NEW ZEALAND INFRASTRUCTURE COMMISSION
Te Waihanga

The Infrastructure Needs Analysis Forecast

Results and Modelling Technical Report

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New Zealand Infrastructure Commission / Te Waihanga

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

We are an autonomous Crown entity, listed under the Crown Entities Act 2004, with an independent board. We were established by the New Zealand Infrastructure Commission/Te Waihanga Act 2019 on 25 September 2019. Information on the Commission is available at www.tewaihanga.govt.nz/

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Contents

1. Introduction

What is the Infrastructure Needs Analysis?

The Infrastructure Needs Analysis (INA) is the Commission's forward guidance on future infrastructure demand. To inform the development of the INA, the Commission has forecast future capital expenditure requirements. These forecasts consider the effects of several key factors the Commission considers are likely to drive investment in infrastructure. The end goal is to give a forward view of where New Zealand's infrastructure currently stands, and what we will need to spend to meet future need.

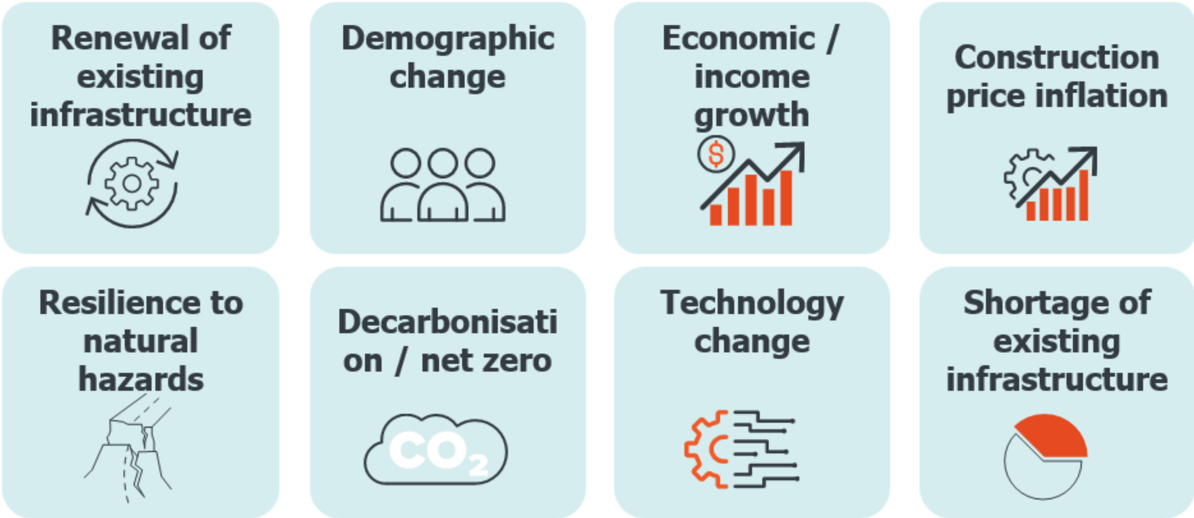
The INA consists of three themes, each with a separate output:

- **Where and how should we invest in the future?** This theme explores what has driven investment in infrastructure in the past, and how might those factors change in the future. The key output of this theme is a quantitative forecast model of infrastructure spending based upon these drivers of demand.
- **What is the current state of our networks?** This theme explores whether there are clear gaps in our infrastructure networks relative to peer countries across spending levels, stocks, usage and quality measures. The key output of this theme is a comprehensive international benchmarking study as a comparison to our quantitative model above.
- **What are we willing to spend on infrastructure?** This theme provides insight into the trade-offs we should expect to make when meeting our needs. Identifying infrastructure needs requires prioritisation that is not possible without knowledge of a constraint. The key output of this theme is a series of analyses showing potential budget envelopes for infrastructure and opportunities for expanding our budgets.

Identifying and forecasting infrastructure needs can involve many different approaches. Our approach for the INA is to study the question of infrastructure needs in a holistic way. The core output is our quantitative forecasting model, supported by parallel work on international infrastructure needs and separate analyses of potential infrastructure needs budgets.

What is the INA quantitative forecast model?

The quantitative forecast model is the key output of the first theme of the INA. It is a forecast model of capital investment levels required to meet infrastructure needs due to various drivers of infrastructure demand. These drivers of demand are detailed below:



The Commission has researched how each of these drivers can affect infrastructure over time and has used this body of work to inform how we forecast them. We call upon this research, as well as the research of other institutions and individuals to assist us in building our forecast model.

Fundamentally, the INA forecast model asks how each of these drivers has affected infrastructure demand in the past and uses new pieces of information to project how they might be different in the future. For example, to estimate the impact of income growth on infrastructure investment, we ask the question "as countries have gotten richer, how have their infrastructure networks responded?"

The purpose of this document is to provide details on technical aspects of the models, such as key assumptions, which can help people to understand how they work.

A few notes up front

For many drivers of demand, the INA forecast model implicitly assumes that over a long period of time, the way New Zealand and other countries have built infrastructure networks is a good approximation of meeting their long-term needs. There may be windows of over or underinvestment but over a 100-year period or more, the long-term trend in investment levels is assumed to be meeting our needs over time.

Given this assumption, we believe the model is best suited for forecasting long-term trends in infrastructure needs, rather than specifying investment levels in any given year. This makes it well-suited for the National Infrastructure Plan, which speaks to our infrastructure needs over the next 30 years. Like all models, however, it has its limitations, which this document documents and explores.

The INA forecast model's main output is investment levels, rather than physical quantities of infrastructure. This output is the level of investment in *capital expenditure* needs, rather than *operational expenditure* needs. As such, maintenance, human resourcing, or financing requirements for the projected capital expenditure are not included in the forecast.

Finally, it is worth elaborating what investment path our model is forecasting. It is designed to incorporates renewal requirements, but also improvements to the network. These include level of services improvements because of rising incomes, increases in capacity for population, investment for resilience and other factors. The output of the model is not the investment path to maintain current levels of service. Rather it enables improvements to the network, but only those that are based upon demonstrated New Zealander's (and other countries) historic willingness to pay.

2. How the model works

Overview

Our model quantifies the investment requirements for each one of the drivers of demand highlighted in the previous section. The only exception is technological change, which is discussed qualitatively in the INA outside of the model.

The core of this model relies upon first estimating infrastructure capital stocks and then forecasting changes to infrastructure stocks (investment less depreciation). This section lays out how the components of the model fit together.

Capital stock estimates

The model relies heavily upon estimates of historical and projected capital stocks. These capital stocks are created with a perpetual inventory model.

The general process is effectively two periods, time t and time t-1. Like financial statements of property plant, and equipment, developing capital stock valuations requires an opening period (time *t-1*) and a closing period *t.*

At the beginning of time *t,* capital stock from time *t-1* is revalued, and then any excess/obsolete stock is written off. For simplicity, we will call this $\chi_{i,t}$

$$\chi_{i,t} = \Delta P(K_{i,t-1}) - w_{i,t} \tag{1}$$

$K_{i,t}$ is capital stock in sector *i* in time *t*

ΔP is the change in real construction prices from time *t-1* to time *t.* This is the revaluation term.

$w_{i,t}$ is a term for write-offs of the existing stock, unrelated to asset depreciation.

The general formula for generating capital stock in year *t* for sector *i,* can be shown as Equation (2):

$$K_{i,t} = \chi_{i,t} + I_{i,t} + \{d_{i,t}[\chi_{i,t} + \frac{I_t}{2}]\} \tag{2}$$

Where:

$\chi_{i,t}$ is revalued stock from time *t-1,* adjusted for any write-offs in time *t*

$I_{i,t}$ is capital investment in sector *i* in time *t.* This term is endogenous to the model.

$d_{i,t}$ is the depreciation rate of sector *i* in time *t*

Equation 2 includes three terms. The first term is effectively the opening stock in time *t* revalued by real construction price growth minus any write-offs of the stock that occur in time *t.* The second term is infrastructure investment in time *t.* The third term is estimated depreciation, calculated as the depreciation rate multiplied by the revalued stock in the period time period *t-1,* plus the investment in the stock in time *t* (the second term) divided by two, assuming only half of the new investment results in depreciable stock in time *t.*

Forecasts for the drivers of demand

This section walks through the calculations for the quantified drivers of demand.

Renewals of existing infrastructure

The first step to addressing needs to is taking care of our existing assets. Renewals of existing infrastructure ($D1_{i,t}$) relies upon estimates of capital stocks, as well as past and future depreciation rates. A generalised formula is below in equation (3):

$$D1_{i,t} = d_{i,t}(\chi_{i,t} + \frac{I_t}{2}) \tag{3}$$

Equation 3 is the same as the third term in Equation 2. It is the depreciation rate multiplied by the previous year's revalued capital stock net of write offs plus a half year of investment in time *t.*

We recognise that replacement costs are often not equal to the sum of depreciation flows. We consider the components that add to this cost captured by other drivers of demand. For instance, a new bridge constructed in 1980 will eventually need to be replaced. The replacement will cost more than the bridge in 1980 (in real terms) because of changes in design standards and rising construction costs. We consider changes in standards and increasing construction prices to be quantified separately in the income driver and construction price driver respectively.

Demographic change

Growing, declining and changing populations influence infrastructure needs. This driver quantifies, using information on infrastructure usage and elasticities of infrastructure stock to population, the investment requirements due to demographic change. The generalised formula for this driver ($D2_{i,t}$) is found in Equation 4 below:

$$D2_{i,t} = \chi_{i,t}[\sum_k \frac{P_t^k W_i^k}{P_{t-1}^k W_i^k} - 1] \tag{4}$$

Where:

$\chi_{i,t}$ is revalued stock from time *t-1,* adjusted for any write-offs in time *t*

P_t is New Zealand's population in time *t*

W_i is weighting factor to account for infrastructure usage by age group *k* in sector *i*

Equation 4 effectively estimates the change in population, weighted by infrastructure usage by age group, multiplied by capital stock. Equation 4 implicitly assumes a non-weighted population elasticity of 1 (a 1% change in population leads to a 1% change in infrastructure stocks). This is broadly in line with the Commission's research which found an elasticity of 0.8.[1]

Economic development and changing standards

As economies develop, greater incomes lead to changing standards for infrastructure. This driver uses income growth as a proxy for rising levels of service expectations for infrastructure in a broad sense. This

[1] https://tewaihanga.govt.nz/our-work/research-insights/paying-it-forward-understanding-our-long-term-infrastructure-needs

can encompass a wide range of possible infrastructure needs such as increases in service standards, either through regulatory settings or societal expectations. The general formula for quantifying this driver ($D3_{i,t}$) can be found in Equation 5 below:

$$D3_{i,t} = \chi_{i,t}[\Delta(\frac{Y_t}{P_t})^{\varepsilon_{i,t}} - 1] \quad (5)$$

Where:

$\chi_{i,t}$ is revalued stock from time *t-1*, adjusted for any write-offs in time *t*

$\Delta\frac{Y_t}{P_t}$ represents the change in real GDP per capita from time *t-1* to time *t*

$\varepsilon_{i,t}$ is the elasticity of infrastructure stock in sector i with respect to income in time *t*

Equation 5 effectively estimates the change in capital stock in response to a change in GDP per capita, which is proxy for a country's income. The elasticity response to that change depends upon the sector, and is derived from Commission research, but also that of the UK National Infrastructure Commission. More information on sources will be detailed in the following section.

Resilience to natural hazards

Our infrastructure is exposed to natural hazard risk. An event that damages our infrastructure networks will require us to repair or replace those affected assets. This driver quantifies that cost.

This estimate can be thought of as the smoothed annual cost of repairing infrastructure assets given a certain level of risk and damage potential. We do not fully know when natural hazards will occur or how destructive they will be. Our conceptual framework for meeting infrastructure resilience needs effectively estimates a long-run insurance premium for rebuilding our assets given the risk of various hazards and their likely severity.

Conceptually, it can also be considered the additional cost of bringing a renewal of an infrastructure asset forward due to a natural hazard. For example, suppose a bridge is exposed to riverine flooding risk. Our model quantifies not the value of the bridge, but the cost of insuring the bridge each year. Quantifying the full cost of the bridge would require us to adjust our estimate for renewal investment to avoid double-counting.

It is important to note that this estimate is the long-run smoothed cost of repairing or replacing infrastructure assets from natural hazards. It is not an estimate of infrastructure requirements to protect private property, such as houses, from natural hazards. It is also not an estimate of building redundancies into an existing network.

To help us estimate this, we commissioned GNS Science to calculate average annual loss (AAL) to infrastructure assets by sector based upon geospatial risk. The methodology for this approach is explained in their accompanying report[2] but is overviewed here.

At the heart of the modelling is a conceptual framework for quantifying risk to assets:

$$R = f_c(H_i, E, V_i) \quad (6)$$

[2] Horspool et el. "Estimating National-Scale Losses to Infrastructure from Natural Hazards." GNS Science Consultancy Report. March 2025.

Where risk R is a function of (f_c) of the consequences of a natural hazard event (*H*) impacting an exposure (E) to risk. Consequences are determined from the exposure vulnerability (*V*) to an impact type and/or magnitude in response to either a single or multiple hazard events (*i*).

To estimate the AAL, GNS spatially mapped the value of infrastructure assets. The information on the assets values was provided to them by the Commission and is drawn from Stats NZ from our previous research.[3] This mapping of asset values was then overlaid onto maps of hazard exposure, hazard intensity, and vulnerability.

Modelling is conducted to calculate the dollar value losses that would occur under different levels of intensity. The losses for a given probability are plotted graphically as a distribution, and the AAL is effectively the integral of this distribution function.

Figure 1: Graphical representation of the calculation of AAL

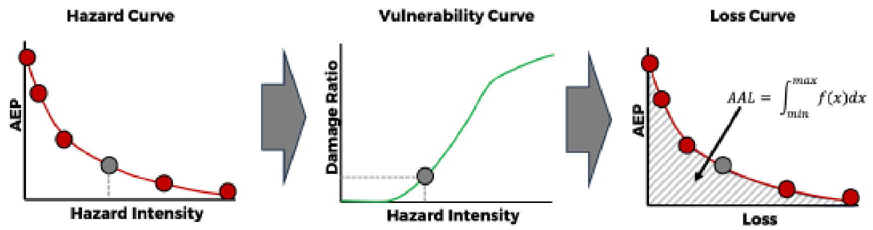


Figure 2.3 Processing steps to convert a hazard curve into a loss curve. For each AEP point that defines the hazard curve, a vulnerability curve that represents that infrastructure sector is used to calculate the damage ratio for that AEP. The damage ratio is multiplied by the exposure value to calculate the loss. When repeated for each AEP, the AEP-Loss points define the loss curve. The area under the curve is calculated through numerical integration to calculate the AAL.

Note: AEP (annual exceedance probability) is defined as the probability of a hazard of a certain intensity in a single year. Hazard intensity is defined as the intensity of a given hazard expressed in defined units (metres of water for a flood). Damage ratio is defined as the ratio of repair costs to replacement costs. Source: Horspool et al, 2025.

These AAL estimates represent the annual expected loss to infrastructure assets exposed to known risks as they exist in the year 2025. To the extent climate change increases the risk of hazards such as coastal flooding, they would not be reflected in this modelling.

The following table shows the AAL estimates by hazard type and sector, as a share of total asset values for the sector. For example, the AAL from all hazards for the water sector is approximately 0.43% of asset value each year, which is approximately $140 million (Table 1).

[3] https://tewaihanga.govt.nz/our-work/research-insights/build-or-maintain

Table 1: Average annual loss (AAL) for each hazard by sector, as a percentage of total asset value

	Earthquake	Coastal Flooding	Flooding	Tsunami	Volcano	Total
Water	0.04%	0.17%	0.21%	0.01%	0.001%	**0.43%**
Electricity	0.02%	0.09%	0.19%	0.01%	0.001%	**0.31%**
Telecommunications	0.001%	0.003%	0.005%	0.002%	0.001%	**0.01%**
Central Government roads	0.03%	0.05%	0.07%	0.0002%	0.01%	**0.16%**
Local governments roads	0.02%	0.12%	0.16%	0.001%	0.005%	**0.31%**
Rail	0.48%	0.06%	0.31%	0.001%	0.005%	**0.31%**
Public administration and safety	0.16%	0.03%	0.05%	0.01%	0.001%	**0.26%**
Hospitals	0.05%	0.004%	0.03%	0.0000%	0.001%	**0.08%**
Education	0.11%	0.01%	0.03%	0.001%	0.001%	**0.15%**
Total	**0.06%**	**0.06%**	**0.1%**	**0.003%**	**0.003%**	**0.24%**

Source: GNS Science modelling for the Infrastructure Commission.

To generate the natural hazard investment requirement, we apply a 30% loading factor to these AAL figures, which represents the markup that insurance premiums might apply for administration costs, profit, and financing risk. The final estimate for natural hazard resilience demand is estimated by applying this AAL figure to our estimates of capital stock (Equation 7).

$$D4_{i,t} = K_{i,t} * 1.3AAL \qquad (7)$$

$D4_{i,t}$ is only estimated for the 2022 through 2055 period.

For some sectors, GNS Science was either unable to model risk to assets or was only able to model them at a high level. These include education, social housing, and other public capital. We incorporated this into the model in two different ways:

- For Education, we apportioned $D4_t$ to primary/secondary and tertiary education sectors by the share of total education infrastructure attributed to each subsector. In this case, primary/secondary education assets account for just over half of total education assets, so are apportioned approximately half of the AAL estimate.
- We apply the AAL for public administration and safety to social housing and other public capital.

One final point is worthy of discussion. Since our model is a modified perpetual inventory model, $K_{i,t}$ is determined endogenously from I_t, which is turn determined from the sum of all investment drivers, including $D4_{i,t}$, the natural hazard driver of demand. $D4_{i,t}$, in turn, is calculated as a share of $K_{i,t}$. We assume that if an infrastructure provider is investing $D4_{i,t}$, on natural hazards, that is the optimal level of investment for resilience to protect against risk in time *t* and therefore assume that the capital stock in time *t* is optimal after that investment. Otherwise, if $D4_{i,t}$, is continually calculated from $K_{i,t}$ in a circular loop, then the model cannot produce an optimal investment or capital stock figure.

Decarbonisation investment demand

For New Zealand to meet its 2050 emissions goals, we will need to invest in infrastructure over and above business-as-usual trends. Conversely, it may require reducing investment in certain types of infrastructure as we transition to low-emissions transport or energy generation.

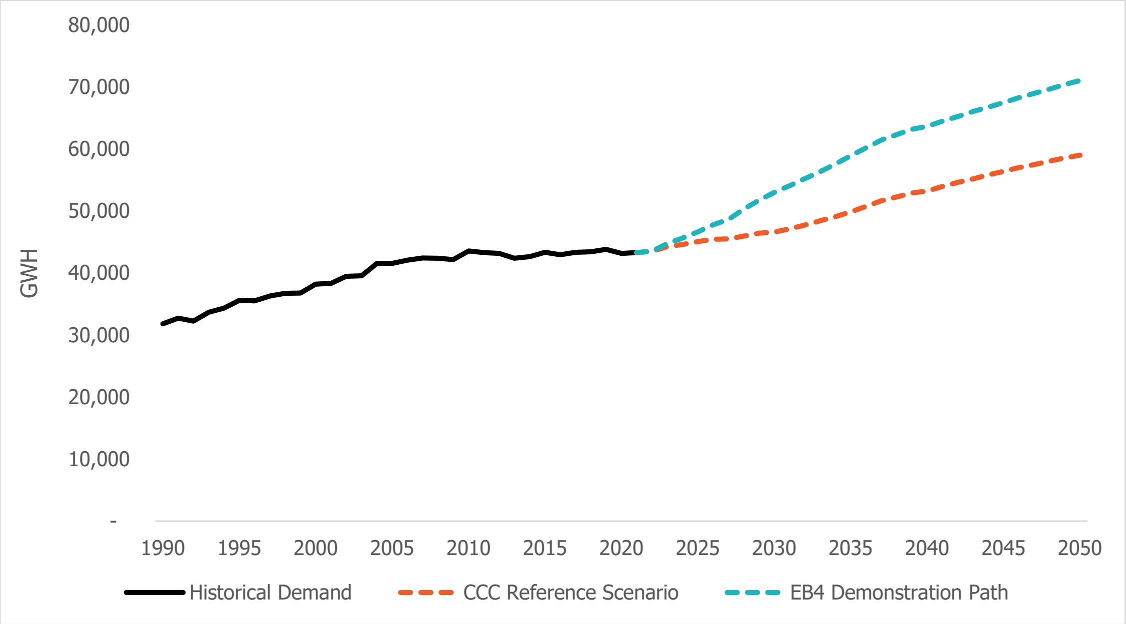
Unlike the previous drivers of demand, we forecast this driver of demand separate from estimates of capital stock. Rather, the method relies upon estimating the energy and transport infrastructure need based upon modelling completed by the Climate Change Commission (CCC) for their advice on the Fourth Emissions Budget.[4] In our analysis, we use their model but 'turn off' the effects within their model driven by population and economic growth, as to not double-count effects with our own model. This analysis was completed by the Commission with support by the Motu Research.

A full discussion of this analysis can be found in the supporting documents 'Infrastructure needs analysis-Decarbonisation'.[5] This analysis can be broken down into three different sectors: electricity, road investment, and public transport and active modes.

Electricity

The CCC's modelling for the Fourth Emission's Budget makes forecasts of electricity generation required to meet demand depending upon the scenario. The reference scenario, which includes current policy settings, forecasts that electricity demand will increase from 43 terawatt hours (TWH) in 2021 to 59 (TWH) in 2050. To meet the fourth emissions budget (the EB4 demonstration path), switching existing fossil fuel usage for transport, industrial, and commercial uses will require over 71 TWH worth of generation (Figure 2).

Figure 2: Electricity generation forecasts, Climate Change Commission ENZ Model for 4th emissions budget



Source: Climate Change Commission ENZ Model for the 4th Emissions Budget.

To estimate the infrastructure capital expenditure requirements to meet this generation, and the corresponding transmission and distribution costs, we draw direct estimates from the CCC's model, which makes monetary estimates for these requirements. We determine the capital requirements for decarbonisation to be the difference between current policy settings (the reference scenario) and the EB4 demonstration path.

The capital investment for electricity in the period 2022–2055 that is implied by the increase in demand above are summarised in Table 2 below. Overall, over the entire period, meeting decarbonisation goals in for electricity will total approximately $24 billion.

[4] https://www.climatecommission.govt.nz/our-work/advice-to-government-topic/preparing-advice-on-emissions-budgets/advice-on-the-fourth-emissions-budget/modelling-and-data-consultation-on-emissions-reduction-target-and-emissions-budgets/
[5] "Infrastructure Needs Analysis-Decarbonisation." Motu Research. June 2025

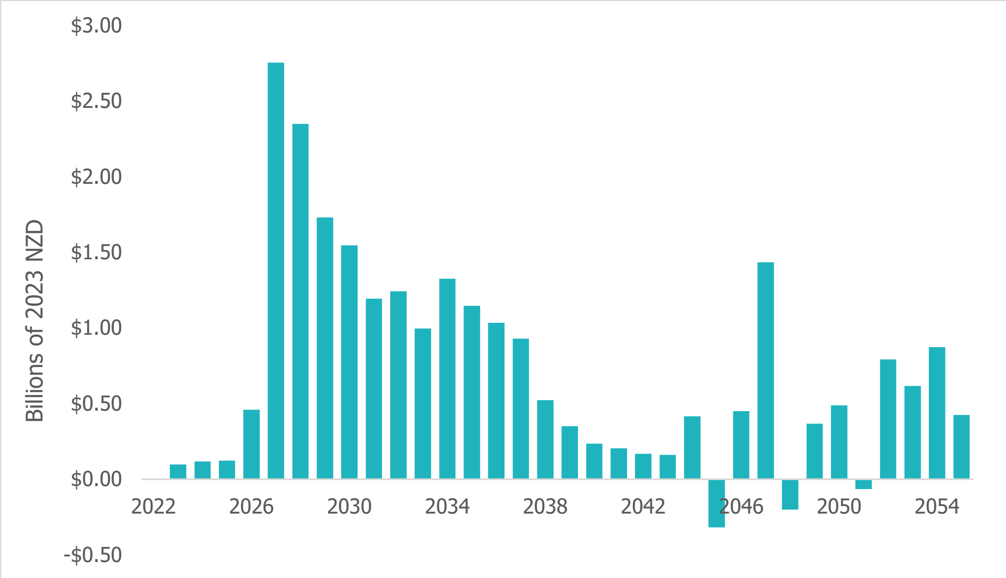
Table 2: Estimated capital investment requirements for decarbonisation for electricity and gas, 2022–2055

Sector	Type	Capital investment [2023 NZD $m.]		
		Reference	**EB4**	**Difference**
Electricity	Generation	$24,734	$47,155	$22,422
	Transmission / Distribution	$49,157	$51,627	$2,470
Gas	Pipeline	$2,707	$1,757	-$950
Totals		**$76,598**	**$100,539**	**$23,942**
% of GDP		0.45	0.59	0.14

Source: Motu Research analysis of Climate Change Commission modelling for the Commission.

The majority of this required in the period from 2025 through 2035 (Figure 3).

Figure 3: Annual investment requirement to achieve decarbonisation for electricity, 2022–2055

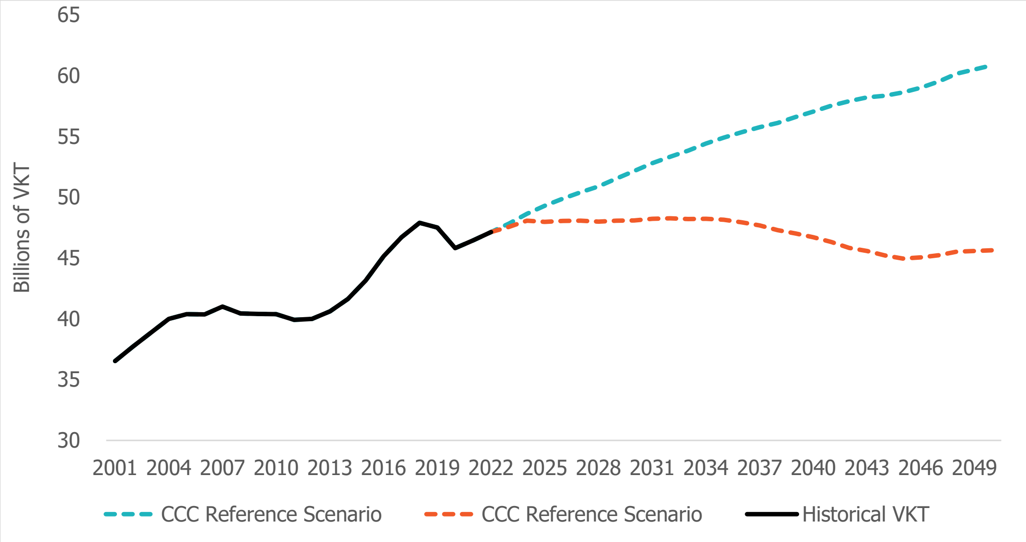


Source: Motu Research analysis of Climate Change Commission modelling for the Commission.

Road transport

In addition to electricity, we estimated the investment demand requirements to meet decarbonisation for the road transport sector. To do this, we draw upon the CCC's modelling of vehicle kilometres travelled (VKT) by cars and motorcycles under both the reference scenario and EB4 demonstration path. Meeting decarbonisation goals will require effectively limiting VKT on the road network to approximately 2022 levels for the next 30 years (Figure 4). This implies that a greater share of travel will need to shift to other modes of transport. Again, we emphasise that we have generated these VKT forecasts using the CCC's model, where we have turned off population and economic growth.

Figure 4: CCC modelling of vehicle kilometres travelled in various scenarios



Source: CCC Commission ENZ Modelling for the 4th Emissions Budget.

To understand capital investment requirements for this VKT path, we specified a model that estimated the elasticity of road capital investment to VKT. The model specification was:

$$\ln I_t = \beta \ln V_t + s^2(t) \qquad (8)$$

$$\ln V_t = \gamma \ln Z_t + s^1(t) \qquad (9)$$

Where:

- $\ln I_t$ and $\ln V_t$ denote the natural log of government capital investment in road transport and vehicle travel demand in year t, respectively
- $\ln Z_t$ denotes an exogenous instrument for $\ln V_t$ that helps to address endogeneity in the model for $\ln I_t$ that we discuss in detail below[6]
- β and γ denote model parameters that are to be estimated, where β is the elasticity of capital investment $\ln I_t$ with respect to vehicle travel demand $\ln V_t$
- $s^1(t)$ and $s^2(t)$ denote non-linear, non-parametric time trends, or GAMs.[7]

There are several alternative ways to define vehicle travel demand, $\ln V_t$. In our baseline model, we defined $\ln V_t$ as the average of the VKT, v_t, in the preceding three years, or:

$$\ln V_t = \ln\left(\frac{v_{t-1} + v_{t-2} + v_{t-3}}{3}\right) \qquad (10)$$

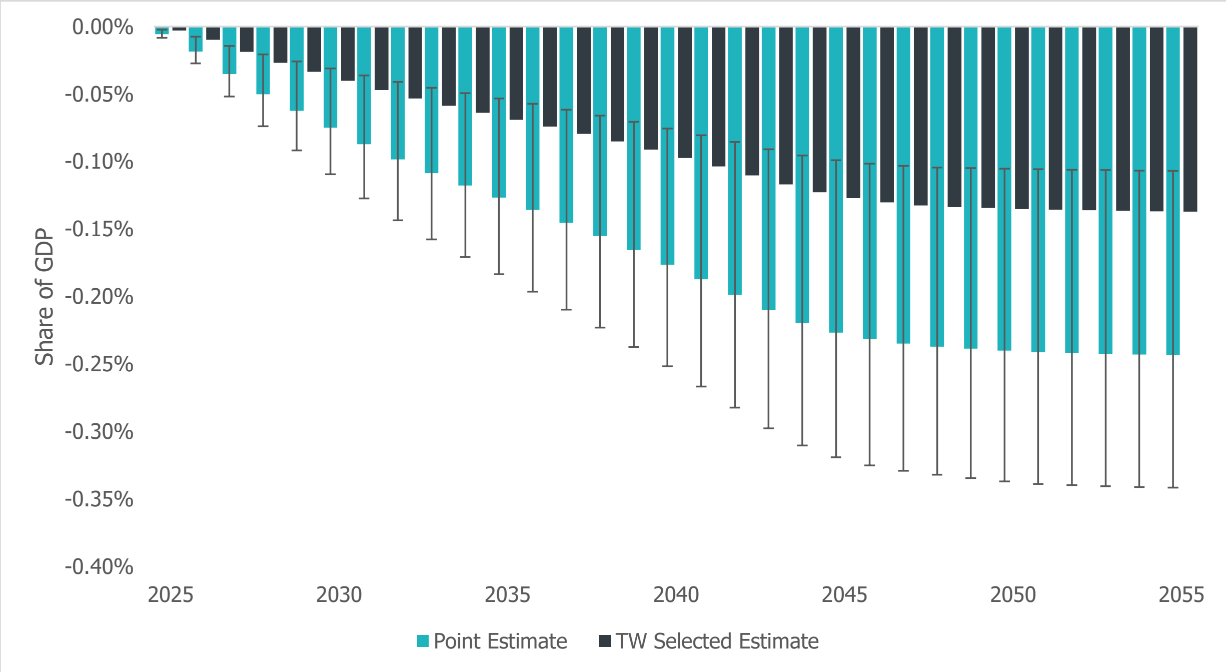
By taking the average of lagged VKT, we smooth the data and reduce the risk endogeneity poses to our estimates of β. We tested alternative definitions for $\ln V_t$ but found similar estimates for β.

[6] Endogeneity in the model for $\ln I_t$ could arise, for example, due to omitted variables and/or reverse causality whereby capital investment $\ln I_t$ affects vehicle travel demand $ln\ V_t$.

[7] Specifically, $s(t)$ denotes a non-linear, non-parametric "generalized additive model", or GAM. The latter provide a flexible way to model trends that – when estimated in a Bayesian setting – reduce, or "penalise", over-fitting. For a background to GAMs, see BaayenLinke2020.pdf.

We then use the results of this model to forecast the response of investment to VKT. The overall forecast is that lower VKT in the EB4 demonstration path relative to the reference scenario could drive sizable downward pressure on investment demand (Figure 5).

Figure 5: Estimates of road investment requirements to meet decarbonisation, 2025-2055



Source: Motu Research analysis of Climate Change Commission modelling for the Commission.

The mid-point estimate of this model estimates a downward pressure on investment of approximately – 0.25% of GDP on average from 2035. However, we opted to use a lower estimate (the 5th percentile of the distribution of coefficients) than the mid-point estimate for the following reasons:

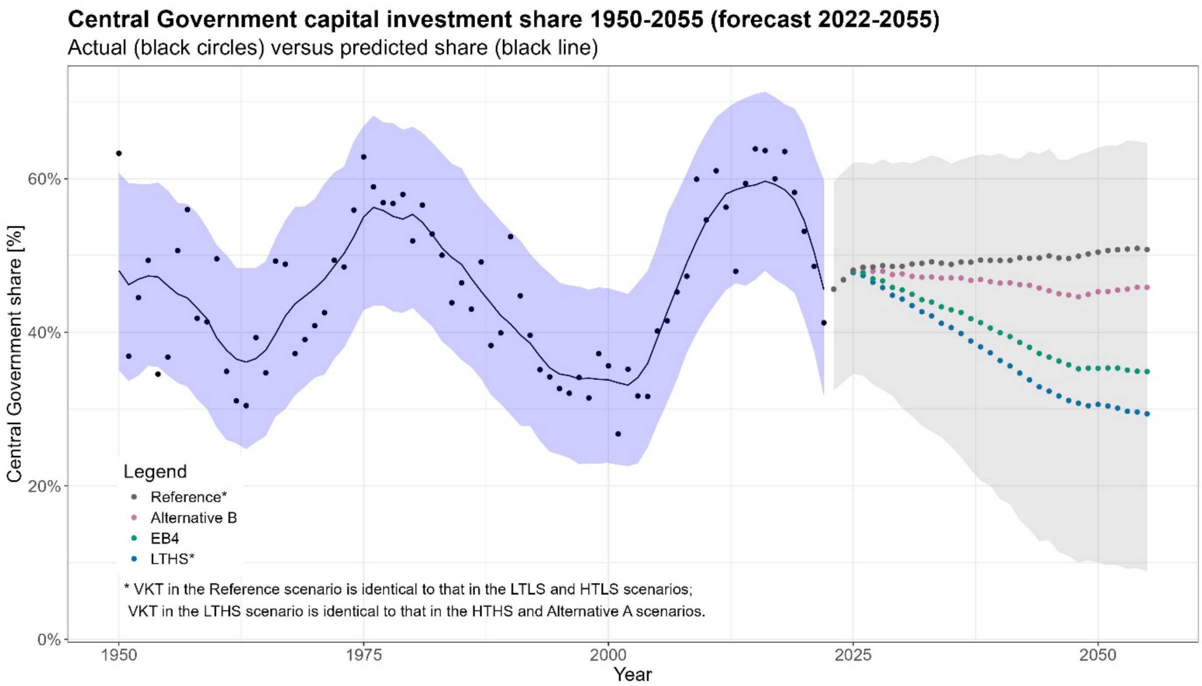
- We wanted to keep our estimates for decarbonisation anchored to the theoretical drivers of VKT, which were population growth and income growth (more people lead to more driving, and more income leads to wider roads, for example). We considered that the point estimate for equation 8 should be roughly similar to the total future demand modelled by the INA model for population and income growth (D2 and D3). As Figure 5 shows, the disinvestment requirement for decarbonisation settles around 0.3% of GDP after 2045, where the overall INA estimates an income and population driver of about 0.2% of GDP. We considered this difference too large to be explainable by theory.

- While the results are technically feasible, similar to our shortage and surplus investment, we assume that government responses to disinvestment in their networks to be slower than responses to the upside. Most of the data in our sample are VKT increases, so we do not observe many periods of investment response to declining VKT. We felt a downward adjustment was required to account for this. There are very few years in our sample where VKT declines. Of the 73 years of data we have available, only 6 saw declines in VKT.

Once we selected our preferred estimate from equation 8, we allocate this impact to central and local government roads using a separate model that effectively estimates the share of total road investment for central and local government respective in a beta model. Further details of this model can be found in the separate technical report for the project.

The results of this model found that central government road investment is more sensitive to changes in travel demand than local government. The model produces a relatively large error band around central government's share, ranging from 10% to 65% (Figure 6).

Figure 6: Forecast CG Share of road investment response to changes in VKT



Source: Motu Research analysis for the Commission.

To summarise, the estimated investment (or rather, disinvestment) required to meet decarbonisation goals for road investment by:

- Estimating equation 8, and using the 5th percentile estimate, rather than the mean, to estimate the total disinvestment requirement for decarbonisation.
- Estimating a beta model to determine how central and local government investment shares change as VKT changes.
- Applied these percentages to the first step, to estimate the relative government shares of the total.

We complete these steps for the reference and EB4 demonstration path and determine the investment requirement for decarbonisation as the difference between the two.

Public transport and active modes

In the Climate Change Commission's modelling, decreases in VKT by private vehicles is partly accompanied by increases in the demand for other forms of travel, such as active modes (walking, cycling), ride-sharing, and public transport. The approach for estimating the investment requirement for this shift in modes is straightforward.

Drawing from the Ministry of Transport's 2018 Domestic Transport Costs and Charges (DTCC) study,[8] we calculate the average unit costs of different transport modes, adjusting for inflation.

[8] Specifically, WP C12 "Urban Public Transport", https://www.transport.govt.nz/assets/Uploads/DTCC-WP-C12-UPT_June-2023.pdf

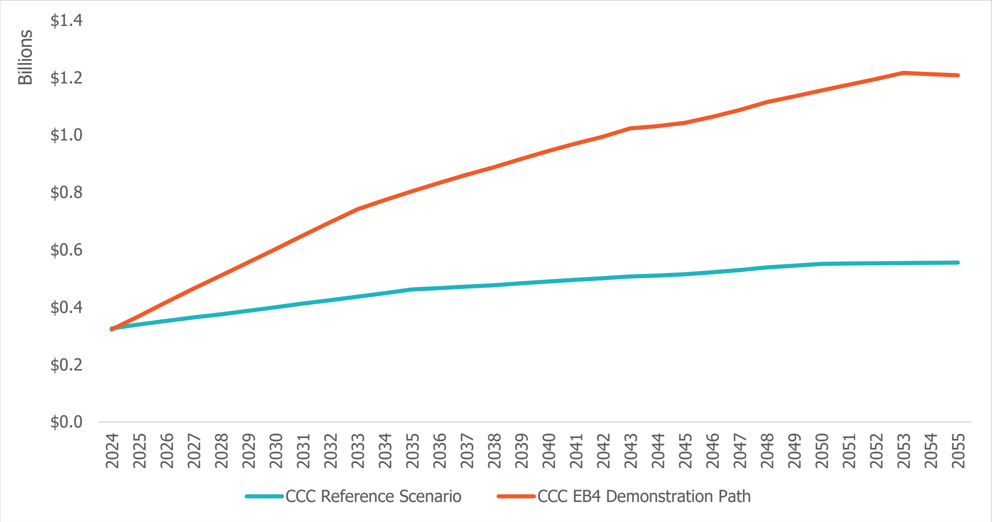
Table 3: Unit cost assumptions used for public transport and active mode investments

Mode	Unit capital costs	Notes
Public transport	$0.1281 per passenger kilometre	Average of rail and bus transport from the DTCC study, inflated to 2023 dollars
Active Modes	$0.0641 per passenger kilometre	Assumed to be half of the unit costs of public transport

Source: Ministry of Transport's 2018 Domestic Transport Costs and Charges (DTCC) study, Motu Research calculations.

From here, we simply apply unit cost estimates to passenger kilometre forecasts from the Climate Change Commission and generate a path of investment requirements for different Climate Change Commission scenarios.

Figure 7: Modelled investment requirements for public transport and active modes to meet decarbonisation, 2024-2055 in 2023 NZD



Source: Motu Research analysis of Climate Change Commission modelling for the Commission.

We estimate that the investment required for decarbonisation is the difference between the reference scenario and the EB4 demonstration path.

Inclusion of these results in the overall model

The results generated from above are purely additive to our other investment demand drivers, and is characterised by $D5_{i,t}$

The estimated investment requirement for electricity is added to the electricity and gas sector investment path. For roads, we add our results to sector models for central and local government roads. For public transport and active modes, since our estimate contains road and passenger rail investment requirements, in addition to active transport (a sector we do not model investment demand for overall), we add these results to a total "Land Transport" investment requirement, which includes roads and rail.

For sectors other than transport and electricity, we did not quantify a decarbonisation requirement.

Shortages or surpluses of existing infrastructure

Because our model makes forecasts of the various drivers of demands in a way that is grounded in theory, it can be thought of as a fundamentals-based forecast. Over the long term, it is implicitly assumed that infrastructure surpluses or deficits do not exist.

However, infrastructure stocks do not correspond to an ideal, fundamentals-based investment path. There are periods of over and underinvestment over short and medium lengths of time. Our model relies upon historical capital stocks for projections in the short and medium term, particularly for renewal requirements, so incorporating deficits or surpluses in stocks is important.

To illustrate this, consider the need for renewal investment in the period 2025 through 2030. The majority the renewal demand in this period will depend upon our capital stock in 2024. If capital stock in 2024 is a level that is well below what our model would have forecast based upon fundamentals, then simply applying a depreciation rate to 2024's capital stock might underestimate what the true renewal requirement should have been. As such, this driver seeks to make a separate adjustment in investment (or disinvestment) to account for this.

The process for accounting for shortages or surpluses begins by calculating a modelled investment path in sector *i* for time *t*. This can be thought of as an ideal investment path:

$$I^*_{i,t} = D1_{i,t} + D2_{i,t} + D3_{i,t} + D4_{i,t} + D5_{i,t} \tag{11}$$

Where $DN_{i,t}$ corresponds to our modelled investment requirements to meet the first five drivers of demand (renewals, demographics, economic development, natural hazard resilience, and decarbonisation). $I^*_{i,t}$ is expressed as either a level or as a share of GDP

We then use this ideal investment path to calculate an ideal capital stock, using a perpetual inventory method, similar to Equation 1:

$$K^*_{i,t} = K^*_{i,t-1} + I^*_{i,t} + d_{i,t}[K^*_{i,t-1} + \frac{I^*_{i,t}}{2}] \tag{12}$$

Where $I^*_{i,t}$ is our estimated ideal investment path in time *t* for sector *i*, and $d_{i,t}$ is the historically observed depreciation rate.

We then estimate an infrastructure shortage or deficit in stocks:

$$\theta_{i,t} = K^*_{i,t} - K_{i,t} \tag{13}$$

This surplus or shortage manifests as an additional investment (or disinvestment) requirement in our model. It is solved over a period of years specified as an assumption, which varies depending upon whether it is a surplus or shortage.

$$D6_{i,t} = \frac{\theta_{i,t-1}}{T} \tag{14}$$

Where $\theta_{i,t-1}$ represents the estimated shortage or surplus in the previous year, and *T* is a constant, representing the number of years it takes to bring total stocks back towards an ideal level. We discuss our assumptions for *T* in the next section.

In our model, we add shortage and surplus investment as a driver of demand in the years beyond 2023 because we account for historical surpluses and shortages using a write-off assumption in the calculation of capital discussed in the following sections.

Construction price inflation

Infrastructure Commission research has highlighted that lagging productivity in the heavy and civil construction sector has led to higher prices for infrastructure.[9] If these trends continue, we might expect to commit a great share of our GDP towards infrastructure to meet our needs, which are often measured in physical quantities, rather than dollars.

To account for this, we include an additional driver of demand in our forecast. While characterised as a driver of demand, it can also be thought of as an adjustment to the previous six drivers of demand to account for rising real construction costs.

We do this by deriving an initial ideal investment figure $I^*_{i,t}$ in time *t* in sector *i*, determined by summing our previous drivers of demand.

$$I^*_{i,t} = D1_{i,t} + D2_{i,t} + D3_{i,t} + D4_{i,t} + D5_{i,t} + D6_{i,t} \tag{15}$$

A key input to our modelling of construction price inflation is a real construction price index, compiled by the Commission using data from New Zealand's Official Yearbooks, Stats NZ Long Term Data series, and other sources. A further discussion of these sources follows in the next section.

Future projections of real construction prices are derived using a model developed by Nordhaus (2008) and adopted by the Commission in its September 2022 *Research Insights* paper. In that work, we found that the elasticity of output prices to labour productivity growth was 0.6.

We forecast future real construction prices with the following equation (15):

$$P_t = (1 + \rho_i)^{\epsilon} \tag{16}$$

Where:

P_t is the real price index in year *t*

ρ_i is an assumption the difference between construction sector productivity and that of the economy as a whole, in sector *i* for the forecast horizon

ϵ is the elasticity of output prices to labour productivity, 0.6.

As such, a larger ρ_i (slower relative construction productivity) will drive faster growth in real prices.

To forecast the additional spending required to accommodate real construction price growth, we first determine the price level in time *t*, relative to a base period. In our model, we set the base period as the average price level from years 2010 through 2023. This provides us with an estimated upward or downward effect on spending as a result of changes to relative real prices.

$$P_t = I^{Adj}_{i,t} = I^*_{i,t}[\left(\frac{P_t}{P\mu_{2010-23}}\right) - 1] \tag{17}$$

Where:

$I^{Adj}_{i,t}$ the ideal investment level adjusted by rising prices

P_t is the price level in year *t*, and $P\mu_{2010-23}$ is the mean price level from 2010 through 2023.

[9] https://tewaihanga.govt.nz/our-work/research-insights/economic-performance-of-new-zealand-s-construction-industry

Finally, we apply a price elasticity to account for shifts in demand as prices rise and fall:

$$D7_{i,t} = I_{i,t}^{Adj} \times \varepsilon_i[\left(\frac{P_t}{P\mu_{2010-23}}\right) - 1] \quad (18)$$

Where ε_i is an estimate for price elasticities for a given sector *i*, derived from previous Commission and other research.

In our model, we only estimate construction price inflation as a driver of demand in the years beyond 2023.

Technological Change

As new technologies emerge, they can have a dramatic impact on the need for investment in infrastructure.

However, we consider technological innovations are largely exogenous shocks to infrastructure demand that could have an upward or downward impact. Because these shocks are largely unforecastable, we do not attempt to quantify them through our forecast model, but note technological innovation's importance in relevant sectors.

Conclusion

Our model quantifies investment demand as the sum of the forecast investment need from each of the drivers. See Equation 16 below:

$$I_{i,t}^{*} = D1_{i,t} + D2_{i,t} + D3_{i,t} + D4_{i,t} + D5_{i,t} + D6_{i,t} + D7_{i,t} \quad (19)$$

$I_{i,t}^{*}$ can be expressed in real dollar terms, or as a share of GDP.

3. Model inputs, sources, and assumptions

Economic and demographic inputs

The model relies on key economic and demographic inputs which are detailed below.

Population and demographics

Total population

Historical data on total population are sourced from the New Zealand Institute for Economic Research's (NZIER) Data1850 tool.[10] We use this source for data from 1870 through 1990. From 1990 through 2023, we use Stats NZ's population estimates.[11]

For population projections beyond 2023, we rely on Stats NZ's national population projections by age and sex.[12] The Stats NZ series begins in 2022, but we use the projections beginning in 2024. This creates a modest discontinuity in 2024. The projection data begins in 2022 and shows a lower figure for population in that year relative to the Stats NZ population estimates. As such, 2024, the first year of the projection, displays a discontinuity in trends, which dissipates thereafter. This issue is largely mitigated by showing our forecast in five-year average increments.

Population by age group

Our model relies on weighting infrastructure usage by age group. Data on population shares from 1990 through the projection are drawn from Stats NZ.

From 1926 through 1989, we rely on Stats NZ's Long Term Data Series for population age and sex[13] which are pieced together from various Censuses from 1926 onwards. These Censuses occur intermittently during these periods, every 5 or 10 years. To generate a complete annual series from 1926 through 1989, we use a linear interpolation between Census years for each age group.

Since no data on population by age groups exists pre-1926, to estimate populations in each age group using data on aggregate population, we apply 1926's relative age group shares to the total New Zealand population estimates pre-1926, generally collected from New Zealand's Official Yearbooks.

Infrastructure usage by age group

Our model weights population demand for investment in a given sector by each age group's relative usage of that infrastructure. Information on network usage by age group is drawn from a variety of sources.

Two assumptions are important to note. First, where we were unable to find data on usage by age group, we assumed the same relative usage across age group. Second, information on usage is drawn from a given time period and applied uniformly across historical periods and the projection. For example, data on transport usage is drawn from recent Household Travel Survey data, and used as the basis for travel patterns and usage going forward.

The below table identifies the sources for each sector:

[10] https://www.nzier.org.nz/data-1850
[11] https://www.stats.govt.nz/topics/population-estimates-and-projections
[12] https://www.stats.govt.nz/information-releases/national-population-projections-2022base2073/
[13] https://statsnz.contentdm.oclc.org/digital/collection/p20045coll35/id/164/rec/6

Table 4: Sources and information on infrastructure usage rates for the INA Model

Sector name	Source	Notes
Land transport- Central Government roads	NZ Household Travel Survey[14]	
Land transport- Local Government roads	NZ Household Travel Survey	
Land transport- rail	NZ Household Travel Survey	
Electricity and gas	Estiri and Zagheni (2019)[15]	
Water and waste	Abu-Bakar, Williams, and Hallett (2023)[16]	
Telecommunications	No information	
Education - primary / secondary	Ministry of Education, Education Counts, School rolls[17]	
Education - tertiary	Ministry of Education, Education Counts, Tertiary participation[18]	Age group buckets did not correspond to Stats NZ's. Groups 30-34 and 35-40 were interpolated using a linear trend
Health - hospitals	Calculated from the Health New Zealand National Minimum Dataset[19]	Data was provided by NZIER to the Commission as part of our *Building a Healthy Future* report.
Public administration and safety	NZ Police, Data and Statistics, Proceedings[20]	Most criminal proceedings are for traffic violations which don't typically result in prison sentences. Instead, number of proceedings for the top ten offenses[21] of the prison population was used to estimate future demand for prisons. Note, this category includes other types of infrastructure beyond prisons.
Social housing	Ministry of Housing and Urban Development	Custom data request on housing tenants by age group
Other public capital	No information	

[14] https://www.transport.govt.nz/statistics-and-insights/household-travel
[15] See Figure 2: https://www.sciencedirect.com/science/article/pii/S2214629618309629
[16] See Figure 6: https://www.sciencedirect.com/science/article/pii/S2666784323000050#bib51
[17] https://www.educationcounts.govt.nz/statistics/school-rolls
[18] https://www.educationcounts.govt.nz/statistics/tertiary-participation#:~:text=Total%20participation,in%202023%20than%20in%202022.
[19] https://www.tewhatuora.govt.nz/for-health-professionals/data-and-statistics/nz-health-statistics/national-collections-and-surveys/collections/national-minimum-dataset-hospital-events
[20] https://www.police.govt.nz/about-us/publications-statistics/data-and-statistics/policedatanz/proceedings-offender-demographics
[21] https://www.corrections.govt.nz/resources/statistics/quarterly_prison_statistics/prison_facts_and_statistics_-_june_2024

Economic variables

Historical gross domestic product (GDP) is pulled from NZIER's Data1850 tool for both nominal and real GDP. We also calculated the GDP deflator from this series. These data were also cross checked against Stats NZ data from National Accounts back to 1972.[22]

Projections of real GDP are drawn from the New Zealand Treasury's 2024 Budget Fiscal Strategy Model[23] (for years 2024 through 2038) and 2021 Long Term Fiscal Model[24] (for years 2039 through 2061).

Infrastructure sector investment, depreciation, stocks, and prices

Infrastructure sector aggregations

Infrastructure sectors in our model are defined using a combination of ANZSIC industry and sector of ownership, similar to those highlighted in our *Build or Maintain* Research Insights paper.[25] The data on investment flows, stocks, and depreciation rates in that paper are from 1990 through 2022.

Because we used alternative sources for this information for the pre-1990 period, we aggregated and defined sectors at the lowest level at which we could generate a continuous data series for the pre-and-post 1990 period. The resulting sectors are as in the table below.

Table 5: Infrastructure sectors modelled in the INA model

Sector	Vertical or horizontal	Sector of ownership
Central government roads	Horizontal	Central government
Local government roads	Horizontal	Local government
Rail	Horizontal	Government and private
Electricity and gas	Horizontal	Government and private
Water and waste	Horizontal	Local government and private
Telecommunications	Horizontal	Government and private
Education-primary/secondary	Vertical	Government and private
Education-tertiary	Vertical	Government and private
Hospitals	Vertical	Central government and private
Public administration and safety	Vertical	Central and local government
Social housing	Vertical	Central and local government
Other public capital	Vertical	Government and private

Sector investment

Data on sector investment levels from 1990 to 2022 are drawn from the Commission's *Build or Maintain* research paper. That paper's data workbook includes a custom data request from Stats NZ on gross fixed capital formation for ANZSIC industry levels across sectors of ownership.

Data prior to 1990 is drawn from a variety of historical sources. These include:

[22] Infoshare series SNE038AA
[23] https://www.treasury.govt.nz/publications/fsm/fiscal-strategy-model-befu-2024
[24] https://www.treasury.govt.nz/publications/ltfm/long-term-fiscal-model-he-tirohanga-mokopuna-2021
[25] See table A8 in Appendix 2: https://media.umbraco.io/te-waihanga-30-year-strategy/djkmtwj4/build-or-maintain.pdf

- Stats NZ National Accounts capital account data at the ANZSIC industry level, for the 1972–2022 period.
- Mulcare's (1994) historical estimates of public-sector capital investment, which are broken down roughly by industry and sector of ownership but not comprehensive of all types of infrastructure included in the post-1990 data.
- Industry- or agency-level capital investment data manually compiled from the New Zealand Official Yearbook (1893 to approximately 2008), which are matched and where possible reconciled with other series.
- New Zealand Infrastructure Commission's imputations using information from these and other sources to fill in gaps in the above sources.

The sources for this data will be discussed more comprehensively in the Appendix of our forthcoming Research Insights report, *Nation Building: 150 Years of Infrastructure Investment*.

Capital stocks

Data on capital stock values from 1990 to 2022 are also drawn from the Commission's *Build or Maintain* research paper.

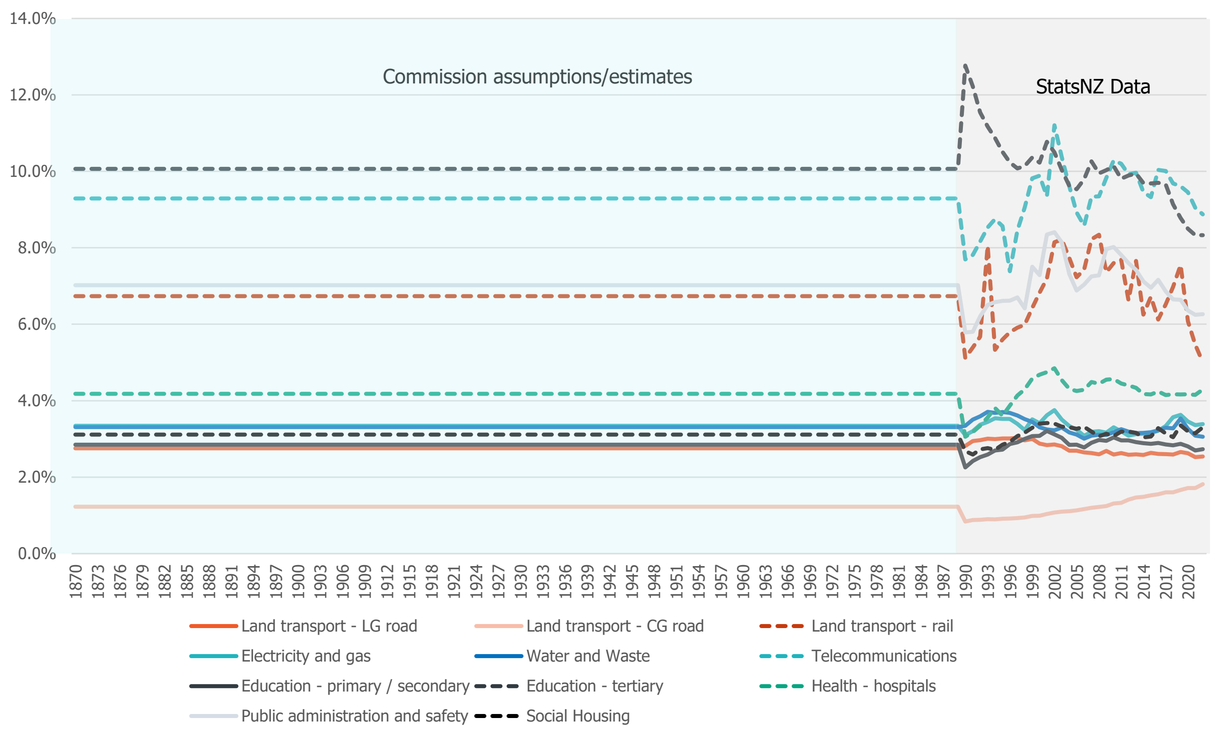
We do not observe data on capital stocks prior to 1990. Prior to 1990, we construct estimated capital stock series using a perpetual inventory model, with the key data input being historical investment levels drawn above and estimated historical depreciation rates (which are discussed below). See equation 1 above.

Projections of capital stock are completed using equation 1, with projected investment levels from equation 18, projected depreciation rates, and write-down assumptions, which are discussed below.

Depreciation rates

The use of the perpetual inventory model requires an estimate of depreciation rates. Data on depreciation rates from 1990 to 2022 are drawn from the Commission's *Build or Maintain* research paper. Data on depreciation rates prior to 1990 do not exist. Instead, we assume the 1990–2022 average depreciation rate applies to all years prior to 1990 (Figure 8).

Figure 8: Estimates of depreciation rates, 1870 through 2022



Source: New Zealand Infrastructure Commission's analysis of Stats NZ data.

For depreciation rates beyond 2023, our central scenario for the model is a depreciation rate that is equal to the 2022 value, although we sensitivity test our results using different rates, including the 1990-2022 historical average.

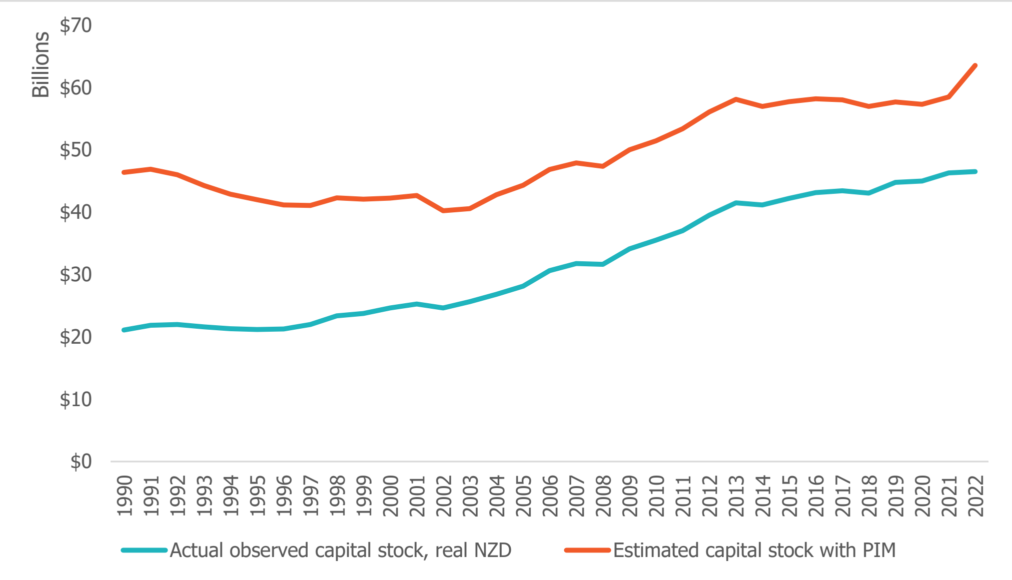
Write-down/re-evaluation assumptions

The development of reasonable estimates of capital stocks is critical for our model. Investment requirements for renewal, population growth, income growth, and natural hazard resilience are derived either using elasticities with respect to capital stock or as a share of total capital stock.

As noted above, we do not observe capital stocks for sectors prior to 1990. We observe investment flows, and we assume that depreciation of assets is similar to the 1990–2022 period (as described above). Using a perpetual inventory model, we can make an estimate of capital stocks for the pre-1990 period. Our goal was to construct a capital stock for the pre-1990 period that closely matched the value of the capital stock in year 1990.

However, using this method, for some sectors, we found that our estimates of capital stock were much higher than the actual year 1990 capital stock. An example of this is the electricity sector (Figure 9).

Figure 9: Estimates and actual capital stock values in electricity and gas



Source: Stats NZ, New Zealand Infrastructure Commission's calculations and analysis.

As Figure 9 shows, in the post-1990, both series track each other closely, but they start from different points. This implies that the PIM approach worked well in the post-1990 period but requires some adjustments in the pre-1990 period. This was not the case for all sectors, but was particularly acute for sectors were one of two events happened in the pre-1990 period: either the sector was previously publicly owned and transferred to private ownership, or there were periods where the sector experienced some sort of technological change that made an existing network obsolete. Both instances imply that a simple depreciation rate was insufficient to capture rapid decreases in the book value of the network.

To adjust for this, we had two possible approaches:

- We could adjust historical depreciation rates assumptions upwards, which would imply that the definition would not just cover the wearing out of assets, but also obsolescence and revaluations. In theory, our shortage/surplus investment adjustment would offset some of this "excess renewal" requirement, but we recognise that our approach to quantifying shortages or surpluses likely includes omitted variables.

- We could include a separate assumption that captured periods of write-downs or revaluations of the stock during observed periods of transition in networks.

We opted for the second approach for most sectors because our driver of renewal investment demand ($D1_{i,t}$) is based upon the depreciation rate. If we revised historical depreciation rates upwards, it would inflate the renewal requirement in historical periods.

The way this is incorporated is similar to a property, plant, and equipment statement where revaluations to the stock occur in the movements between years. We write off a percentage of the existing stock between opening and closing stock between time *t-1* and time t, highlighted in equation 1 in the second term ($w_{i,t}$).

$$\chi_{i,t} = \Delta P(K_{i,t-1}) - w_{i,t} \tag{1}$$

The following table describes our write-down/revaluations of historical stock and a justification.

Table 6: Commission write-down/revaluation assumptions used for the INA model

Sector	Assumption	Justification
Central government roads	2% write down each year from 1955-1980	Reflects a transitioning of the network from metalled and gravelled roads. During this period, the length of the state highway network experienced little growth and declined in some years.
Local government roads	2% write down each year from 1955-1980	Reflects a transitioning of the network from metalled and gravelled roads, particularly during the 1960s and 1970s.
Rail	5% write down each year from 1945-1980. 30% and then 45% write down in 1993 and 1994.	The length of the rail network declined quickly from 1945 through 1990. Rail network profitability started declining considerably after 1950, and experiences heavy losses from 1975 through 1990[26]. In 1993, the Government sells NZR, and it appears the network is revalued based upon discounted future cash flows, resulting in large write-offs.
Electricity and gas	50% write-down in 1987, 10% in 1988 and 10% in 1989.	Corresponds to the commercialisation of electricity assets in New Zealand, the establishment of Electricorp and Transpower. Implies the valuation of the network changed from depreciated replacement cost to discounted future cash flows during this time.
Water and waste	Used the average depreciation rate from 1990-2000, which is slightly higher than the 2000-2022 period	The consistently higher depreciation rates at the start of the 1990s imply that an assumption of a 1990-2022 historical average is too low. The difference is not too significant, however: 3.5% in the first ten years versus 3.2% in the next 20.
Telecommunications	15% write down in 1990	Corresponds to the sale of Telecom to Ameritech and Bell Atlantic. Implies the valuation of the network changed from depreciated replacement cost to discounted future cash flows during this time.
Education-primary/secondary	2% from 1929 through 1950. 2% from 1970 through 1990.	Corresponds to periods where there were declines in the number of schools in New Zealand.
Education-tertiary	None	Not applicable
Hospitals	None	Not applicable
Public administration and safety	None	Not applicable
Social housing	None	Not applicable
Other public capital	None	Not applicable

Other key model assumptions and inputs

Construction price inflation

The previous section's discussion of the model walks through our calculation of construction price inflation's effect on the drivers of demand. This calculation required the Commission to generate a long-term real infrastructure price series.

[26] https://ir.wgtn.ac.nz/server/api/core/bitstreams/423cb474-fcb8-44b5-974f-afa70d53e894/content

The sources and methodology for this series will be discussed more comprehensively in the Appendix of our forthcoming Research Insights report, *Nation Building: 150 Years of Infrastructure Investment*

Briefly, the sources are composed of the following:

- Stats NZ National Accounts capital account NKS deflators for 'other construction' assets, for the 1972-2023 period (table SNE062AA).
- Mulcare's (1994) historical estimates of infrastructure construction price indices, which cover the 1870-1989 period. These estimates consist of several overlapping series with different sectoral/asset coverage over time. These include price indices for road construction, non-transport prices, structures, equipment, residential and nonpresidential construction. These are spliced together and rebased to create a continuous series.
- The series is also validated against data collected on costs to build different infrastructure assets found in the New Zealand Official Yearbook. For example, the Yearbooks contain information maintenance costs for the railway network and its length, allowing us to construct unit maintenance costs. The growth in these costs serves as a validation to our constructed series.

To generate a projection of construction price inflation, we used a model developed by Nordhaus (2008) and adopted by the Commission in its September 2022 *Research Insights* paper. Equation 15 in the previous section highlights that the growth in the index is a function of construction's relative productivity performance to the entire economy.

$$P_t = (1 + \rho_i)^{\epsilon}$$

Where:

P_t is the real price index in year t

ρ_i is an assumption the difference between construction sector productivity and that of the economy as a whole, in sector i for the forecast horizon

ϵ is the elasticity of output prices to labour productivity, 0.6.

The table below lays out our input assumptions for the difference between economy-wide productivity growth and construction sector productivity growth, depending upon the scenarios selected in our model. The source for this difference is our September 2022 Research Insights paper on construction productivity.[27]

Table 7: Commission assumptions on the difference between economy-wide and construction productivity growth

	Difference between economy and construction productivity growth		
	Central scenario	High scenario	Low scenario
All sectors	0.9%	0.72%	1.08%

The final step to constructing a construction price projection is to apply a price elasticity assumption to account for substitution from more or less expensive infrastructure (Equation 15). These price elasticities vary by sector and are detailed in the table below.

[27] https://tewaihanga.govt.nz/our-work/research-insights/economic-performance-of-new-zealand-s-construction-industry

Table 8: Price elasticities used in the construction of real construction price impacts on investment demand

Sector	Price elasticity			Source
	Central scenario	High scenario	Low scenario	
Central government roads	-0.45	-0.8	-0.1	UK National Infrastructure Commission[28]
Local government roads	-0.45	-0.8	-0.1	UK National Infrastructure Commission
Rail	-0.45	-0.8	-0.1	UK National Infrastructure Commission
Electricity and gas	-0.2	-0.3	-0.1	UK National Infrastructure Commission
Water and waste	-0.25	-0.3	-0.2	UK National Infrastructure Commission
Telecommunications	-0.5	-0.6	-0.4	UK National Infrastructure Commission
Education-primary/secondary	-0.2	-0.26	-0.14	No information. Assumed as a less elastic sector, similar to electricity and gas above
Education-tertiary	-0.2	-0.26	-0.14	No information. Assumed as a less elastic sector, similar to electricity and gas above
Hospitals	-0.2	-0.26	-0.14	No information. Assumed as less elastic sector, similar to electricity and gas above
Public administration and safety	-0.45	-0.585	-0.315	No information. Assumed as more elastic sector, similar to transport above
Social housing	-0.2	-0.26	-0.14	No information. Assumed as less elastic sector, similar to electricity and gas above
Other public capital	-0.45	-0.585	-0.315	No information. Assumed as more elastic sector, similar to transport above

These elasticities are constant across years. This is a limitation of our model, as there is evidence that price elasticities have declined over time (see Fouquet 2014).[29] If the latter trend persists into the future, then it would be expected to cause us to underestimate both actual construction price inflation and, in turn, capital investment requirements.

Income elasticities

The third driver of infrastructure investment demand is economic development and changing standards. The process for calculating this driver is to estimate the change in GDP per capita and apply an income elasticity for the sector (Equation 4).

The income elasticities we use in our model are in the table below.

[28] See table 2: https://nic.org.uk/app/uploads/2906219-NIC-Technical-Paper-Economic-Driver-v1_0A-WEBACCESSIBLE-4.pdf
[29] https://www.journals.uchicago.edu/doi/10.1093/reep/reu002

Table 9: Income elasticity assumptions used in quantifying income-based investment demand

Sector	Income elasticity			Source
	Central scenario	High scenario	Low scenario	
Central government roads	0.65	1.1	0.2	UK National Infrastructure Commission[30]
Local government roads	0.65	1.1	0.2	UK National Infrastructure Commission
Rail	0.65	1.1	0.2	UK National Infrastructure Commission
Electricity and gas	0.55	0.9	0.2	UK National Infrastructure Commission
Water and waste	0.25	0.3	0.2	UK National Infrastructure Commission
Telecommunications	0.8	1.04	0.56	UK National Infrastructure Commission. Low and high estimates are calculated as 70% and 130% of the central estimate.
Education-primary/secondary	0.52	0.8	0.24	Low: Infracom (2023)[31], High: Infracom (2024)[32]. Central scenario is the midpoint.
Education-tertiary	0.52	0.8	0.24	Low: Infracom (2023), High: Infracom (2024). Central scenario is the midpoint.
Hospitals	0.52	0.8	0.24	Low: Infracom (2023), High: Infracom (2024). Central scenario is the midpoint.
Public administration and safety	0.52	0.8	0.24	Low: Infracom (2023), High: Infracom (2024). Central scenario is the midpoint.
Social housing	0.52	0.8	0.24	Low: Infracom (2023), High: Infracom (2024). Central scenario is the midpoint.
Other public capital	0.52	0.8	0.24	Low: Infracom (2023), High: Infracom (2024). Central scenario is the midpoint.

Like our price elasticity assumptions, our income elasticity assumptions do not change across time periods. Fouquet (2014) observed declining income elasticities across heating, transport and lighting from 1870 through 2010. Conversely, the Commission, through engagement with stakeholders for the INA, has heard that changing quality standards for infrastructure have accelerated in recent years, despite slower income growth than previous decades. Future research into the infrastructure response to economic development will improve our ability to model this driver more accurately.

Addressing infrastructure shortages and deficits

The sixth driver of demand is investment or disinvestment to address infrastructure deficits or surpluses. A key assumption in our modelling is the speed at which these deficits or surpluses are addressed. Equation 13 demonstrates that our approach is solving the deficit/shortage over the course of T years.

$$D6_{i,t} = \frac{\theta_{i,t-1}}{T}$$

In our model, we assume that adjusting infrastructure stocks for shortages occurs faster than for surpluses, particularly for infrastructure that tends to be publicly owned like schools or hospitals.

[30] See table 2: https://nic.org.uk/app/uploads/2906219-NIC-Technical-Paper-Economic-Driver-v1_0A-WEBACCESSIBLE-4.pdf
[31] https://media.umbraco.io/te-waihanga-30-year-strategy/3segaqje/household-spending-on-infrastructure-services.pdf
[32] https://media.umbraco.io/te-waihanga-30-year-strategy/43ikcme0/paying-it-forward-understanding-our-long-term-infrastructure-needs.pdf

The adjustment periods for shortages and surpluses are detailed in the tables below.

Table 10: Assumptions on adjustment times for shortages/surpluses of infrastructure networks used in the INA model

Sector	How long to address shortages?			How long to address surpluses?		
	Central scenario	Fast scenario	Slow scenario	Central scenario	Fast scenario	Slow scenario
Central government roads	12	8	25	35	25	50
Local government roads	12	8	25	35	25	50
Rail	12	8	25	25	15	50
Electricity and gas	10	6	20	15	10	25
Water and waste	12	8	25	35	25	50
Telecommunications	10	6	20	15	10	25
Education-primary/secondary	12	8	25	35	25	50
Education-tertiary	12	8	25	35	25	50
Hospitals	12	8	25	35	25	50
Public administration and safety	12	8	25	35	25	50
Social housing	12	8	25	35	25	50
Other public capital	12	8	25	35	25	50

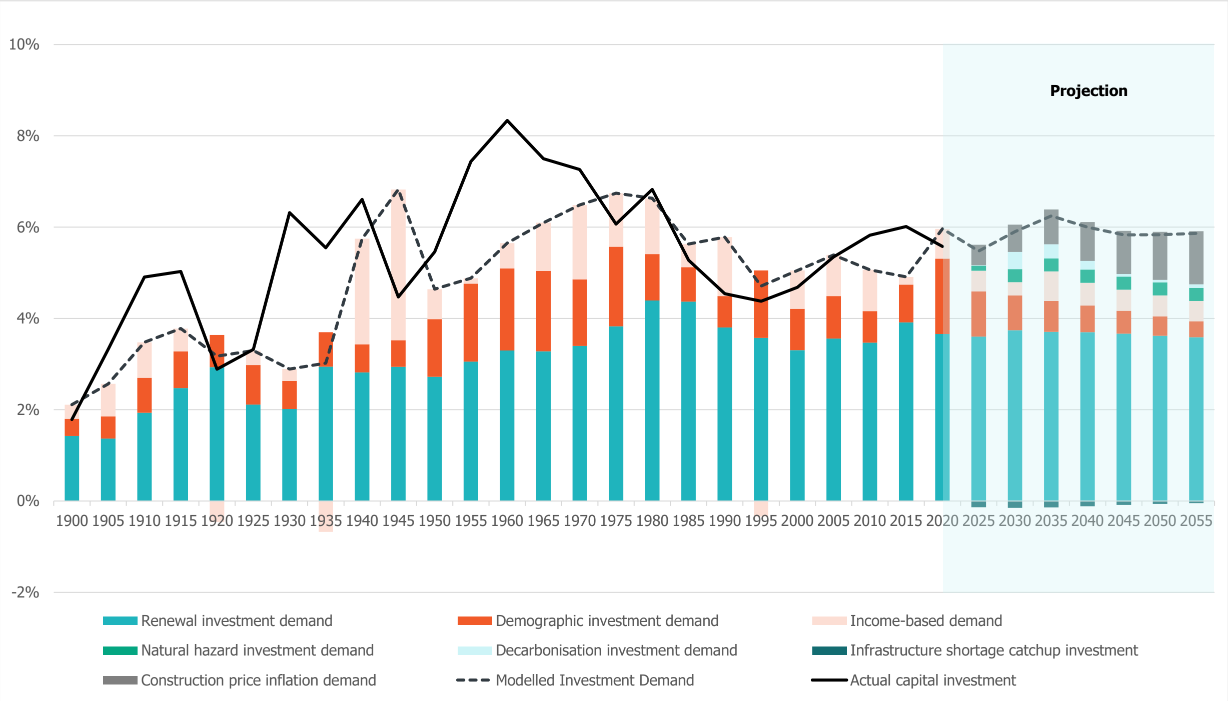
4. Overview of our results

In this section, we show the high-level results of the model for all infrastructure, as well as the sectors along with brief commentary.

Total Infrastructure Investment Demand

The results of our model for the overall infrastructure system are below in Figure 10.

Figure 10: Modelled and historical investment demand as a share of GDP, decomposed by driver of demand, 1900-2055



Source: New Zealand Infrastructure Commission's analysis and modelling.

Our model forecasts that meeting investment demand will require approximately 5.9% of GDP worth of spending over the next thirty years. For reference, we estimate that infrastructure investment as a share of GDP since 1870 has averaged about 5.6%.

Much of this investment is driven by the need to renew or replace existing assets. Population and income driven demand are the next largest drivers, although combined, they account for less than a third of the renewal requirement. Decarbonisation is a notable driver in the first half of the forecast, as the need for increased renewal electricity generation drives a significant amount of investment demand. This need tails off towards the end of the forecast period. Construction price inflation factors significantly into investment demand, particularly in the later parts of the forecast period, largely a function of diverging productivity trends between construction the overall economy.

Looking at model performance, our modelled investment demand tracks reasonably well with actual historic investment demand. It captures booms in investment overall (albeit sometimes with delays), and slowdowns. It also confirms anecdotal evidence of infrastructure deficits building during the 1980s, 1990s, and early 2000s, where actual spending is well below our modelled investment path.

Sector-by-sector infrastructure demand forecasts

The following table shows high level results for our analysis.

Table 11: Summary of modelled investment demand by sector

Sector	Recent investment trends, % of GDP (2010– 2022)	Forecast future investment demand, % of GDP (2024–2054)	Key drivers of future investment
Network infrastructure			
Land transport – road, public transport, rail	1.3%	0.8% ↓	Decarbonisation, slowing income and population growth
Electricity and gas	0.8%	1.4% ↑	Decarbonisation, renewals
Water and waste	0.6%	0.4% ↓	Renewals and natural hazards
Telecommunications	0.7%	0.8%	Renewals, stable investment trends
Social infrastructure			
Education – primary/secondary	0.4%	0.2% ↓	Demographic change
Education – tertiary	0.6%	0.5% ↓	Demographic change
Hospitals	0.2%	0.4% ↑	Demographic change, renewals
Public administration and safety – government buildings, prisons, defence, justice	0.9%	0.8%	Renewals, stable investment trends
Social housing	0.1%	0.3% ↑	Population growth, catchup investment
Other public capital	0.2%	0.2%	stable investment trends

Each sector has its own dynamics, but some key insights that hold across most or all sectors.

First, renewals and replacements of existing assets is the largest driver of demand across all sectors. In some sectors, like education, renewal demand is almost 80% of investment demand. Electricity is the only network where renewals do not account for more than 50% of forecast investment demand.

Second, our modelling suggests that infrastructure shortages, at the prices people are willing to pay, do not currently exist across all networks. Rather, it is nuanced story. Our modelling highlights the need for increased investment in electricity networks and hospitals. However, it also suggests that recent investment trends in the state highway network and surprisingly, water networks, go beyond what is expected based on fundamentals.

Third, historically, population, demographic and income dynamics drive the largest amount of investment demand outside of renewals. New Zealand's ageing population and relatively poor productivity performance resulting in slowing GDP per capita growth[33] means it is hard to see a path where these traditional drivers of demand result in significantly greater willingness to pay for new infrastructure. In other words, we foresee trends in these drivers being quite subdued over the next 30 years. There are some exceptions to this. For instance, our projections for growth for hospital investment demand is almost entirely driven by the ageing of the population from now to about 2040.

Appendix A shows figures for our investment forecasts for each sector.

[33] Based upon 2021 Treasury's Long Term Fiscal Model: https://www.treasury.govt.nz/publications/treasurys-stewardship-reports/long-term-fiscal-position/long-term-fiscal-model

5. Scenario testing and robustness checks

Parameters available for scenario testing

In our model, we allow for a variety of scenarios to be tested around the key drivers of demand. The following table lays out the various parameters we can change within the model related to the driver of demand.

Table 12: Scenario parameters in the INA Model

Driver of demand	Parameter	Scenarios available
Population and demographics	Overall population growth	Stats NZ projections, ranging from the 2.5th percentile to the 97.5th percentile. Also includes Stats NZ scenarios of high fertility, low mortality, no migration, cyclic migration
Income growth and economic development	GDP per capita growth	Low: Central scenario less 30% Central: Treasury's estimate of real GDP per capita growth from the 2024 BEFU and 2021 LTFM High: Central scenario plus 30%
Income growth and economic development	Elasticity of infrastructure to income growth	See Table 9
Renewals	Depreciation rates for the projection	2022's value, 1990–2022 historical value, rising depreciation rates (based upon rising depreciation rate trends for overall public capital from the IMF).[34,35]
Shortages/surplus	Surplus adjustment (how many years to correct a surplus?)	See Table 10
Shortages/surplus	Shortage adjustment (how many years to correct a surplus?)	See Table 10
Construction prices	Long run construction productivity trend	See Table 7
Construction prices	Price elasticities	See Table 8
Natural hazard resilience	Future risk profiles	Steady risk – flat projection for AAL across sectors Increasing risk – 20% increase in AAL relative to 2022 levels, beginning in 2030
Decarbonisation	Elasticity of road investment to VKT	Various percentiles of the estimate for β in equation 8

[34] https://www.imf.org/en/Publications/WP/Issues/2016/12/30/New-Estimates-of-Government-Net-Capital-Stocks-for-22-OECD-Countries-1960-2001-17318
[35] https://infrastructuregovern.imf.org/content/dam/PIMA/Knowledge-Hub/dataset/WhatsNewinIMFInvestmentandCapitalStockDatabase_May2021.pdf
https://infrastructuregovern.imf.org/content/dam/PIMA/Knowledge-Hub/dataset/InvestmentandCapitalStockDatabaseUserManualandFAQ_May2021.pdf

Scenario modelling

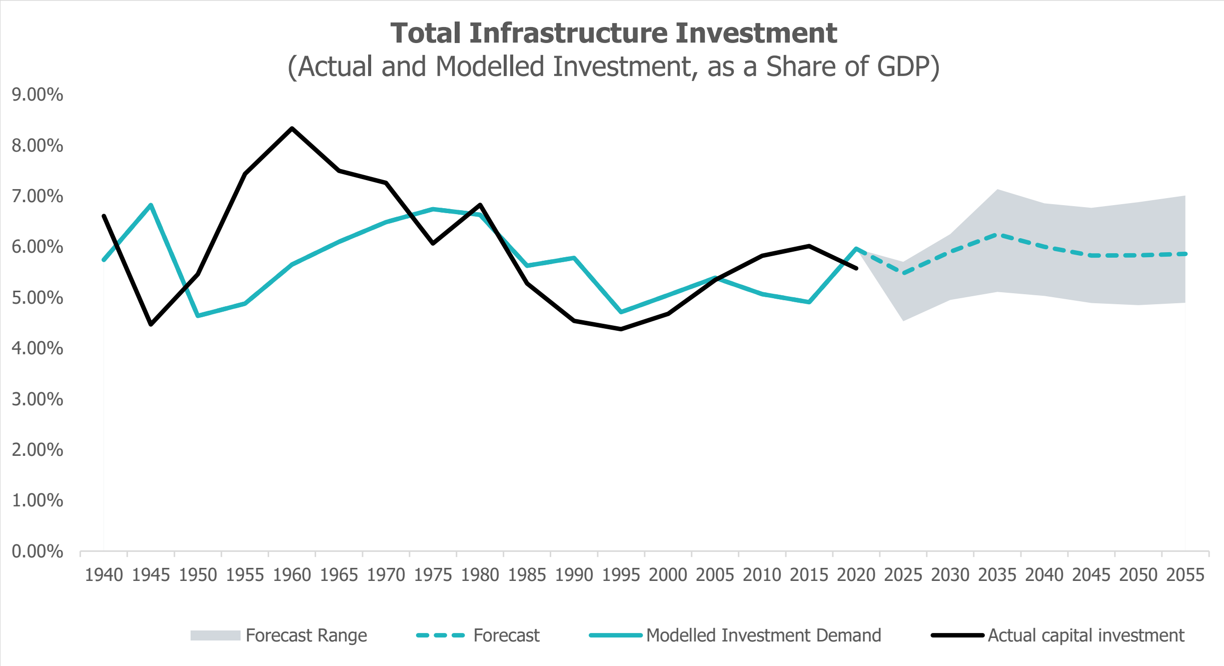
Given the range of parameters around seven different drivers of demand, we opted to select two key model scenarios for our model. The bounds of our scenario are as follows:

Table 13: Parameters used in the Commission's high, low, and central modelling scenarios

Parameter	Low Scenario	Central Scenario	High scenario
Overall population growth	25th percentile Stats NZ projection	50th percentile Stats NZ projection	75th percentile Stats NZ projection
GDP per capita growth	Low GDP per capita growth	TSY GDP per capita growth	High GDP per capita growth
Elasticity of infrastructure to income growth	Low	Central	High
Depreciation rates for the projection	2022 value	2022 value	2022 value
Surplus adjustment (how many years to correct a surplus?)	Central	Central	Central
Shortage adjustment (how many years to correct a surplus?)	Central	Central	Central
Long run construction productivity trend	Central	Central	Central
Price elasticities	Central	Central	Central
Future risk profiles	Central	Central	Rising
Elasticity of road investment to VKT	5th percentile estimate	5th percentile estimate	5h percentile estimate

The results of this scenario test can be seen in Figure 11.

Figure 11: Total infrastructure investment demand: scenario testing of projection to various parameters



Based upon this range of parameters, total infrastructure investment demand could range between 4.9% and 7% of GDP. In 2024, the difference between this range is approximately $8 billion.

We also tested the parameters to determine the sensitivities of the model. In general, we found the model is most sensitive to depreciation rates, income elasticities, and the parameter for elasticity of road investment:

- Depreciation rates relate to renewal requirements, and since renewals are the largest driver of investment demand, even relatively small changes can make a notable difference on investment requirements.
- While income-driven demand is a smaller driver, for some networks like transport and electricity, the difference between the low and high estimates from the literature can be sizeable. For instance, for transport, the UK National Infrastructure Commission found a central elasticity of 0.65, but with a range of 0.2 to 1.1. Since transport is the largest infrastructure network in New Zealand by value, this range can make a significant difference.
- Similarly, the range of estimates for the elasticity of road investment to VKT ranges from 0.4 to 1.3.

Robustness checks

To test the results of our model, we specified two separate models for forecasting investment. The first was an autoregressive distributed lag model, and the other was a vector autoregression. Our goal for these models was not to provide structural explanations of investment paths, but simply to generate alternative forecasts that could be used to test our base INA model.

Autoregressive Distributed Lag Model

Appendix A shows figures for our investment forecasts for each sector.

The first was an autoregressive distributed lag model:

$$I_t = \beta_0 + \beta_1 I_{t-1} + \beta_2 \Delta Y + \Delta\beta_3 W + \beta_4 \Delta S + \beta_5 \Delta P + \beta_6 d_t + \beta_7 \Delta\pi_t + \varepsilon_t \quad (20)$$

Where:

I_t is total infrastructure capital investment, expressed as a share of GDP

Y is real GDP, expressed on a per capita basis, with three coefficients for *t, t-1,* and *t-2*

W_t is the working age population, defined as the population between 15 and 64

S is the population aged 65 or older, with two coefficients for *t* and *t-1*

P is the total population, with two coefficients for *t* and *t-1*

d_t is the depreciation rate in time *t*

π_t is real construction prices, indexed 1870=100

I_t was confirmed as stationary using a Dickey-Fuller test, as was d_t. The combination of I(0) and I(1) variables informed the decision to use an ARDL without an error correction term. Variables expressed in first difference were found to be nonstationary. Lag lengths were chosen using the Akaike information criterion. The model was found to have little serial correlation (Durbin-Watson statistic 2.108).

Results are shown below:

Table 14: Results for ARDL model for investment

Variable	Coefficient	Standard Error
Investment, t-1	0.8257***	0.0446
Real GDP per capita, t	-0.0415**	0.019
Real GDP per capita, t-1	0.0653***	0.0179
Real GDP per capita, t-2	0.0275	0.0183
Depreciation rate	-0.2687	0.5119
Real construction prices	-0.0032	0.0155
Working age population	-0.3175**	0.1565
Age 65+	0.3798**	0.1522
Age 65+, t-1	-0.4223***	0.151
Total population	-0.0497	0.1792
Total population, t-1	0.4371***	0.1537
Constant	0.0206	0.0227
R-Squared	0.7459	

From this model, we generated forecasts for the years 2023 through 2055.

Vector Autoregression Model

To provide another forecast to compare with our results, we specified a simple vector autoregression (VAR) model, informed by the results of our ARDL model. Based upon the statistical significance of the variables in the ARDL model (real GDP per capita, working age population, population aged 65+, total population), we estimate a system with five equations.[36] Our equation of interest includes investment as a share of GDP as the dependent variable:

$$I_t = \beta_0 + \beta_1 I_{t-1} + \beta_2 \Delta Y_{t-1} + \Delta\beta_3 W_{t-1} + \beta_4 \Delta S_{t-1} + \beta_5 \Delta P_{t-1} + \varepsilon_t \quad (21)$$

The optimal lag length for the system was selected using Akaike information criterion. We did not impose any specific restrictions on the system and defaulted to a Cholesky ordering. We are less concerned with the interactions between variables and structural explanations of investment, and more with forecasting, but consider that if we were to perform any economic interpretation with this model, a model with block restrictions would be more suitable.

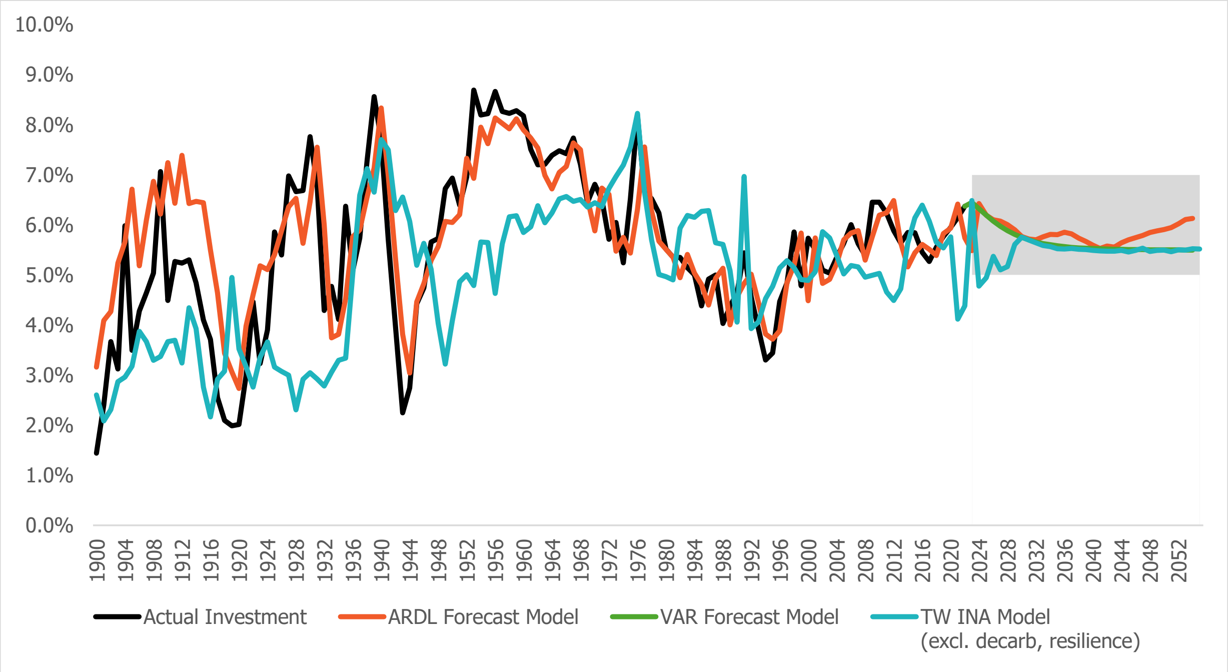
Table 15: Results for VAR model of investment

Variable	Coefficient	Standard Error
Investment, t-1	0.826***	0.043
Real GDP per capita, t-1	0.067***	0.017
Working age population, t-1	-0.368**	0.147
Age 65+, t-1	-0.557	0.067
Total population, t-1	0.452***	0.147
Constant	0.008	0.003
R-Squared	0.724	

INA Model performance against ARDL and VAR

The results of our forecast are laid out in Figure 12. To make the forecasts comparable, we exclude the demand drivers for resilience and decarbonisation (D4 and D5) from the INA Model.

Figure 12: Total investment forecasts: INA Model, ARDL, and VAR

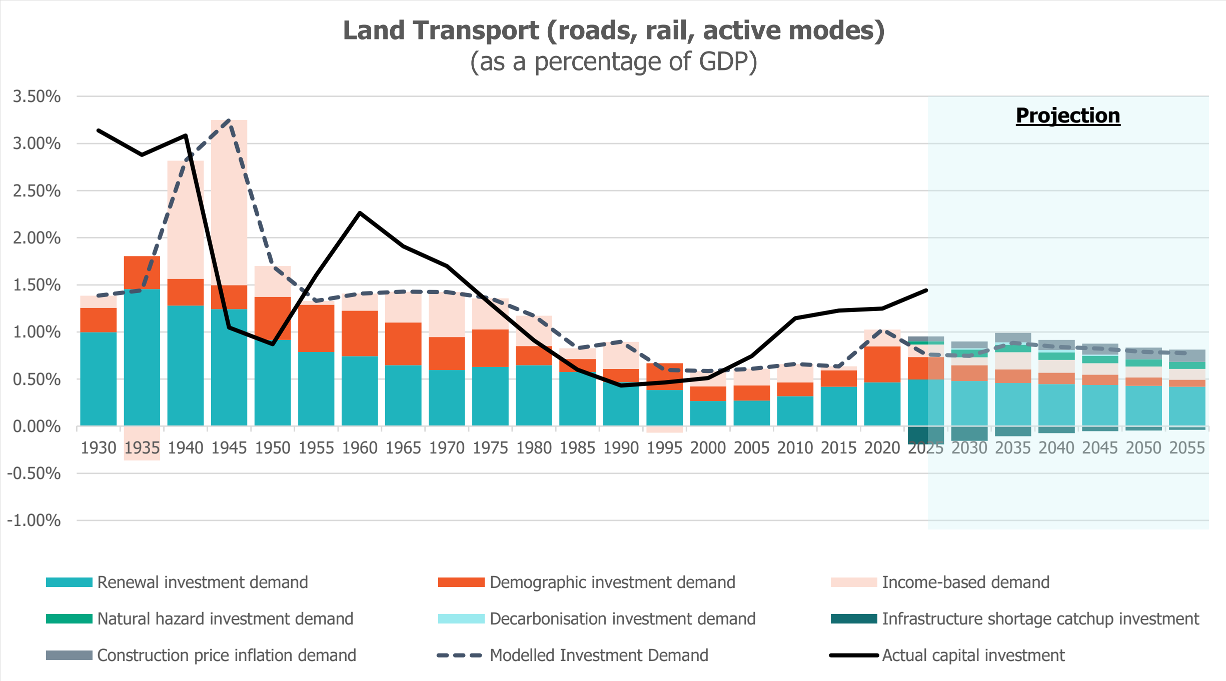


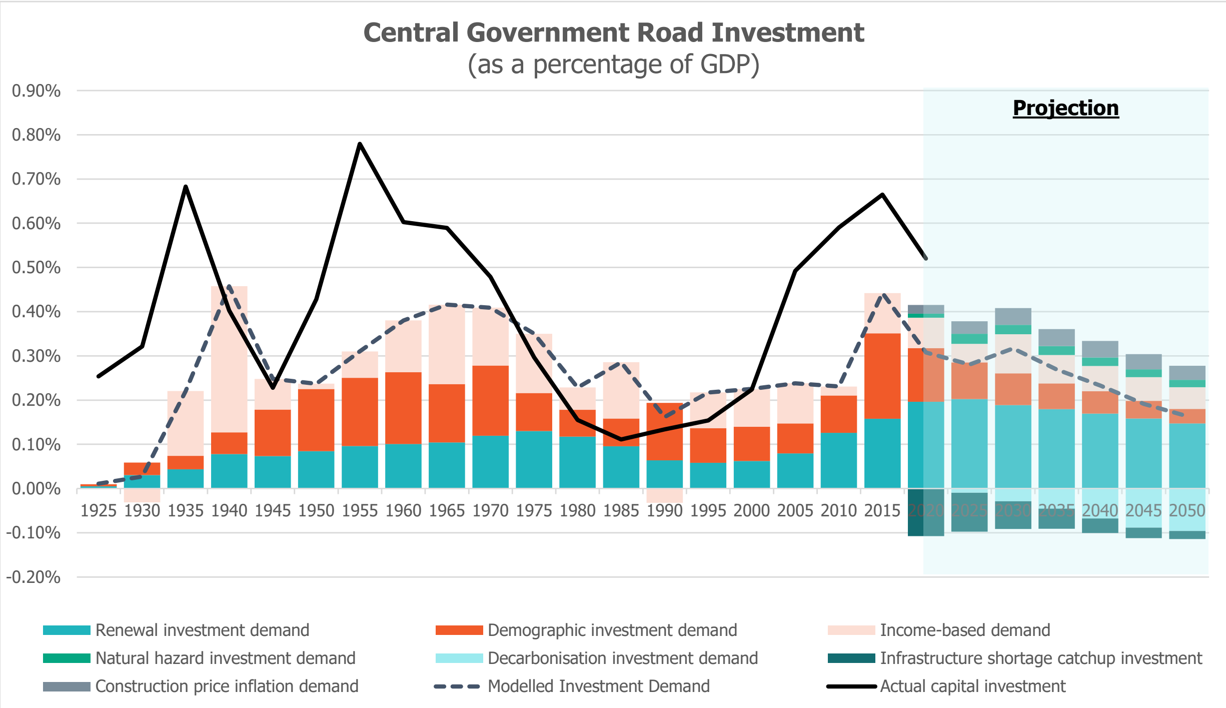
[36] This was done to limit the number of equations, given the number of observations for investment (154).

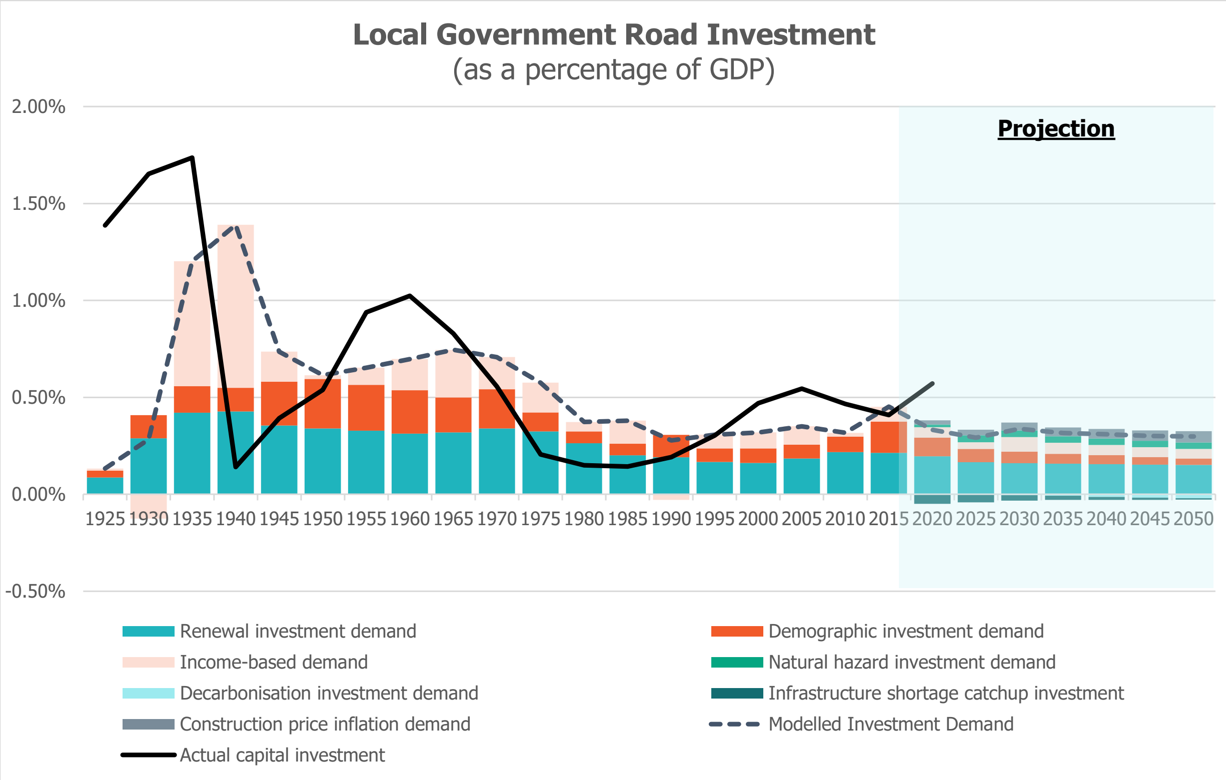
What we find is that total forecast investment beyond 2023 falls with a range of 5% to 7% of GDP, which is in line with our upper and low bound scenarios for our INA model. Interestingly, the results from the VAR model are nearly identical to the INA model. We consider this reasonable evidence to suggest that if investment if to go beyond this range, it is because there is an out-of-sample event or shift we are not capturing that will drive higher investment demand.

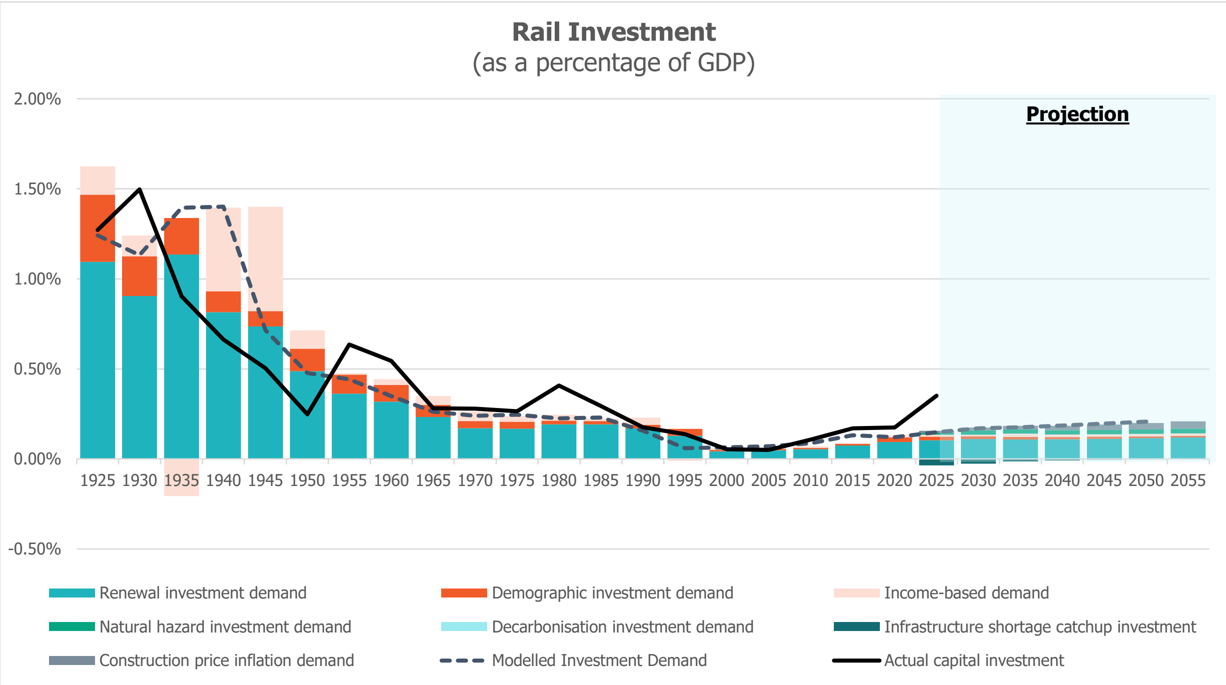
An overall interpretation of these models is that total investment is, in large part, a function of past investment. In the short, term, this could be as a result of investment plans which are typically carried out over several years. In the long term, past investment flows determine future investment flows through renewal needs. In addition to this autoregressive trend, as our INA model and these model demonstrate, population and income can drive deviations from long term average investment patterns. However, given the relatively smooth and subdued profile for income and population growth (based upon Stats NZ and Treasury forecasts), these models do not forecast a significant uptick in investment.

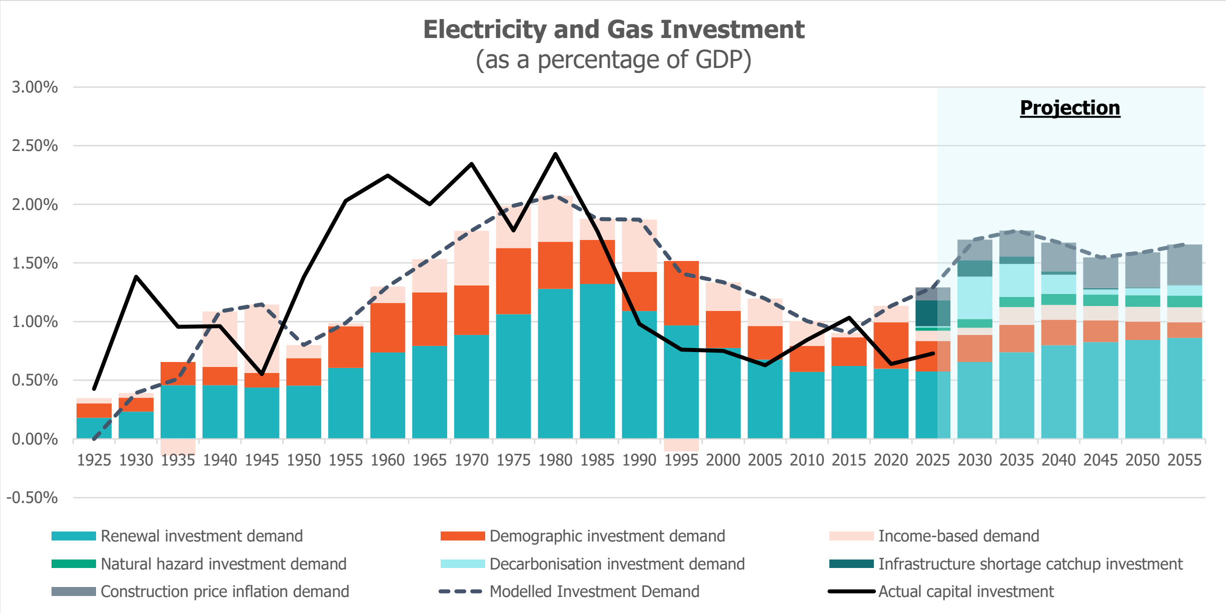
Appendix A: Sector-by-sector investment forecasts

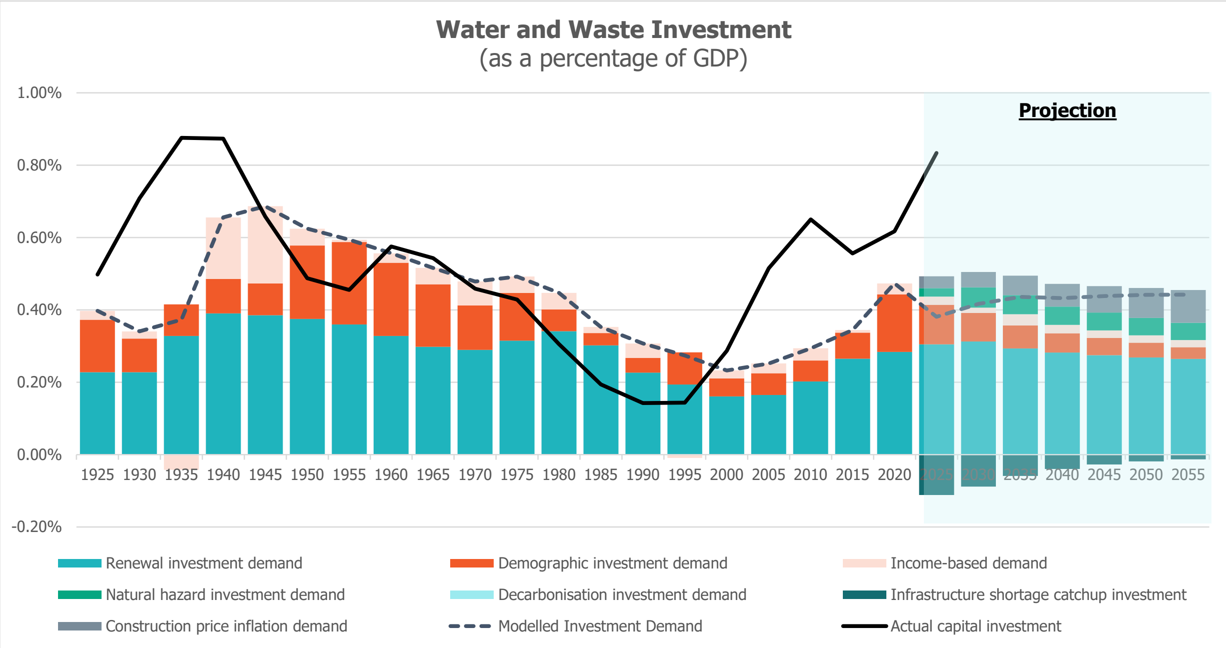


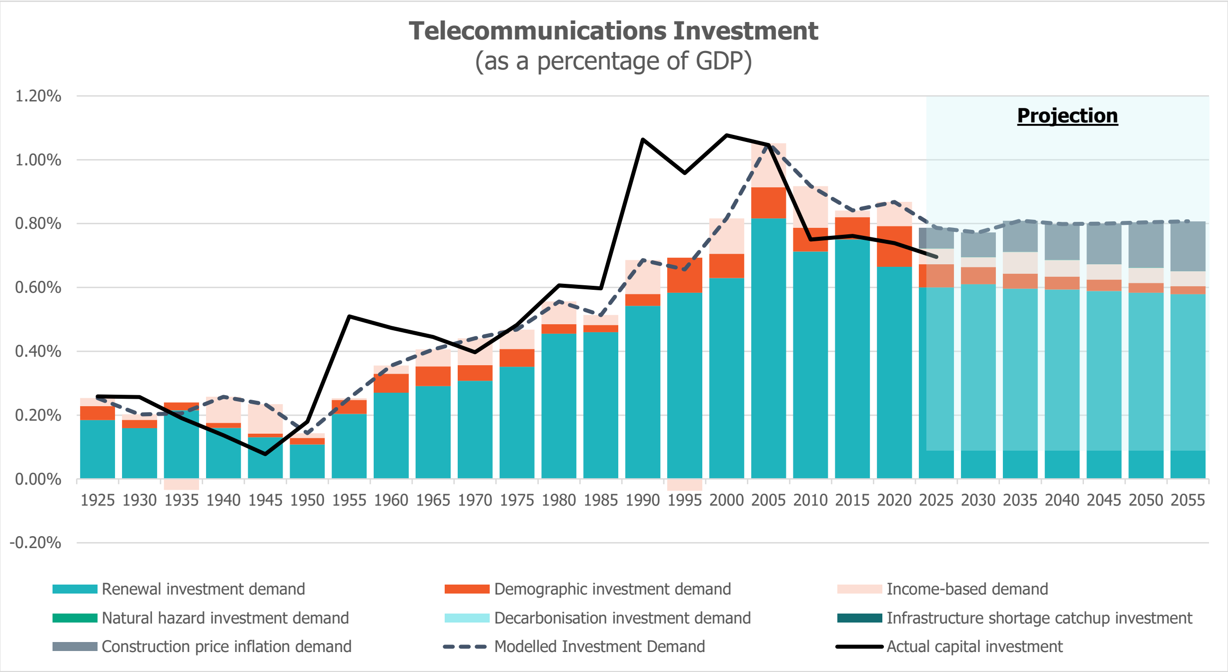



Local Government Road Investment
(as a percentage of GDP)
Projection
2.00%
1.50%
1.00%
0.50%
0.00%
-0.50%
1925 1930 1935 1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005 2010 2015 2020 2025 2030 2035 2040 2045 2050
Renewal investment demand
Demographic investment demand
Income-based demand
Natural hazard investment demand
Decarbonisation investment demand
Infrastructure shortage catchup investment
Construction price inflation demand
Modelled Investment Demand
Actual capital investment

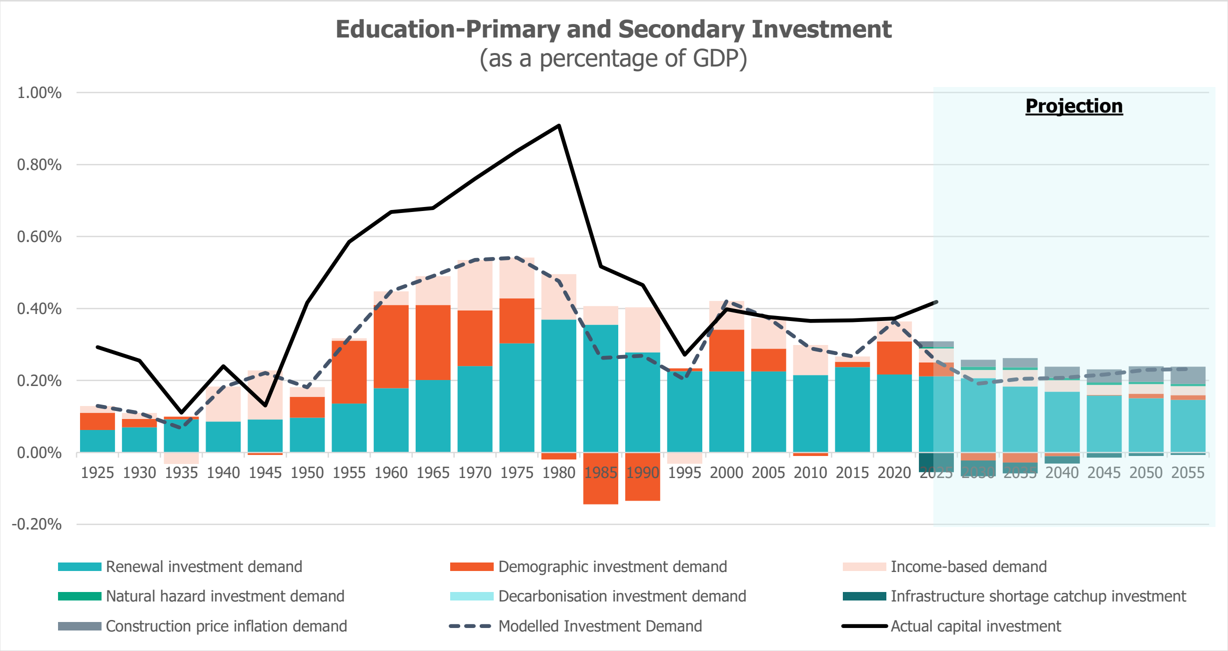

Rail Investment
(as a percentage of GDP)
Projection
2.00%
1.50%
1.00%
0.50%
0.00%
-0.50%
1925 1930 1935 1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005 2010 2015 2020 2025 2030 2035 2040 2045 2050 2055
Renewal investment demand
Demographic investment demand
Income-based demand
Natural hazard investment demand
Decarbonisation investment demand
Infrastructure shortage catchup investment
Construction price inflation demand
Modelled Investment Demand
Actual capital investment


Electricity and Gas Investment
(as a percentage of GDP)
3.00%
2.50%
2.00%
1.50%
1.00%
0.50%
0.00%
-0.50%
Projection
1925 1930 1935 1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005 2010 2015 2020 2025 2030 2035 2040 2045 2050 2055
Renewal investment demand
Demographic investment demand
Income-based demand
Natural hazard investment demand
Decarbonisation investment demand
Infrastructure shortage catchup investment
Construction price inflation demand
Modelled Investment Demand
Actual capital investment

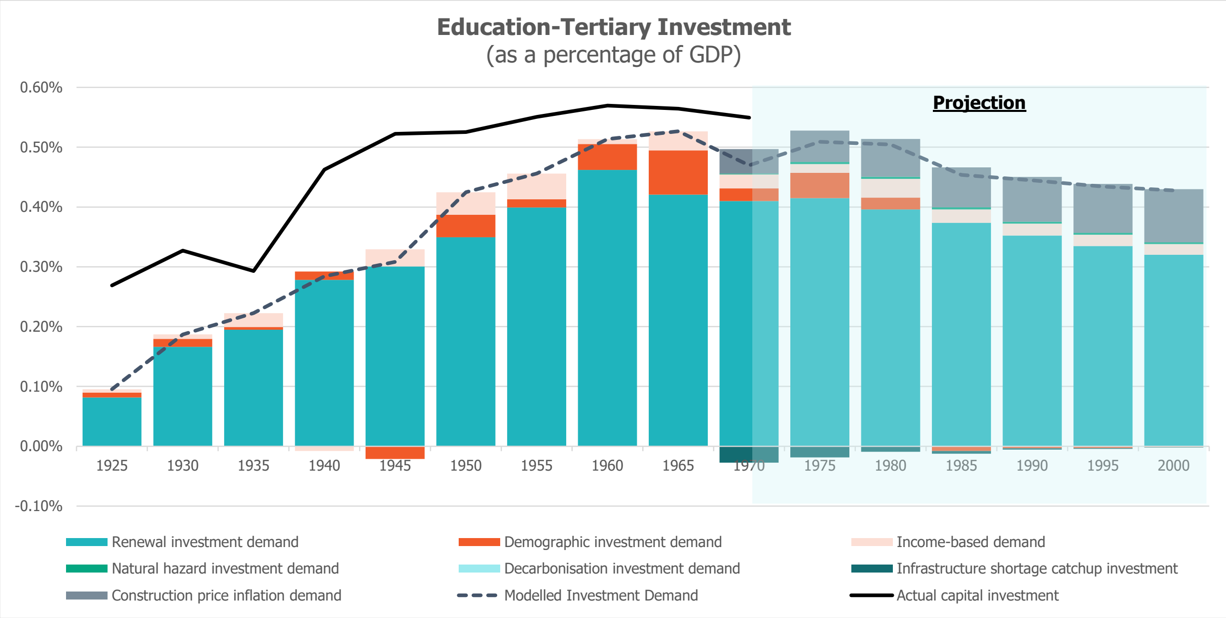

Water and Waste Investment
(as a percentage of GDP)
1.00%
0.80%
0.60%
0.40%
0.20%
0.00%
-0.20%
Projection
1925 1930 1935 1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005 2010 2015 2020 2040 2045 2050 2055
Renewal investment demand
Demographic investment demand
Income-based demand
Natural hazard investment demand
Decarbonisation investment demand
Infrastructure shortage catchup investment
Construction price inflation demand
Modelled Investment Demand
Actual capital investment

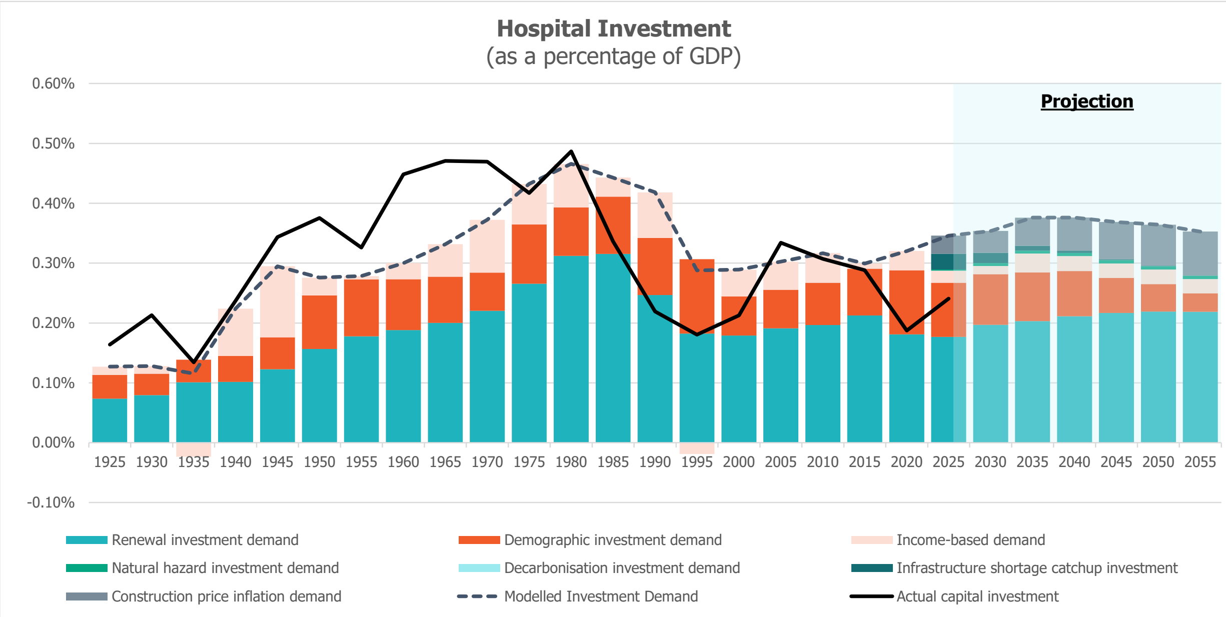


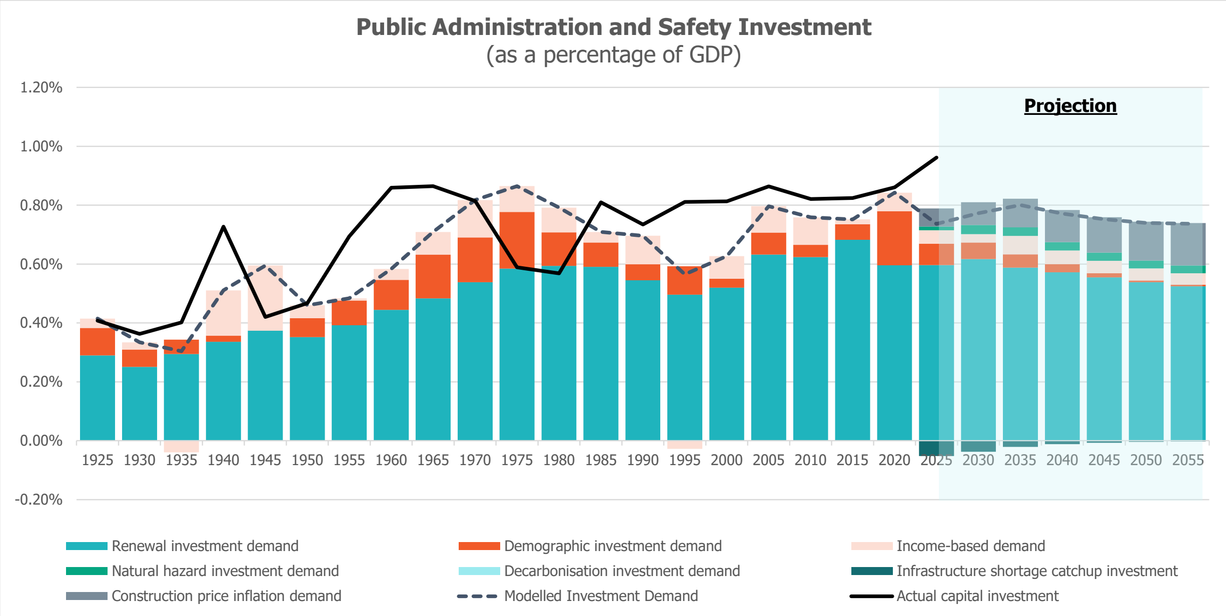
Telecommunications Investment
(as a percentage of GDP)
Projection
1.20%
1.00%
0.80%
0.60%
0.40%
0.20%
0.00%
-0.20%
1925 1930 1935 1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005 2010 2015 2020 2025 2030 2035 2040 2045 2050 2055
Renewal investment demand
Demographic investment demand
Income-based demand
Natural hazard investment demand
Decarbonisation investment demand
Infrastructure shortage catchup investment
Construction price inflation demand
Modelled Investment Demand
Actual capital investment

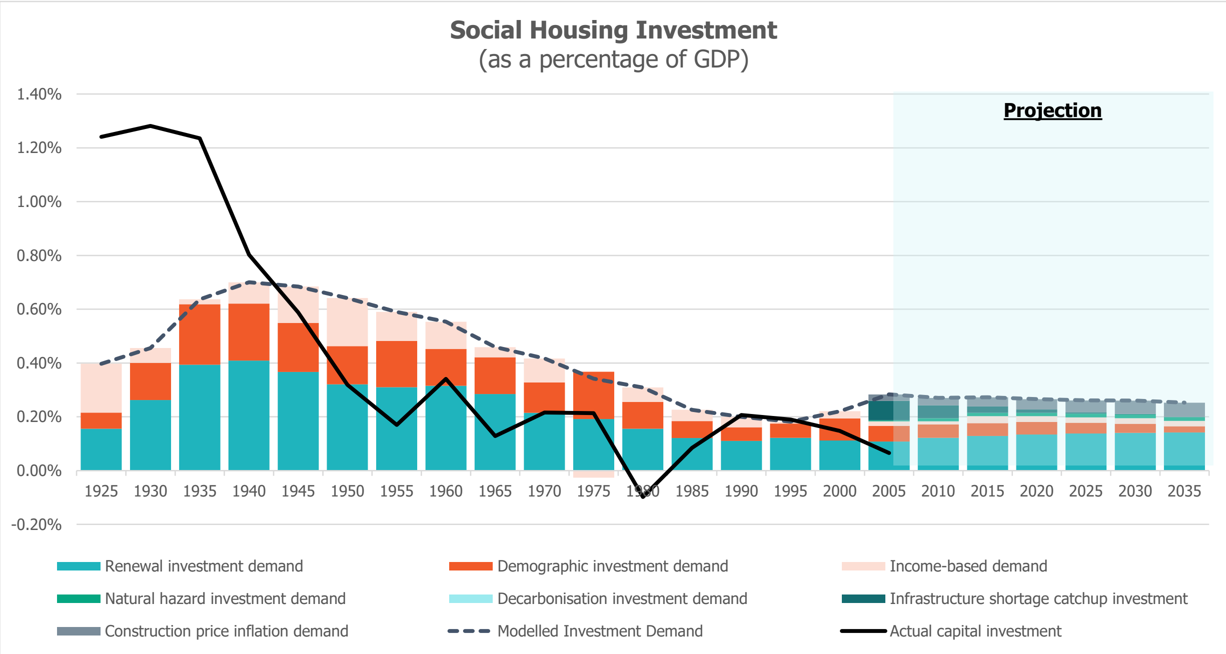


Education-Primary and Secondary Investment
(as a percentage of GDP)
Projection
1.00%
0.80%
0.60%
0.40%
0.20%
0.00%
-0.20%
1925 1930 1935 1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005 2010 2015 2020 2025 2030 2035 2040 2045 2050 2055
Renewal investment demand
Demographic investment demand
Income-based demand
Natural hazard investment demand
Decarbonisation investment demand
Infrastructure shortage catchup investment
Construction price inflation demand
Modelled Investment Demand
Actual capital investment

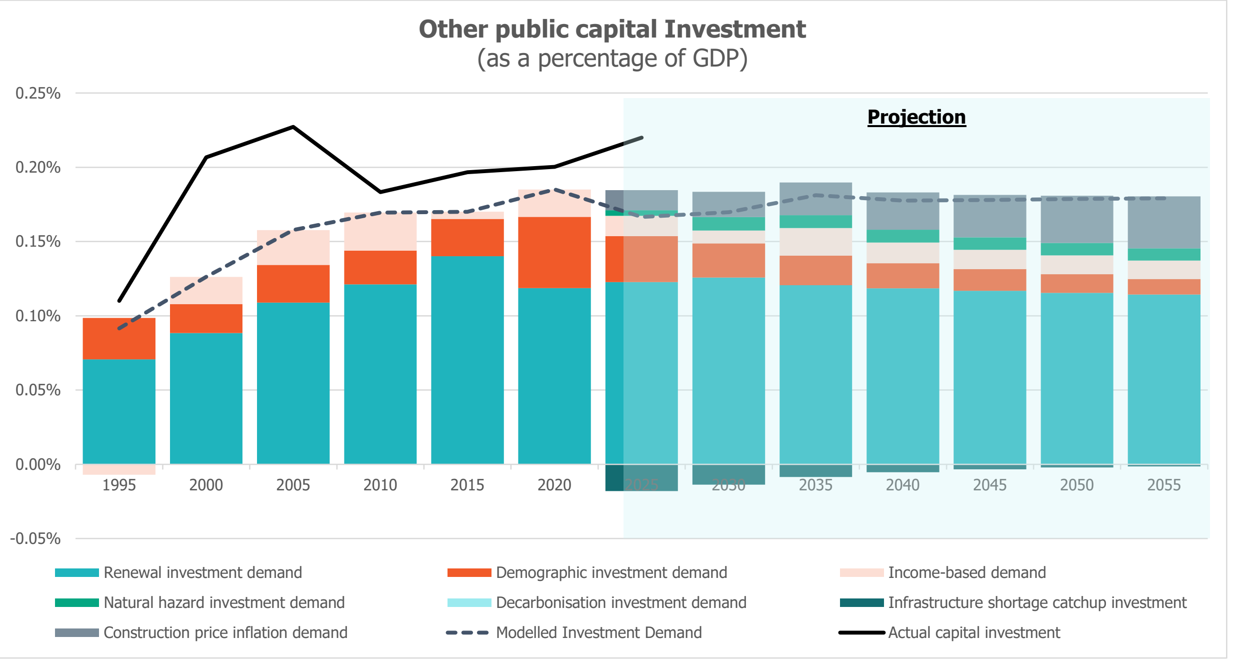

Education-Tertiary Investment
(as a percentage of GDP)
Projection
0.60%
0.50%
0.40%
0.30%
0.20%
0.10%
0.00%
-0.10%
1925 1930 1935 1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000
Renewal investment demand
Demographic investment demand
Income-based demand
Natural hazard investment demand
Decarbonisation investment demand
Infrastructure shortage catchup investment
Construction price inflation demand
Modelled Investment Demand
Actual capital investment


Hospital Investment
(as a percentage of GDP)
Projection
0.60%
0.50%
0.40%
0.30%
0.20%
0.10%
0.00%
-0.10%
1925 1930 1935 1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005 2010 2015 2020 2025 2030 2035 2040 2045 2050 2055
Renewal investment demand
Demographic investment demand
Income-based demand
Natural hazard investment demand
Decarbonisation investment demand
Infrastructure shortage catchup investment
Construction price inflation demand
Modelled Investment Demand
Actual capital investment





Note: we suspect that investment figures post-2018 may not contain investment by Kainga Ora. We are following up with Stats NZ about this and may update this forecast in a future version of the model.


Other public capital Investment
(as a percentage of GDP)
Projection
0.25%
0.20%
0.15%
0.10%
0.05%
0.00%
-0.05%
1995
2000
2005
2010
2015
2020
2030
2035
2040
2045
2050
2055
Renewal investment demand
Demographic investment demand
Income-based demand
Natural hazard investment demand
Decarbonisation investment demand
Infrastructure shortage catchup investment
Construction price inflation demand
Modelled Investment Demand
Actual capital investment