MERIT

Development of Reference Economic Futures

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Resilient ORGANISATIONS

GNS SCIENCE TE PŪ AO

m.e market economics research & consulting

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1. Overview

When we evaluate the future impact of investment or policy decisions, we often use models that represent the economy of today. But the future is unpredictable. When evaluating decisions, it is useful to think about the ways in which our economy might change and how this might influence the impacts of our current decisions.

Scenario analysis is a powerful tool to explore divergent possibilities for the future that cannot be predicted by extrapolation of past and current trends. Rather than advancing a single 'best guess' of the future, scenario analysis allows us to consider several alternative future trajectories.

The developed *reference economic futures* are not intended to be predictive, nor do they aim to forecast the future. Instead, the primary objective is to define a range of possibilities to test investment or policy decisions against. Stress testing decisions against a range of potential futures enables decision-makers to identify interventions, strategies and policies that are robust and adaptable in an uncertain world.

In this report we describe the process used to develop a set of three reference economic futures that can be used to test and evaluate investment decisions. Although these reference economic futures have been developed specifically for applications involving the MERIT (Modelling the Economics of Resilient Infrastructure Tool) Dynamic Economic Model, it is envisaged that they could also be used in a range of other modelling applications.

The focus in this work has been on determining possible future conditions in the world economy (for example technology change, level of environmental concerns) and the resulting implications for the New Zealand economy at a national level. When using these reference economic futures in modelling application, especially when it is necessary to consider outcomes for specific regions within New Zealand, researchers may need to extend the scenarios to incorporate any conditions or changes at sub-regional or local level.

The development of the reference economic futures commenced with a literature review of major national and international studies involving scenario analysis. From the review, four key uncertainties emerged as the most frequently cited, regardless of the context of the study: (1) economic growth; (2) global cooperation (economic and political co-operation); (3) technological change; and (4) prioritisation of environmental issues. A cluster analysis was then performed to identify groups of the reviewed scenarios with common assumptions. Three reference economic futures transpired from this process, which we named (1) Fragmented Future, (2) Techno-global Future, and (3) Green-oriented Future.[1] In addition, the Techno-global Future contains two sub-scenarios, which differ based on whether technological advances are relatively more job-replacing or job-augmenting. We then identified and quantified the inputs to change in the MERIT Dynamic Economic Model in order to be able to model each of the three reference economic futures.

Each of the reference economic futures described in this report are only intended to capture a future period of 1-1.5 generations. We envisage this is a sufficient period of time for current preferences, behaviours, and practices to change in order to influence new and potentially diverging outcomes. At the same time, it would be inappropriate to assume that a single future direction or trajectory would continue over a very long period, as over time economic systems are likely to be influenced by new outcomes and feedbacks, potentially leading to new trends and trajectories to take over. For example, a period of high economic growth and

[1] We emphasise here that these reference economic futures are *alternative* future states of the global economy. We therefore maintain that the ordering of these is inconsequential. That is, we do not purport that Fragmented Future is the most likely to eventuate since it appears first on the list; nor do we view Green-oriented Future as the 'best' future since it is the final future mentioned. We instead advise that each reference economic future be understood/interpreted as being a deviation from the current state of the world.

development may exacerbate environmental degradation and as a result be followed by increased environmental awareness and heightened actions to reduce human-induced environmental harm with economic structural change. Similarly, although one of the reference economic futures identified is oriented towards ‘green-oriented’ growth, societies’ knowledge of human-environmental relationships is changing over time, as are value systems, so the notion of green-oriented economic growth is likely to also evolve. The global economic is dynamic and the accuracy of predictions made today naturally diminishes the further into the future we consider. We therefore advise that our reference economic futures should be interpreted in light of these constraints.

The report is structured as follows:

Section 2 describes the methodology used to develop a set of three reference economic futures based on existing scenarios in the literature. This section also describes the basic narratives of each reference economic future;

Section 3 provides a brief overview of the MERIT Dynamic Economic Model and then describes in detail the model inputs that are likely to change in each reference economic future, along with how we determined their trajectories. This section also provides commentary on the implications of the transition to cleaner economic systems and details productivity changes, highlighting potential implications of technological change on the New Zealand labour market;

Section 4 describes how the diverging characteristics of the reference economic futures suggests that different consequences are likely to ensue in the event of a disaster in the future, depending on global and local economic changes. This section also discusses the varying degrees of socio-economic vulnerability of communities toward a disaster in each reference economic future.

2. Development of Reference Economic Futures

2.1 Identification of critical uncertainties

To inform the construction of our reference economic futures, we reviewed 30 future scenarios previously developed by other authors under 8 extant studies (see Table A1 in the Appendix). Scenarios are typically organised around drivers of change that are likely to have a profound yet unpredictable effect in the future. These key drivers of change often termed "critical uncertainties". A scenario is characterised by a unique set of trajectories for each of the critical uncertainties examined. We identified the critical uncertainties used to drive the scenarios in each of the reviewed studies and detail these in Table 1. The spectrum of potential trajectories of each uncertainty is also included in Table 1.

Table 1: Summary of critical uncertainties in the reviewed study scenarios

Study / Author origin	Scope of study / Geographical scope	Critical uncertainties	Spectrum	
World Energy Council (2016) UK	World energy outlook World	Policy co-operation Economic co-operation Technological change	Global co-operation Globalisation Slow/no technological change	Isolationism Fragmented Rapid technological change
World Economic Forum (2017) Switzerland	Future global food systems World	Economic co-operation Resource consumption	Connected markets Resource-intensive	Fragmented markets Efficient consumption
Ercin & Hoekstra (2014) The Netherlands	Future water footprint Europe & World	Economic co-operation Economic growth	Globalisation Economy-driven development	Regional self-sufficiency Environmental sustainability
IPCC (2000) Switzerland	Emissions scenarios World	Economic co-operation Environmental concern	Globalisation Low environmental conservation	Fragmentation High environmental conservation
Millennium Ecosystem Assessment (2005)	Evolution of ecosystem services World	Policy co-operation Economic co-operation Technological change	Global co-operation Globalisation Rapid technological change	Isolationism Regional self-sufficiency Slow technological change
Enriquez, Smit, & Ablett (2015) McKinsey & Company (Belgium, the Netherlands, USA)	Global economic outlook World	Economic growth rate Economic growth convergence Economic co-operation Technological change	Rapid growth Economic growth convergence Global connectivity High technology innovation	Slow growth Economic growth divergence Fragmented markets Slow/no technology innovation

NZ Productivity Commission (2018) New Zealand	Low emissions economy New Zealand	Technological change Industry composition change	Rapid technological growth No industry composition changes	Slow technological change High industry composition change
NZ Business Council for Sustainable Development (2003) New Zealand	Sustainable NZ future (energy) New Zealand	Economic growth Energy demand	High GDP Low energy demand	Low GDP High energy demand

The critical uncertainties vary between studies, as they are largely context specific and are often determined based on the objective of the assessment. However, we found that three critical uncertainties appear frequently, regardless of the context of the study. These are: (1) economic growth; (2) global co-operation (economic and policy co-operation); and (3) technological change. The environment, and humanity's efforts to protect or restore it, was also included in some of the studies. Because of the potential significant implications for the economy at large, we are including the prioritisation of addressing environmental challenges (i.e. the level of concern over environmental sustainability) as a fourth critical uncertainty that, along with the other three uncertainties, will underpin our reference economic futures.

2.2 Clustering scenarios

Each critical uncertainty has a spectrum of possible outcomes and we need to realistically combine the uncertainties to generate a set of reference economic futures that are both internally consistent and cover a wide range of possible future pathways. Leveraging the existing work that has gone into developing the scenarios reviewed in Table 1, we performed a cluster analysis to consolidate the existing reviewed scenarios into groups with shared trajectories of the uncertainties.

In general terms, a cluster analysis seeks to group a set of objects in such a way that the objects are more similar to those within the same group than to those in other groups. That is, a cluster is a collection of objects that exhibit high intra-class similarity and low inter-class similarity. The greater the similarity within a cluster and the greater the difference between clusters, the better or more distinct the clustering. In our case, the cluster analysis identifies clusters of scenarios with common assumptions.

The scenarios typically describe critical uncertainty trajectories as being either low or high relative to the current pathway (i.e. medium/baseline). For example, in the case of global co-operation, 'low' suggests regional economies that have become self-sufficient, 'high' suggests globalisation, and 'medium' is representative of the current regime, which is akin to a balance of the two extremes.

To enable the cluster analysis, a 3-step numerical scale (low – medium/baseline – high) was created for each critical uncertainty, see Table 2. These values were used to score or categorise each scenario in Table 1. If the uncertainty was not mentioned in the study, we assigned the numerical value corresponding to the medium/baseline trajectory, since the scenario is effectively assuming no change to the specific uncertainty. To group the scenarios, both *Hierarchical clustering* and *K-means cluste*ring were carried out and compared (Everitt, Landau, Leese, and Stahl, 2011).

Table 2: Discrete numerical scale for the four critical uncertainties

Numerical scale	Economic growth	Global co-operation	Technological change	Environmental focus
1	Slower growth	Increased fragmentation	Slow technological change	Low priority
2	Current level of growth	Current regime	Current level of technological change	Medium priority
3	More rapid growth	Increased globalisation	Rapid technological change	High priority

K-means clustering with the *Hartigan–Wong algorithm* produced potential groupings for between 2 and 10 clusters. *Silhouette* analysis from these groupings enabled us to investigate the optimum cluster numbers. We found that the greatest separation (highest silhouette score) was highest for large numbers of clusters, indicating some inconsistencies between the combinations of uncertainties in the reviewed scenarios. Indeed, this result is somewhat expected given the nature of silhouette analyses. That is, the more clusters that are formed, the more distinct the clusters are, and therefore a higher silhouette score is calculated. However, scenario analyses typically examine around three to four scenarios, as more than that would often complicate or confuse communication of the analysis. Focusing on the lower numbers of clusters, the results showed that grouping into three clusters performed better than four (for the groupings found by the k-means algorithm).

Agglomerative hierarchical clustering with *Euclidean distance* as the distance metric and *complete-linkage criterion* were chosen in order to identify fewer and more aggregated groups. The dendrogram generated from the hierarchical cluster analysis is shown in Figure 1, where height is a measure of dissimilarity between clusters. An example of how to create clusters by cutting the dendrogram at an appropriate height is shown with coloured boxes for the four cluster solution.

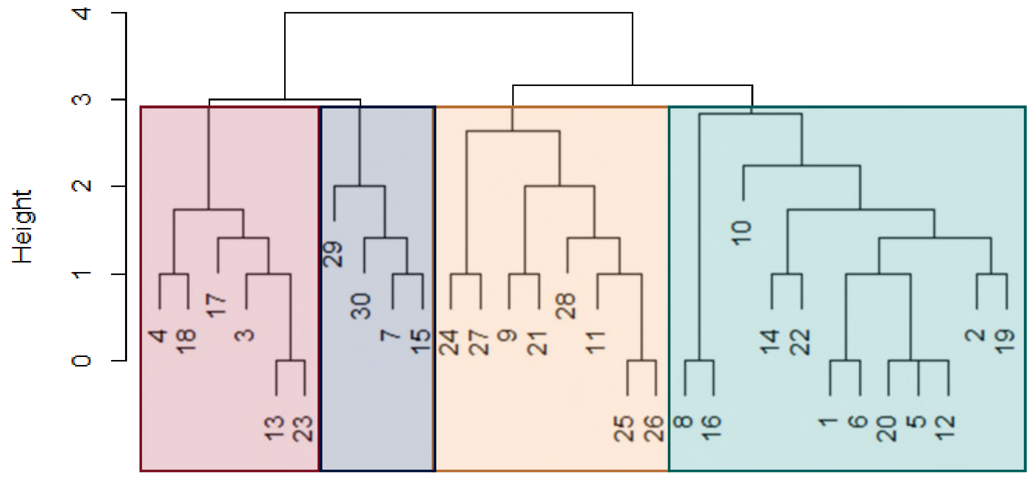

Figure 1: Hierarchical clustering – dendrogram (Euclidean distance, Complete-linkage), showing how four clusters would be selected. Note: the number displayed beneath each branch of the dendrogram represents a numbered scenario from the literature.

2.3 Selection of cluster groupings

To decide whether to base our reference economic futures on the clusters formed by either of the two different clustering methods, we plot the *Hierarchical* clusters by each possible pair of the critical uncertainties (six in total) and compare these against the corresponding plots of the *K-means* clusters.

Mappings of the clusters produced by either of the two methods on a two-dimensional feature space shows rather indistinct clustering as objects are somewhat poorly grouped. However, this is to be expected since the clusters are mapped according to only two of the four critical uncertainties at a time, and therefore some information used to develop the clusters are missing. Nevertheless, a visual comparison of the plots reveals that the K-means clustering method produces clusters that are relatively more coherent; that is, clusters whose members are relatively less sparse over the feature space. We therefore use these three clusters of existing scenarios to form our three reference economic futures.

To determine the trajectory of each critical uncertainty for each reference economic future (i.e. cluster), we start by taking the average score among the cluster's members. For example, the average economic growth scores among the scenarios grouped under cluster 2 (Techno-global Future) is approximately three and so this reference economic future is characterised by high economic growth. In some cases, however, we adjusted the score in order to create variation and to align with the literature. As an example of this process, the economic growth trajectory for cluster 1 (Fragmented Future) was inconclusive, falling between medium and low, with the other attributes of the reference economic future being increased regionalisation and slow technological change. Others have asserted that such economies turn inward and thus are limited to local resources (World Energy Council, 2016; Enriquez *et al*., 2015; New Zealand Business Council for Sustainable Development, 2003). We therefore decided to allocate cluster 2 a low growth trajectory.

The selected critical uncertainties for the three reference economic futures created in this process are provided in Table 3, on the 3-step numerical scale from Table 2 (low – medium/baseline – high). It is important to note that although the cluster analysis provided a strong first step by consolidating existing literature on global economic scenarios; our informed judgement was applied to the clustering results to produce the final reference economic futures.

Table 3: Reference economic futures

Reference economic future	Economic growth	Global co-operation	Technological change	Environmental focus
Fragmented Future	Low	Low	Low	Low
Techno-global Future	High	High	High	Medium / baseline
Green-oriented Future	Medium / baseline	Medium / baseline	High	High

2.4 Narratives for the created reference economic futures

To build the narrative of each reference economic future, we draw upon the descriptions of the existing reviewed scenarios within the same cluster and with the same score as the cluster.

Reference economic future 1: Fragmented Future

This reference economic future depicts a fragmented world, where countries are increasingly concerned with national security and protection. Nationalist interests prevent countries from collaborating effectively on a global level, leading to slower global economic growth, and a weakening of the social fabric. Low prioritisation of environmental concerns leads to irreversible environmental damage. Key features of the reference economic future are:

- Breakdown in partnerships across global institutions, governments, and industry and private investors

- Fewer and weaker multilateral trade agreements as protectionism supplants free trade
- Markets are increasingly disconnected as economies turn inward and pursue self-sufficiency
- Export businesses, in particular, suffer from volatile markets, decreased trade, and inconsistent access to raw materials
- Global growth is slower than historically observed as poor countries face resource limitations and wealthier countries serve smaller markets
- Real interest rates remain in the low to negative territory, but the bleak growth outlook fails to encourage renewed investment and provides limited economic incentive to invest in R&D
- Isolationist policies inhibit migration, restrict access to information, and impede the diffusion of new technologies. Technological innovations are confined to fewer regions and are adopted based on the availability of local resources
- An individualistic sentiment dominates, leading to failures in managing global commons. Environmental policies focus on securing national natural resources

Reference economic future 2: Techno-global Future

This reference economic future describes a state of the world in which economic growth is high and international trade is liberalised. A highly competitive market landscape drives efficiency, innovation, open access to information and rapid deployment of new technologies. Key features of the reference economic future are:

- Removal of trade and migration barriers as well as revivals of cross-border activity due to the proliferation of free market agreements
- Booming markets as trade accelerates
- Global interest rate returns to 'old normal' levels of pre-GFC years
- Rapid diffusion of innovations is bolstered by broader trade agreements
- Digital economy brings revolutionary change in many industries and helps upskill the workforce, ultimately improving productivity across sectors
- Energy and commodity prices are buoyed as productivity-induced supply gains cannot keep pace with greater demand
- Fossil fuel continues to dominate, albeit with a notable uptake of biofuel and battery technology

Sub-scenarios: Informed by the approach taken by the NZ Productivity Commission (2018) in developing their rapid technological change scenario, we create two sub-scenarios for Techno-global Future – one in which the nature of technological advances has a significant negative impact on employment in New Zealand (job-replacing) and one in which technological growth is more of the nature of job-augmenting and thus significant job losses are not experienced (job-augmenting):

1. Job-replacing
    - Technological change that disrupts current economic structures, with new technologies and products creating new markets, destroying demand in traditional industries
    - New technologies are focused on automation, replacing existing jobs
2. Job-augmenting
    - Rapid technological change that stabilises existing industry structures
    - Technology is designed and implemented to be labour-augmenting, increasing the productivity of the existing workforce

Reference economic future 3: Green-oriented Future

In this reference economic future, the world is making a transition toward a cleaner, more sustainable economy. There are co-ordinated efforts to address the challenge of climate change. New societal goals and behaviours pursuant to a 'shared economy' ideology clearly emerge. Growth in GDP is qualitatively different as environmental conservation and energy efficiency are emphasised ('green GDP'). Key features of the reference economic future are:

- Wide consensus on the importance of making renewable energy sources more reliable and more widely affordable
- Reduced dependence on fossil fuels as the use of biofuel and battery technology drastically expands
- Resource-efficient consumption as demand for traditional meat and dairy products declines, while the demand for timber as a substitute for emissions-intensive building materials rises
- Cleaner industry activity is a focus, with a reduction in agrochemical use
- Governments provide policy support for conservation projects through an extensive network of financial incentives such as green subsidies and carbon pricing
- With changing preferences and devotion of significant resources to creating and implementing environmental practices and technologies, global household consumption is moderate

Baseline scenario

In the context of this study, the baseline scenario is characterised by recent trends projected forward in time (i.e. business-as-usual). This scenario is intended to be the point of reference against which our three reference economic futures are compared.

Discrete and continuous numerical scales

In order to perform the cluster analysis, a discrete numerical scale was necessary to measure the key uncertainties, as it enabled us to clearly score each existing reviewed scenario. By consequence, the cluster analysis also resulted in unambiguous, distinct groups of scenarios. As intended, this made the narratives of each reference economic future, and the scenarios to draw upon and imitate, clear. However, when we are considering how these reference economic futures sit within the full 'space' of potential futures, it more reasonable to recognise that each type of uncertainty has many different potential outcomes other than just the three initially considered (ie. low, medium and high) and indeed could probably be measured instead by a continuous numerical scale. As is attempted to be represented by Figure 2, there is thus a vast range of potential trajectories that could be selected, of which only three have been chosen.

The use of a continuous scale in Figure 2 is also helpful in communicating where we believe the Green-oriented Future is positioned in relation to environmental concerns. The primary characteristic that embodies our Green-oriented Future is a re-orientation of perspectives where households, firms and governments are more conscious of the implications of their decisions and actions on the environment and more dedicated towards achieving sustainability. Although the Green-oriented Future has a much stronger environmental focus than either of the two other futures selected, it is certainly possible to envisage other futures where environmental focus is still stronger. For this reason, we place our trajectory for the environmental focus uncertainty as being located between medium and high, albeit closer to high, for this scenario. It is also worth noting that no judgements have been made as to whether the actions taken, and behavioural changes described, for the Green-oriented Future will indeed achieve 'sustainability'.

In translating the reference economic futures onto Figure 2 and its continuous numerical scales we have also placed other scenarios which scored 'high' for an uncertainty at points below the upper most extreme of each scale. This is to further illustrate the possibility of other scenarios with more extreme outcomes. Nonetheless, the set of described trajectories for the Fragmented Future and the Techno-global Future remain materially the same.

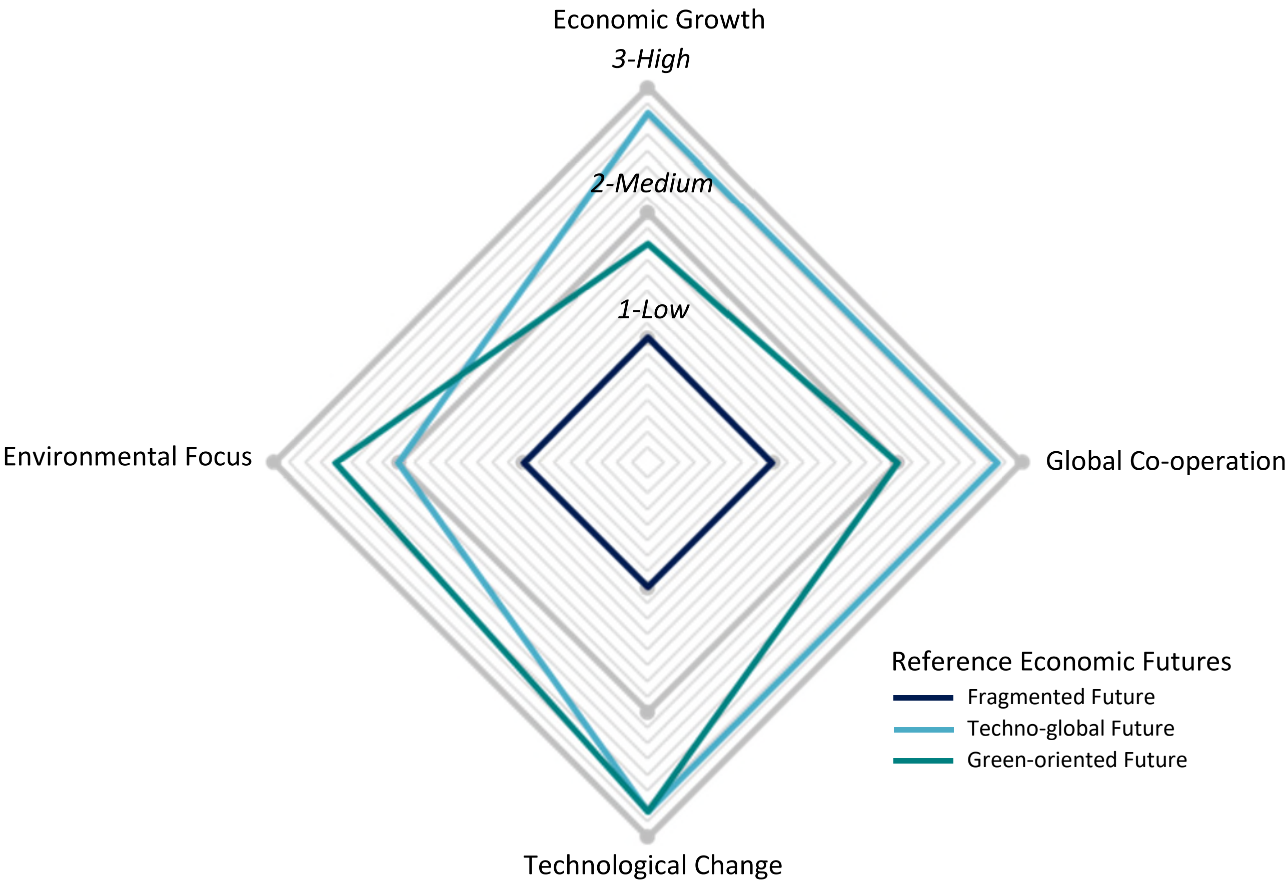

Figure 2: Possible alternative economic futures – Continuous key uncertainties

3. Economic model inputs for reference economic futures

3.1 Overview

MERIT is an integrated decision support system that enables an assessment, through time, of the economic consequences of disruption events.

Central to MERIT is a multi-sectoral, multi-regional and fully dynamic economic model (i.e. MERIT Dynamic Economic Model) which is intentionally designed to imitate the core features of a Computable General Equilibrium (CGE) model. CGE models tend to be the favoured approach and considered 'state-of-art' in modelling of regional and national-level economic impacts. Among the advantages of these types of models are the whole-of-economy coverage, the capture of not only indirect (i.e. so-called upstream and downstream multiplier effects generated through supply chains) and induced (i.e. as generated through household consumption) impacts, but also the 'general equilibrium' impacts (i.e. price changes, factor substitution and transformation).

Although MERIT incorporates the core features of a CGE model, it is formulated as a System Dynamics model using finite difference equations. This is an innovative extension to economic modelling undertaken in part to improve our ability to capture the impacts of events over time. Standard economic models are 'equilibrium' models that describe conditions of demand for all commodities and factors when a set of pre-determined conditions are met i.e. supply equates to demand for commodities and factors, and income equates to expenditure for all economic agents. MERIT however is a simulation model, acknowledging that in meeting these constraints there is a transition pathway through which the economy must pass. MERIT is particularly useful when dealing with natural hazard events as it can directly account for out-of-equilibrium dynamics that often emerge in a disrupted economy.

When using the MERIT Dynamic Economic model, we essentially simulate an economic system, producing a set of core indicators that change over time (e.g. industry value added, employment, Gross Domestic Product). The simulations produced by the model depend on the structure (equations and connections) within the model and the parameters/ input data used in each simulation. Running different scenarios in the model essentially involves using different sets of parameters/input data. The following sections of this report describe the different types of inputs, and the way in which these inputs are altered, in order to run the three reference economic futures.

Details on how the suite of MERIT tools was developed, how it works, and previous applications are available in a series of research reports, journal articles and conference presentations. Some key publications are listed below:

- Buxton, R.; Wright, K.C.; Daly, M.C.; Timar, L.; Mieler, D. (2014) *Single Infrastructure Failures: capturing outage information for MERIT - Modelling the Economics of Resilient Infrastructure Tool.* Economics of Resilient Infrastructure Research Report 2014/01. 56p.
- Smith, N.J., Zhang, Y., Cardwell, R., McDonald, G.W., Kim, J.-H., and Murray, C.F. (2015). *Development of a Social Accounting Framework for New Zealand*. Economics of Resilient Infrastructure Research Report 2015/01. 71p.
- Brown, C., Giovinazzi, S., Seville, E., Vargo, J., Stevenson, J.R. (2015) *Developing the Business Behaviours Module within MERIT*. Economics of Resilient Infrastructure Research Report 2015/02. 71p.- addendum added January 2016.

- Deligne, N.I.; Blake, D.M.; Davies, A.J.; Grace, E.S.; Hayes, J.; Potter, S.; Stewart, C.; Wilson, G.; Wilson, T.M. 2015. *Economics of Resilient Infrastructure Auckland Volcanic Field Scenario*, Economics of Resilient Infrastructure Research Report 2015/03. 151 p.
- Smith, N.J.; McDonald, G.W.; Kim, J-H. (2016). *Economic Impacts of the State Highway 4 Outage – June 2015*, Economics of Resilient Infrastructure Research Report 2016/03. 15 p.
- Smith, N.J., Harvey, E., and McDonald, G.W. (2016). *Dynamic Economic Model. A technical report*. Economics of Resilient Infrastructure Research Report 2017/02. 109p.
- McDonald G, Smith N, Kim J.-H, Brown C, Buxton R, Seville E. 2018. Economic Systems Modelling of Infrastructure Interdependencies for an Alpine Fault Earthquake in New Zealand. *Civil Engineering and Environmental Systems*, DOI:10.1080/10286603.1018.
- Brown C et al. 2019. Accounting for Business Adaptations in Economic Disruption Models. *Journal of Infrastructure Systems*, 25, doi:10.1061/(ASCE)IS.1943-555X.0000470

3.2 Export and import commodity prices

Export and import commodity prices are exogenous time series inputs in the model. Each of the reference economic futures requires projections for commodity prices through time.

Consistent with the high economic growth observed in the Techno-global Future, the world price of all commodities are assumed to be growing at a faster pace relative to the baseline projections. To execute this, we increased the quarterly growth rate of the baseline commodity price projections by 0.1 percentage points, this is equivalent to an increase in the annual growth rate of just over 0.4 percentage points. I.e., a price that was growing at an annual rate of 2% would now be growing at approximately 2.4%.

In the Green-oriented Future, the focus on environmental sustainability implies that the prices of crop-related commodities will be growing faster (by 0.1 percentage points per quarter) than the baseline projections, while fossil-fuels- and plastics-related commodities will be growing slower (0.1 percentage points per quarter) than the baseline projections. The price forecasts of all other commodities, however, are unaffected by the change in policy objective and so will follow the baseline projections.

In the Fragmented Future, the prices of export and import commodities also follow the baseline projections as the world commodity price is assumed to continue 'business-as-usual'. However, to reflect the effect of isolationism on commodity prices, tariffs are introduced in this reference economic future and imposed on imported commodities (see Import tariffs section below).

The figures below plot both the historical time series (black lines) and the trajectories (coloured lines) that the commodity price indices are assumed to follow in each reference economic future. Using petrol as an example, Figure 3 shows the three different price trajectories of fossil-fuel- and plastics-related commodities. Figure 4 illustrates the projections of crop-related commodities, using grain products as a representative commodity. All other commodities including wood, chemicals, metal products, and manufactured goods, for example, are assumed to follow the trajectories modelled in Figure 5.

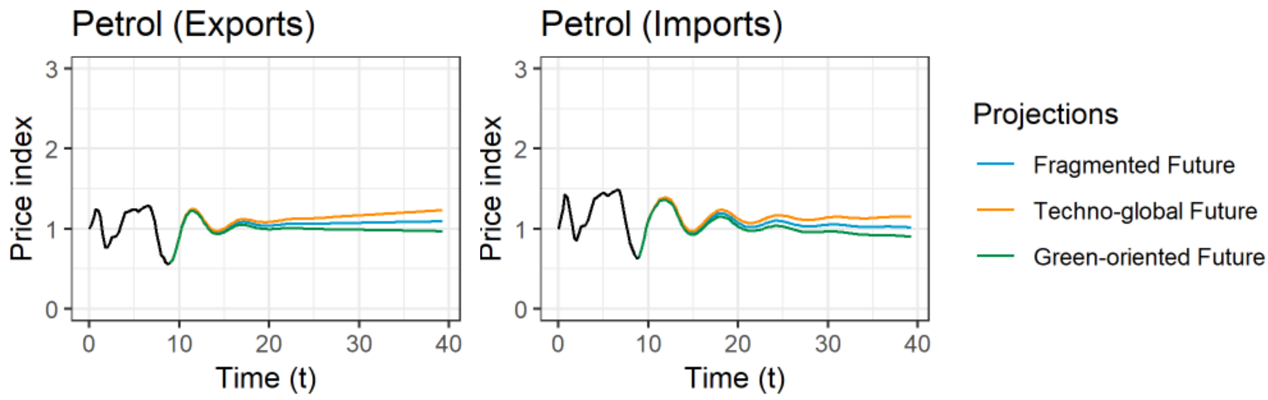

Figure 3: Fossil-fuel- and plastics-related commodities are high for the Techno-global Future, medium/baseline for the Fragmented Future (but with tariffs imposed), and low in the Green-oriented Future.

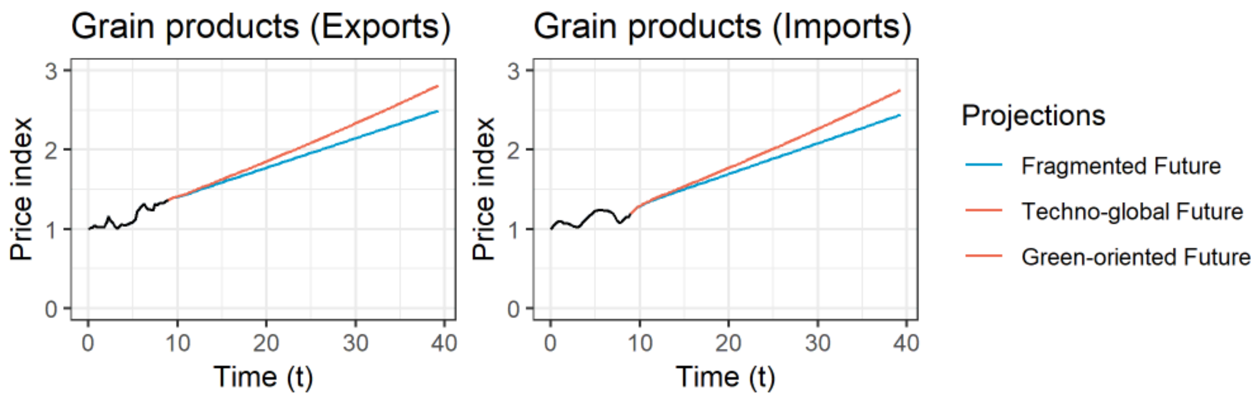

Figure 4: Crop-related commodities are high in the Techno-global Future and the Green-oriented Future, and medium/baseline in the Fragmented Future

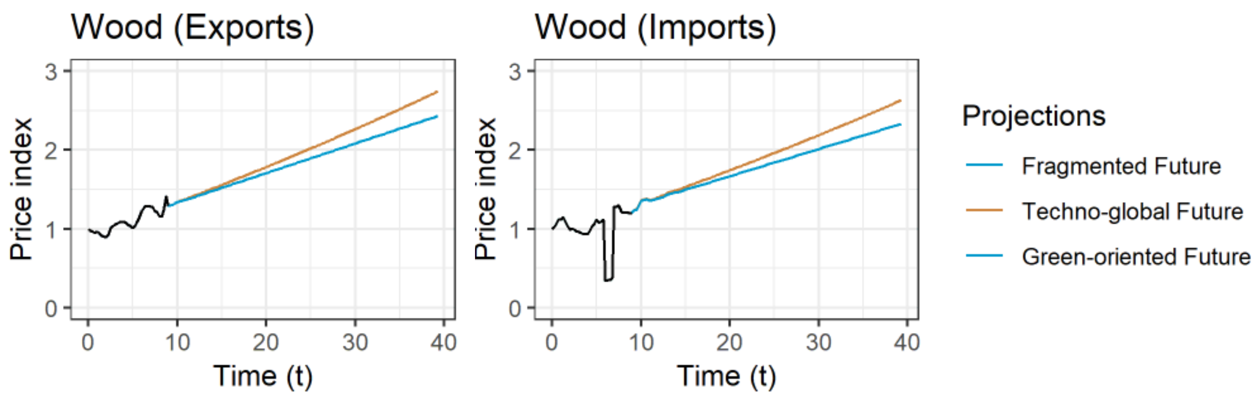

Figure 5: All other commodities are high in the Techno-global Future and medium/baseline in the Fragmented Future and the Green-oriented Future.

Forecasting commodity prices

The following describes the econometric methodology used to develop the baseline projections of the price indices of traded commodities over a 30-year horizon.

Available historic data

Statistics New Zealand (hereafter, Stats NZ) publishes the Overseas Trade Price (OTP) index, which measures the relative change in the price levels of imports and exports of merchandise and service trade data to and from New Zealand. The data are classified using the New Zealand Harmonised System Classification (NZHSC) in which there are over 18,600 10-digit items. The OTP index is high-level as it is an aggregation of all of these 10-digit items to a grouping of 35 commodities.

We however aim to forecast a larger set of commodities. Accordingly, we formed a set of commodity trade price indices which aggregates the NZHSC 10-digit items to a set of 205 commodities (hereafter, 205IOC price indices). This is the same commodity classification used in Stats NZ's national supply and use tables.

Forecasting approach

To forecast the 205IOC price indices, we adopted a hybrid modelling approach which combined two forecasting methodologies – endogenous multivariate regression modelling and dynamic regression modelling – and used both the OTP index series and the 205IOC price index series.

Although we ultimately aim to forecast the 205IOC price indices, the OTP indices were used to establish the relationship between commodity prices given that these indices are relatively less 'noisy' than the 205IOC price indices, precisely because they are of a higher level of aggregation. Our forecasting approach is two-stage.

First Stage

A Vector Autoregressive (VAR) or Vector Error Correction (VEC) model was used to forecast a given group of correlated OTP indices since these models treat all variables in the system as endogenous, capturing underlying feedback and bi-directional relationships among the OTP indices.

Ideally, we would apply a VAR/VEC model on groups of correlated 205IOC price indices directly, rather than the OTP indices. However, doing so is likely to result in over-specification since many indices at the 205IOC level are likely to be correlated. The problem with over-specified models is that it increases the estimation error which may inadvertently offset the advantages of including additional indices for greater insight when forecasting. With the OTP indices, fewer variables enter the system, simplifying specification and estimation, while still capturing the relationship between commodity prices.

The OTP indices included in VAR/VEC framework were those not only strongly correlated (as determined by a correlation analysis) but also whose co-movement could be justified which eliminates the possibility of spurious correlation. The inclusion of additional interdependent variables indeed strengthens the accuracy of resulting forecasts as more information is used to understand the dynamics of the indices. In contrast, simpler forecasting approaches, particularly exponential smoothing models, forecast a time series variable based solely on the past of the variable without considering the potential influence of external factors.

In fact, the VAR/VEC framework not only considers interdependence but also recognises that macroeconomic variables, such as commodity price indices, typically display autocorrelation. Accordingly, the VAR/VEC modelling included lagged terms of the indices in the system. For most of the groups of OTP indices, a maximum of two lags was found to be sufficient to capture the dynamics of the indices over time.

The decision to forecast using either a VAR or VEC model ultimately depended on the characteristics of the OTP indices in terms of trend. If the data were stationary, then we ran a VAR model (VAR in levels); if the data were non-stationary but also cointegrated, then we ran a VEC model; if the data were not stationary nor cointegrated, we differenced the data to achieve stationarity, then fitted a VAR model (VAR in differences).

In our analysis, majority of the groups of OTP indices were non-stationary in levels and so were forecasted using a VAR in differences; some groups were stationary in levels and so were forecasted using a VAR in levels; and fewer than three groups of OTP indices were found to be non-stationary and cointegrated which were forecasted using a VEC model.

Forecasts produced by a VAR and VEC model are generated in a recursive manner. That is, with each step ahead, the errors are set to zero, the parameters of the model are replaced by their estimates, and the unknown values of the indices are replaced by their forecasts. Forecasts generated by a VAR in differences however are not of the same scale as the original data. To back-transform the forecasts and return them to the original scale, we cumulatively added the regression forecasts to the last cumulative observation. A flow-chart of the steps involved in stage 1 of forecasting is provided in Figure 6 below.

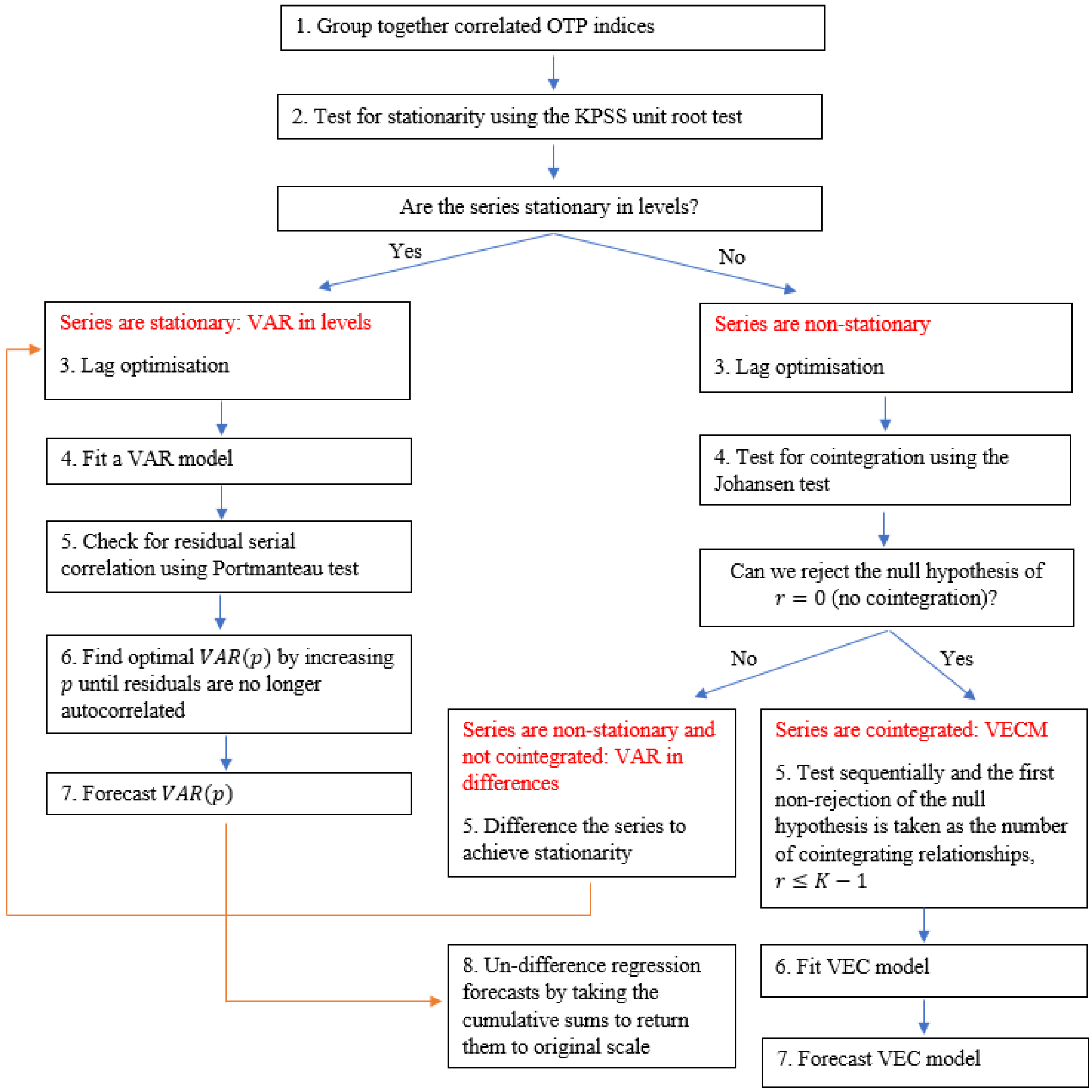

Figure 6: Flow-chart of stage 1 forecasting

Second stage

The second stage of our hybrid modelling approach used a dynamic regression model to forecast each of the 205IOC price indices that correspond to the previously forecasted set of OTP indices (according to the concordance between the two price index series).

The dynamic regression model extends the Autoregressive Integrated Moving Average (ARIMA) model by allowing the inclusion of additional exogenous predictors. Accordingly, the set of OTP indices that were forecasted in stage 1 were included in the regression and thus, the forecasts thereof were used to forecast the 205IOC price indices. The advantage of this is that the underlying relationship between commodity prices captured in the forecasts of the OTP indices were used to forecast the 205IOC price indices. In this way, we are able to account for interdependence when forecasting the 205IOC prices, albeit indirectly, without risking over-specification as would be the case if we instead applied a VAR/VEC model. Essentially, our structure of the dynamic regression model, which included the VAR/VEC-generated forecasts, performed as a quasi-endogenous multivariate regression model.

One limitation of our hybrid modelling approach is that the forecasts of the dynamic regression model do not consider the uncertainty in the forecasts of the exogenous predictors. The forecasts of the 205IOC price indices should therefore be interpreted as being conditional on the estimated future values of the OTP indices.

Correcting for downward trending price indices and ETS models

By definition, the value of an index cannot fall below zero. Our methodology, however, often predicted negative values for those 205IOC price indices with observations close to zero and trending downward. For these indices, we used an ETS model to ensure the forecasts would remain strictly positive.

3.3 Import and export tariffs

A key feature of the Fragmented Future is the loss of international co-operation in trade. We assume that this will be accompanied by the introduction of import tariffs. In the case of imports into New Zealand, this can be applied directly in the economic modelling by an '*ad valorem'* import tariff (i.e. a tariff that is calculated as a *percentage increase* in the current price) on domestic goods. Note that these tariffs also operate as a form of tax income and therefore increase government's budget.

In the case of exports, we do not model the rest of the world economy and so do not need to model the flow of income generated from export tariffs. We simply apply a 'pseudo' *ad valorem* tariff that causes the price 'experienced' by the rest of the world for New Zealand's goods to increase. This serves to alter the demands by the rest of the world for New Zealand goods.

3.4 World GDP and world interest rate

World GDP

Fragmented Future characterises a fragmented and disconnected world economy. Given that economies are increasingly turning inward, it is reasonable to assume world GDP growth to be lower than the baseline projections.

Techno-global Future is characterised by thriving global growth and liberalised international trade. Accordingly, this reference economic future assumes world GDP growth to be higher than the baseline projections.

The natural consequence of altering the qualitative composition of GDP to be better aligned with environmental sustainability is a slowdown in GDP growth. We therefore assume world GDP growth in the Green-oriented Future to be slightly lower than the baseline projection.

World interest rate

In the Fragmented Future, we assume that economies have failed to stimulate aggregate demand and continue to rely on unconventional monetary stimulus. Accordingly, we assume that the global interest rate remains low.

In the Techno-global Future, we assume that in the major economies, the liquidity resulting from past unconventional monetary policies is gradually absorbed or withdrawn thereby returning the global interest rate to pre-GFC levels.

In the Green-oriented Future, we assume that the global interest rate returns to the pre-GFC levels, as in the Techno-global Future.

3.5 Trade in Services

Over the last few decades we have seen the rapid globalisation of markets for professional services such as IT, banking and customer services. As ongoing globalisation is also a key tenant of the Techno-global Future, it is considered appropriate for this trend to continue and even intensify under this reference economic future. With ongoing globalisation, it is envisaged that many of New Zealand's service industries will be at a comparative disadvantage compared to their global counterparts, as New Zealand is a small country and thus has likely less ability to capitalise on the agglomeration of services into key centres and networks.

In order to create a future that sees New Zealand's service sector receive a declining share of service trade (both for services required by the New Zealand domestic market and services required by the international market) we apply:

1. A 'pseudo' ad valorem negative price on imported services. For New Zealand consumers this makes the price of international services appear relatively cheaper than the equivalent New Zealand services, and thus demands for New Zealand produced services will decrease relative to imported services.

2. A 'pseudo' ad valorem positive price on exported services. For international purchasers of services, this makes New Zealand services appear relatively more expensive compared to international services, leading to a decline in the international demand for New Zealand services.

3.6 Productivity and Labour Markets

Total Factor Productivity

At present, the model incorporates a total factor productivity (TFP) index that is used to adjust the initial calculation of industry production (based on available capital and labour inputs), to account for growth in productivity over time. For all industries, the index is set at 1 at t=0, but adjusts upwards or downwards over time, depending on the reference economic future

Using annual data published by Stats NZ, dating back to 1978, we forecast the TFP index of each industry over a 30-year horizon. The resulting point forecasts form the baseline projections, upon which the forecasts for each reference economic future are based.

A visual analysis of the multifactor productivity (MFP) index of each industry over time reveals that the data are trending, which suggests that the observations may be serially dependant. Accordingly, we used the standard macroeconomic forecasting model, the ARIMA model, which specifically accounts for potential autocorrelation by including lagged terms of the index in the regression.

The $auto.arima()$ function in R selects the most suitable ARIMA model for a given MFP index. Given that the data for some indices also displayed cyclical behaviour, we amended the function to include a stochastic trend in the regression. In doing so, we account for trends in the data that increase and decrease inconsistently, as opposed to including a deterministic trend which assumes that the slope of a trend does not change over time. Furthermore, given our long forecast horizon, it was considered safer to forecast with stochastic trends rather than deterministic trends as the wider prediction intervals allow for greater uncertainty in future growth.

- *Fragmented Future* – Under this reference economic future, restricted access to external/offshore resources drives efficiency down. In this case, it is reasonable to assume the TFP rate to be growing at a slower rate than the baseline projections for all industries.
- *Techno-global Future* – Under this reference economic future, efficiency gains (e.g., productivity, technical) are inevitable with the rapid development and increased adoption of new technologies. It is therefore reasonable to assume the TFP growth rate of all industries to higher than the baseline projections described above.
- Green-oriented Future – We assume the TFP rate to align with the baseline rate for all industries except the agricultural and energy industries. For these industries, a decreased TFP rate is assumed due to the necessary adoption of mitigation/adaptation measures which consequently dampens the rate of growth in 'effective' output in these industries.

Implications of technological change on labour markets

The Techno-global Future splits into two sub-scenarios, each focusing on a different impact that technological change might have on the workforce. Under the 'job-replacing' sub-scenario, it is assumed that the new technologies enable greater automation of processes thereby leading to the redundancy of labour. Under the 'job-augmenting' sub-scenario it is assumed that new technologies improve the efficiency and productivity of economic processes, with minimal disruption to labour markets.

To help implement these dynamics, two sets of exogenous time series, respectively termed LABINDEX and CAPINDEX are added to the model. These time series specify, for each industry, an index that commences at 1 and adjusts upwards over time. Each industry's supply of labour is multiplied by the LABINDEX, providing the 'effective' supply of labour factors, while each industry's stock of capital is multiplied by its CAPINDEX, producing the 'effective' supply of capital for each industry.

Due to the use of nested *Constant Elasticity of Substitution* (CES) functions in the economic modelling (refer to Smith *et al*. 2016), these changes to the productivity as specified by the MFP index discussed above occur on top of the productivity changes resulting from increases in the LABINDEX and CAPINDEX indices.

Perhaps somewhat counterintuitively, it is a significant appreciation in the LABINDEX of an industry compared to its CAPINDEX that causes losses in jobs. This occurs because while labour effectively becomes cheaper and the productivity growth will drive some expansion in economic production, it is also the case that less people are required to do the same task, so less people need to be employed.

Since no assumptions were made in the Fragmented Future and the Green-oriented Future regarding the impact of technology on the workforce, the capital and labour parameters remain at 1 for both reference economic futures.

3.7 Transition to cleaner economic systems

Economic systems operate within the environment, using natural resources to produce products and producing residuals such as greenhouse gas emissions and other wastes as by-products. A movement towards cleaner, more sustainable economic systems is likely to be highly complex, entailing a scale-back in the size of economic activities, as well as changes in production methods and consumption patterns such that similar functions are performed while consuming less resources and producing less wastes. In creating the Green-oriented Future, which is focused on improvements in environmental performance, we have considered it necessary to pick out a few additional economic features or trends that are likely to be involved in an environmentally sustainable transition, above those already highlighted so far. We have chosen to focus specifically on changes in the tax system and the way in which investment funds are allocated, as discussed further in the subsections below.

Taxes on greenhouse gas emissions

The tax system is a key mechanism that can be used by policy makers to encourage movements towards cleaner production (e.g. through taxing the highest polluters), incentivizing changes in consumption choices (e.g. because consumers will face higher prices for certain goods) and funding investments in new technologies and sustainability research. There are many different types of taxes that could potentially be used, and many different types of pollutants or environmental quality issues that could be targeted (e.g. greenhouse gases/climate change, freshwater water quality, biodiversity).

Recognising the immense importance of climate change risks, we have focused specifically on the possibility of new production-based taxes (i.e. taxes charged on businesses producing goods and services) based on their level of greenhouse gas emissions. These taxes operate as an additional tax over and above any of the normal taxes already faced by industries. The taxes are also applied only in the case of the Green-oriented Future. Like other taxes, in the economic modelling the government is the recipient of any additional tax payments and thus these funds form part of the government's budget to spend on savings/investments, pay for climate change adaptations, purchase goods and services on behalf of populations, or to fund payments of any negative taxes (i.e. subsidies).

Investments in cleaner technologies

An important aspect of the transition to a more sustainable economic system will be that some of the technologies used within the economic system (includes equipment, infrastructure, energy harnessing processes etc) will not be considered appropriate for continued use because there are alternative technologies that would produce less environmental harm. There is also likely to be a need to undertake investments in completely new types of technologies that, while producing better environmental outcomes, do not necessarily result in any increase in the level of outputs that can be produced from economic activities. For the purposes of the economic modelling, we can think of this as the need to retire and replace capital despite that capital not otherwise being at the end of its economic life, or the use of investment funds to create capital that does not increase production activities. Either way, the outcome is the expenditure of investment funds on creating new capital without any material gain in the quantity of 'effective capital' available to the economic system. We have implemented this trend within the Green-oriented Future that a proportion of capital investments during each year does not add to any industry's capital stock. Like in the case of greenhouse gas emissions taxes, this trend is applied only in the case of the Green-oriented Future.

Structural changes and consumption changes

In accordance with the transition to a more sustainable economic system, we would expect from industries and households an accelerated uptake of alternative technologies that would produce less harm to the environment. For example, we would expect an increased use of timber to substitute emission-intensive building materials such as concrete and metal across the construction industry. Consequently, investment in timber is likely to rise to accommodate the greater demand.

The aim to reduce greenhouse gas emissions could also be achieved by switching away from fossil-fuels as a source of energy. For example, we would expect demand by the transport industry and households for vehicles with internal engines to decline concurrently with the rise in demand for electric motors. Households may also be encouraged to invest in local generation of power (particularly solar), which would in turn reduce reliance on the electricity industry to power their homes. Moreover, the strive for cleaner systems would see industries increasingly replace coal with more sustainable forms of energy to power their production processes. The greater emphasis on environmental sustainability and conservation may prompt a shift in the dietary consumption of households towards more plant-based foods. On the production side, a related trend would be an increasing proportion of plant-based foods used in food manufacturing.

4. Community susceptibility to disasters

While not modelled in this project, the alternative reference economic futures will change socio-economic vulnerability to, and impact of, disaster events. In this section we aim simply to highlight some important considerations that may need to be covered in addition to the trends and issues highlighted above, particularly when modelling applications relating to future economic and societal resilience to disasters. Implementing these additional components of scenarios in MERIT does not necessarily involve changes to the Dynamic Economic Model – many of the changes required will occur in other models/modules that form part of the MERIT suite (e.g. the Business Behaviours Model).

Reference economic future 1: Fragmented Future

In this reference economic future, organisations are going to be more reliant on local, regional and national markets – for both the supply of goods and for their customers. Thus, in a regional disruption event (like an earthquake or weather event) there is likely to be an increase in disruption to both customers and suppliers compared to current conditions.

Reference economic future 2: Techno-global Future

The rapid technological growth within this reference economic future will likely lead to an increased dependence on electricity and data networks. Increased connectivity (internet of things, cloud computing, autonomous vehicles, cryptocurrencies) and reliance on electricity (electric vehicles, advanced robotics, 3D printing, knowledge work automation) will mean communities and economies will be much more heavily impacted by disruption to these critical infrastructure services. For some industries technological growth will also mean that there is a high dependence on equipment (computers, machinery) to meet demands, which if damaged in an earthquake or other disruptive event may take longer to replace.

The potential for cascade failures and the dual risks of natural and man-made threats (such as cyber attack) may also increase the impact of hazard events.

As part of a process of technological growth and implementation, it is possible that concerted efforts will also be made to increase resilience to disruption (e.g through more robust design or redundant system design). If this occurrs, some of the above effects could be mitigated.

Sub-scenario – Job-replacing

In a scenario where technology replaces jobs, and organisations are less reliant on people to meet demands, organisations will become less place-dependent. This could mean that in situations where there is significant population relocation, businesses are able to relocate and return to full production more quickly (without spending time finding or training skilled staff). Increased unemployment will also introduce social problems that may negatively impact societal resilience to disruption.

Reference economic future 3: Green-oriented Future

In this reference economic future, organisations will be less reliant on fuel but more reliant on electricity or other alternative sources of energy – to commute to work, to produce and transport commodities. Depending on technology advancements in the supply of energy this will likely change the vulnerability of communities and economies to disruption rather than reduce it. With a moderate level of technology growth there will also likely be increased reliance on data services.

Depending on the blend of modes and systems used to replace fossil fuel driven cars, there may also be an increased vulnerability to transport system disruption. Currently transportation disruption is driven by physical disruption to roads or fuel supply. If integrated, centrally managed transportation systems increase (public transport) there will be vulnerability to transport service disruptions. On the flip-side, a focus on reduced resource use may also encourage distributed and home-based working arrangements.

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6. Appendix

Table A1: Reviewed scenarios from the literature

Study		Reviewed scenario	Economic growth	Global co-operation	Technological change	Environmental focus
World Energy Council (2016)	1	Modern jazz	High	High	High	High
	2	Unfinished symphony	Medium / baseline	High	High	Medium / baseline
	3	Hard rock	Low	Low	Low	Low
World Economic Forum (2017)	4	Survival of the richest	Medium / baseline	Low	Medium / baseline	Medium / baseline
	5	Unchecked consumption	High	High	High	Medium / baseline
	6	Open-source sustainability	High	High	High	High
	7	Local is the new global	Low	Low	Medium / baseline	High
Ercin & Hoekstra (2014)	8	Global market	High	High	High	Low
	9	Regional markets	High	Low	High	Medium / baseline
	10	Global sustainability	Low	High	High	High
	11	Regional sustainability	Medium / baseline	Low	High	High
IPCC (2000)	12	A1	High	High	High	Medium / baseline
	13	A2	Low	Low	Low	Medium / baseline
	14	B1	Medium / baseline	High	Medium / baseline	High
	15	B2	Low	Low	Low	High
Millennium Ecosystem Assessment (2005)	16	Global orchestration	High	High	High	Low
	17	Order from strength	Medium / baseline	Low	Low	Low

	18	Adapting mosaic	Medium / baseline	Low	Medium / baseline	Low
	19	TechnoGarden	Medium / baseline	High	High	High
Enriquez, Smit, & Ablett (2015)	20	Global synchronicity	High	High	High	Medium / baseline
	21	Pockets of growth	High	Low	Medium / baseline	Medium / baseline
	22	Global deceleration	Medium / baseline	High	Medium / baseline	Medium / baseline
	23	Rolling regional crises	Low	Low	Low	Medium / baseline
NZ Productivity Commission (2018)	24	Policy driven	Medium / baseline	Medium / baseline	Low	High
	25	Disruptive decarbonisation	Medium / baseline	Medium / baseline	High	High
	26	Stabilising decarbonisation	Medium / baseline	Medium / baseline	High	High
NZ Business Council for Sustainable Development (2003)	27	Growth	High	Medium / baseline	Low	High
	28	Transformation	High	Medium / baseline	High	High
	29	Shielded	Low	Low	High	High
	30	Conservation	Low	Medium / baseline	Medium / baseline	High