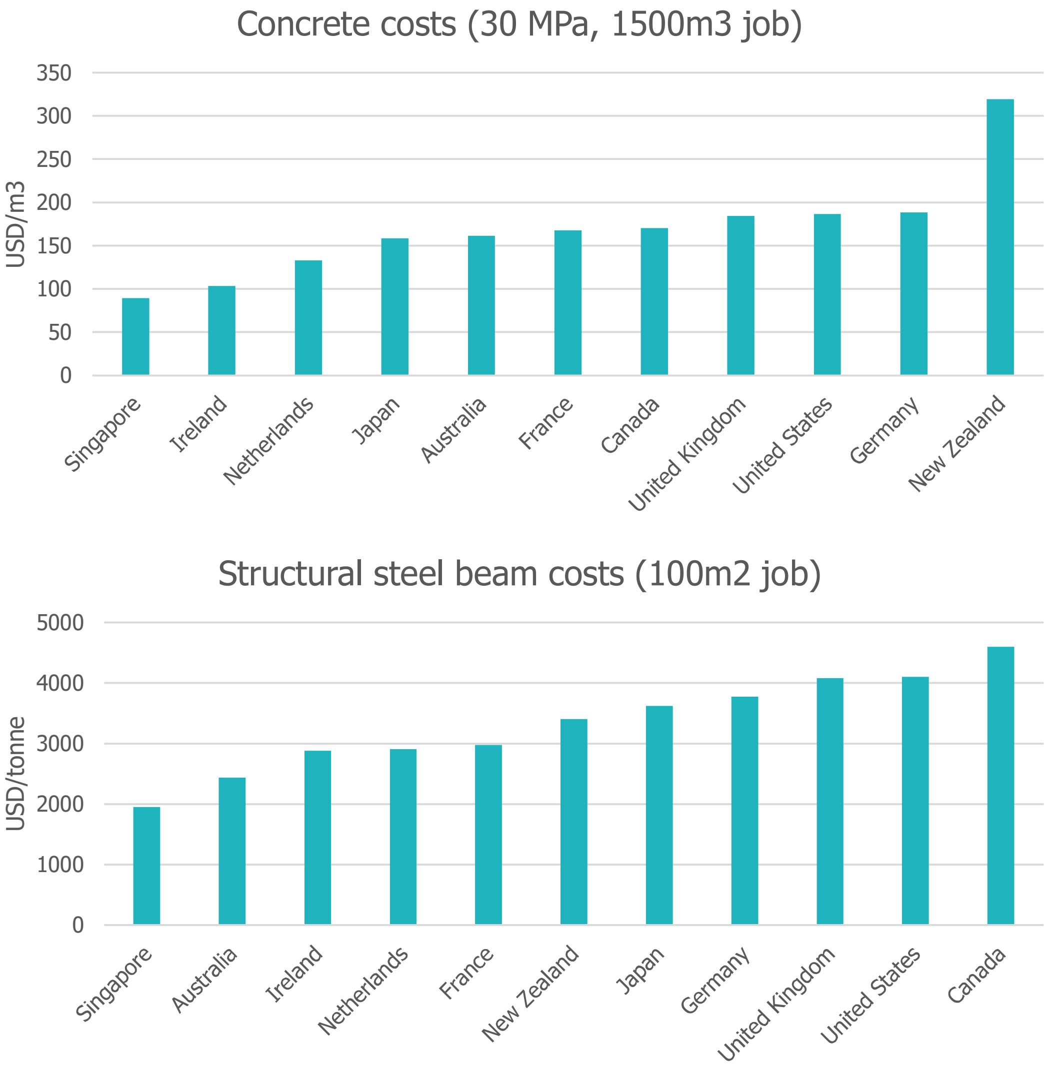
Figure 20: Construction material cost index in urban areas of 11 high-income countries



Source: Te Waihanga analysis of Turner and Townsend (2022) data.

New Zealand has high costs for some infrastructure materials but not others. Figure 21 shows that we have higher concrete costs than other high-income countries, but average costs for structural steel beams. Concrete is 50% cheaper in Australia and steel is almost 30% cheaper.

Figure 21: Concrete and steel costs in urban areas of 11 high-income countries

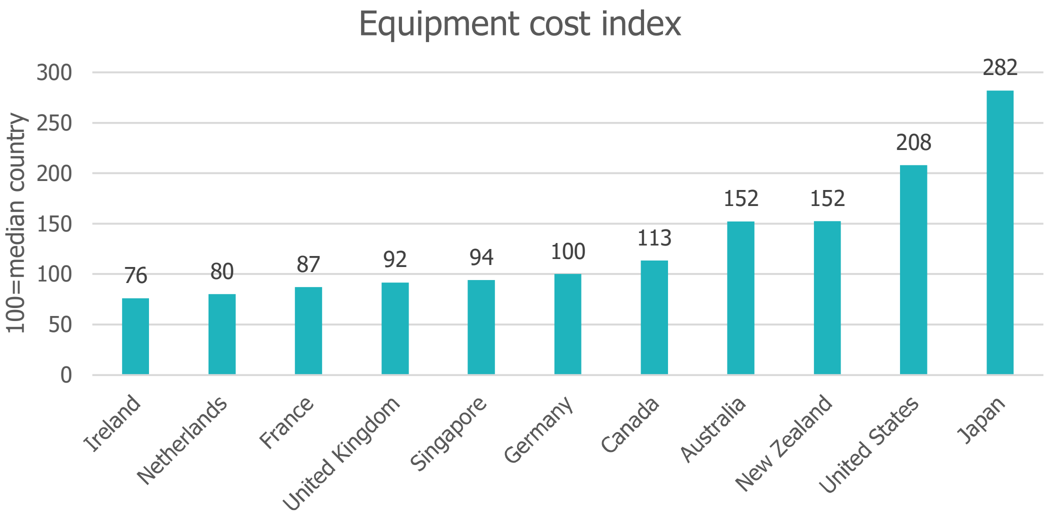


Source: Te Waihanga analysis of Turner and Townsend (2022) data.

Equipment costs

Figure 22 presents a construction equipment cost index that includes the cost to hire a crane and crane operator (the only type of construction equipment surveyed by Turner and Townsend). There are large variations in equipment costs. Equipment costs in the highest-cost country (Japan) are over 3.5 times higher than equipment costs in the lowest-cost country (Ireland).

Figure 22: Construction equipment cost index in urban areas of 11 high-income countries

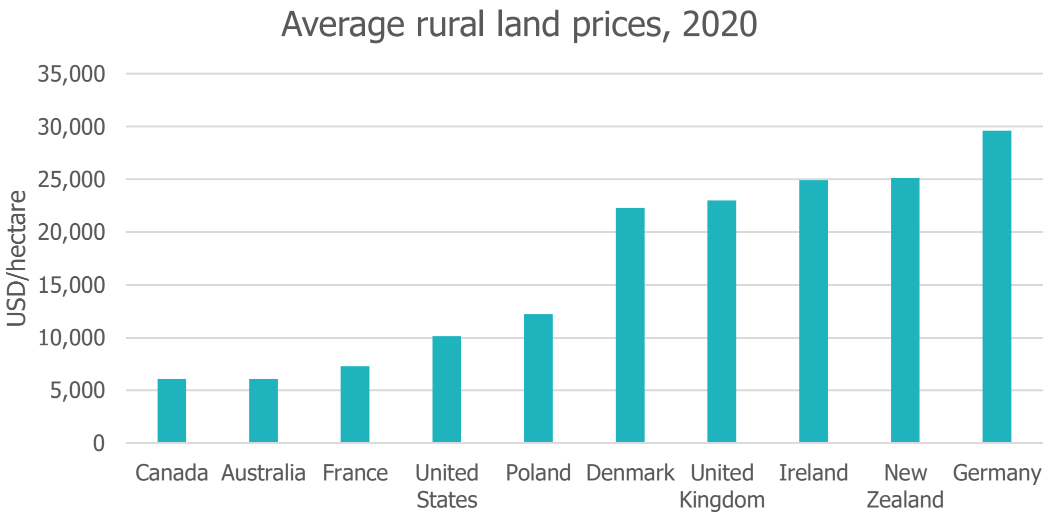


Source: Te Waihanga analysis of Turner and Townsend (2022) data.

Land prices

Figure 23 compares average rural land prices in New Zealand and nine other high-income countries. New Zealand has comparatively high agricultural land prices, reflecting the fact that we have comparatively productive agricultural land.

Figure 23: Average rural land prices in 10 high-income countries



Source: Savills (2020).

Estimating relative productivity levels

Table 7 summarises input cost indices, output costs (high-rise office construction costs per square metre), and relative productivity indices for the 21 high-income cities in the Turner & Townsend data. It also shows the share of the input cost index that is accounted for by materials, labour, and equipment. In the average (mean) city, materials accounted for 56% of the cost of the BLOC, labour accounted for 35%, and equipment accounted for 9%. However, there were significant variations in these shares between cities.

In the charts in the body of the report, we take the unweighted average across all cities in each country. These averages are more likely to be representative of conditions in large urban areas than the countries as a whole.

Table 7: Input cost indices and relative productivity indices for 22 high-income cities

City	Country	Input cost index (US$/BLOC)				Output cost (High-rise CBD offices, $/m^2)	Productivity index
		Materials	Labour	Equipment	Total input index		
Melbourne	Australia	$4,968	$6,591	$1,170	$12,729	$3,726	3.4
Sydney	Australia	$6,894	$5,699	$1,500	$14,092	$4,124	3.4
Toronto	Canada	$8,626	$5,023	$946	$14,595	$3,768	3.9
Vancouver	Canada	$10,662	$4,151	$1,041	$15,855	$5,207	3.0
Paris	France	$5,782	$4,366	$763	$10,912	$4,039	2.7
Munich	Germany	$7,247	$6,112	$877	$14,236	$4,760	3.0
Dublin	Ireland	$7,273	$3,489	$666	$11,427	$4,660	2.5
Tokyo	Japan	$8,942	$2,525	$2,471	$13,939	$4,943	2.8
Amsterdam	Netherlands	$6,262	$4,357	$702	$11,321	$4,549	2.5
Auckland	New Zealand	$6,922	$3,807	$1,336	$12,065	$4,027	3.0
Singapore	Singapore	$6,241	$1,956	$824	$9,021	$2,659	3.4
Birmingham	United Kingdom	$7,226	$3,534	$658	$11,418	$3,888	2.9
Glasgow	United Kingdom	$7,833	$3,389	$723	$11,945	$3,683	3.2
Leeds	United Kingdom	$8,019	$3,510	$855	$12,384	$3,551	3.5
London	United Kingdom	$10,492	$4,014	$921	$15,427	$5,261	2.9
Manchester	United Kingdom	$8,147	$3,542	$855	$12,544	$3,814	3.3
Chicago	United States	$7,504	$5,807	$1,800	$15,111	$5,938	2.5
Houston	United States	$7,504	$4,764	$1,203	$13,471	$4,008	3.4
Los Angeles	United States	$7,250	$7,110	$1,760	$16,120	$6,602	2.4
New York City	United States	$8,825	$8,887	$2,250	$19,962	$9,146	2.2
San Francisco	United States	$7,172	$9,070	$2,100	$18,342	$7,920	2.3

Source: Te Waihanga analysis of data from Langston (2013) and Turner & Townsend (2022).

Addressing challenges with currency conversions

Several sources, including the Australian Productivity Commission (2014) and Best (2010, 2012) note that currency conversions pose a challenge for international infrastructure cost benchmarking. Because construction is a non-tradable activity, using market exchange rates for currency conversions may mis-estimate the relative level of infrastructure costs in different countries.

Throughout this report, we use economy-wide purchasing power parity (PPP) exchange rates published by the World Bank for currency conversions. Because PPP exchange rates account for both the tradable and non-tradable parts of the economy, they are less likely to bias comparisons of infrastructure costs than market exchange rates.

Here, we examine the correlation between economy-wide PPP exchange rates and two construction-specific PPP exchange rates: the BLOC measure outlined here and a civil construction-specific PPP index that Eurostat developed for European countries.[36] We use these comparisons to understand the potential magnitude of bias caused by using an economy-wide PPP exchange rate, rather than a construction-specific rate.

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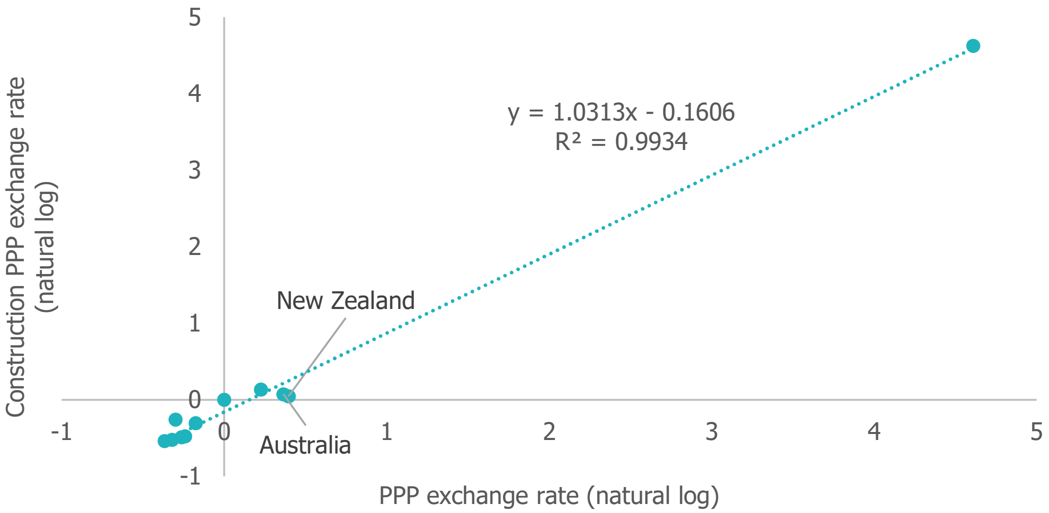
[36] https://ec.europa.eu/eurostat/web/purchasing-power-parities/data/database

This analysis suggests that economy-wide PPP exchange rates are strongly, although not perfectly, correlated with construction-specific PPP exchange rates. Errors are generally within +20% to -20%. This suggests that modest differences in infrastructure construction costs between countries – on the order of +20% to -20% – could simply be an artefact of currency conversions, but that larger differences are likely to be real.

Correlation between economy-wide PPP and BLOC measure

Figure 24 shows the correlation between the BLOC vertical construction input cost index (aggregated to country level by taking the unweighted average of all cities in each country) and PPP exchange rates (at a country level) for high-income countries in the Turner & Townsend data. We find that there is a strong, approximately one-to-one correlation between these two variables after they have been log-transformed.

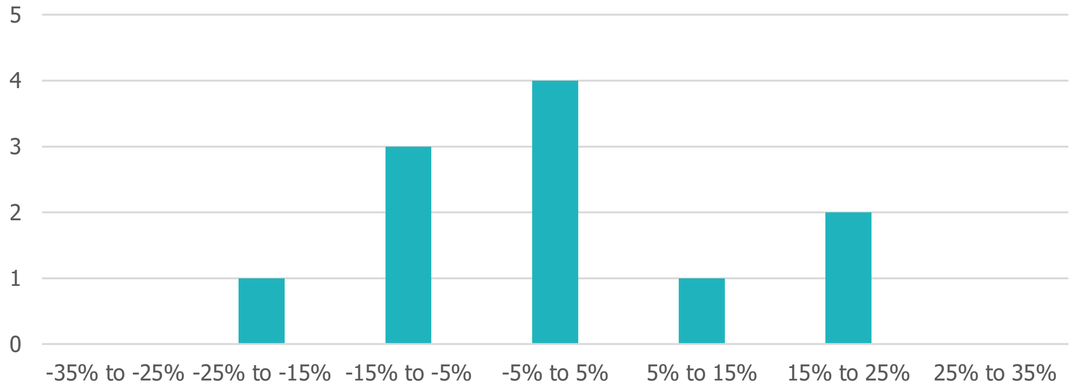
Figure 24: Correlation between PPP exchange rates and BLOC input cost index



Source: Te Waihanga analysis of data from Langston (2013), Turner & Townsend (2022), and World Bank (2022).

Figure 25 shows the distribution of residuals from the above linear model, which capture the degree to which using an economy-wide PPP exchange rate might cause us to mis-estimate the relative level of construction costs. All residuals lie between +20% and -21%, and most are smaller than this. New Zealand has a comparatively large *negative* residual, which suggests that using an economy-wide PPP exchange rate rather than a construction-specific PPP exchange rate may cause us to under-estimate costs in New Zealand relative to other countries.

Figure 25: Distribution of residuals for regression of PPP exchange rate on BLOC cost input index

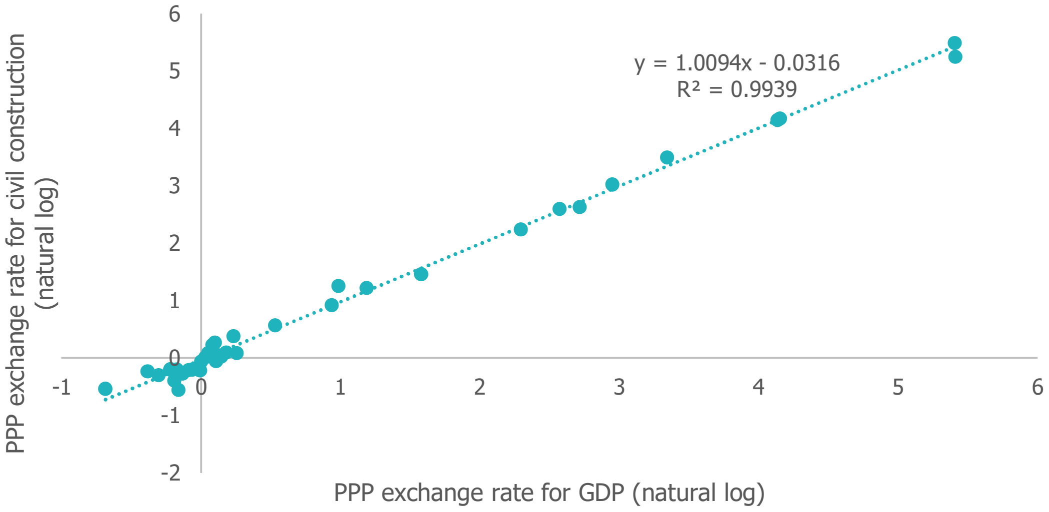


Source: Te Waihanga analysis of data from Langston (2013), Turner & Townsend (2022), and World Bank (2022).

Correlation between economy-wide PPP and civil construction PPP in European countries

Figure 26 shows the correlation between a civil construction PPP exchange rate and an economy-wide PPP exchange rates among 37 European countries. We find that there is a strong, almost exactly one-to-one correlation between these two variables after they have been log-transformed.

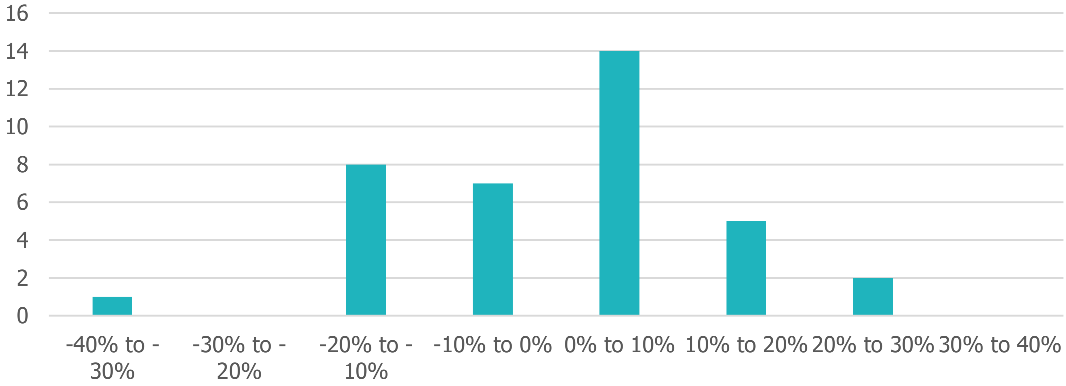
Figure 26: Correlation between economy-wide PPP and civil construction PPP exchange rates



Source: Te Waihanga analysis of data from Eurostat (2022).

Figure 27 shows the distribution of residuals from the above linear model, which capture the degree to which using an economy-wide PPP exchange rate might cause us to mis-estimate the relative level of civil construction costs. Almost all residuals lie between +20% and -20%.

Figure 27: Distribution of residuals for regression of PPP exchange rate on BLOC cost input index



Source: Te Waihanga analysis of data from Eurostat (2022).

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