Economics of Fuel Supply Disruptions and Mitigations

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Executive Summary

Fuel is a key economic enabler. Disruptions to fuel availability and/or price changes potentially have considerable impacts across both regional and national economies. Understanding the potential impacts of disruptions can help decision-makers to determine the best mitigation and management strategies.

MBIE has engaged Market Economics Ltd (M.E) to evaluate the economic consequences of fuel outage scenarios, with and without mitigation options, to improve New Zealand's fuel security. The economic evaluation is undertaken using MERIT's (**M**easuring the **E**conomics of **R**esilient **I**nfrastructure **T**ool) Dynamic Economic Model (www.merit.org.nz). MERIT is a state-of-the-art, integrated, spatial decision support system that enables a high-resolution assessment across space and through time of the economic consequences of infrastructure failure.

MERIT is applied to five disruption scenarios: 1) international fuel disruption; 2) long-term refinery outage; 3) short-term refinery outage; 4) long-term disruption to RAP/Wiri[1]; and 5) short-term disruption to RAP/Wiri. The disruption scenarios and mitigation options used were predominantly developed by Hale and Twomey (2012 and updated by Twomey and West (2017)) and NZIER (2012).

International Disruption

The international disruption scenario involves a 10% reduction of global crude oil supply for a duration of around six months, which is triggered by a major international event. It was suggested that such an event has a 25% probability over a 10-year period (i.e. 2.5% per annum) of occurring.

The direct impacts considered in the MERIT modelling of the international supply disruption are principally the changes in export/import commodity prices and export demands. As estimated by Twomey and West (2017), this includes an initial price increase of around 74% for a 10% supply disruption. Release of emergency stocks, globally, will help to alleviate supply shortages so that the experienced oil disruption will settle at 5%, with an associated price increase of 37%.

The total estimated impact on New Zealand's GDP over the first year is $\$_{2017}$1.58 Billion or a 0.6% drop in GDP. There is an increase in the total value of imports relative to the total value of exports which causes some depreciation of the exchange rate. The losses are felt fairly evenly across all industry sectors, especially those dependent on fuel as inputs to production, those that rely on tourism, and those that rely on imported commodities experiencing relatively high price increases. The oil and gas exploration industry, however, shows increases in value added under the scenario as it benefits from the higher global fuel prices.

No mitigation options were modelled for the international disruption scenario. This was because it was considered that the most pertinent mitigation for fuel disruptions, i.e. additional domestic fuel storage, would most likely be used as a replacement for New Zealand's IEA 90-day stock holding requirement, rather than an additional storage. In an international supply disruption, IEA will collectively manage these emergency stocks, and will determine when to release the stock at market rates. A significant

[1] This involves a disruption to Wiri storage terminal

fuel price increase would still be experienced, even if some of the emergency fuel stocks are held domestically. We nevertheless note that having IEA-required fuel storage in New Zealand, rather than abroad, could potentially reduce the time lag for obtaining fuel stocks, and potentially reduce transportation costs. We have not included any assessment of these benefits in this report.

If New Zealand did choose to hold additional domestic storage, but maintain the same system of ticket contracts, this additional storage could potentially be drawn down during an international disruption in addition to the stocks mobilised by IEA. However, as the fuel stored will inevitably be small relative to global supply/demand, it is not envisaged that this extra storage will significantly impact the global price of fuel. Thus, much of the causes for economic disruption in New Zealand (e.g. flow-on changes in commodity prices, loss of tourism demands) would remain.

Domestic Disruption – Refinery Outage

Marsden Point refinery is New Zealand's only refinery and a vital link to the local petroleum supply chain. Two refinery disruption scenarios were included in this analysis:

- *Long-term refinery outage*: a 6-week disruption to the refinery (the time it takes to re-establish full supply via imports). The annual probability of occurrence of this event is estimated at 0.20-0.25%.
- *Short-term refinery outage*: a 3-week disruption to the refinery. The annual probability of occurrence of this event is estimated at 0.5-1.0%.

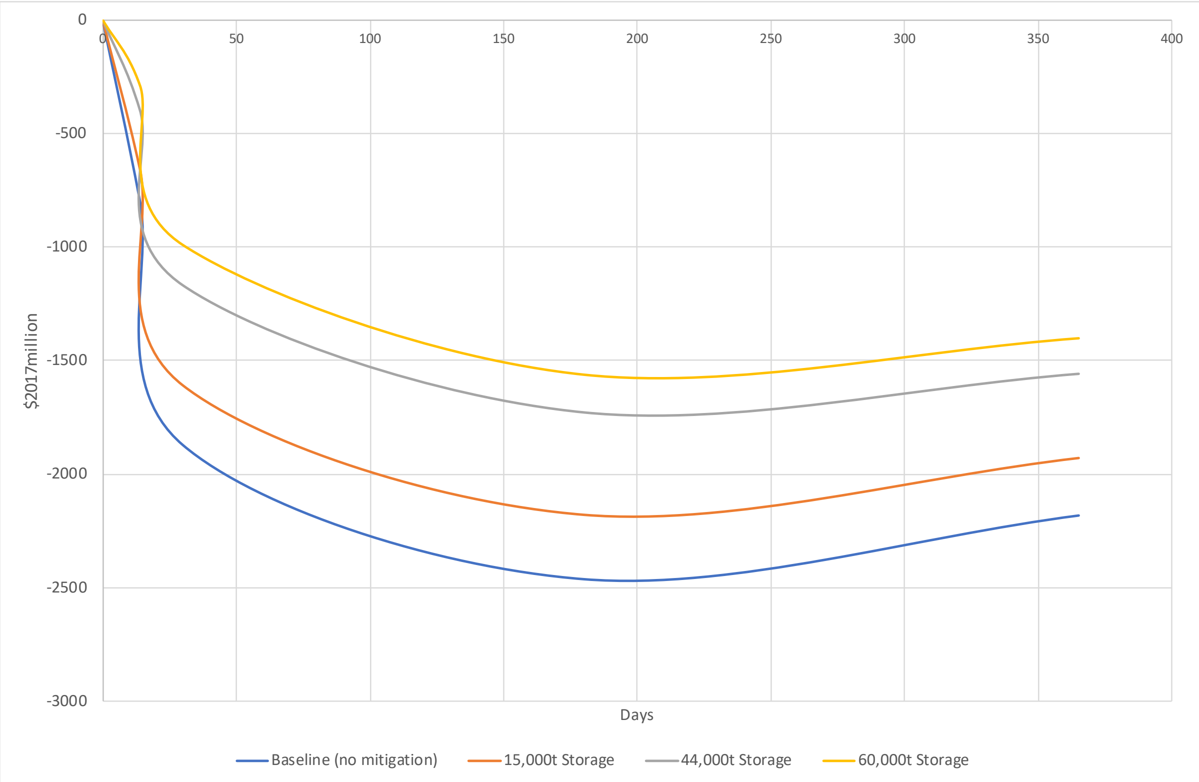
The analysis was conducted with and without the inclusion of mitigation measures. The primary mitigation option included was fuel storage – 15,000t, 44,000t and 60,000t storage options.

The long-term refinery outage scenario causes a loss of nearly $2.2 billion or 0.8% of GDP over the entire year of analysis. While such percentages may not seem significant, these are indeed large in the context of a disruption event and have the potential to be serious, particularly if realised during a period of relatively poor economic performance. For example during the 2009 global financial crisis, although New Zealand's GDP fell by only 1.6%, unemployment climbed to 7.3% in early 2010 (Becken & Lennox, 2012).

Given the relative value added contributions of industries to total GDP, value added impacts are overrepresented in the primary and manufacturing sectors, and underrepresented in the service sectors. For example, while manufacturing and tertiary industries currently constitute around 11% and 82% respectively of total industry value added, they are responsible for 25% and 67% respectively of the total value added loss under the scenario. Notably, one of the industries included within the manufacturing sector is the petroleum refining industry which is directly impacted and experiences significant losses in production under this scenario. GDP impacts are, nevertheless, relatively evenly spread across the country, with just under a third (32%) of the total GDP loss over one year being in Auckland and the remainder in the rest of New Zealand.

With the application of the storage mitigation, the estimated GDP impact over the year for a long-term refinery outage reduces by $250, $620, and $780 million for 15,000t, 44,000t and 60,000t storage options respectively. The reduced losses to GDP enabled by storage do not increase linearly with the volume stored. For the 15,000t, 44,000t and 60,000t storage options the reduced losses to GDP per unit volume of storage are calculated as $16,700/t, $14,000/t and $13,000/t respectively. Note that these calculations did not account for the costs and implications of putting in place the storage in the first place. The largest benefits of the mitigation (i.e. reduced losses to industry value added) are felt in trade and hospitality, followed by transport and storage, and construction.

The short-term refinery outage scenario causes a loss of nearly $80 million over a year of analysis. The majority of the losses in this scenario are felt in the manufacturing industry, with the lion's share being in the petroleum manufacturing industry itself. The storage mitigation reduces the net loss of GDP by $30, $40, $50 million in the event of a short-term refinery outage for the 15,000t, 44,000t and 60,000t storage options respectively. As for the long-term refinery outage scenario, the additional storage volumes offer reducing returns on investment (i.e. avoided losses to GDP) in this scenario.



Long-Term Refinery Outage Scenario – Cumulative Impact on New Zealand's Gross Domestic Product, with and without Storage Mitigations

Domestic Disruption – Wiri Storage Terminal / Refinery to Auckland Pipeline Disruption

These two disruption scenarios are regional- rather than national-based and both involve outages to the infrastructure supplying fuel into Auckland with implications for fuel supply in the Upper North Island:

- *Long-term RAP/Wiri disruption*: involves a disruption to the Wiri Storage Terminal that causes a reduction in normal petroleum/diesel supply for 60 days as supplies are reestablished from neighbouring terminals. Jet fuel experiences a longer disruption of four months while an alternative supply mechanism to Auckland Airport is established. The probability of the event is estimated at 0.2-0.3% per annum.

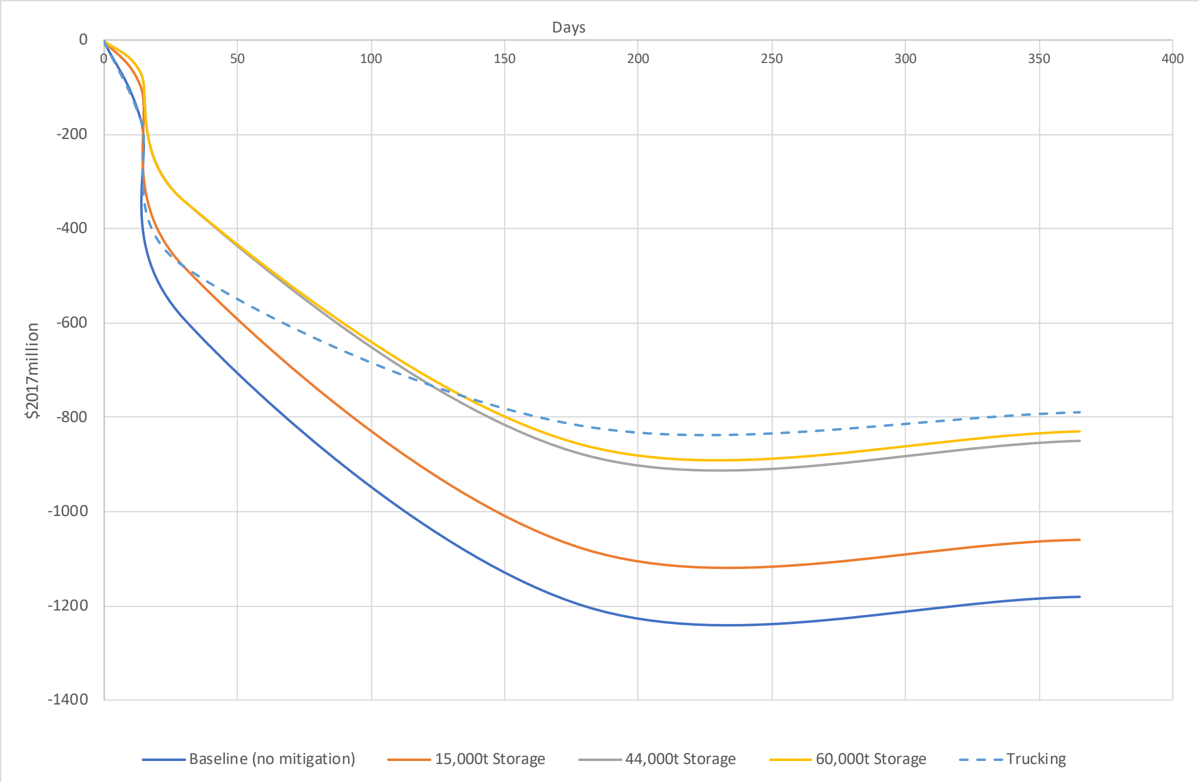
- *Short-term RAP/Wiri disruption*: involves a 9-day disruption to the Refinery to Auckland Pipeline (RAP). The probability of this event is estimated at 0.5-1.0% per year.

The analysis was conducted with and without the inclusion of mitigation measures. The primary mitigation option included was fuel storage (15,000t, 44,000t and 60,000t storage options) as well as a trucking mitigation option for the long-term RAP/Wiri disruption scenario.

The long-term RAP/Wiri disruption causes a loss of $1.1 billion or 0.4% GDP over the entire year of analysis. Reflecting the spatial nature of the disruption, GDP impacts are disproportionately high in Auckland with 65% of the total GDP loss over one year being just in the Auckland region.

Within the Auckland region, the transport and storage sector, especially air transportation, is hit particularly hard in the first six months, with a total loss estimated for this sector of around $130 million. Given the nature of the Auckland economy, among the industrial activities most significantly affected are food manufacturing and equipment/machinery manufacturing. In the rest of New Zealand, the principle impact on manufacturing is indeed within the petroleum refining industry itself. Also notable is that with flow-on impacts through the economy, particularly through reduced tourism expenditure, and losses in household incomes, tax revenues and spending, there are also widespread impacts for service industries in New Zealand (e.g. trade and hospitality experience a loss of $220 million over one year, and the government/education/health and other services sectors each have an estimated loss of $120 million).

The GDP saving per unit volume of storage is similar for the 15,000t and 44,000t options but reduces significantly for the 60,000t option: with net GDP savings per unit volume of storage being $7,600/t, $7,500/t and $5,700/t for 15,000t, 44,000t and 60,000t storage respectively. The largest benefits of the mitigations are experienced in trade and hospitality, followed by transport and storage, government/education/health and manufacturing. For the trucking mitigation option there is a significant reduction in losses of $380 million.



Long-Term RAP/Wiri Disruption Scenario – Impact on Gross Domestic Product

The short-term RAP/Wiri disruption causes a loss of $23 million assessed over two months. The short duration of the outage means the majority of the petrol/diesel fuel shortage will be mitigated by private fuel stores and conservation measures. As for the other scenarios, the additional storage volumes offer reducing returns on investment, in terms of reduced losses to GDP, once a certain proportion of losses have been mitigated. The majority of the losses in this scenario are felt in the manufacturing industry, principally petroleum refining associated with lost sales in refined fuel.

Welfare Impacts

To measure welfare impacts of the scenarios and mitigations analysed in this report, we have used Gross National Disposable Income (GNDI) as a proxy welfare measure. This is in line with guidance in Treasury's Social Cost Benefit Analysis Guide (The Treasury, 2015).

The percent change in GNDI for an international supply disruption is felt most strongly in Auckland at 0.7% and is 0.5% across New Zealand. Impacts are felt partly less in the rest of New Zealand compared to Auckland because it has a higher concentration of the few economic activities (i.e. those engaged in energy extraction including oil extraction in Taranaki) that will benefit and generate higher returns under a situation of higher energy prices.

For the long-term refinery outage scenario, losses equate to 0.8% of GNDI in Auckland and 0.9% for the whole of New Zealand, equalling around $2.2 billion. The proposed mitigation measures result in a reduced loss of $240, $600 and $760 million for 15,000t, 44,000t and 60,000t respectively over the year of the analysis. For the short-term refinery outage scenario, losses reduce to $110 million of GNDI.

For the long-term RAP/Wiri disruption scenario, GNDI losses are $1 billion or 0.4% of GNDI over the entire year of analysis. The proposed mitigation measures reduce this loss by $110, $270, $340 and $240 million for 15,000t, 44,000t, 60,000t storage and trucking options respectively over the year of the analysis. The short-term RAP/Wiri disruption scenario results in lower GNDI impacts; losses of $20 million are felt across the country.

Mitigations

The results from the domestic scenarios indicate that, generally, there are diminishing returns for increased storage volumes. Although, the results differ depending on the scenario considered which suggests that it is challenging to determine an 'optimal' level of storage. Storage mitigations provide a much greater positive benefit under the severe outage scenarios even when the quantity of stored fuel depleted is identical across scenarios. This reflects that households and industries have some capacity to cope with minor fuel shortages through behavioural change and adaptation, but when shortages become severe the inherent coping mechanisms are exhausted and impacts become significant.

To generate the most benefits from any storage options, the distribution and location of storage options must be considered in light of the potential reduction in losses that can be achieved by the storage across multiple types of disruptions or risks as well as any potential benefits that might be offered for day-to-day operations (e.g. reducing distribution costs and avoiding small scale disurptive events such as late arrival of shipments). Given that fuel is a key enabler of economic recovery after a natural hazard or other large scale damage events (because it is used in vital earthworking machinery, transport equipment and back up generators), it is also pertinent to consider whether any storage options provide improved resilience through enabling fuel to be supplied quickly to locations where this would not otherwise be possible after a large scale event.

The mitigation options considered in this report for the domestic scenarios have been supply-oriented and have been limited to storage and increased trucking (RAP/Wiri scenarios only) options. Some demand side measures or mitigations (e.g. fuel prioritisation to emergency vehicles and buses, promoting ride sharing, increased public transport patronage, increased work from home) were nevertheless considered in that they were assumed to be consequential responses to a fuel supply disruption. If we were to identify additional demand measures possible, or that their effectiveness could be increased, this would impact the severity of the impacts experienced under a supply disruption, and by implication, the relative benefits of investing in demand side mitigations. Similarly, potential investments in supply mitigations also need to be considered alongside long-term fuel use trends such as associated with electrification of vehicles and increased remote working, as these may alter the relative severity of disruptions should they occur.

Decision Evaluation

Often economic impact analyses, such as carried out here, are used as an input to a decision evaluation tool, typically cost-benefit analysis (CBA). The differences reported here between the estimated economic impacts, with and without mitigations, are relevant to the assessment of the *benefits* side of the project/option evaluation. These benefits can be conceived as the 'avoided losses' under a disruption. When we are considering investing in the mitigation of a societal risk, we inevitably encounter benefits that, like in this situation, the receipt of which are uncertain. In other words, because disruption events may not occur, it is possible that the avoided losses from mitigations will not be realised. This is quite different from the costs of mitigations which typically are realised with high certainty.

In CBA studies, uncertain benefits (or costs) are often quantified simply as the expected monetary value – the calculated monetary benefits under each contingency, multiplied by the probability of that contingency occurring. The major difficulty with this approach, however, is that it does not account for people's risk aversion. There is ample evidence that in risky situations, many individuals will be willing to pay more than expected monetary benefits to avoid an adverse situation. The difference between the expected monetary benefits and willingness-to-pay is often termed the 'risk premium'.

CBA presupposes that it is the role of government when selecting among options to account for all of society's preferences/choices (which requires accounting for risk premiums), as it is these preferences which determine whether a policy is ultimately viewed as a cost or benefit for individuals. A failure to consider peoples' risk preferences and risk premiums is justified only when (a) the relative changes in wealth under any of the options are relatively small or; (b) there will be methods of compensation available such that individuals never experience the full impact.

Despite the clear need, determining an appropriate 'social risk premium' is a highly challenging task given that, unless there is already an established measure relevant to the situation being modelled, primary data will need to be collected and analysed. In the case of disruption events, there is also the challenge that the cause-effect chains from an initial triggering event through to the impacts on society are very complex. Thus, individuals will often not even have enough information or understanding to determine appropriate risk premiums. We should also note that even if perfect information were to be available, conflicting views on appropriate risk premiums is likely, as some individuals are inherently risk takers while others are risk avoiders.

Given the complexity of this problem we can identify two key roles for scenario-based economic impact analyses such as provided in this report: (1) the process of modelling a disruption event through to its economic impacts helps to elucidate the cause-effect chains initiated by such disruptions, reducing uncertainty in the potential outcomes and the changes in outcomes that occur with different mitigation measures; and (2) through achieving (1), the modelling exercise also serves as a common focus for robust debate on the appropriate level of societal investment in mitigating/avoiding the adverse outcomes of such disruption events which necessarily requires determining the appropriate 'social risk premium'.

Future Research and Modelling Priorities

Several research and modelling extensions have been identified that may provide additional insights into the risks and consequences of fuel disruption. These include:

- Research targeted towards identifying circumstances under which fuel shortages may significantly hinder natural disaster event responses and the potential mitigations that might be put in place to enable better recovery;
- Investigating the impact of the changing future of petroleum-based energy use in New Zealand, and the resulting impact on fuel/energy security;

- Analysis of storage option configuration (location and volume);
- Further analysis of potential fuel disruption response strategies (e.g. industry specific prioritisation, freight movement prioritisation, private transportation policies, and appropriate split of fuel types between available fuel tankers); and
- Analysis of welfare impacts by household group.

Figures

Tables

Glossary

Computable General Equilibrium (CGE): A class of applied economic models typically used to illustrate an economy's responses to changes in policy, technology or other external shocks. Typically, CGE models recognise several types of economic agents (usually different types of industries, households and government), conceptualised as either profit or utility maximisers. Optimisation algorithms are employed to determine the set of prices for all commodities and factors of production that would prevail subject to selected constraints (e.g. all commodity and factor markets clear, and total income equals total expenditure for all agents).

CPI: Consumer Price Index

GDP: Gross Domestic Product

GNDI: Gross National Disposable Income

IRFs: Impulse Response Functions

MERIT: Measuring the Resilience of Infrastructure Tool (www.merit.org.nz)

PED: Price Elasticity of Demand

RAP: Refinery to Auckland Pipeline

SVAR: Structural Vector Autoregression

1 Introduction

Fuel is a key economic enabler. Disruption to fuel availability and/or price changes potentially have considerable impacts across both regional and national economies. Understanding the potential impacts of disruptions can help decision-makers to determine the best mitigation and management strategies.

MBIE has engaged Market Economics to evaluate potential mitigation options to improve New Zealand's fuel security. The analysis in this report uses a series of disruption scenarios and mitigation options developed by Hale and Twomey (2012 and updated by Twomey and West (2017)) and NZIER (2012) and applies the MERIT (**M**easuring the **E**conomics of **R**esilient **I**nfrastructure **T**ool) Dynamic Economic Model (www.merit.org.nz) to evaluate the economic impact of each disruption scenario with and without the use of mitigation measures.

MERIT was developed in the 2012-16 MBIE funded Economics of Resilient Infrastructure (ERI) research programme.[2] MERIT is a state-of-the-art integrated spatial decision support system that enables a high-resolution assessment across space and through time of the economic consequences of infrastructure failure.

In this report, MERIT is applied to five disruption scenarios: 1) international fuel disruption; 2) long-term refinery outage; 3) short-term refinery outage; 4) long-term disruption to RAP/Wiri[3]; and 5) short-term disruption to RAP/Wiri. The analysis reports economic impact across time in the Auckland region and across the rest of New Zealand. It also outlines the distribution of losses across industries and describes the welfare losses.

The report is structured as follows:

> **Section 2** provides a brief overview of the literature related to the current research;
>
> **Section 3** outlines the international and domestic scenarios and the assumptions that underpin each;
>
> **Section 4** briefly describes the MERIT Dynamic Economic Model used in this report / provides a brief description of the MERIT toolkit;
>
> **Section 5** details the sub-models and key assumptions applied in the analysis;
>
> **Section 6** presents the results of the modelling; and
>
> **Section 7** discusses the report findings.

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[2] https://www.naturalhazards.org.nz/NHRP/Hazard-themes/Societal-Resilience/EoRI;

[3] This involves a disruption to Wiri storage terminal

2 Literature Review

In this section of the report we briefly review previous economic analyses of 1) international supply disruptions and 2) domestic supply disruptions. We describe the primary methods used to evaluate economic losses, including the relative strengths and weaknesses of each method. For the domestic supply disruptions we also describe some the impacts of several domestic supply disruptions to supplement the low number of published economic evaluations of domestic supply disruptions (Rose *et al.,* 2018).

2.1 International Supply Disruptions

Various economic models and techniques have been employed by researchers to investigate the implications of a global supply disruption. The most commonly used and highly cited in the literature include: Structural Vector Autoregression (SVAR) models; Cointegration analyses; and Computable General Equilibrium (CGE) models. For each of the aforementioned models, we provide a brief description and highlight prominent studies in the literature that have applied these techniques

Much of the literature has concentrated on disentangling supply- and demand-driven shocks. It is hypothesised that different shocks have different impacts on the same variables of interest, depending on the cause of the shock. Supply-driven shocks (i.e. reduction in oil supply) generally have negative consequences for growth, whereas demand-driven shocks (i.e. greater economic activity) are typically associated with increasing GDP trends, and this may initially outweigh the growth-hindering effect of higher oil prices.

Also often considered are the implications of higher oil prices on commodity prices and the variation of impacts among countries and/or industrial sectors. The common finding is that the commodities and countries/sectors most adversely affected are those that depend significantly on oil, while those less reliant on purchasing oil may even gain from higher prices (particularly oil-exporting countries).

That international tourism is largely a discretionary as well as oil-intensive activity suggests that the tourism industry might be more vulnerable to higher oil prices than other industries. This finding is particularly concerning for New Zealand given that the tourism industry is a major export earner. Indeed, one study (further discussed below) found that the macroeconomic impacts of higher oil prices are comparable to those resulting from the 2007-09 recession. Moreover, the shift in global preferences away from long-haul destinations and toward short-haul destinations may prove problematic for New Zealand since it is considered a long-haul destination by many of its major markets.

SVAR Models

SVAR models are employed to examine the underlying relationships between economic variables. Essentially, these models measure the correlations among a set of variables. Once these correlations are determined, Impulse Response Functions (IRFs) are constructed as an extension of the model. IRFs computationally analyse the effect of a shock to one variable on another variable. This methodology has been used predominantly by economists in oil-related macroeconomic analyses because of an interest in understanding the drivers of oil price fluctuations. SVAR models have the capability to identify whether a change in the price of oil is supply- or demand-driven. The advantage of this approach is not only to better explain oil price fluctuations; but also, to gain a more informed understanding of the response of economic activity to price fluctuations as prompted by different factors.

For instance, Kilian (2009), Ahmadi *et al.,* Manera (2016), and Wang *et al.,* (2014) have each built a SVAR model to compare the responses of economic variables to a change in the price of oil due to either a supply disruption, aggregate demand shock, or precautionary demand.

Kilian (2009) studied the implications of an oil shock on specifically US macroeconomic aggregates such as the consumer price index (CPI) and real gross domestic product (GDP). The author found that unanticipated oil supply disruptions significantly lower GDP upon impact. This decline however is only temporary. The corresponding response of the price level was found to be more moderate as the CPI remained largely flat and statistically insignificant. The effects of a positive aggregate demand shock are also recessionary but delayed. In the short-run, the stimulating effect of higher global demand on the US economy outweighs the growth-hindering effect of higher oil and commodity prices. Over time, the adverse effect of higher prices dominates, and output eventually recedes. Lastly, a shock to precautionary demand triggered by the expectation of future oil supply shortfall decreases real GDP and increases the price level.

Ahmadi *et al.,* (2016) extended the analysis by comparing the responses of metal commodity prices to oil price shocks before and after the 2008 financial crisis. The IRFs suggest that oil supply shocks do not have a statistically significant impact on the volatility of metal commodity prices. For a positive global demand shock however, a rise in the price of oil has a significant impact on metal commodity prices before the crisis but then an insignificant impact thereafter. The reason for the pre-crisis period result is straightforward: a demand shock raises the price of oil which prompts an increase in the demand for metals as they are production inputs for the economy and the prices of these commodities consequently rise. As for the insignificant impact that occurs in the post-crisis period, the authors speculate that this is due to the diminishing importance of metal commodities as financial assets after the 2008 crisis.

In the context of agricultural commodities (e.g. corn, barley, soybean, cocoa, rice, etc.), Wang *et al.,* (2014) found that the price response of these commodities to an oil supply shock were either significant for a brief period, or insignificant. That the oil supply shocks were found to be less relevant in driving real oil prices is a likely explanation for this. Higher agricultural commodity prices were only significant if it is the result of an increase in the price of oil driven by aggregate demand for oil. Furthermore, the authors highlight how the state of the economy when the price of oil rises (for any type of shock) can greatly influence the speed and magnitude of a change in agricultural commodity prices. That is, agricultural commodity prices responded faster and the change in prices was relatively greater when the price of oil rose following the 2006-08 food crisis as opposed to an oil price increase in the pre-crisis period.

Cointegration Analyses

A cointegration analysis provides a robust measure that ascertains whether there exists a long-run relationship between two or more variables of interest. If the time-series of a set of variables have a fixed, stationary relationship in the long-run such that its statistical properties (e.g. mean, variance, autocorrelation etc.) are constant over time, then the variables are said to be cointegrated.

Harri *et al.,* Hudson (2015) adopt this methodology to examine the relationship between oil prices, commodity prices and exchange rates; and thus determine the strength of the linkage between these markets over time. As expected, the results of the cointegration analysis suggest that oil is strongly related to most of the agricultural commodities considered, particularly those for which oil is a crucial production input such as corn, cotton and soybean. Furthermore, given that exchange rates impact the export and import of goods and services and therefore the price of the products traded, the finding that a strong relationship among exchange rates, oil prices and agricultural commodity prices exists is not surprising.

CGE Model: GTAP Model and NZTGEM

Lastly, CGE models fit economic data to a set of equations to capture the structure of the economy and the behavioural response of agents including households, firms and the government. The GTAP model is a variant of a CGE model. It is multi-regional (113 countries/regions), multi-industry (57 industries) and assumes perfect competition and constant returns to scale.

Using the GTAP model, Yahaba (2010) studied the impact on global economic activity of an oil price shock due specifically to a reduction in oil production. The author found that the GDP of oil-exporting countries increased while that of the oil-importing countries decreased. Moreover, among the oil-importing countries, the decline in GDP was of a larger magnitude for the developing countries than the developed countries, primarily because of their greater dependence on oil. Similarly, the output generated by industries for which oil is a crucial production input, generated a greater decline in output than the industries less reliant on oil.

It is expected that the impact on different industries would be relatively larger for those that depend significantly on oil. The model's simulations show this to be true. In the case of an 8.26% reduction in oil supply, output of the trade and transport industry declined by 1.48%. Apart from the declines in output of industries directly related to oil (i.e. oil industry and gas and coal industry), this decline was the largest. From this result, we would expect that the decline in output of the trade and transport industries in small open economies to be among the largest since they engage largely in outsourcing. Again, the model's simulations support this hypothesis. The ASEAN-5, India and Brazil generated the largest declines of 5.50%, 3.82% and 4.14% respectively, compared to the 1.83% and 1.3% output declines of the US and EU, respectively.

It is reasonable to expect the demand for gas and coal to increase when the price of oil increases since these are substitutes for oil. However, the model's simulations present opposing results. Instead, output from the gas and coal industry was found to decrease (Yahaba, 2010). A likely reason for this is the adoption of a Leontief production function to describe firm behaviour in the economy. The functional form of a Leontief production function is such that it does not allow substitution between production inputs. As a result, the model shows that when the output of oil decreases and the price of oil then increases, the consumption of gas and coal also decrease, and overall firm activity shrinks (Yahaba, 2010). This illustrates the high sensitivity of CGE modelling results to the way in which the underlying model is structured, including the specification of substitution possibilities.

As for trade, Yahaba (2010) found that the value of imports and exports increases because the prices of imports and exports rises as a result of higher oil prices, not necessarily because of an increase in the quantities of imports and exports, which in fact decreased. Furthermore, and as expected, the simulations reveal that the increase in the value of imports was relatively larger for commodities that depend significantly on oil such as petroleum/coal products which increased by 72.65% in the case of an 8.26% decline in oil output. Similarly, the rise in the value of oil-dependent exports such as agriculture was relatively high, especially among the countries with agriculture as their main export commodity. Such countries include India and China who are expected to experience increases of 31.62% and 8.29%, respectively, when oil supply decreases by 8.26%.

Becken and Lennox (2012) also employ a CGE model to examine the impact of a decline in global oil production. The study focuses specifically on the implications of the resulting high oil prices on the tourism industry in New Zealand. Regardless of the model used, most of the aforementioned studies found that particular industries may be more vulnerable than others depending on the relative importance of oil in their production. Becken and Lennox (2012) provide two reasons as to why the tourism industry may be volatile when global oil prices change. First, international tourism is largely a discretionary activity. When incomes are relatively low, tourists may be more inclined to travel to destinations in closer proximity to home or reduce travelling altogether. Second, international tourism is an oil-intensive activity. According to Ringbeck *et al.,* (2009), fuel costs as a percentage of an airline's operating costs are in the order of 30% for long-haul flights and 17% for short-haul flights. Both these reasons suggest that countries heavily dependent on tourism as an export industry, such as New Zealand, are potentially more vulnerable to oil price increases than those reliant on more diversified export portfolios. Although New Zealand's energy portfolio provides some buffering against the direct consequences of a global oil supply shock, the economy remains exposed to indirect impacts.[4] This is especially so considering that changes in global oil prices will most likely be concomitant with global changes in other commodity prices, exchange rates and incomes, all of which carry implications for the New Zealand tourism industry.

Becken and Lennox (2012) use a two-stage CGE modelling approach to investigate the impact on the tourism industry of high oil prices. This involves first modelling the impact of high oil prices from a global general equilibrium perspective. Similar to Yahaba (2010), the GTAP model was employed to simulate a negative productivity shock to global oil production that leads to a 100% increase in global oil prices. The simulation results determine (a) the macroeconomic impacts on the tourist origin countries and thus the effect on tourism demand from these countries; (b) the changes in relative prices of goods and services imported to and exported from New Zealand; and (c) changes in demand for New Zealand's non-tourism exports. The limitation of the GTAP model is that since it is considered a 'general purpose'

[4] While New Zealand is a net oil importer, it currently produces around a third of its own consumption. Moreover, approximately two-thirds of electricity is generated by hydro, with additional renewable contributions from geothermal and wind.

model, tourism supply and demand are not well accounted for. In light of this, Becken and Lennox (2012) use the outputs from the GTAP scenario as inputs in the tourism-specific New Zealand Tourism General Equilibrium Model (NZTGEM). The advantage of this two-stage CGE modelling approach is that it not only accounts for global general equilibrium effects, but also models the impacts on both the New Zealand tourism industry and wider New Zealand economy. The limitation of this approach however is that it precludes substitution between different destination countries. Destination preferences will certainly change when oil prices rise, with preference of short-haul destinations over long-haul destinations. Given that New Zealand is considered a long-haul destination by many of its major markets, this approach omits a critical component of the analysis.

As for macroeconomic impacts specific to the New Zealand economy, a 100% increase in global oil prices was shown to lead to a 0.9% decrease in GDP. In terms of New Zealand's trade balance, higher import prices, particularly for oil and petroleum products, cause the aggregate volume of imports to fall by 3.8%, although the real value of imports falls by less (1.8%). The simulations generate a similar result for exports whereby a decline in demand causes the aggregate export volume to fall by 2.6% while real value falls only by 2.4% due to higher prices. The tourism industry will be more negatively affected by higher oil prices than the wider New Zealand economy as tourism exports fall by 9% in real value, equivalent to a loss of NZ$960 million in export revenue. Domestic tourism was shown to partly compensate for losses in international tourism given that the propensity to travel overseas among domestics reduces with higher oil prices. The problem with domestic tourism however is that expenditure is heavily dominated by transport. Naturally, the price of domestic tourism increases substantially, while quantity expands slightly due to substitution away from outbound international travel.

Summary

Extant empirical studies which have sought to investigate the macroeconomic implications of oil shocks have focused primarily on disentangling demand and supply shocks as well as the relationship between oil and other economic variables such as GDP, inflation and commodity prices. From this brief literature review, it is clear that very different results are produced depending on the model employed and the specifications thereof. The studies demonstrate key interdependencies and cause and effect relationships that support a systems-based assessment approach to fuel disruption events.

2.2 Domestic Supply Disruptions

Most energy security studies focus on the vulnerability of nations in the event of a disruption such as a geopolitical crisis (Rose *et al*., 2018). There are limited studies that focus on the impact of domestic and/or regional petroleum supply disruption. Below we describe some relevant studies and the approaches taken.

The first group of studies use a cost-benefit analysis (CBA) that focuses on direct economic welfare benefits related to consumer and, in some cases, producer savings. NZIER (2012) conduct a CBA for a number of domestic disruption scenarios in New Zealand. The analysis focuses on changes in consumer surplus as a measure of welfare as well as taxation losses and externalities avoided (e.g. pollution, road accidents etc.). The calculation of consumer welfare losses is based on estimates of fuel price elasticities and changes in the quantity of fuel available during the disruption period. In Appendix A we provide some notes on special considerations and limitations regarding elasticity-based methods to estimate changes in consumer surplus in the context of short-run disruptions. The NZIER (2012) analysis assumes that there are no price rises for the domestic disruption, however, there are likely to be 'shadow price' effects arising from the supply shortage. The CBA is supplemented by analysis using a modified CGE model to estimate the distribution of losses across industries, however, this is not directly included in the CBA.

Finizza (2002) takes a similar CBA approach to estimate the economic benefits of fuel storage in California. The aim of this modelling is to mitigate price spikes through the use of storage. A Monte Carlo approach is employed to account for uncertainty related to: price spikes (relative to inventory levels); disruption duration; size; frequency; and variability in short-term supply and demand elasticities. Stillwater Associates (2002) take a similar approach to evaluating the benefit of fuel reserves by only considering price changes to consumers through reduction in price spikes.

Input-output models are also used for regional economic disruption modelling. Gordon *et al*., (2010) use the National Interstate Economic model (NIEMO) – a multi-regional input-output model – to estimate the impact of Hurricane Katrina – a predominantly petroleum disruption. The model includes both supply and demand losses (loss of imports and exports respectively) to allow for indirect costs to be captured but does not include price changes. The study found that adjusting for supply-side factors such as substitution, significantly reduced the multiplier effect of the direct impact – from 1.83 to 1.07. This result indicates the importance of including downstream dampening effects in modelling.

Another, more recent study is Rose *et al*., (2018) which includes the ability of industries to dampen the effects of economic shocks. Rose *et al.,* (2018) examined the economic consequences of disruption to seaports where fuel is a dominant import and export commodity. Regional and national input-output analyses are used to estimate both the direct and indirect impacts of fuel disruption. The study includes the ability of businesses to absorb some of the impact through 'resilience tactics'. These include drawdown of inventories, input conservation, input substitution, input importance, export diversion for import use, production recapture, and commodity substitution.

A third type of model is simulation modelling. Ford (2005) uses a System Dynamics model to estimate the impacts of a refinery disruption in California and the benefits of storage. The model is based on supply-demand ratios and their relationship to wholesale spot price changes. Storage volumes and drawdowns are used to moderate the model to identify ideal storage volumes. The model assumes a delay of 18 days for price increases to transfer from wholesale to resale. The model was shown to be insensitive to changes in price elasticity.

There are merits to draw on from the three modelling approaches mentioned here. The majority of the studies have taken a multi-regional approach which is useful to disaggregate the dampening effect of regional substitution (Koks *et al*., 2016) and to understand the spatial distribution of the losses. The input-output studies demonstrate the advantages of including indirect effects in the modelling and the resilience of businesses to withstand disruption. CGE modelling has not been used extensively in these analyses because CGE models are often designed for analysis of price effects (Koks *et al*., 2016).

Furthermore, CGE models are typically designed to capture relatively-business as usual behaviour and the behavioural changes under fuel shortages may be very 'non-business-as-usual', which would require significant modification or extension of the base model. However, as demonstrated in the NZIER (2012) study, CGE models can capture indirect, distributional effects which are useful for some analyses.

In addition to economic analyses, there are several qualitative studies that investigate petroleum disruptions and the types of impacts as well as the likely private/public responses to disruption. These events provide a useful picture for the types of behaviours and disruptions that might be observed following a fuel shortage in New Zealand.

Over the past 40 years the UK has experienced two major strikes that have affected transportation and fuel networks: the 1979 lorry driver strike and the 2000 fuel protest. The protest in 2000 lasted five days, affecting fuel distribution hubs and refineries. Half of the nation's petrol stations were depleted of fuel within two days. Truck traffic was reduced by 10-12% and as the protest ended, the manufacturing, food supply and hospital sectors were in a critical state. The disruption caused an estimated 10% loss in national industrial output per day during the remaining four days of the disruption. A significant portion of households (29%) switched travel modes, stopping their use of private transport and shared car trips. According to McKinnon (2011), rail use increased by 20%. The event had a greater impact on car travel than goods vehicles, and the biggest change was observed in motorway traffic. Following the disruption, there was a delay in return to normal car traffic levels (Hathaway, 2000).

In the US context, recent hurricanes have caused significant disruption to petroleum supplies. For example, the damage to refineries during Hurricane Harvey in 2017 saw a rise in gasoline costs by 6.3%, consequently increasing airline industry fuel bills by 0.3% (IATA Economics, 2017). In another instance, refineries were shut down for several weeks due to Hurricane Sandy in 2012, which damaged storage terminals and halted marine and pipeline deliveries for three to four days. For approximately one month, supply was noticeably limited. Long queues formed as less than 20% of gas stations had access to fuel during this time. In response, the state and federal government established priority fuelling programmes for emergency responders, utility vehicles, ambulances and school buses. License-place rationing was implemented for private vehicles and regulatory waivers helped to increase supplies (PlaNYC, 2013).

In 2017, the pipeline joining the Marsden point refinery to the Wiri oil terminal failed causing a dramatic shortage in jet fuel to Auckland Airport. Jet fuel was initially reduced to 30% of normal supply, gradually returning to full supply after 16 days. Over this time airlines went to extraordinary lengths to minimise impact to customers. The measures, such as refuelling stopovers, longer crew hours, crew relocation, increasing plane sizes, and compensating for passenger disruption were made largely at their own cost. After just four days, and still with only 30% of jet fuel available at Auckland airport, 95% of scheduled flights were operating.

3 Scenario Details

This section of the report describes the fuel outage scenarios that are assessed in our MERIT modelling. We have assessed five of the eight scenarios set out in the Twomey and West (2017) report: (1) international disruption; (2) long-term refinery outage; (3) short-term refinery outage; (4) long-term RAP/Wiri disruption; and (5) short-term RAP/Wiri disruption. As the short-term RAP/Wiri disruption is very similar in nature to the outage that did occur in New Zealand in 2017, and a detailed analysis/review of the outage implications is being undertaken as part of a Board of Enquiry, we have not placed significant attention within this particular report on this scenario.

Also, given the significant differences between the way the scenarios impact society, for most of the remainder of this report we separate the discussion of the international supply disruption scenario, and its related modelling, from the various domestic supply disruption scenarios. The Twomey and West (2017) study concentrated largely on specifying the supply aspects of these scenarios. There are, however, many demand aspects of each of these scenarios that are also uncertain and need to be specified as a set of assumptions underpinning each scenario. The following sub-sections provide a summary of each scenario, as well as the key assumptions we make concerning certain economic agents. The mitigation schemes suggested in the Twomey and West (2017) report, applicable to the domestic supply shortage scenarios, are also described below.

3.1 International Supply Disruptions

3.1.1 Summary

As detailed by Twomey and West (2017), the international disruption scenario involves a 10% reduction of global crude oil supply for a duration of around six months, which is triggered by a major international event. It was suggested that such an event has a 25% probability over a 10-year period (i.e. 2.5% per annum) of occurring.

From an analysis of the net price elasticities of supply and demand, it is assumed that crude oil prices will rise by 7.35% for every 1% reduction in oil supply.[5] Therefore, the initial shock of a 10% disruption would prompt a price increase of around 74%.

When considering the response of countries that hold emergency stock, the actual shortage may in fact be less. The release of oil reserves would inject more oil into the market, consequently dampening the initial price rise. Therefore, the impact on prices may also be more moderate than first presumed. Given that the length and severity of the disruption is unlikely to be known, it is reasonable to expect countries to exercise caution in the rate of releasing reserves. Ultimately, it is assumed that the reserves released will offset half of the base disruption, thus leaving a net disruption of 5%. Once emergency oil stocks begin to be released, the initial price rise would fall to and settle at an increase of 37%. That the higher price of oil will indeed stimulate supply (i.e. rising prices will encourage additional supply and use of

[5] See Brown and Huntington (2010).

any spare capacity) and reduce demand is another reason why the actual shortage may be less than the base case.

It is understood that the main economic impacts of an international disruption would come predominately via the price channel in the form of increased prices. A summary of the price impacts is presented in Table 1 below.

Table 1 Impact of International Disruption. Table from Twomey and West (2017)

		Initial response (10%)	Likely settled response (5%)
Increase in base price		74%	37%
Crude oil price (assuming base price US$50/bbl)	US/bbl	$87	$68.5
NZ petrol price increase	Cpl (%)	+45 (22%)	+22 (11%)
NZ diesel price increase	Cpl (%)	+45 (34%)	+22 (17%)
NZ jet fuel price increase	Cpl (%)	+45 (75%)	+22 (37%)

3.1.2 Key Assumptions

The MERIT model which is used to analyse the economic consequences of the disruption scenarios (see Section 4 below) is a single-country model designed predominantly for analysis of 'shocks' to the New Zealand economy. Although financial flows between New Zealand and the rest of the world (e.g. through import and export trade, factor income remittances and net foreign investment) are included in the model, it would normally be assumed that the rest of the world is operating under business-as-usual conditions. The international supply disruption scenario, however, implies a special set of circumstances where it is not appropriate to assume that the business is occurring largely unaffected in the rest of the world. We therefore need to change some of the base parameters and assumptions in MERIT to reflect changes occurring at the international level.

The literature review outlined above highlights that two key and related considerations are:

(1) How might commodity prices in addition to oil change under the disruption?
(2) How might demands for New Zealand exports change?

The literature review also highlighted that there is relatively little information and previous modelling studies available upon which we can build a comprehensive account of likely changes in these key economic variables. We have developed at set of assumptions, informed mainly by the two GTAP studies, regarding changes in international commodity prices and export demands under a price increase scenario of 37% (see Table 2 and Table 3). It is worth emphasising that given the significant uncertainties, these assumptions should be recognised as one among a number of potential scenarios that could be established for the impacts of an international fuel shortage on the New Zealand economy.

Table 2 Assumed Changes in International Commodity Prices under the International Disruption Scenario

Industry Sector	Price Change (%)
Agriculture, food & extracts	0.58
Gas and coal	-0.68
Oil	37.00
Textiles and apparel	0.50
Wood and paper products	0.57
Petroleum, coal products	28.62
Chemical products	2.76
Metal and Mineral products	1.12
Transport equipment	0.50
Electronic equipment	0.33
Machinery	0.38
Utilities and construction	0.72
Trade and transport	1.59
Other services	-0.11

Table 3 Assumed Changes to International Export Demands under the International Disruption Scenario

Export Group	Change in demands (%)
Tourism exports	-4.07
Other exports	-0.40
Total exports	-0.96

3.2 Domestic Supply Disruptions

In addition to the international disruption scenario, the 2017 Twomey and West report describes seven supply disruption scenarios within the domestic context. These disruptions vary in terms of duration (i.e. short- or long-term) as well as the location of the disruption:

(1) Long-term refinery outage

(2) Short-term refinery outage

(3) Long-term disruption to RAP/Wiri

(4) Short-term disruption to RAP/Wiri

(5) Long-term disruption at Wellington

(6) Long-term disruption at Lyttelton

(7) Multiple terminal disruption

In this report we consider the first four of these domestic scenarios. Below we provide a summary of (1) supply shortage aspects of the scenarios considered, (2) the mitigations considered for each of these scenarios and how the mitigations alters the supply shortages, (3) key assumptions around behavioural change under the domestic scenarios, and (4) the way in which the supply shortages will be distributed and experienced by different economic agents.

3.2.1 Summary of Supply Shortages

(1) Long-Term Refinery Outage

The long-term refinery outage scenario involves a disruption to the Marsden Point refinery. This is New Zealand's only refinery and a vital link the local petroleum supply chain. The supply aspects of this scenario are described in detail in Twomey and West (2017), and thus only a short summary is provided here:

- The scenario assumes an incident (e.g. natural disaster) takes the refinery out of action, requiring customers to re-establish supply routes using 100% imported supply.
- It takes six weeks (42 days) for companies to re-establish full supply via imports.
- Immediately following the disruption, companies will draw down existing buffer and safety stocks allowing for 7-9 days consumption at normal rates.
- Imports already meet some of New Zealand's demand. Some of the larger oil companies will also be able to secure additional short-term imports commencing from around 2-3 weeks.
- The refinery is a significant stock holding and distribution location. It is not, however, assumed that there are any significant impacts resulting from delay in re-establishing these functions.
- It is assumed that the shortage is evenly spread over the country and the shortage for petrol/diesel is about 50/50.
- The proportional shortage in jet fuel is worse than for petrol and diesel, because imports make up a smaller proportion of current supply.
- The probabilities for an event of this scale were assessed at a range of 0.20-0.25% per year (1 in 400 to 500 years).

A summary of the supply shortages over time is provided in Figure 1.

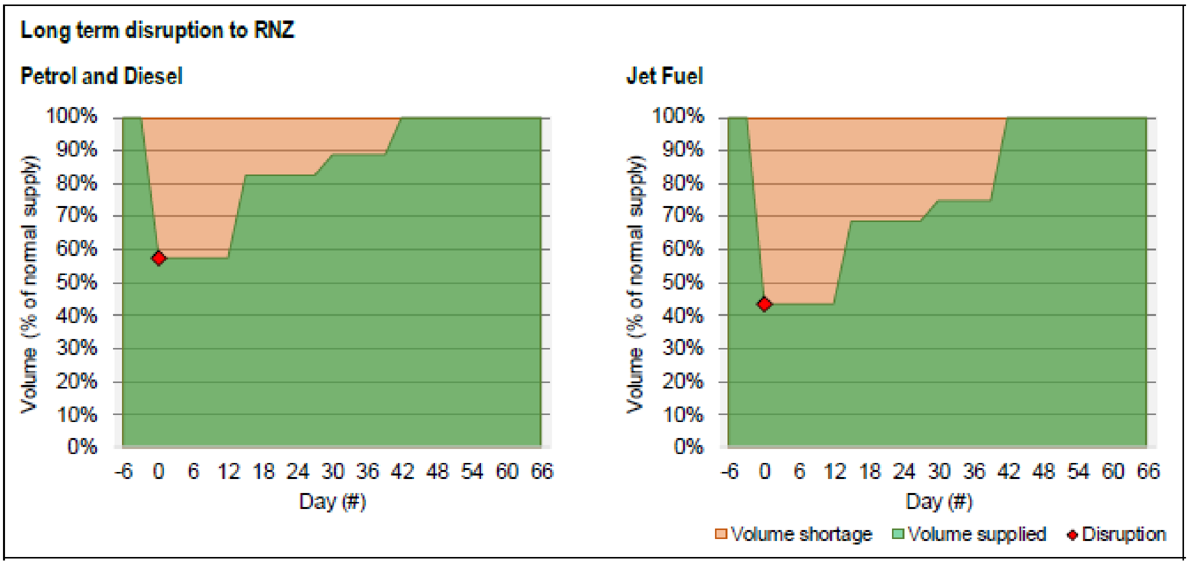

Figure 1 Long-Term Refinery Outage – Impact on Supply over Time. Figure from Twomey and West (2017).

Notes: RNZ = Refinery New Zealand

(2) Short-Term Refinery Outage

The short-term refinery outage scenario assumes a 3-week disruption to the Marsden Point refinery. As above, the supply aspects of this scenario are described in detail in Twomey and West (2017). In summary:

- The scenario assumes an incident (e.g. natural disaster or incident) takes the refinery out of action, requiring customers to manage the shortage using short term imports and inventories.
- It takes three weeks to re-establish full supply.
- Some larger oil companies will be able to secure short-term imports
- Companies will draw down buffer and safety stocks more quickly than for the long-term refinery disruption.
- Oil companies are likely to experience increased costs to secure additional supply and manage the disruption.
- The airline industry would have to manage disruption through flight rationalisation and trans-Tasman fuel tankering.
- The estimated probability of the outage is 0.5-1%.

A summary of the supply shortages over time is provided in Figure 2. In practice there is likely to be a delay in experiencing the shortage (likely week two to four/five) as companies ration stocks.

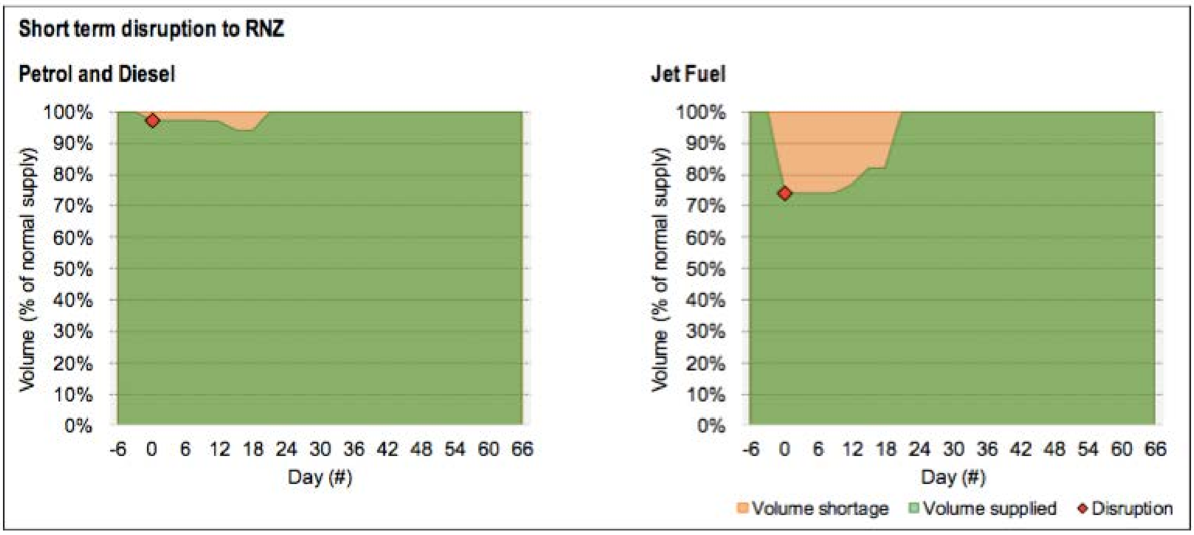

Figure 2 Short-Term Refinery Outage – Impact on Supply over Time. Figure from Twomey and West (2017).

Notes: RNZ = Refinery New Zealand

(3) Long-Term Disruption to RAP/Wiri

The long-term RAP/Wiri disruption scenario involves a disruption to the Wiri storage terminal that causes the terminal inoperable and stock inaccessible for an extended period. As explained by Twomey and West (2017):

- The scenario assumes an incident takes the terminal out of action for an extended period.
- 100% of the supply of petrol and diesel is assumed to be met using neighbouring terminals, but it is expected to take considerable time to set-up and operationalise the new supply routes.
- Maximum use of the trucking fleet is expected which will involve deploying the 10 spare tankers currently available for emergencies over the first week.
- 14 extra trucks from offshore would be required, arriving between 4-8 weeks after the incident. These additional trucks concentrate on restoration of the petrol/diesel supply only (not jet fuel).
- Trucking utilisation is expected to be optimised by day 15.
- The supply of jet fuel to Auckland Airport is expected to be the most significantly disrupted, as there is no alternative supply chain. Only 26% of the normal demand can be met by other New Zealand airports. Some of the balance can be met through flight rationalisation, re-routing, and off-shore re-fuelling.
- The probability of the event is estimated at 0.2-0.3% per annum.

In addition, we also assume the following for this scenario:

- Although the estimated restoration times depend on the availability of storage facilities at Wynyard wharf, and these facilities are currently being decommissioned as part of the redevelopment of the wharf, it is assumed that a suitable alternative and equivalent storage facility will be in place.

- As part of the rationalisation of the trucking fleet during the first week of the outage, 10% of normal jet fuel supply will be re-established to Auckland Airport.
- By four months a solution to the jet fuel shortage to Auckland Airport will be resolved. One option might be to install a connecting pipeline from the RAP directly to the airport (In the Twomey and West (2017) report it is noted that six months had been identified as a potential timeframe for such a solution, however it might also be shorter if preparations have been put in place).

A summary of the supply shortages over time is provided in Figure 3.

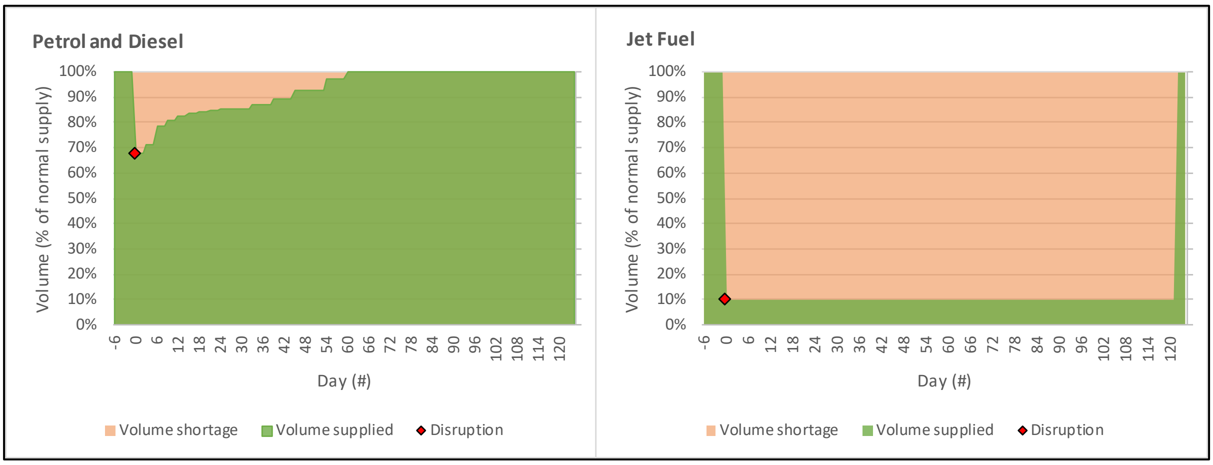

Figure 3 Fuel Availability Following a Long-Term RAP/Wiri Disruption

Notes: For petrol and diesel the percentages are expressed relative to normal Upper North Island (Northland, Auckland, Waikato & Bay of Plenty) supply. For jet fuel the percentages are expressed relative to normal supply to Auckland Airport.

(4) Short-Term Disruption to RAP/Wiri

The short-term RAP/Wiri disruption scenario involves a nine-day shutdown of the RAP pipeline. As described in detail in Twomey and West (2017):

- The scenario assumes an incident causes damage to the pipeline which would take nine days to restore operation.
- It is assumed that four days of stock will be accessible at the terminal at the time of the incident.
- Over the first week, spare trucks are expected to be used to redistribute fuel from neighbouring terminals.
- The most significant impact will likely be on jet fuel given the significant quantity needed at Auckland Airport and the impracticality of trucking this to the airport from the refinery.
- The probability of this event is estimated at 0.5-1.0% per year.

In addition, we also added the following assumptions for this scenario:

- In line with experience from the 2017 outage, supply rationalisation measures will be implemented for jet fuel. The shortage experienced by airlines progresses initially from only 30% of normal fuel available and the fuel ration is stepped upwards over time as more certainty on the pipeline restoration becomes available.

- The experienced supply shortages for petrol/diesel will be very minimal as these can be largely buffered by drawing down stocks (during the 2017 outage just a few petrol stations ran out of a single fuel type). In the modelling we have assumed simply a fall of 0.5% in petrol and diesel availability for the Upper North Island over days 9-11. This is likely still a higher impact that what was experienced in 2017.

A summary of the supply shortages over time is provided in Figure 4.

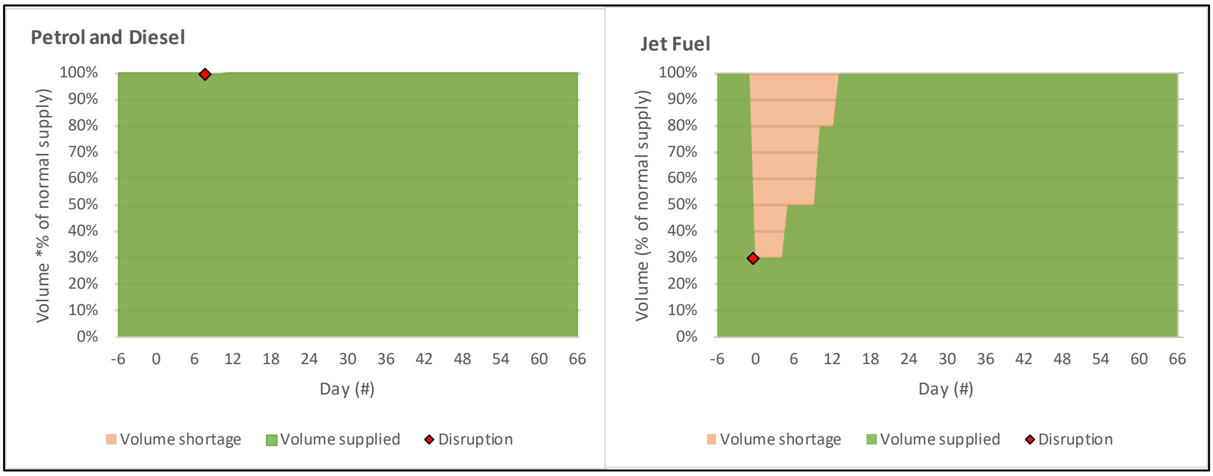

Figure 4 Fuel Availability Following a Short-Term Disruption to the RAP pipeline

Notes: For petrol and diesel the percentages are expressed relative to normal Upper North Island (Northland, Auckland, Waikato & Bay of Plenty) supply. For jet fuel the percentages are expressed relative to normal supply to Auckland Airport.

3.2.2 Mitigations

The principal mitigation considered for the refinery outage scenarios is the installation of increased domestic storage.[6] There are many potential storage configurations and locations. For this project we considered, for each domestic scenario, one option also considered in the NZIER (2012) study, i.e. a 44,000 tonne terminal. We have then supplemented this with two further storage options of 15,000 tonnes and 60,000 tonnes. Note that we have not attempted to develop specific details around these mitigations, such as tank location and configurations. It has also been simply assumed that distribution of fuel types stored is the same as the current distribution of fuel use in the economy. It is envisaged that specific details would need to be further developed, should domestic storage be considered worthy enough for further investigation.

During a fuel disruption event, it is possible that reserves held in storage will not be drawn down optimally due to uncertainty around timing and duration of the event as well as difficulties in planning. Nevertheless, for the purposes of this analysis, we have assumed that reserves are used efficiently in that they are completely depleted over the outage (unless the quantity stored is greater than the total outage), and they are used to reduce the most significant periods of shortage (i.e. to minimise the

[66] The storage mitigation was not considered in relation to the international disruption scenario. Domestic storage would likely be used in replacement of international storage purchased through the ticketing system. As such, it would need to be made available to the international market during an international disruption thus providing limited mitigation potential for the New Zealand economy – see also the Discussion section.

maximum % disruption experienced over any one day for each fuel type). For the refinery outage scenarios, we have furthermore assumed that the storage is available as a mitigation across the whole country, which, in reality, might imply some splitting up of the storage at multiple locations.

The principal effect of additional storage as modelled in the mitigation scenarios is to replace otherwise missing fuel supplies with supply from storage. For the long-term RAP/Wiri disruption scenario, if the storage mitigations can be restocked by ship this would also alleviate pressure on trucking resources and potentially lead to faster fuel restoration. For this report we have not, however, modelled this potential additional benefit of storage.

The impacts of storage in terms of mitigating the supply disruption for each scenario are show in Figures 5-11.

There are many possible scenarios of a trucking mitigation that could be considered for the long-term RAP/Wiri disruption. Potentially, with enough resources invested in the purchase/lease of imported trucks and fast transportation of these vehicles to New Zealand, the fuel shortages could be alleviated quite quickly, even for jet fuel. For this report we have assumed that the trucking mitigation moves the arrival of overseas vehicles for petrol/diesel forward in time so that full restoration is achieved by one month (i.e. rather than two months). Furthermore, the trucking mitigation also involves arrival of vehicles specifically for the transport of jet fuel. Given the significant number of trucks required (estimated at around 70% of the number of trucks required to achieve complete restoration for petrol/diesel), and the special requirements to move jet fuel, we have assumed that only enough trucks are brought in to achieve 30% of normal fuel supply to Auckland Airport. It is also assumed that these trucks come online slower than the general petrol/diesel vehicles and take two months until all are operational.

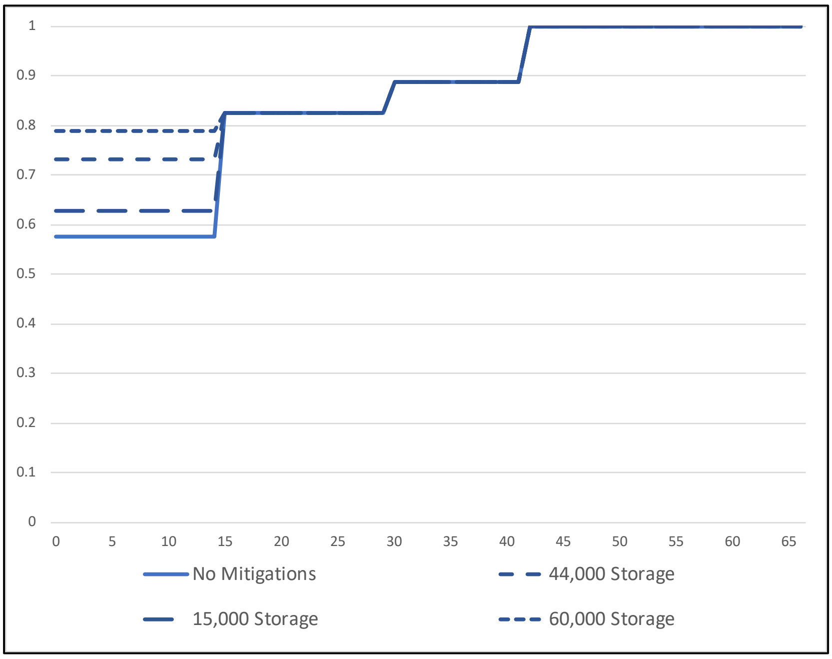

Figure 5 Petrol and Diesel Fuel Availability Following the Long-Term Refinery Outage Scenario – with and without Storage Mitigations

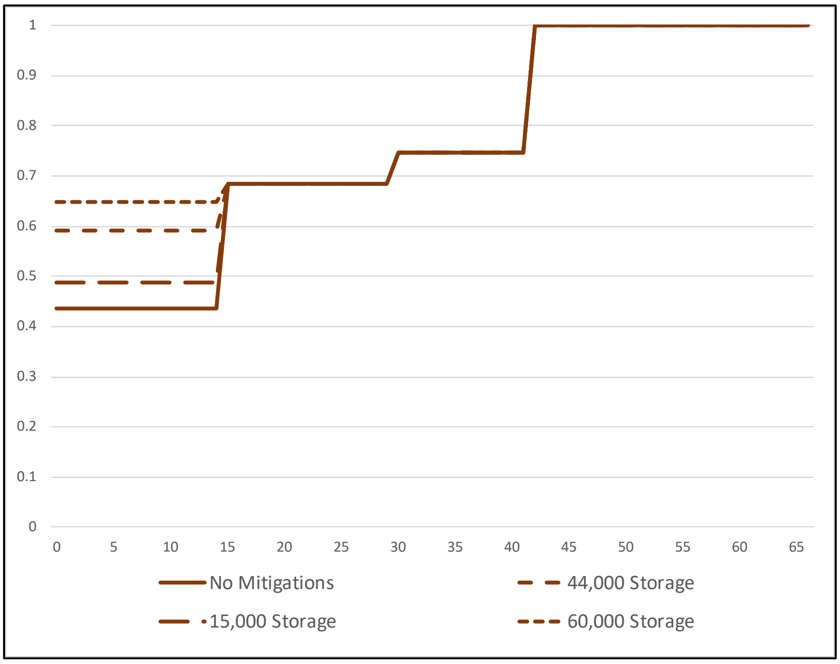

Figure 6 Jet Fuel Availability Following the Long-Term Refinery Outage Scenario – with and without Storage Mitigations

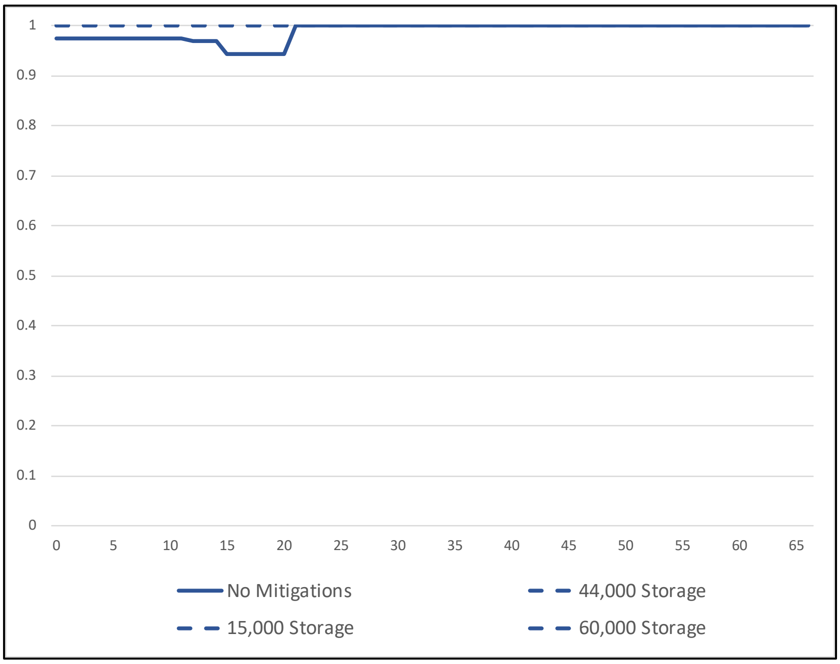

Figure 7 Petrol and Diesel Fuel Availability Following the Short-Term Refinery Outage Scenario – with and without Storage Mitigations

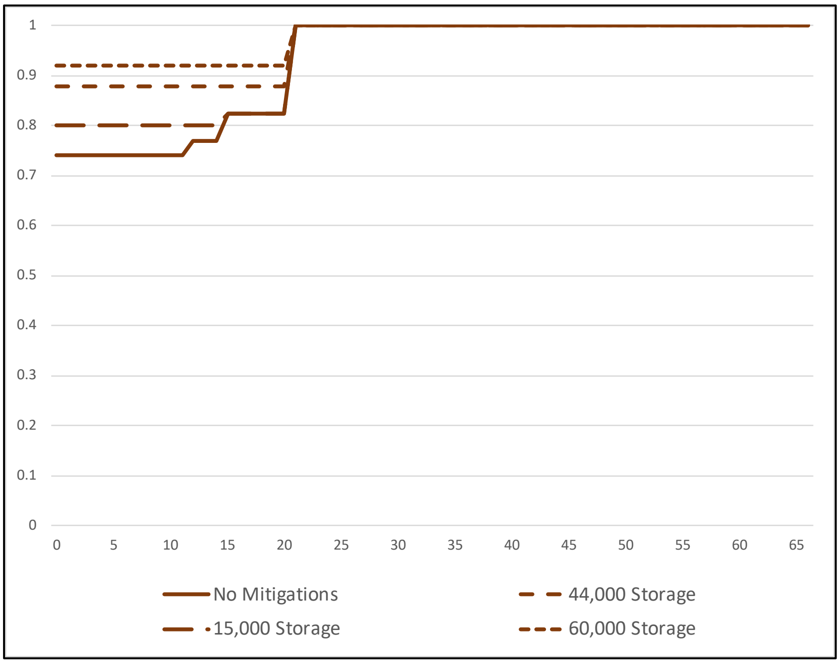

Figure 8 Jet Fuel Availability Following the Short-Term Refinery Outage Scenario – with and without Storage Mitigations

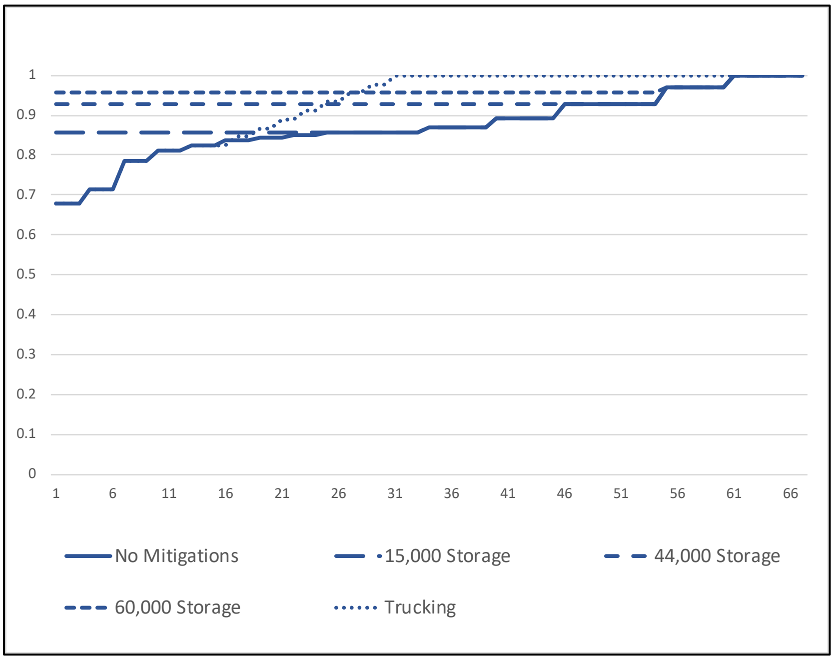

Figure 9 Petrol and Diesel Fuel Availability Following the Long-Term RAP/Wiri Outage Scenario – with and without Storage and Trucking Mitigations

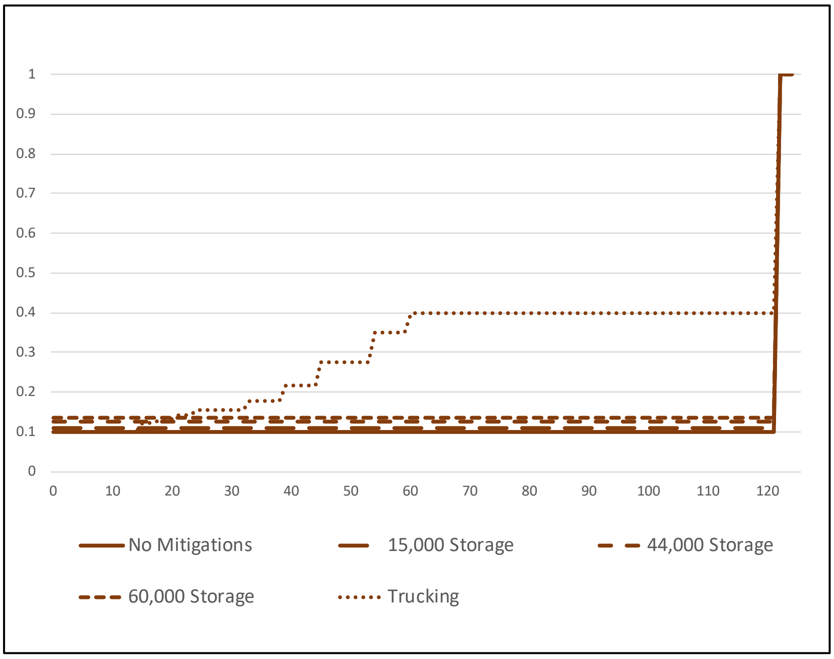

Figure 10 Jet Fuel Availability Following the Long-Term RAP/Wiri Outage Scenario – with and without Storage and Trucking Mitigations

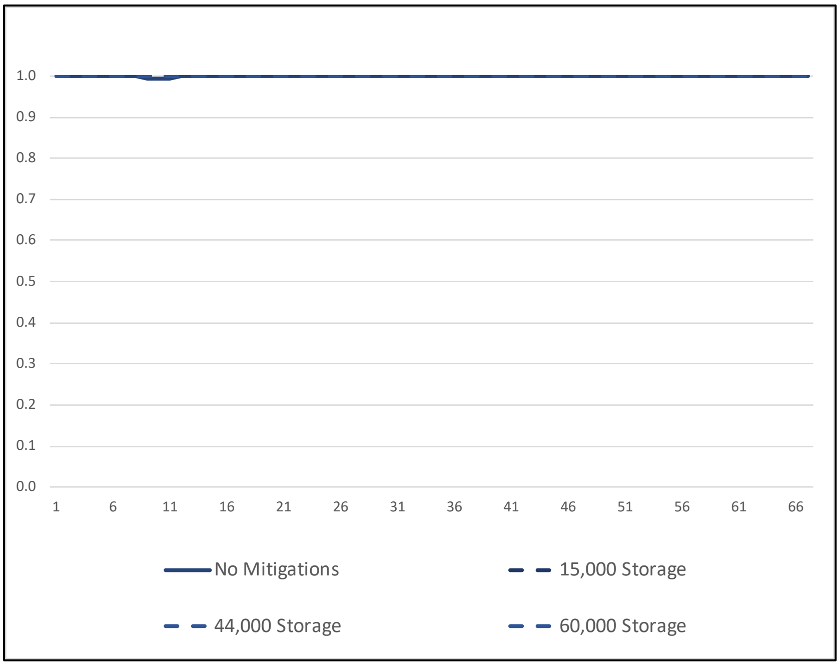

Figure 11 Petrol and Diesel Fuel Availability Following the Short-Term RAP/Wiri Outage Scenario – with and without Storage Mitigations

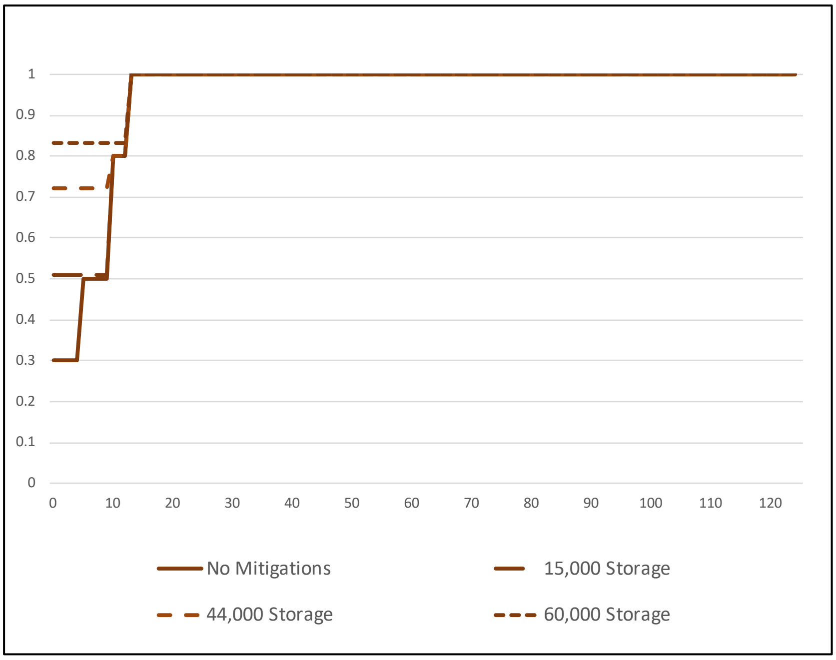

Figure 12 Jet Fuel Availability Following the Short-Term RAP/Wiri Outage Scenario – with and without Storage Mitigations

3.2.3 General Behavioural Assumptions

We anticipate that in the event of a significant fuel supply disruption, the government and communities will be involved in implementing a variety of actions to encourage fuel saving, discouraging adverse behaviours such as fuel hording, and attempt to share the hurt over the population. [7] The exact measures implemented are unknown but at the very least we can expect:

- Facilitation of reliance of *force majeure* contractual provisions (so that fuel can be supplied more evenly to consumers, with priority to certain emergency and welfare-oriented users).
- Widespread education and promotion of fuel saving measures in transportation, such as 'eco-driving' (e.g. reducing unnecessary loads, correct tyre pressure, driving with fuel-efficient speeds and acceleration), carpooling (multiple people per vehicle), trip-pooling (multiple purposes in each trip), increasing patronage of public transport where possible, using active transport modes (walking, cycling) where possible, and avoiding non-essential vehicle use.
- Encouragement of telecommuting. Although the potential of this measure will be largely restricted to those employed in information-based, largely service and management roles. Government organisations will themselves likely take this on themselves where possible, as exemplars for the public (Sampson *et al*., 2018).

[7] According to the IEA 'Guidelines for Demand Restraint' pamphlet, the I.E.P Agreement of 1974 requires all IEA member countries to maintain at all times a programme of oil demand restraint measures sufficient to reduce oil consumption by 7%-10%.

- Substitution of fuel for alternative energy sources where possible. However, technologies and processes reliant on petroleum-based fuels generally have low substitutability in the short term.[8]

The potential economic and social consequences of the supply shortage can be elevated by adverse behaviours such as fuel hoarding, and furthermore competition over a scarce resource can lead to significant adverse community outcomes (e.g. people subject to very long queue times and potentially conflictive situations). Thus, there is also potential that government will resort to implementation of rules regarding fuel saving and rationing. For example, limiting cars with number plates of certain types from driving on certain days, limiting the volume of fuel that can be purchased at each refuel, prohibiting overnight courier deliveries. Rule-based measures are however likely to be the last resort. Overall, accurate and timely information provision will be very important in helping to ensure consumers act rationally and responsibly towards their community, and that fuel is utilised in an economically-efficient manner.

It is not possible to know from the outset exactly how consumers will react to the situation, and how fuel will be rationalised. Behavioural changes in a disruption event can quite significantly alter the economic consequences. For the purposes of our analysis we have assumed that the situation is relatively well-managed and fuel shortages will be relatively evenly spread across users and across time. We furthermore assume that communities become actively engaged in fuel savings in a responsible way. This, added to by the additional inconvenience of the situation, will mean that there will be quite significant reductions in fuel demands from 'normal' fuel use. The greatest voluntary reductions in fuel use are likely to come from those consumers and fuel-using purposes for which reductions will provide relatively little 'hurt'. This will effectively free-up some fuel use for allocation to other consumers and or purposes, meaning the experienced fuel shortages for these users/purposes will be less than the economy-wide shortage from normal use.

3.2.4 Experienced Fuel Shortages

The purpose of this section is to examine the categories of key fuel consumers and set out some broad assumptions regarding the actual fuel shortages that will be experienced by those consumers, taking into consideration the economy-wide shortages that are set out in the first section, and rationing behaviour which may allow for some fuel reallocation.

Households

Among the agents in the economy, households are arguably those with the greatest ability to adjust their behaviour according to the changing economic conditions. It is difficult to know for certain how households will react to the situation and how they decide to ration fuel. If consumers overestimate the fuel shortage they expect to experience, they may over-restrict their fuel consumption behaviour (e.g. over-save fuel for more essential trips when in fact there is sufficient fuel for these journeys). In a similar vein, if consumers underestimate the likely shortage, they may under-restrict their fuel

[8] Although space heating is one option where substitution is relatively easy, even in the short-term, there is currently relatively low use of petroleum-based fuels for heating in New Zealand (EECA Energy Use Database).

consumption behaviour (e.g. continue largely as normal, exhausting fuel for essential journeys). To avoid such extreme scenarios, we assume that the situation is relatively well-managed with provision of accurate and timely information to ensure consumers will act rationally and responsibly.

It is reasonable to assume that households will prioritise essential transportation trips for work and collection of essential household items, and reduce more discretionary trips relating to shopping and leisure. This provides very high capacity for households to reduce fuel use, and thus, even in the most severe period of the most significant scenario (i.e when there is greater than 40% reduction in fuel supply under the long-term refinery outage scenario), there should be relatively little reduction in people's ability to get to their place of employment, should they choose to do so.[9]

Despite fuel being generally available to travel to work, given the strong pressure to save fuel (and additional inconvenience likely with obtaining fuel) we assume, for example, that the number of people who work from home or choose not to travel to work doubles over the most severe period of the long-term refinery outage and is 1.5 times the normal levels towards the latter periods of the scenario. For the less severe domestic scenarios, whereby the pressure to conserve fuel will be less, the assumed increase in work from home is peeled back, based on the relative petrol/diesel shortages between the scenarios. As reflected in the Census travel to work statistics, the ability to work at home varies across industry sectors, depending on the nature of the work involved. For industries such as professional, scientific and technical services as well as administrative and support services, the transition to working from home would be relatively smooth due to the option of telecommuting. These industries will therefore be responsible for the greatest shares of additional people working from home during the outage.

Given the prioritisation of travel to work, the fuel shortage for non-work travel will be greater than the average supply shortage. Our estimate of this shortage is however moderated because it takes into account households further reducing their fuel use for travel to work by engaging in demand restraint measures:

- *Public transport* - It is likely that households would also be encouraged to switch to public transportation for travel to work, where possible. Although the IEA (2015) broadly assumes that passenger transport fuel use for Australia/New Zealand/other OECD can be reduced by around 4% under a disruption event through additional public transport patronage, in the case of New Zealand it is highly unlikely that the existing public transport networks have capacity to take up this level of additional patronage. We have more conservatively assumed that public transport patronage will increase by up to 15% in both Auckland and the rest of New Zealand

[9] As an example, for modelling with the Wellington Transport Model, it is estimated that less than 20% of car trips (excluding employee-business car trips) are for the purpose defined as 'Home-Based Work'. Even if we assumed that up to half of the purpose 'Non-Home-Based Other' could also relate to work trips (as trip purposes are difficult to assign when there are multiple destinations), and half of all other trips are essential, there is still capacity for total trips to be reduced by 40% while maintaining travel to work trips. This also does not take into consideration the significant fuel savings that can be made by households through eco-driving, car-pooling and so on. Similarly, we can use the same assumptions and approach to examine potential capacity in Auckland, but this time using data derived from the Auckland Transport Model (ART). Although in the case of Auckland the 'Home-Based Work' purpose makes up a greater proportion of total car trips compared to Wellington (24% compared to 18%), there is still capacity for trips to be reduced by around 38% while maintaining travel to work. On top of this there are savings that can be made from eco-driving and so on. Although these examples are both urban, we can note that the majority of New Zealand's population is urban. Furthermore in rural areas, many persons are employed in agriculture and live at their place of employment.

under the long-term refinery outage scenario, and only marginally (c1%) under the short-term refinery outage scenario. For long-term RAP/Wiri disruption scenario, the assumed maximum increase in public transport patronage is set a little less for the affected areas than in the long-term refinery outage scenario (c11%), given that there is slightly less-extreme loss in fuel supply. For the short-term RAP/Wiri disruption scenario, the assumed increase in public transport patronage is minor. Adopting these demand restraint measures have the potential to reduce work-travel fuel use by respectively 1.5% and 0.8% within Auckland and the rest of New Zealand for the long-term refinery outage scenario.

- *Carpooling/ Ridesharing* - Consistent with the IEA's (2015) range of modest assumptions, we assume that vehicle occupancy rates in Auckland and the rest of New Zealand will increase by 15% at the most severe initial stage of the long-term refinery outage scenario (with lesser increases under the short-term refinery outage scenario). For the long-term RAP/Wiri disruption scenario, the assumed maximum increase in vehicle occupancy rates is again set lower for the affected areas than in the long-term refinery outage scenario at 11%.
- *Eco-driving* - This refers to modifications in driving behaviour in order to minimise fuel consumption and the emission of CO_2. The IEA report indicates that an aggressive promotion of eco-driving, coupled with incentives, might achieve fuel savings of 10% or more. In our analysis, we assume that households can achieve a maximum of 7% fuel savings from eco-driving (again, this is for the long-term refinery outage scenario with a lesser maximum saving of around 5% for the long-term RAP/Wiri disruption scenario and only a marginal saving assumed for the short-term refinery outage scenario). The IEA (2015) note that driving habits, traffic conditions, road design and the rules of the road will likely influence how effective this measure is both in terms of the potential savings and adoption rates.

Although fuel consumption for travel to work decreases after the onset of the disruption, we expect that it will gradually increase over the course of the disruption. That the fuel supply is slowly being restored is one reason for this. Another reason is that the inconvenience of working from home, using public transport and/or carpooling/ridesharing may become more apparent over time such that the benefits of private transport outweigh the potential fuel savings. Households therefore may become less committed and less eager to engage in fuel-saving measures. Consequently, households gradually return to their normal routine as prior to the disruption. Provided that households receive timely information of the status of fuel supply and thus are aware that fuel is being restored, then this reversion to normality becomes increasingly feasible.

For transportation other than travel to work, households will also have available some measures to reduce fuel consumption, moderating the impact of the disruptions to transportation. We assume that these fuel savings are at maximum 20% under the long-term refinery outage scenario, and again less under the long-term RAP/Wiri disruption scenario (15%) and short-term refinery outage scenario (1.2%), due to smaller shortages and lesser impetus to save. As with travel to work, we assume the desire and need to save fuel reduces over the course of the outages (e.g. reducing to 10% savings at the end of the long-term refinery outage scenario).

Commercial Users

As for industries, they may indirectly benefit from the fuel-saving behaviour of households in that the experienced fuel shortage may be less than the average supply shortage. Given that households are likely to utilise public transport, namely buses, it is sensible to prioritise buses when rationing the surplus. Moreover, if the government intends to promote greater use of buses then they must ensure that buses will be able to meet the expected greater demand.

Essential Welfare Providers

Essential welfare providers (e.g. police, ambulances, hospitals) will be given priority. Fuel shortages experienced by these users will therefore not be of such significance to impact directly on their operations.

4 Summary of the MERIT Dynamic Economic Model

Cost-Benefit Analysis Versus Economic Impact Assessment and Simulation

Many of the extant fuel security studies use CBA based analyses to evaluate the feasibility of mitigation measures such as strategic fuel reserves. The CBA studies take costs of potential mitigation measures and compare these against the estimated savings (based on consumer saving calculations, or more sophisticated simulation modelling) which these measures will generate during a disruption.

A frequently occurring limitation of studies investigating the economic consequences of mitigating low probability, high impact events, is the lack of explicit consideration of social risk preferences. Often it is simply assumed that societies are risk neutral as this significantly reduces the complexity of the assessment methodology. Societies are, however, typically risk averse (not risk neutral) in that they would rather pay now to avoid potential losses later. Methods such as expected utility theory (Smith and Vignaux, 2006) are available to adjust for risk preferences but these are not commonly applied.

Here we undertake a scenario-based Economic Impact Analysis using the suite of MERIT tools (described below) to model international and domestic disruption scenarios. For a given disruption scenario, we analyse the whole-of-economy impacts. The assessment is presented irrespective of the scenario probability to avoid the pitfalls and imbedded assumptions of discounting and risk preferences. The analysis results, including temporal industry and household impacts, can then be reviewed by decision-makers in a more nuanced fashion.

Description of MERIT

MERIT is an integrated spatial decision support system that enables a high-resolution assessment across space and through time of the economic consequences of infrastructure failure, business response, and recovery options.

Central to MERIT is a multi-sectoral, multi-regional and fully dynamic economic model, designed to imitate the core features of a 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 important to note that it differs from a standard CGE model in that 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.

Once information is transformed into appropriate inputs and MERIT is run, it can produce a variety of indicators to help us assess economic impacts of an infrastructure outage in aggregate and by industry. The model can thus not only be used to assess the economic consequence of a natural hazard event resulting from infrastructure failure, but also to inform on resilience-building and investment initiatives. The steps that are required to transform information on physical disruptions into appropriate input parameters can vary can from application-to-application, depending on the types of physical information provided, as well as the extent and nature of impacts arising out of the disruption event.

The technical report by Smith *et al.,* (2016) provides a full mathematical description of the model. Details on how the suite of MERIT tools was developed, how it works, and previous applications are also provided in various reports listed at the end of the References section.

5 Modelling of Direct Impacts

The core task faced in undertaking the MERIT modelling is to translate descriptions of a physical disruption, in this case we are concerned with infrastructure and other forms of disruption that lead to fuel supply outages, into estimates of economic impacts. Here, the descriptions of the physical disruption have been provided by Twomey and West (2017) (as described in Section 3). Because MERIT is a multi-regional model, the regional distribution of the fuel disruption needs to be defined. In this case the fuel shortage is assessed for Auckland and the rest of New Zealand.

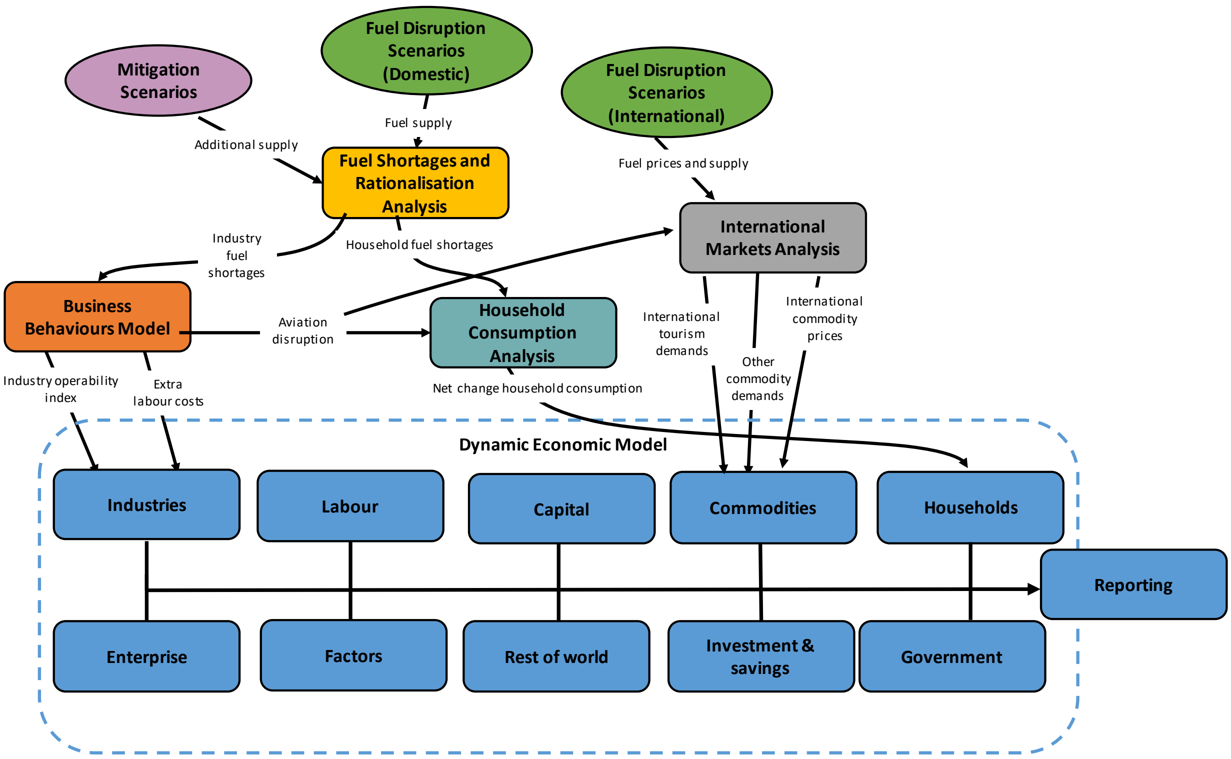

Figure 13 Process for MERIT Modelling of Fuel Disruption Scenarios

Figure 13 provides an overall scheme of the MERIT modelling process. To assist in the conceptualisation, the mathematical procedures that constitute the modelling process have been grouped into a series of 'models', some of which have underlying sub-components or 'modules'. The Dynamic Economic Model (DEM) is the core economic model constructed within the System Dynamics modelling language, and it is underpinned by several modules that cover Enterprises, Factors, Capital, Labour, and so on (see also Smith *et al.,* (2016)). For the international scenario, where the only direct impact is international price and demand changes, the DEM is the sole model in use. For the domestic scenario, a revised Business Behaviours Model is also employed to account for the impact of fuel shortages on industries. The Business Behaviours Model (BBM) (Brown *et al.*, 2015) calculates the 'operability' of different economic industries, across time, and given differing combinations of infrastructure service and other types of disruption. Once calculated, the industry operability parameters were incorporated directly within the DEM, to modify the 'as normal' levels of productivity within each economic industry. The original BBM was designed based on data from the 2010-2011 Canterbury earthquakes. In that event, fuel quantity disruption was not experienced. Therefore, a new set of operability functions have been designed. Given the nature of the fuel outage scenarios, special consideration has also been given to changes in household consumption and international tourism demands, for the domestic outage scenarios.

In the following sections of this report we set out the key assumptions underpinning the modelling for each scenario. Please note that the entire modelling process was relatively complex with many steps, we concentrated only on describing aspects that were not already covered by the technical reports listed above.

5.1 International Supply Disruptions

The direct impacts considered in the MERIT modelling of the international supply disruption are principally the changes in export/import commodity prices and export demands as set out in Section 3.1.2. Although the Twomey and West (2017) report notes that the initial phase of the disruption will likely be characterised by higher price increases (as it will take some time for supplies and demands to adjust), we have not attempted to include this 'settling in phase' in the model run – i.e. we have just taken a six-month disruption, where prices and changes in export demands are at the settled level.

To provide additional coherence to the scenario, a few other adjustments are made to the model as follows:

- *Net foreign savings* – As discussed above, MERIT was principally designed for analysis of domestic economic shocks. When very high rates of price increase happen in the model, this is assumed to create a government response in relation to interest rates which, while dampening inflation through reduced household expenditure can also cause a reasonably significant change to the level of foreign savings (as foreign investment will be attracted to high interest rates, all other things being equal). Similarly, when high rates of deflation occur in the model (e.g. as happens when the disruption ends), the dynamics occur in the same manner but in opposite directions. In the case of a worldwide disruption, however, other countries will also be experiencing disruption, and so there is no reason to expect significant changes in the foreign investment. We have therefore held foreign investment as the same as the base (non-impacted) model run.
- *Investment in oil exploration and petroleum manufacturing* – All other things being equal, the response of the MERIT model to significant appreciation in petroleum commodity prices would be to allocate higher rates of investment to oil exploration and petroleum manufacturing to increase production. We have, however, assumed that the disruption is known to be of relatively short duration and have instead kept the rates of investment in these industries the same as in the base (non-impacted) model run.

5.2 Domestic Supply Disruptions

For this study we have split the direct impact scenario development and assessment of direct impacts into three key matters of consideration: (1) impacts on industry supply; (2) changes in household consumption or, in other words, demands for goods and services; and (3) changes in tourism demands.

5.2.1 Impacts on Industry Supply

A major component of the modelling of direct impacts is to establish how the disruption under consideration will impact 'as normal' levels of production, which in MERIT modelling we term 'operability'. The impact of fuel disruption on the ability of industries to produce goods and services, or operability, will depend on their dependence on fuel, how fuel shortages impact their staff and how resilient and adaptive they are to fuel disruption.

For this study, we have grouped industries together based on key factors that are likely to impact on operability and the relative susceptibility of industries to these factors. The relative factors considered are: (1) labour travel (i.e. staff getting to work); (2) work-related travel (i.e. travel to deliver the service, such as a mobile nurse or plumber); (3) freight (i.e. reliance on freight movement for key production inputs, or for delivery of goods produced); and (4) production (i.e. where petroleum products are a direct input into production of a good or service, such as forestry or petroleum retailers). To develop and verify how these four principal factors of disruption impact on industry operability, we drew on relevant literature and conducted a series of interviews with industry representatives (see Appendix B for details).

Altogether, 12 industry groups are identified (Table 4). For each industry group, we developed functions that describe how operability changes over time depending on fuel availability. An operability score of 1 means that industries are fully able to meet normal levels of production, while a score of 0 means that industries are completely out of production. Key assumptions underpinning the operability functions are detailed in Table 4. Note that while many industries will experience multiple causes for disruption, for example, some industries will experience disruptions to staff travel to work as well as reduced ability to transport key goods used in production processes, generally the operability functions consider only the factor(s) likely to cause the *largest* impact on production; an approach used by other economists (e.g. Rose *et al.,* (2018)). Importantly, the operability functions represent not only the vulnerability of the industry to disruption[10], but also the capacity of the industry to respond and adapt to the disruption, for example through telecommuting and more efficient use of resources. Some other general points regarding the development of the operability functions are:

(1) *Efficiency of fuel use* - IEA (saving oil in a hurry) assumed that 5% reduction in fuel use could be achieved as a natural behavioural response to an oil supply disruption. We take this to be the level of fuel saving that can at the least be achieved by all industries (except petroleum manufacturers and retailers) without any real impacts on production. For some industries we assume greater gains in the efficiency of fuel use can be made before any substantial changes in operability.

[10] The operability functions represent the average response across an industry. There will be variability between organisations within each industry.

(2) *Telecommuting* - Telecommuting has been used as an adaptive mechanism in response to disruptions such as the 2010/2011 Canterbury earthquakes. The shift toward increased use of telecommuting however is sure to involve several challenges, namely: information system challenges, adjusting to smaller screens/home workspaces, home distractions, communication and collaboration challenges, and social isolation. These negative impacts however can be balanced by positive gains including staff being able to personalise their work environment, work flexible hours as well as building a greater trust culture (Green, n.d.).
Other studies examining the long-term productivity of organisations that utilise telecommuting indicate that productivity can be positively affected (Gajendran & Harrison, 2007). This may however depend on the task. That is, creative tasks could be accomplished more effectively, while more monotonous tasks suffer productivity losses (Dutcher, 2012).
Overall, as observed following the Canterbury earthquakes, we anticipate that a fuel supply shortage will have a relatively low impact on these information-based services due to their ability to utilise telecommuting (Brown *et al*., 2015), and that the efficiency of remote working arrangements will improve over time.

(3) *Work Travel* - Industries such as trades and mobile community services rely heavily on transportation to conduct business with their customers. Although their core service does not rely on fuel, these industries will experience some disruption if they are unable to reach their customers or their supply chains are disrupted. In light of this, we have assumed that there is a moderate initial drop in operability under the premise that organisations can still deliver their service but may be unable to travel to all customers.

(4) *Freight* - For industries that are heavily reliant on freight (fast-moving consumer goods, food manufacturing), we have disaggregated them into 'fast-turnover' and 'slow-turnover' industries. 'Fast-turnover' industries are those that typically have low supply lead-time, low inventory levels (such as fast-moving consumer goods) and/or time-sensitive delivery (perishable goods, such as milk). These industries will be almost immediately impacted by disruption to freight movements (McKinnon, 2011). 'Slow-turnover' industries are those that are less time-dependent on freight movements, for example manufacturing industries that either hold stockpiles of input materials or can hold goods produced until freight movement is available. Previous studies such as Barker and Santos (2010) have taken a similar approach by adjusting disruption for inventory levels.

(5) *Petroleum inputs to production* - Generally, for industries in which petroleum products are essential inputs to production (such as petroleum retailers, transport services, construction, logging contractors) we assume that production is initially proportional to the reduction in fuel allocated to each industry. This is a similar approach taken by other studies including NZIER (2012) and Rose *et al.,* (2018).

(6) *Recovery in operability over time* - In our previous studies that involve a major hazard event (e.g. a Wellington Fault earthquake event), we have applied operability curves that exhibit business recovery (i.e. increasing operability) over time. The underlying assumption, supported by our research following the Canterbury Earthquakes, is that businesses are highly adaptive and will seek out ways to deal with the disruption, but it may take some time to identify and implement adaptation strategies (e.g. setting up work-from-home information systems, finding new suppliers or outsourcing relationships). Interviews with organisations have, however, also shown that when a disruption event involves only a single infrastructure or resource type, and where there is more certainty of the event being of relatively short duration, there is more likelihood that organisations will simply "sit the event out" rather than start the

implementation of new methods to mitigate the disruption (Hatton, Brown, Seville, & Stevenson, 2016).

In this study, although we are concerned with a single infrastructure type, the events are of a relatively long duration for certain scenarios. There is also quite significant recovery in the supply shortages themselves for some of the scenarios. We have generally assumed that impacts on operability are more severe in the first 1-2 weeks of the event as businesses set-up some coping mechanisms. However, in some cases this will be overridden through inherent reliance provided by the presence of inventories that delay inoperability. After this 1-2 week period, rates of recovery in operability relative to fuel supply are generally not assumed to be high. However, industries also experience actual recovery in the fuel supply shortages for many of the scenarios.

(7) *Costs of fuel savings and mitigations* - When organisations implement measures to cope with reduced fuel supply, many of these measures will incur costs for the organisation. For example, trip rationalisation will often involve extra staff time devoted to planning. Similarly, allowing staff to work from home may incur some initial information system set-up costs. For the most part we have not attempted to account for such additional costs incurred. As an exception, we have taken into consideration additional labour costs incurred with production recapture (see point (5) below). It is worth noting that our research on disruptions to government organisations following the Kaikoura Quakes (Sampson *et al*., 2018) and interviews with airlines following the Wiri pipeline disruption have indicated that many of the costs will be incurred by employees without additional financial renumeration, i.e. through extra demands and stress placed on them, and needing to work harder and overtime. These non-market costs are not in any case included in a MERIT assessment given that MERIT is concerned with simulation of a market-based economy.[11] Nevertheless, there will be some costs that are incurred with market transactions that have not been captured.

(8) *Consumer-held fuel inventories* – For some industries, the presence of fuel stocks which can be utilised in a supply shortage will delay the onset of inoperability. We believe this effect is likely to be most relevant to those organisations/industry types which utilise fuel in their production processes and therefore likely to hold fuel inventories. Rose *et al.,* (2018) indicate that, at least in the US economy, manufacturing sectors may hold on average 16 days of fuel. In New Zealand, fuel deliveries to farms are typically once a month (pers. comm. Beef & Lamb, DairyNZ), while restocking of fuel supplies for forestry operations are usually more often. We have taken into account that some fuel is on-hand for these sectors which effectively delays inoperability.[12]

(9) *Production recapture* – This is one of the principal mitigation tactics typically discussed in the disruption literature (Multihazard Mitigation Council, 2005; Rose *et al*., 2016; Rose *et al*., 2018) and refers to the ability to compensate lost production by working overtime or extra shifts once supply chains resume (Rose *et al*., 2018). Our process for considering supply-side impacts has been to first determine reductions in operability, then apply a further adjustment to account for lost production that can be recaptured. The proportion of total production which can be

[11] In potential future extensions to MERIT relating to development of welfare metrics it will be important to consider how some of these non-market costs (and potentially benefits) can be included.

[12] If fuel is restocked approximately once a month, and all producers have at least one week of fuel on hand, the expected average coverage is 22 days. It is also reasoned that due to uncertainty, consumers will be reluctant to draw on the last seven days of storage, giving 15 days of supply.

recaptured is effectively added to our first estimates of operability for each industry.[13] For this study we have adopted the same method as Rose *et al.,* (2018) and applied production recapture rates that are half of those specified for the HAZUS model (see Table 4).[14] As production recapture is principally concerned with utilising labour to enable greater than normal levels of production (once the disruption effects cease), we have also considered potential increases in labour costs faced by industries.

[13] We recognise that lags will exist between when inoperability is experienced and when the production is recaptured. We have not, however, attempted to account for these time delays.

[14] HAZUS is a US-based natural hazard analysis tool developed by FEMA. The tool models geographical hazard exposure and associated losses. The production recapture rates specified in HAZUS are deemed suitable for short-term (less than three months) disruptions but acknowledges that they may need to be reduced for longer-term disruptions where recapture becomes more challenging.

Table 4 Operability Assumptions for Industry Groups

Industry group	Example industries	Dominant disruption type	Resilience measures	Operability	Production recapture
Information services	Professional services, Insurance and Financial services	Labour travel	Telecommuting	Week 1: 5% reduction for every 10% staff that cannot or choose not to go to work Week 2+: 2% reduction per 10% staff not at work	0.45
	Government				1
Destination services	Medical services Education Recreation	Labour travel		As above	0.3
Freight reliant - fast turnover	Fast Moving Consumer Goods, Milk production Accommodation Hospitality[15] Hospitals	Freight	Inventories	Gradual fall from 100% operability to the operability level of Freight Transport Services by day 5.	0.1[16]
Freight reliant - slow turnover	Non-oil dependent manufacturing	Freight	Inventories	Gradual fall from 100% operability to 20% of inoperability of Freight Transport Services sector by day 5 (i.e. 10% reduction in freight service operability = 2% reduction in operability). By 4 weeks, operability is equivalent to Freight Transport Services operability.	0.48
	Retail trade Wholesale trade and services				0.43
Freight transport services	Road freight, rail freight, coastal shipping	Production input	Fuel-efficiencies	Week 1: Operability is proportional to fuel allocated to freight transport (less 5% for fuel efficiency savings possible.	Based on recapture rates of

[15] 80% of acommodation and hospitality organisations are in this category and 20% in destimation services category due to their high reliance on freight (linen and food)

[16] Rose *et al.,* (2018) do not have an equivalent industry category. We assume production recpature capacity is low.

				Week 2+: Same as week 1 but also assumed that over time increasing ability to adapt to fuel shortages meaning small increases in inoperability, even if fuel shortage is constant.	industries that use freight transport
Transport services - passenger	**Bus, Train**	Production input		100% operability as priority user	N/A
Transport Services - international air		Production input	Route rationalisation Using & fuelling at other airports Trans-Tasman fuel tinkering	Operability is determined by jet fuel availability. The first 10% loss of normal supply can be met through flight rationalisation, a further 9% can be met through trans-Tasman tinkering, and 16% can be met through diverting to Christchurch (regional RAP/Wiri scenarios only). Of the remaining losses, 50% can be met by extreme measures taken by airlines and the rest leads to inoperability.	0.1[17]
Transport Services - domestic air		Production input	Route rationalisation Fuelling other airports	Operability is determined by jet fuel availability. The first 10% loss of normal supply can be met through flight rationalisation. Of the remaining losses, for a national outage 50% can be recaptured by extreme measures taken by airlines and 95% for a regional outage.	0.15[18]
On-site services	**Tradesmen Community healthcare**	Work-related travel	Fuel efficiencies Trip rationalisation	Operability is reduced by 5% for every 10% loss of fuel availability (less initial 5% loss of fuel). After two weeks this reduces to 3% per 10% loss of fuel. Operability also cannot exceed that of the Freight Reliant (slow-turnover) group.	0.47
Oil-dependent production	**Dairy farming**[19]	Production input and Freight	Fuel efficiencies Industry held fuel inventories	The first 5% of fuel shortage can be absorbed with no material impacts on operability. For remaining fuel shortages, operability reduces in direct proportion to fuel shortage. However, inventories of fuel held by industries will delay the onset of this inoperability. On average, assumed fuel delivered every 30 days and farmers are evenly distributed within this delivery cycle at the time of the outage.	0.38

[17] Rose *et al.,* (2018) do not have an equivalent industry category. We assume production recpature capacity is low.

[18] Rose *et al.,* (2018) do not have an equivalent industry category. We assume production recpature capacity is low but slightly higher than international travel as a higher proportion may be non-substitutable (e.g. visiting family and work travel)

[19] Dairy cattle farming is given special treatment because, given the significant environmental implications of raw milk unable to be transported to processing, it is assumed that fuel provision will be prioritised for milk transportation and thus the same level of fuel shortages will not be experienced with regards to raw milk production.

	Other producers of highly perishable goods, e.g. poultry egg farming, fishing			As above for dairy farming. Also, if operability calculated by these assumptions is higher than that calculated for the freight reliant – fast turnover group, the operability of that group is instead applied (to account for freight disruptions instead being the dominant form of disruption).	0
	Oil dependent producers with also freight dependence (fast turnover), e.g. fruit growers (non-harvest season)			Same as Agriculture - other highly perishable.	0.48
	Oil dependent producers with also freight dependence (slow turnover), e.g. mining, some construction, livestock farming			The first 5% of fuel shortage can be absorbed with no material impacts on operability. For remaining fuel shortages, operability reduces in direct proportion to fuel shortage. However, inventories of fuel held by industries will delay the onset of this inoperability. On average, assumed fuel delivered every 30 days and consumers are evenly distributed within this delivery cycle at the time of the outage. If operability calculated by these assumptions is higher than that calculated for the freight reliant – slow turnover group, the operability of that group is instead applied (to account for freight disruptions instead being the dominant form of disruption).	0.48
	Forestry			Same as for Agriculture – other freight dependent, fast turnover except that the average timeframe for fuel store restocking is only 5 days.	0.38
Petroleum retailers		Production input		Operability is in direct proportion to fuel availability.	Based on recapture by other industries
Emergency Services	Police, ambulance, fire	Work-related travel		100% operability	N/A

To generate the operability curves for each of the 41 industry types in the MERIT model by each MERIT region (Auckland and Rest of New Zealand), we start by assigning each of the 6-digit ANZSIC industries (around 500 industry types in total) to one of the 12 industry types identified in Table 4[20]. These are then weighted according to each industry's relative contribution to employment and its value of production, to generate operability curves at the 41 industry level for each region.

5.2.2 Changes in International Tourism Demands

There is limited systematic research on the impacts of disruptions on tourism demands, and even less relating specifically to fuel disruption. Below we describe a range of disruptions and their effect on tourism (both domestic and international) to provide context for the assumptions we have developed for tourism demand changes.

Despite being a relatively significant loss of fuel[21], the 2017 disruption to jet fuel supply in Auckland was described as relatively minor, akin to a Winter Storm (Robson, 2017). This minor impact was largely due to a huge effort from airlines to reorganise their operations and minimise disruption to passengers. By day four, 95% of domestic and international flights had resumed, despite still operating on 30% of usual fuel supply levels. There were some losses of customers due to uncertainty, however the potential tourism disruption could have been much higher if the airline industry had not been so effective at minimising disruptions to travellers.

The UK fuel tax protests in 2000 caused significant disruption to fuel availability for five days, with protesters targeting fuel distribution hubs and refineries (McKinnon, 2011). The event had significant impacts on car travel, in particular motorway travel (Hathaway, 2000). During this period central city hotels in London experienced both significant cancellations and reservations as employers accommodated staff in the central city to avoid the travel disruption. Bookings increased and were back to normal a week or so after the event. There was also a small reduction in visits to tourism destinations but was not found to be significant (Marsden & Beecroft, 2017).

The eruption of Eyjafjallajökull in Iceland in 2010, caused some initial disruption to tourism in Iceland (decline of 17.5% during the disruption and a month thereafter). This initial disruption was largely in line with a 20% disruption to flights. Tourism numbers however rebounded soon after, potentially due to public exposure during the eruption (Jonsdottir, 2011) and tourist interest in the eruption (Benediktsson, Lund, & Mustonen, 2010).

The way in which a disruption is portrayed by media can have an impact on tourism market response – both initially and in the long-term (Tanger & Clayton, 2013). Following the 2010/2011 Canterbury earthquakes, there was a notable (and sustained) decline in international visitors from Australia, however this was largely countered by the burgeoning tourism market from Europe, China and other Asian countries. International tourists tended to redistribute from the most heavily impacted region to other parts of New

[20] We actually allow for some 6-digit level industries to be assigned to multiple groups (e.g. 50% oil dependent production, 50% freight slow turnover) to reflect that even at the 6-digit level, different components of the industry's activity may be associated with different key drivers for disruption.

[21] The disruption lasted 14 days. Fuel was gradually restored from an initial 70% fuel supply loss. The timeline for return to full supply was approximately: 70% loss of fuel for six days, 50% loss for a further five days and a 20% loss for the final three days of disruption).

Zealand (N. Smith, Orchiston, Harvey, Kim, & Brown, 2016). (N. Smith *et al*., 2016). The 2016 Kaikoura earthquakes showed similar patterns in tourism behaviour. Canterbury experienced a loss of international tourism, although New Zealand showed considerable gain (McDonald *et al*., 2017).

Domestic tourism numbers in Canterbury following the earthquakes have evidently been slow to recover, most likely a result of the negative media and concerns over safety. Due to the large disruption, there has been a net outflow of tourism as residents seek to leave the city as a respite from the ongoing aftershocks. However, some of the lost domestic tourism has been replaced with work-related visitors contributing to the rebuild effort (Smith, Orchistron *et al*., 2016).

Based on the above, we anticipate that a reduction in fuel availability in New Zealand will impact tourist behaviour in three ways: (1) through potential initial disruption to flights and subsequent cancellation or re-routing of travel; (2) through negative media and fear that trips will be disrupted once in New Zealand; and (3) a desire to contribute to fuel conservation efforts. These factors play out differently for domestic and international tourists. However, counterintuitively, international tourism spend may actually increase in the immediate aftermath of an event, presumably because in the short-term many tourists cannot shorten trips and coping with the disruption may generate a need for additional expenditure (Smith, Orchistron *et al*., 2016). Domestic tourism behaviours will begin to return to normal once confidence returns about flight scheduling and fuel supply restoration. International tourists are likely to be more affected by negative media and reduced demand may be sustained until sometime after the end of the fuel disruption.

The modelling assumptions are:

- The percentage reductions to international tourism demands will generally reflect the percentage disruption to air transport services. There will however be an extra disruption penalty of 0.05% for every 1% disruption to air transport to account for likely additional cancellations.
- The disruption to tourism demands will also lag the actual disruption to air transport services. This reflects that while demands will decrease from losses in arrivals, tourists will already be in the country at the time of the disruption, and some may even be forced to stay longer. Furthermore, perceptions of the disruption, and associated behavioural changes, may take time to adjust.
  The lag is incorporated by taking the rolling average of the aviation disruption over 18 days (the period was chosen as it reflects the average length of a tourist stay). It is the rolling average of the aviation disruption rather than the immediate disruption level that is then used for the purposes of calculating the tourism demand disruption.
- Finally, to maintain consistency with experiences after the Kaikoura and Canterbury earthquake events, it is assumed that regardless of the results of the calculations, there is no experienced changes to international tourism demands over the first five days of the disruption.

5.2.3 Changes in Household Consumption

Our analysis of direct impacts on household consumption commences by considering the proportion of household consumption of goods and services that cannot occur due to a loss of household's ability to travel. This analysis is undertaken separately for four categories:

(1) *International imports of tourism-related goods and services* - We assume that 100% of demands from this category are dependent on the provision of international aviation, and hence reduce in

direct proportion to experienced losses in operability of international aviation. However, 10% of lost demands will be recaptured in the relative short term (thus providing consistency with the operability analysis above).

(2) *Other international imports* - Only demands for commodities that are sourced largely through retail are assumed to be impacted by fuel shortages. For these commodities it is assumed that for every 1% reduction in household fuel available for non-work travel results in a 0.4% reduction in demands. However, 43% of lost demands are recaptured.

(3) *Domestically sourced* tourism-related *goods and services (i.e. inter-regional tourism products*) - We estimate that 17% of demands from Auckland households are dependent on aviation and 16% of demands from rest of New Zealand households. These demands are assumed to reduce in direct proportion to experienced disruptions to aviation. The remaining purchases in this category depend on the provision of household fuel for vehicle transportation and are therefore assumed to reduce in direct accordance with the percentage reductions to fuel use for non-work travel. For this category, it is also assumed that 30% of lost demands can be recaptured in the relative short-term.

(4) *Other goods and services from the domestic market* - there is variation among these commodity purchases regarding the importance of access to fuel. Goods that are highly discretionary and generally require travel to access (e.g. restaurant services) are assumed to decrease in demands by 0.8% for every 1% reduction in household fuel availability. Demands for goods and services that do not depend on household travel (e.g. telecommunications), or that households are likely to prioritise (e.g. food items) are assumed unaffected. All remaining commodities are assumed to decrease in demands by 0.3-0.5% for every 1% reduction in fuel availability. For the highly discretionary goods, production recapture is set at 43%. Pre-school and childcare services are assigned a 0% production recapture rate, and all other commodities with reduced demands are assumed to have a production recapture possibility of 30%.

Once we have determined the proportions of household consumption that cannot occur for each MERIT commodity, these proportions are used to adjust down household consumption from that which would otherwise be expected. In the MERIT modelling, however, we have also been careful to account for the financial savings that accrue from reduced household demands, and the potential flow-on impacts of these savings. This occurs by creating a financial stock in the model that collects all unspent household consumption, and this stock is redistributed back into the system over a half-year period as income available to households to spend according to normal expenditure patterns (i.e. as savings, consumption, transfers to other agents, etc.)

6 Model Results

6.1 International Supply Disruption

The economic impacts over time for the international disruption scenario are summarised in Table 5. MERIT outputs show a GDP loss of around $1.28 billion or just under 1% of New Zealand GDP for the six months over which the supply shortage event occurs. The losses in economic activity have some flow-on effects into the following six months even once prices return to normal, meaning that the total loss of GDP reaches around $1.58 billion over the year considered.

The price shock caused by this international disruption scenario has implication for New Zealand's international trade and balance of payments. In line with studies considered in the literature review, MERIT demonstrates that under this scenario, there is an increase in the total value of imports relative to the total value of exports which causes some depreciation of the exchange rate.

Table 6 shows the distribution of losses across different industry groups. Most industries show a loss – particularly those dependent on fuel as inputs to production, those that rely on tourism demands, or those that rely on imported commodities experiencing relatively high price increases. The oil and gas exploration industry, however, (included under 'Other primary' in Table 6) shows increases in value added under the scenario as it benefits from the higher global fuel prices.

Table 5 International Supply Disruption – Impacts on Gross Domestic Product (GDP)

	Cumulative Net Change in GDP ($$_{2017}$mil)			% change in GDP		
	2 months after event	6 months after event	1 year after event	0-2 months after event	0-6 months after event	0 - 1 year after event
Auckland	-160	-640	-770	-1.0%	-1.3%	-0.8%
Rest of New Zealand	**-60**	**-640**	**-810**	**-0.2%**	**-0.8%**	**-0.5%**
Total New Zealand	-230	-1,280	-1,580	-0.5%	-0.9%	-0.6%

Notes: Time = 0 is at the commencement of the disruption. All results rounded to nearest $10mil

Table 6 International Supply Disruption – Accumulated Loss of Industry Value Added ($$_{2017}$mil)

Industry	2 Months			6 Months			1 Year		
	Auckland	Rest of NZ	Total NZ	Auckland	Rest of NZ	Total NZ	Auckland	Rest of NZ	Total NZ
1 Agriculture	0	-30	-30	0	-100	-100	0	-110	-110
2 Other primary	0	230	230	0	680	680	0	630	630
3 Manufacturing	-40	-100	-140	-100	-320	-420	-100	-210	-310
4 Utilities & communications	-10	-50	-60	-40	-190	-230	-40	-210	-250
5 Construction	10	20	20	-20	-50	-60	-80	-160	-230
6 Trade and hospitality	-50	-10	-60	-130	-110	-240	-140	-120	-260
7 Transport & storage	-10	10	0	-90	-80	-170	-110	-100	-210
8 Financial & business services	-10	-10	-20	-40	-40	-80	-50	-40	-90
9 Government, education and health servi	-20	-20	-40	-60	-110	-170	-80	-140	-220
10 Other services	-20	-50	-70	-70	-180	-260	-90	-210	-300
Other value added	-20	-30	-60	-80	-130	-220	-90	-140	-230
Total	-160	-60	-230	-640	-640	-1,280	-770	-810	-1,580

Notes: Time = 0 is at the commencement of the disruption. All results rounded to nearest $10mil.

6.2 Domestic Disruptions

6.2.1 Long-Term Refinery Outage

The long-term refinery outage scenario causes a loss of nearly $2.5 billion or 1.8% of GDP over the first six months, see Figure 14 and Table 7. Over the following six months there is some small recovery, in part due to household expenditure that is initially delayed and carries forward into this period. Over the entire year of analysis, the GDP impact of the long-term refinery outage scenario is estimated as $2.2 billion, or nearly 0.8% of total GDP compared to the baseline scenario.

While such percentages may not sound significant, these are indeed large in the context of a disruption event and have the potential to be serious, particularly if realised during a period of relatively poor economic performance. For example, during the 2009 global financial crisis, although New Zealand's GDP fell by only 1.6%, unemployment climbed to 7.3% in early 2010 (Becken & Lennox, 2012).

Table 8 provides a breakdown of losses across industries. Given the relative value added contributions of industries to total GDP, value added impacts are overrepresented in the manufacturing sector and underrepresented in the tertiary sector. For example, while manufacturing and tertiary industries currently constitute around 11% and 82% respectively of total industry value added, they are responsible for 25% and 67% respectively of the total value added loss under the scenario. Notably, one of the industries included within the manufacturing sector is the petroleum refining industry, which is directly impacted and experiences significant losses in production under this scenario. GDP impacts are, nevertheless, relatively evenly spread across the country, with just under a third (32%) of the total GDP loss over one year being in Auckland and the remainder in the rest of New Zealand.

With the application of the storage mitigation, the estimated GDP impact over the year for a long-term refinery outage reduces by $250, $620, and $780 million for 15,000t, 44,000t and 60,000t storage options respectively. For this scenario, the benefit of increased storage volume is not linear and offers some decreasing return on investment – net GDP savings per unit volume of storage being $16,700/t, $14,000/t and $13,000/t for 15,000t, 44,000t and 60,000t storage, respectively. The largest benefits of the mitigation are felt in trade and hospitality, followed by transport and storage and construction.

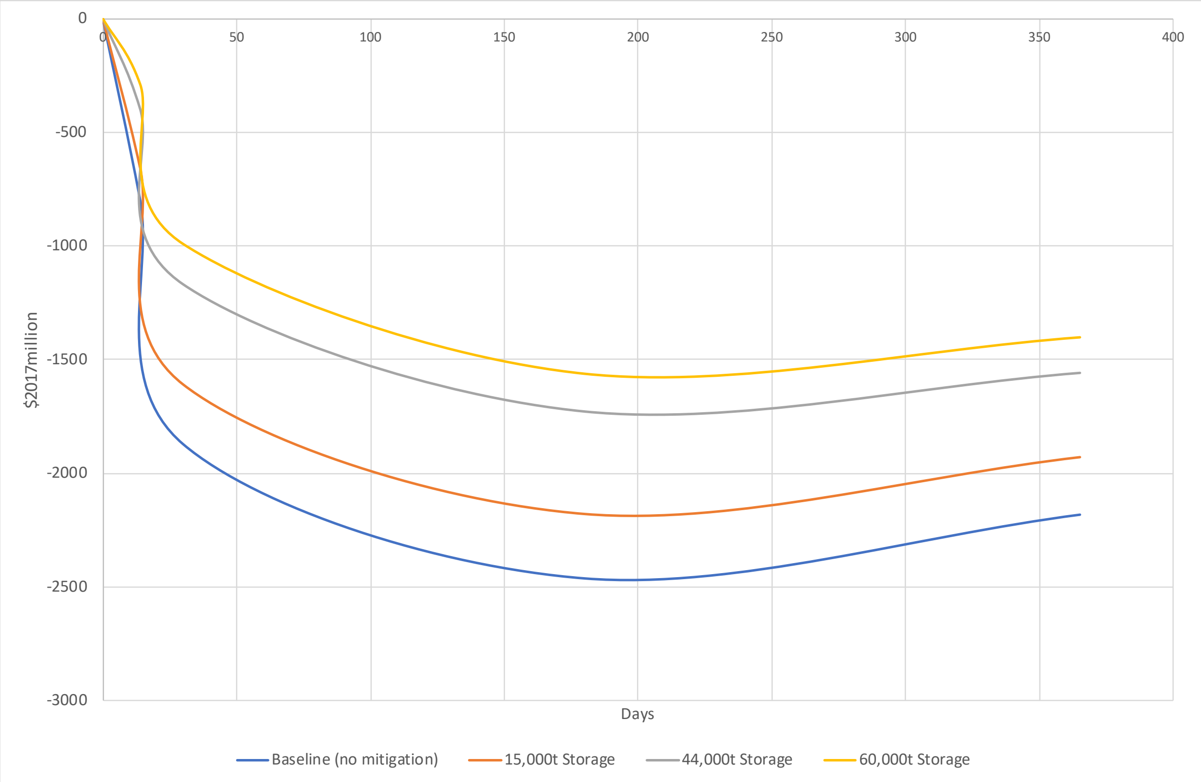

Figure 14 Long-Term Refinery Outage Scenario – Cumulative Impact on New Zealand's Gross Domestic Product, with and without Storage Mitigations. Note: costs of putting in place storage not included.

Table 7 Long-Term Refinery Outage Scenario – Impacts on Gross Domestic Product (GDP) with and without Storage Mitigations ($_{2017}$mil)

	Cumulative Net Change in GDP ($2017mil)				% change in GDP		
	2 weeks after event	2 months after event	6 months after event	1 year after event	0-2 months after event	0-6 months after event	0 - 1 year after event
Baseline (no mitigation)							
Auckland	-260	-560	-730	-700	-3.3%	-1.4%	-0.7%
Rest of New Zealand	-530	-1,300	-1,730	-1,480	-4.6%	-2.0%	-0.9%
Total New Zealand	-800	-1,870	-2,460	-2,180	-4.1%	-1.8%	-0.8%
Reduction in losses (15,000t Storage)							
Auckland	50	80	90	80	0.5%	0.2%	0.1%
Rest of New Zealand	90	170	190	170	0.6%	0.2%	0.1%
Total New Zealand	140	260	280	250	0.6%	0.2%	0.1%
Reduction in losses (44,000t Storage)							
Auckland	130	220	240	200	1.3%	0.5%	0.2%
Rest of New Zealand	270	480	490	420	1.7%	0.6%	0.2%
Total New Zealand	400	700	720	620	1.6%	0.5%	0.2%
Reduction in losses (60,000t Storage)							
Auckland	170	280	300	260	1.6%	0.6%	0.3%
Rest of New Zealand	340	600	600	520	2.1%	0.7%	0.3%
Total New Zealand	510	880	900	780	2.0%	0.7%	0.3%

Notes: All results rounded to nearest $10mil. Costs of putting in place storage not considered.

Table 8 Long-Term Refinery Outage Scenario – Accumulated Loss of Industry Value Added ($\$_{2017}$mil)

	2 Months			6 Months			1 Year		
	Auckland	Rest of NZ	Total NZ	Auckland	Rest of NZ	Total NZ	Auckland	Rest of NZ	Total NZ
Baseline (no mitigation)									
1 Agriculture	0	-50	-50	0	-50	-50	0	-50	-50
2 Other primary	0	-60	-70	0	-100	-100	0	-110	-120
3 Manufacturing	-90	-280	-370	-150	-520	-670	-140	-340	-490
4 Utilities & communications	-10	-30	-40	-20	-40	-60	-20	-30	-60
5 Construction	-30	-110	-140	-60	-140	-200	-50	-100	-150
6 Trade and hospitality	-140	-190	-330	-160	-200	-350	-150	-170	-320
7 Transport & storage	-90	-110	-200	-90	-110	-200	-90	-120	-210
8 Financial & business services	-20	-40	-60	-40	-50	-80	-40	-40	-70
9 Government, education and health servi	-80	-190	-270	-90	-220	-310	-90	-210	-300
10 Other services	-40	-130	-160	-50	-160	-220	-50	-150	-210
Other value added	-50	-120	-170	-70	-150	-220	-70	-150	-220
Total	-560	-1,300	-1,870	-730	-1,730	-2,460	-700	-1,480	-2,180
Reduction in losses (15,000t Storage)									
1 Agriculture	0	10	0	0	10	10	0	10	0
2 Other primary	0	0	10	0	10	10	0	0	10
3 Manufacturing	10	30	30	10	30	30	0	20	30
4 Utilities & communications	0	10	10	0	10	10	0	0	10
5 Construction	10	30	40	20	30	50	20	30	50
6 Trade and hospitality	20	30	60	30	40	60	30	20	50
7 Transport & storage	10	10	20	10	10	30	10	20	30
8 Financial & business services	0	0	0	10	10	0	10	10	0
9 Government, education and health servi	10	20	30	0	30	30	10	20	30
10 Other services	0	10	10	0	10	20	0	10	20
Other GDP components	10	20	30	10	20	30	10	20	30
Total	80	170	260	90	190	280	80	170	250
Reduction in losses (44,000t Storage)									
1 Agriculture	0	20	20	0	20	20	0	20	20
2 Other primary	0	20	20	0	20	20	0	20	20
3 Manufacturing	20	60	80	20	50	70	20	40	60
4 Utilities & communications	10	10	20	10	10	20	10	10	20
5 Construction	40	90	120	40	90	120	30	70	110
6 Trade and hospitality	70	90	160	70	90	150	60	70	130
7 Transport & storage	30	50	80	40	50	90	40	50	90
8 Financial & business services	0	10	10	0	10	10	0	0	10
9 Government, education and health servi	20	60	80	20	70	90	20	60	80
10 Other services	0	30	30	10	30	40	10	30	40
Other GDP components	30	50	80	30	60	80	20	50	70
Total	220	480	700	240	490	720	200	420	620
Reduction in losses (60,000t Storage)									
1 Agriculture	0	20	30	0	30	30	0	30	30
2 Other primary	0	30	30	0	30	30	0	30	30
3 Manufacturing	30	70	100	30	60	80	20	40	70
4 Utilities & communications	10	20	30	10	20	30	10	10	20
5 Construction	40	100	130	40	90	130	30	80	110
6 Trade and hospitality	80	110	200	90	110	190	70	90	160
7 Transport & storage	50	70	120	50	70	120	50	70	120
8 Financial & business services	0	10	10	0	10	10	0	0	0
9 Government, education and health servi	30	80	110	30	90	120	30	80	110
10 Other services	10	40	40	10	40	60	10	40	50
Other GDP components	30	70	100	30	70	100	30	60	90
Total	280	600	880	300	600	900	260	520	780

Notes: All results rounded to nearest $10mil. Costs of putting in place storage not considered.

6.2.2 Short-Term Refinery Outage

As is expected, the short-term refinery outage scenario has a much lower impact than the long-term refinery outage scenario. The first six months result in a $100 million loss for New Zealand, see Figure 15 and Table 9. As with the long-term refinery outage scenario, some losses are recovered over the next six months with a total loss over one year estimated at $80 million, i.e. less than 0.1% of GDP. The short duration of the outage means that a higher proportion of the fuel shortage will be mitigated by private fuel stores and conservation measures. Correspondingly, the effect of the storage mitigation measures is that losses only reduce slightly, returning a $30, $40, $50 million net GDP benefit in the event of a short-term refinery outage for 15,000t, 44,000t and 60,000t storage options respectively. As for the long-term refinery outage scenario, the additional storage volumes offer reducing returns on investment in this scenario. In part this is because even the smallest storage option is sufficient to meet business-as-usual supply in petrol/diesel and thus there are no additional benefits of increased storage with regards to these fuels.

The majority of the losses in this scenario are felt in the manufacturing industry (Table 10), with the lion's share of manufacturing losses being in the petroleum manufacturing industry itself. For most of the other sectors, the estimated impacts by MERIT are sufficiently small so that when the results are rounded the reported figures are either zero or +/- $10 million. The transport and storage sector benefits the most under the highest storage option (e.g. an estimated reduced GDP impact of $9 million), followed by other services (reduced GDP impact of $8 million). This reflects the benefit of having more jet fuel available to mitigate disruptions to air transport, and the related impacts this has on transport services and tourism-related activities.

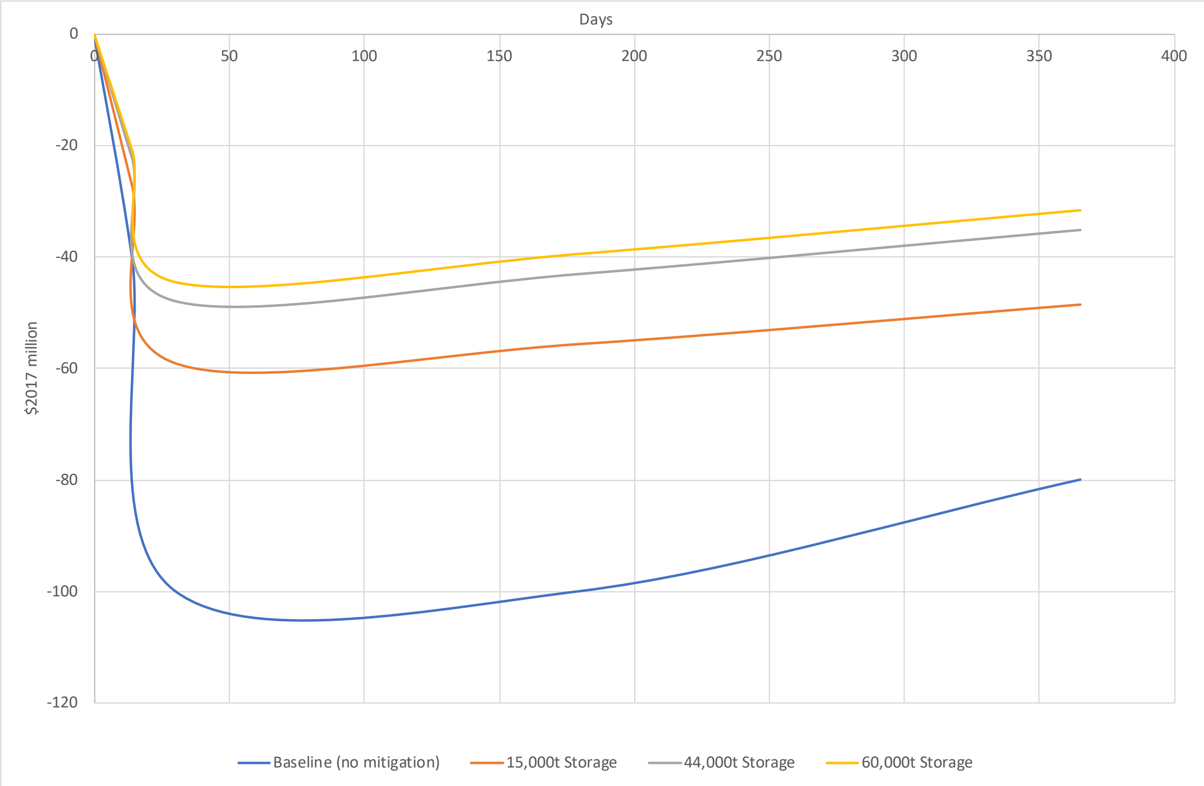

Figure 15 Short-Term Refinery Outage Scenario – Cumulative Impact on New Zealand's Gross Domestic Product, with and without Storage Mitigations. Note: costs of putting in place storage not included.

Table 9 Short-Term Refinery Outage Scenario – Impacts on Gross Domestic Product (GDP) with and without Storage Mitigations ($_{2017}$mil)

	Cumulative Net Change in GDP ($2017mil)				% change in GDP		
	2 weeks after event	2 months after event	6 months after event	1 year after event	0-2 months after event	0-6 months after event	0 - 1 year after event
Baseline (no mitigation)							
Auckland	-10	-30	-30	-30	-0.2%	-0.1%	0.0%
Rest of New Zealand	-30	-70	-60	-50	-0.2%	-0.1%	0.0%
Total New Zealand	-40	-100	-100	-80	-0.2%	-0.1%	0.0%
Reduction in losses	**(15,000t Storage)**						
Auckland	0	20	20	20	0.1%	0.0%	0.0%
Rest of New Zealand	10	20	20	20	0.1%	0.0%	0.0%
Total New Zealand	10	40	40	30	0.1%	0.0%	0.0%
Reduction in losses	**(44,000t Storage)**						
Auckland	10	20	20	20	0.1%	0.0%	0.0%
Rest of New Zealand	10	30	20	20	0.1%	0.0%	0.0%
Total New Zealand	20	50	60	40	0.1%	0.0%	0.0%
Reduction in losses	**(60,000t Storage)**						
Auckland	10	20	30	30	0.1%	0.1%	0.0%
Rest of New Zealand	10	30	30	20	0.1%	0.0%	0.0%
Total New Zealand	20	60	60	50	0.1%	0.0%	0.0%

Notes: Results rounded to nearest $10mil. Costs of putting in place storage not considered.

Table 10 Short-Term Refinery Outage Scenario – Accumulated Loss of Industry Value Added ($\$_{2017}$mil)

	2 Months			6 Months			1 Year		
	Auckland	Rest of NZ	Total NZ	Auckland	Rest of NZ	Total NZ	Auckland	Rest of NZ	Total NZ
Baseline (no mitigation)									
1 Agriculture	0	0	0	0	0	0	0	0	0
2 Other primary	0	0	0	0	0	0	0	-10	-10
3 Manufacturing	-10	-40	-50	-10	-30	-40	-10	-30	-30
4 Utilities & communications	0	0	0	0	0	0	0	0	0
5 Construction	0	0	0	0	0	-10	0	0	0
6 Trade and hospitality	0	0	-10	0	0	-10	0	0	0
7 Transport & storage	-10	0	-10	-10	0	-10	-10	0	-10
8 Financial & business services	0	0	-10	0	0	-10	0	0	-10
9 Government, education and health servi	0	0	-10	0	0	-10	0	0	-10
10 Other services	0	0	-10	0	-10	-10	0	0	-10
Other value added	0	0	-10	0	0	-10	0	0	-10
Total	-30	-70	-100	-30	-60	-100	-30	-50	-80
Reduction in losses (15,000t Storage)									
1 Agriculture	0	0	0	0	0	0	0	0	0
2 Other primary	0	0	0	0	0	0	0	0	0
3 Manufacturing	0	0	0	0	0	0	0	0	0
4 Utilities & communications	0	0	0	0	0	0	0	0	0
5 Construction	0	0	0	0	0	0	0	0	0
6 Trade and hospitality	0	0	0	0	0	0	0	0	0
7 Transport & storage	0	0	0	0	0	0	0	0	0
8 Financial & business services	0	0	10	0	0	10	0	0	10
9 Government, education and health servi	0	0	10	0	0	10	0	0	10
10 Other services	0	10	10	0	10	10	0	0	10
Other GDP components	0	0	0	0	0	0	0	0	0
Total	10	20	40	20	20	40	20	20	30
Reduction in losses (44,000t Storage)									
1 Agriculture	0	0	0	0	0	0	0	0	0
2 Other primary	0	0	0	0	0	0	0	0	0
3 Manufacturing	0	0	0	0	0	0	0	0	0
4 Utilities & communications	0	0	0	0	0	0	0	0	0
5 Construction	0	0	0	0	0	10	0	0	0
6 Trade and hospitality	0	0	10	0	0	10	0	0	0
7 Transport & storage	10	0	10	10	0	10	10	0	10
8 Financial & business services	0	0	10	0	0	10	0	0	10
9 Government, education and health servi	0	0	10	0	0	10	0	0	10
10 Other services	0	10	10	0	10	10	0	0	10
Other GDP components	0	0	10	0	0	10	0	0	0
Total	20	30	50	30	30	50	20	20	40
Reduction in losses (60,000t Storage)									
1 Agriculture	0	0	0	0	0	0	0	0	0
2 Other primary	0	0	0	0	0	0	0	0	0
3 Manufacturing	0	0	0	0	0	0	0	0	0
4 Utilities & communications	0	0	0	0	0	0	0	0	0
5 Construction	0	0	0	0	0	10	0	0	0
6 Trade and hospitality	0	0	10	0	0	10	0	0	0
7 Transport & storage	10	0	10	10	0	10	10	0	10
8 Financial & business services	0	0	10	0	0	10	0	0	10
9 Government, education and health servi	0	0	10	0	0	10	0	0	10
10 Other services	0	10	10	0	10	10	0	0	10
Other GDP components	0	0	10	0	0	10	0	0	10
Total	20	30	50	30	30	60	20	20	50

Notes: Results rounded to nearest $10mil. Costs of putting in place storage not considered.

6.2.3 Long-Term RAP/Wiri Disruption

The long-term RAP/Wiri disruption scenario causes a loss of nearly $1.2 billion or 0.9% of GDP over the first six months, see Figure 16 and Table 11. Over the following six months there is some small recovery so that over the entire year of analysis, the GDP impact of the long-term RAP/Wiri disruption scenario is estimated as $1.1 billion, or 0.4% of total GDP. Reflecting the spatial nature of the disruption, GDP impacts are disproportionately high in Auckland with 65% of the total GDP loss over one year being just in the Auckland region (Auckland accounts for around 37% of national GDP).

Table 12 provides a breakdown of losses across industries. Within the Auckland region, the transport and storage sector, especially air transportation, is hit particularly hard in the first 6 months, with a total loss estimated for this sector of around $130 million. Over this period there are also some quite significant losses experienced by Auckland's manufacturing sector, estimated at $80 million. Given the nature of the Auckland economy, among the industrial activities most significantly affected are food manufacturing and equipment/machinery manufacturing. In the rest of New Zealand, the principle impact on manufacturing is indeed within the petroleum refining industry itself. Also notable is that with flow-on impacts through the economy, particularly through reduced tourism expenditure, and losses in household incomes, tax revenues and spending, there are also widespread impacts for service industries in New Zealand (e.g. trade and hospitality have a loss of $220 million over one year, and the Government/education/health and other services sectors each have an estimated loss of $120 million).

With the application of the storage mitigation, the estimated GDP impact over the year for a long-term RAP/Wiri disruption reduces by $120, $330, and $340 million for 15,000t, 44,000t and 60,000t storage options respectively. As for the long-term refinery outage scenario, the benefit of increased storage volume is not linear. The saving per unit volume of storage is similar for 15,000t and 44,000t option but reduces for the 60,000t option: net GDP savings per unit volume of storage being $7,600/t, $7,500/t and $5,700/t for 15,000t, 44,000t and 60,000t storage respectively. The largest benefits of the mitigations are felt in trade and hospitality, followed by transport and storage, Government/education/health and manufacturing. For the trucking mitigation option there is a significant reduction in losses of $380 million.

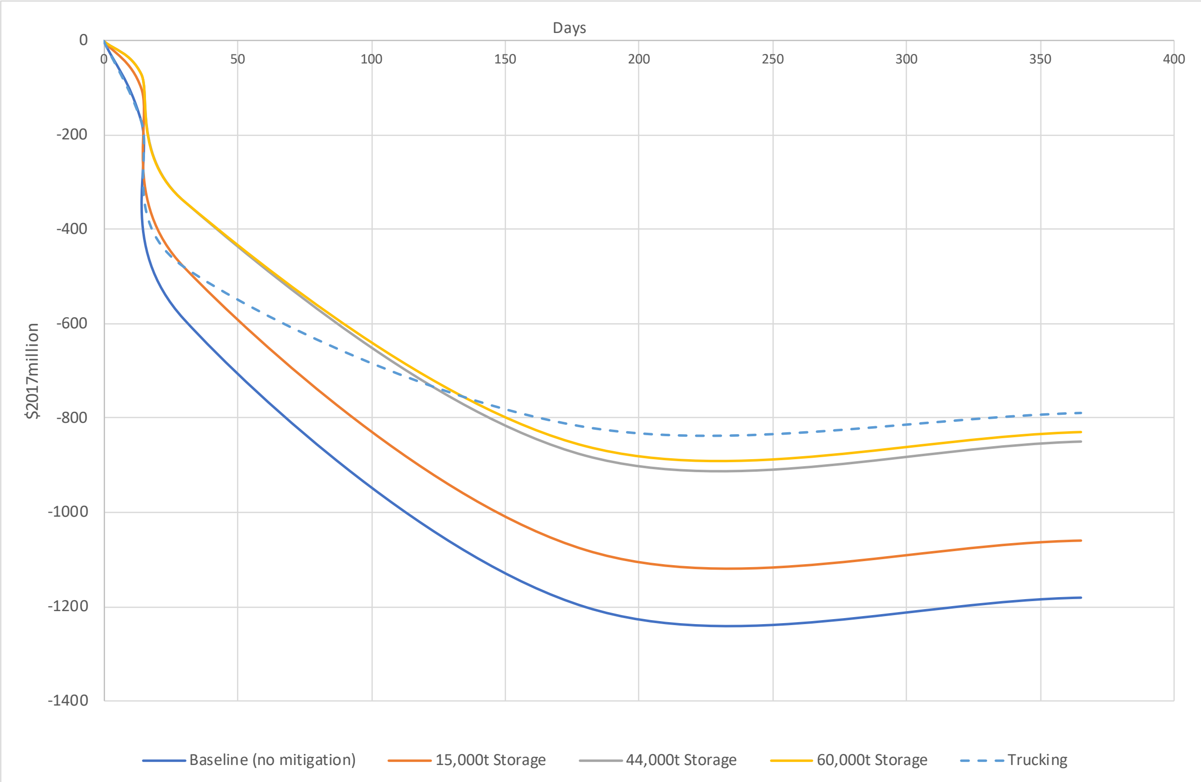

Figure 16 Long-Term RAP/Wiri Disruption Scenario – Cumulative Impact on New Zealand's Gross Domestic Product, with and without Mitigations. Note: costs of putting in place mitigations not included.

Table 11 Long-Term RAP/Wiri Disruption Scenario – Impacts on Gross Domestic Product (GDP) with and without Mitigations ($_{2017}$mil)

	Cumulative Net Change in GDP ($2017mil)				% change in GDP		
	2 weeks after event	2 months after event	6 months after event	1 year after event	0-2 months after event	0-6 months after event	0 - 1 year after event
Baseline (no mitigation)							
Auckland	-120	-370	-720	-730	-2.2%	-1.4%	-0.7%
Rest of New Zealand	-50	-220	-450	-380	-0.8%	-0.5%	-0.2%
Total New Zealand	-170	-590	-1,170	-1,110	-1.3%	-0.9%	-0.4%
Reduction in losses (15,000t Storage)							
Auckland	50	70	70	70	0.4%	0.1%	0.1%
Rest of New Zealand	20	40	50	50	0.1%	0.1%	0.0%
Total New Zealand	70	110	120	110	0.2%	0.1%	0.0%
Reduction in losses (44,000t Storage)							
Auckland	70	160	170	150	0.9%	0.3%	0.2%
Rest of New Zealand	30	90	130	110	0.3%	0.1%	0.1%
Total New Zealand	100	250	290	260	0.5%	0.2%	0.1%
Reduction in losses (60,000t Storage)							
Auckland	70	160	200	200	0.9%	0.4%	0.2%
Rest of New Zealand	30	90	130	140	0.3%	0.2%	0.1%
Total New Zealand	100	250	330	340	0.6%	0.2%	0.1%
Reduction in losses (Trucking)							
Auckland	0	60	200	200	0.3%	0.4%	0.2%
Rest of New Zealand	0	50	150	120	0.2%	0.2%	0.1%
Total New Zealand	0	110	350	320	0.2%	0.3%	0.1%

Notes: Results rounded to nearest $10mil. Costs of putting in place storage and trucking mitigations not considered.

Table 12 Long-Term RAP/Wiri Disruption Scenario – Accumulated Loss of Industry Value Added ($2017mil)

	2 Months			6 Months			1 Year		
	Auckland	Rest of NZ	Total NZ	Auckland	Rest of NZ	Total NZ	Auckland	Rest of NZ	Total NZ
Baseline (no mitigation)									
1 Agriculture	0	0	-10	0	-10	-10	0	-10	-10
2 Other primary	0	-10	-10	0	-20	-20	0	-20	-20
3 Manufacturing	-60	-70	-130	-80	-110	-190	-80	-50	-130
4 Utilities & communications	-10	0	-10	-20	-10	-30	-20	-10	-30
5 Construction	-10	-20	-20	-40	-50	-90	-30	-30	-70
6 Trade and hospitality	-70	-20	-100	-150	-60	-220	-150	-60	-210
7 Transport & storage	-70	-10	-80	-130	-40	-170	-130	-40	-170
8 Financial & business services	-30	-10	-40	-50	-20	-70	-50	-20	-60
9 Government, education and health servi	-60	-30	-90	-100	-50	-150	-100	-50	-150
10 Other services	-40	-20	-60	-70	-40	-120	-80	-40	-120
Other value added	-30	-20	-50	-70	-40	-120	-80	-50	-120
Total	-370	-220	-590	-720	-450	-1,170	-730	-380	-1,110
Reduction in losses (15,000t Storage)									
1 Agriculture	0	0	10	0	10	0	0	0	0
2 Other primary	0	0	0	0	0	0	0	0	0
3 Manufacturing	10	0	20	10	10	20	10	0	10
4 Utilities & communications	0	0	10	0	0	10	0	0	0
5 Construction	0	10	0	0	0	10	0	0	10
6 Trade and hospitality	20	0	30	20	0	30	20	10	30
7 Transport & storage	10	0	20	10	10	20	10	10	20
8 Financial & business services	0	0	0	0	0	0	0	10	-10
9 Government, education and health servi	10	10	20	10	10	20	10	10	20
10 Other services	0	0	10	0	0	10	0	0	0
Other GDP components	10	10	10	0	0	20	10	10	10
Total	70	40	110	70	50	120	60	50	110
Reduction in losses (44,000t Storage)									
1 Agriculture	0	10	10	0	10	10	0	10	10
2 Other primary	0	10	10	0	10	10	0	10	10
3 Manufacturing	40	20	60	50	20	60	40	20	60
4 Utilities & communications	0	0	10	10	10	10	10	10	10
5 Construction	-10	0	-10	0	10	10	0	10	0
6 Trade and hospitality	50	10	60	60	20	80	60	20	80
7 Transport & storage	30	10	40	30	10	50	40	10	50
8 Financial & business services	-10	0	-10	-10	0	-10	-10	0	-10
9 Government, education and health servi	30	20	50	30	20	60	30	20	60
10 Other services	0	0	0	10	10	10	10	10	10
Other GDP components	10	10	20	20	10	30	20	20	40
Total	160	90	250	190	130	320	190	130	320
Reduction in losses (60,000t Storage)									
1 Agriculture	0	10	10	0	10	10	0	10	10
2 Other primary	0	10	10	0	10	10	0	10	10
3 Manufacturing	40	20	60	50	20	60	40	20	60
4 Utilities & communications	0	0	10	10	10	10	10	10	10
5 Construction	-10	0	-10	0	10	10	0	10	0
6 Trade and hospitality	50	20	60	60	20	80	60	20	80
7 Transport & storage	30	10	40	40	10	50	40	10	50
8 Financial & business services	-10	0	-10	-10	0	-10	-10	0	-10
9 Government, education and health servi	30	20	50	30	20	60	30	30	60
10 Other services	0	0	0	10	10	10	10	10	20
Other GDP components	20	10	20	20	10	30	20	20	40
Total	160	90	250	200	130	330	200	140	340
Reduction in losses (Trucking)									
1 Agriculture	0	0	10	0	10	10	0	10	10
2 Other primary	0	0	0	0	10	10	0	10	10
3 Manufacturing	20	20	40	30	40	70	30	20	50
4 Utilities & communications	0	0	0	10	0	10	10	0	10
5 Construction	-10	0	-10	10	20	30	10	10	20
6 Trade and hospitality	10	10	20	50	20	70	50	20	70
7 Transport & storage	10	0	20	40	10	50	40	10	50
8 Financial & business services	0	0	0	0	0	10	0	0	0
9 Government, education and health servi	10	10	20	30	10	40	30	20	40
10 Other services	0	0	0	10	10	20	20	10	20
Other GDP components	10	0	10	20	10	40	20	10	40
Total	60	50	110	200	150	350	200	120	320

Notes: Results rounded to nearest $10 mil. Costs of putting in place storage and trucking mitigations not considered.

6.2.4 Short-Term RAP/Wiri Disruption

The short-term RAP/Wiri disruption scenario has a much lower impact than the any other outage and hence the MERIT model is only run for two months. Also, as discussed above, given that there is real-world information available on the impacts of an outage of this type (i.e. from the 2017 RAP outage), we do not put significant effort into reporting the modelled results for this outage. For completeness, we do however provide a short summary of the MERIT results.

- The total loss for New Zealand is estimated at around $23 million. Just over a third of this impact is in the manufacturing sector, principally petroleum refining associated with lost sales in refined fuel.
- Overall, the impact of the storage mitigations is a reduced loss of $11, $18, and $21 million to GDP for 15,000t, 44,000t and 60,000t storage options respectively.
- The short duration of the outage means the majority of the petroleum/diesel shortage will be mitigated by private fuel stores and conservation measures. Even the smallest storage option has significantly more petroleum/diesel necessary to completely avoid the supply shortages in these fuels. Thus, any additional benefits received by the higher storage accrue principally to air transportation (as less disruption to jet fuel) and related activities, particularly tourism. There are also avoided losses in fuel sales.[22]

As discussed above, the MERIT modelling has not attempted to capture all of the costs placed on industries when adapting to the mitigation measures. For example, while we have attempted to account for increased costs of staff overtime (where paid), there may be other changes to input costs not captured – such as the increased fuel costs associated with tankering in jet fuel from Australia to avoid flight cancellations. There will also be non-market costs not captured, for example stress and inconvenience faced by staff. These factors may underlie some differences between the results reported here and those emphasised after the 2017 outage.

6.3 Welfare Impacts

One of the aims of this project has been to consider the extent to which, in addition to undertaking MERIT modelling and providing standard GDP/value added metrics, it may be possible to supplement or extend the welfare reporting metrics as were provided in previous commissioned evaluations of fuel supply outage scenarios for New Zealand. A key reason for deriving welfare-based metrics is that these can be incorporated within CBAs, and this tends to be the selected methodology applied for investment option evaluation.

As explained above, for this analysis of fuel supply disruptions we have chosen to apply an economic simulation model (MERIT), coupled with the derivation of detailed scenarios, to investigate the economic implications of the disruptions. We believe this approach allows us to consider in depth the cause-effect relationships that lead to economic consequences in the face of a disruption and helps to avoid challenges associated with applying standard economic methods for the analysis of non-standard events. In Appendix

[22] While the additional fuel being supplied under the mitigations comes from storage rather than the normal supply arrangements, presumably the normal suppliers will benefit from the opportunity to re-stock the storage holds once the outage is finished.

C we have provided a short review of the potential avenues for extending multi-sectoral economic models to allow for welfare metrics to be reported. Some key points are:

- Like MERIT, many multi-sectoral models capture household behaviour through a single representative household. When calculating welfare metrics, it is preferable to capture more diversity among households so that, for example, the effects of changes in income distributions can be captured.
- Although there are examples in the literature of models that incorporate multiple household types or are coupled with other models to enable more nuanced impact evaluation among households, large resourcing (time, data) is required to implement the necessary extensions.

Although it may be desirable to undertake such extensions in a future programme of MERIT development, for the time being we believe the best approach is to use Gross National Disposable Income (GNDI) as a proxy welfare measure. Note that this is also a suggested proxy in the Treasury's Social Cost Benefit Analysis Guide (The Treasury, 2015). We have found that it has been relatively straightforward to extend MERIT for the reporting of GNDI, as it is a metric similar to GDP but includes adjustments to account for foreign transfers. Impacts on GNDI under each of scenario are presented below.

The percent change in GNDI for an international supply disruption is felt most strongly in Auckland, at 0.7%, see Table 13. Across New Zealand the change in GNDI is 0.5%. Impacts are less in the rest of New Zealand compared to Auckland because it has a higher concentration of the few economic activities (i.e. those engaged in energy extraction) that will benefit and generate higher returns under a situation of higher energy prices.

Table 13 International Supply Disruption Scenario – Impacts on Gross National Disposable Income (GNDI) ($\$_{2017}$mil)

	Cumulative Net Change in GDP ($\$_{2017}$mil)			% change in GNDI		
	2 months after event	6 months after event	1 year after event	0-2 months after event	0-6 months after event	0 - 1 year after event
Auckland	-120	-520	-660	-0.7%	-1.1%	-0.7%
Rest of New Zealand	**0**	**-450**	**-690**	**0.0%**	**-0.6%**	**-0.4%**
Total New Zealand	-120	-970	-1,350	-0.3%	-0.8%	-0.5%

Notes: all results rounded to nearest $10mil.

For the long-term refinery outage scenario, losses equate to 0.8% of GNDI in Auckland and 0.9% for the whole of New Zealand, equalling around $2.2 billion. The proposed mitigation measures result in a reduced loss of $240, $600, $760 million for 15,000t, 44,000t and 60,000t respectively over the year of the analysis.

Table 14 Long-Term Refinery Outage Scenario – Impacts on Gross National Disposable Income (GNDI) ($$_{2017}$mil)

	Cumulative Net Change in GNDI ($2017mil)			% change in GNDI		
	2 months after event	6 months after event	1 year after event	0-2 months after event	0-6 months after event	0 - 1 year after event
Baseline (no mitigation)						
Auckland	-610	-750	-710	-3.8%	-1.6%	-0.8%
Rest of New Zealand	-1,290	-1,680	-1,480	-5.0%	-2.2%	-1.0%
Total New Zealand	-1,890	-2,430	-2,200	-4.5%	-1.9%	-0.9%
Reduction in losses (15,000t Storage)						
Auckland	80	90	80	0.5%	0.2%	0.1%
Rest of New Zealand	170	180	160	0.6%	0.2%	0.1%
Total New Zealand	250	270	240	0.6%	0.2%	0.1%
Reduction in losses (44,000t Storage)						
Auckland	230	240	200	1.4%	0.5%	0.2%
Rest of New Zealand	460	460	400	1.8%	0.6%	0.3%
Total New Zealand	690	700	600	1.7%	0.6%	0.2%
Reduction in losses (60,000t Storage)						
Auckland	290	300	260	1.8%	0.6%	0.3%
Rest of New Zealand	580	570	500	2.2%	0.7%	0.3%
Total New Zealand	870	870	760	2.1%	0.7%	0.3%

Notes: Results rounded to nearest $10mil. Costs of putting in place storage mitigations not included.

The short-term refinery outage scenario produces significantly lower GNDI losses (Table 13). Over the entire year of analysis, losses of $110 million or less than 0.1% of GNDI are felt across the country. With the implementation of storage mitigation, there is a saving in GNDI losses of $30, $40, $50 million for 15,000t, 44,000t and 60,000t storage respectively.

Table 15 Short-Term Refinery Outage Scenario – Impacts on Gross National Disposable Income (GNDI) ($2017mil)

	Cumulative Net Change in GNDI ($2017mil)			% change in GNDI		
	2 months after event	6 months after event	1 year after event	0-2 months after event	0-6 months after event	0 - 1 year after event
Baseline (no mitigation)						
Auckland	-30	-30	-30	-0.2%	-0.1%	0.0%
Rest of New Zealand	-70	-80	-80	-0.3%	-0.1%	-0.1%
Total New Zealand	-100	-110	-110	-0.2%	-0.1%	0.0%
Reduction in losses (15,000t Storage)						
Auckland	20	20	10	0.1%	0.0%	0.0%
Rest of New Zealand	20	30	20	0.1%	0.0%	0.0%
Total New Zealand	40	40	30	0.1%	0.0%	0.0%
Reduction in losses (44,000t Storage)						
Auckland	20	20	20	0.1%	0.1%	0.0%
Rest of New Zealand	30	40	30	0.1%	0.0%	0.0%
Total New Zealand	50	60	40	0.1%	0.0%	0.0%
Reduction in losses (60,000t Storage)						
Auckland	20	20	20	0.1%	0.1%	0.0%
Rest of New Zealand	30	40	30	0.1%	0.0%	0.0%
Total New Zealand	50	60	50	0.1%	0.0%	0.0%

Notes: Results rounded to nearest $10mil. Costs of putting in place storage mitigations not included.

For the long-term RAP/Wiri disruption scenario (Table 16) GNDI losses are $1 billion or 0.4% over the entire year of analysis. The proposed mitigation measures reduce this loss by $110, $270, $340 and $240 million for 15,000t, 44,000t, 60,000t storage and trucking options respectively over the year of the analysis.

Table 16 Long-Term RAP/Wiri Outage Scenario – Impacts on Gross National Disposable Income (GNDI) ($2017mil)

	Cumulative Net Change in GNDI ($2017mil)			% change in GNDI		
	2 months after event	6 months after event	1 year after event	0-2 months after event	0-6 months after event	0 - 1 year after event
Baseline (no mitigation)						
Auckland	-320	-560	-590	-2.0%	-1.2%	-0.6%
Rest of New Zealand	-210	-360	-350	-0.8%	-0.5%	-0.2%
Total New Zealand	-530	-920	-930	-1.3%	-0.7%	-0.4%
Reduction in losses (15,000t Storage)						
Auckland	60	70	60	0.4%	0.1%	0.1%
Rest of New Zealand	50	50	50	0.2%	0.1%	0.0%
Total New Zealand	110	120	110	0.3%	0.1%	0.0%
Reduction in losses (44,000t Storage)						
Auckland	150	160	140	0.9%	0.3%	0.2%
Rest of New Zealand	110	140	120	0.4%	0.2%	0.1%
Total New Zealand	260	300	270	0.6%	0.2%	0.1%
Reduction in losses (60,000t Storage)						
Auckland	150	180	180	1.0%	0.4%	0.2%
Rest of New Zealand	110	150	150	0.4%	0.2%	0.1%
Total New Zealand	270	330	340	0.6%	0.3%	0.1%
Reduction in losses (Trucking)						
Auckland	60	140	150	0.4%	0.3%	0.2%
Rest of New Zealand	60	110	90	0.2%	0.1%	0.1%
Total New Zealand	110	250	240	0.3%	0.2%	0.1%

Notes: Results rounded to nearest $10mil. Costs of putting in place storage mitigations not included.

The short-term RAP/Wiri disruption scenario results in very low GNDI impacts; losses of $20 million are felt across the country. With the implementation of storage mitigation, there is a saving of around $7-$14 million across the storage options.

7 Discussion

7.1 Comparison with Earlier Studies

The results from this study differ notably from the 2012 NZIER study. There are small differences in the disruption scenario, but it is also useful to identify and discuss the differences between the two studies.

First, the NZIER (2012) study found that the international disruption was approximately double the impact of the long-term refinery outage. In this study the relative placement of the impacts from the scenarios is switched, with the long-term refinery outage being about 63% higher than the international disruption (in terms of impacts on GNDI).

The two studies used significantly different methodologies. The NZIER (2012) study was based on price elasticity and subsequent reduction in consumption. As noted in Appendix A, estimating losses for fuel disruptions based on elasticities has some limitations in that it does not account for the non-linear behaviour of demand for fuel (that is, the demand response to a small price change might be radically different to the demand response to a much larger price change). It also does not include for the system-wide effects of fuel price changes, such as physical disruptions to production processes, supply chains and changes to exchange rates.

The NZIER (2012) report also evaluates the proposed storage mitigation measures by developing a benefit cost ratio. We have not attempted, at this stage, to develop a benefit cost ratio because the analyses presented here are for single scenarios. To truly estimate a benefit cost ratio, the benefits of any mitigation measure beyond that which would accrue under the few scenarios considered should be included (e.g. a storage mitigation will likely also generate benefits under multiple disruptions) as well as co-benefits realised during business-as-usual (redundancy, robustness in the system). We also believe that a benefit-cost type analysis should account for the 'insurance benefit' of preventing future losses and recognise that society is not necessarily risk neutral (see discussion below). Furthermore, it is important to note that some mitigations have very high emergency response benefits, for example fuel storage might prove highly valuable after a tsunami event for fuelling vehicles needed for life safety activities, critical infrastructure restoration and in supplying debris-removing machinery. These potential resilience benefits of mitigations require further consideration and if more than insignificant should also be included in a full CBA.

The current study also has some modelling limitations. The MERIT results are highly sensitive to the elasticities[23] incorporated in the model and this is a source of uncertainty. A special project around further calibration of the model is currently underway which will help to quantify some of the inherent uncertainties in the model. This study is also based on expert assessment of behavioural responses (business and household) to fuel disruption. Where possible we have supported the assumptions with evidence, however, with limited studies and observations (particularly related to domestic disruptions) these assumptions create uncertainties and represent one of a range of plausible sets of behaviours.

[23] The number of elasticity parameters in the model is in the order of hundreds.

7.2 Model Result Interpretation

Storage Mitigations

When evaluating the benefit of additional storage, it is important to consider the benefits (and costs) in terms of both international and domestic disruption events. Additional storage could potentially be used in lieu of the requirements for international ticket contracts, thus the costs of storage could be partially offset by savings in payments for ticket contracts. Storage also provides ready stocks of fuel to respond to domestic disruptions (both direct to the fuel system and other events where fuel is a key recovery enabler), such as those included in this report. And as discussed above, additional storage may also improve the resilience of the fuel network by providing additional redundancy during day-to-day operations.

Having domestic stocks as part of the 90-day IEA requirements, however, has few benefits during an international disruption scenario. In an international supply disruption, IEA will collectively manage the global emergency stocks and will determine when to release the stock at market rates. A significant fuel price increase would still be experienced, even if some of the emergency fuel stocks are held domestically. Moreover, our modelling shows that two of the largest contributors to economic impact on New Zealand in an international scenario is changes in relative physical commodity prices and hence demands for those commodities, including a decrease in tourism demands. We can nevertheless note that having additional storage in New Zealand rather than abroad could potentially reduce the time lag for obtaining fuel stocks (and potentially reduce transportation costs as the majority of ticket contracts are held in Europe (Hale and Twomey, 2012)). It may also be possible that during an international disruption, fuel stocks released for sale will fetch a higher price than that which applied when the fuel was accumulated for storage. If an international disruption occurs the ability to receive a price differential could therefore potentially reduce the 'effective costs' of storage.

New Zealand could in theory also choose to hold domestic stocks outside of the 90-day IEA requirements (either by holding storage in excess of the 90-day requirement or holding ticket contracts as well as domestic storage). These additional stocks could be drawn down during an international disruption in addition to the stocks mobilised by the IEA. This could arguably give New Zealand greater control over the impacts of the disruption on the economy, for example helping to alleviate the more severe short-term shortages prior to IEA mobilisation. However, as the fuel stored will inevitably be small relative to global supply/demand, it is not envisaged that this extra storage will significantly impact the global price for fuel. Thus, we would only expect high fuel prices to be alleviated for the New Zealand public if those who own the fuel stocks *choose* to forgo selling at the high international price. Furthermore, many of the adverse effects experienced in New Zealand under an international disruption scenario (e.g. international freight costs, aviation costs faced by potential tourists) occur because of changes abroad, and it is unlikely that additional storage in New Zealand could significantly alter these effects.

In terms of the domestic disruption scenarios, storage mitigations clearly provide a much greater benefit under the more severe outages, even when the quantity of stored fuel is identical across scenarios. This reflects that households and industries have some capacity to cope with minor fuel shortages, through behavioural change and adaptation but when shortages become severe the inherent coping mechanisms become exhausted and impacts become significant.

If storage is desired, then consideration will be given to choosing an 'optimal' level of storage. The modelling results show that this is a challenging question, with trends varying depending on the outage scenarios investigated. For the minor disruption scenarios, there was a strong trend of diminishing returns from additional storage, whereas for the long-term RAP/Wiri disruption scenario, every additional litre of fuel stored going between the 15,000t and 44,000t options provided almost as much benefit as provided, on average, by the first 15,000t option. To take most advantage of storage it will also be important to carefully consider storage locations. For example, storing some fuel in the South Island may help to reduce transportation costs during a refinery outage, but will be of little benefit under a RAP outage. Furthermore, as was briefly discussed in Section 3.2.2, storage or distribution options that are near to consumers and can be replenished through marine tankers may have significant advantages under outage situations where supply restoration is constrained by trucking resources.

Storage also needs to be considered in light of alternative, demand management measures of fuel disruption response – such as fuel prioritisation for at-risk activities, enabling ride share and public transport, electrification of vehicles and manufacturing sector, encouragement of remote working. In this report we characterised industries based on their use of fuel. The four main fuel uses were: (1) input to production; (2) freight; (3) staff travel; and (4) work-based travel. Any response or preparedness efforts should consider the relative contribution of each of these to overall economic impact. Disruption to freight was a dominant or contributing disruption to the majority of industries. How freight services are managed and prioritised during a disruption could generate significant economic saving – particularly in primary and manufacturing industries.

Risk Preferences and 'Risk Premiums' in Decision Evaluation

Often economic impact analyses, such as carried out here, are used as an input to a decision evaluation tool, typically CBA. In CBA studies, when there is uncertainty or risk that a benefit will be achieved, the benefit is commonly quantified as the 'expected monetary value' of the benefit. In the case of increased storage, for example, the benefit of the mitigation would be taken simply as the reduced monetary losses when the event occurs (due to mitigation), multiplied by the probability of the event occurrence. These benefits would be compared against the expected monetary value of the costs for storage to determine the net benefits (or costs) of the mitigation. Note that unlike in the case of the benefits calculations, costs of storage are not weighted by a probability because there is almost certainty that the costs of storage will be realised if it is selected as a mitigation.

One difficulty with this approach is that it does not account for people's risk aversion which can be easily justified based on the concept of diminishing-marginal-utility-of wealth. That is, as long as we accept that a person would value the loss of a dollar more greatly the more poor they become, expected utility theory can demonstrate why in many situations people are willing to invest in risk-reduction strategies, even when the 'expected monetary benefit' is less than the cost of the strategy (i.e. a negative expected monetary benefit or value).[24] In these cases, we would say that while the expected monetary benefit is negative, the 'expected utility' is positive and a CBA (and welfare economics in general) would therefore support the selection of the mitigation.

While the concept of expected utility is well-recognised, it is often not applied in CBA. For one, there are often information limitations that prohibit quantification of the necessary utility functions. The modelling

[24] A worked example is provided by Kind *et al.,* (2017, pp4-5).

required for the calculations can also become very complex when it is necessary to account for income changes across whole communities with varying starting incomes. Nevertheless, in theory, the use of 'expected monetary benefits' in an analysis (which effectively assumes people are risk neutral), rather than expected utilities, is justified only when (cf. Kind *et al.,* 2017): (1) the relative changes in wealth are small enough that the implications of diminishing marginal utility of wealth would not have a material impact on the calculations; or (2) there exists methods of compensation available so that when an event occurs individuals never experience the predicted wealth changes (this is discussed more below in relation to the role of government).

We should also acknowledge that expected utility theory has been critiqued on the basis that it cannot fully explain people's behaviour under risk (e.g. Rabin, 2000). In some cases, this may simply be because the utility models constructed are too simple – they do not consider some of the intangible losses faced under different contingencies in addition to the monetary losses. For example. in the case of economic disruptions, loss of confidence in government and social unrest may justify a high willingness to pay (WTP) to avoid disruptions above a certain threshold. However, it also appears that there are a variety of psychological factors underpinning people's behaviour and choices, and thus it is not always possible to predict people's behaviours by the functions or 'curves' generated by expected utility theory (or at least the ones that are drawn from relatively simple models)[25]. It has, for example, been shown that people can more easily perceive risks if they can imagine the event in a detailed way, rather than in an abstract, non-detailed way (Ganderton *et al.,* 2000). Similarly, if an event has recently been experienced, individuals are more likely to try and avoid its occurrence than another event which has not recently occurred but has a similar probability (Petrolia *et al.,* 2013; Kunreuther 1996). These observations highlight that it is not so much the level of 'objective' risk that is important, but rather how people subjectively view or 'perceive' risk. Furthermore, there is much evidence that different people simply have different risk appetites – some people have a stronger aversion to risk than others and so risk aversion cannot be explained based only on predicted wealth changes (cf. Petrolia *et al.,* 2013).

Regardless of the underlying theory, ample experimental and survey findings (McClelland *et al*., 1993; Ganderton *et al*., 2000; and Botzen and van den Bergh, 2012) suggest that many individuals are risk-averse toward low-probability, high-impact events to the extent that they are willing to pay to avoid these events values that are significantly higher than the expected monetary losses. However there does tend to also be quite significant variation within populations in their WTP, reflecting differences in risk preferences.

Within CBA, there are tools to account for the desire to pay more than the expected monetary benefits for a policy or investment. It does so by including the risk premium in its calculation of (WTP). The risk premium signifies how much an individual is WTP above the expected value of loss, therefore capturing the individual's degree of risk-aversion. However, true implementation of WTP in a CBA is resource-intensive, as, unless there is already an established measure relevant to the situation being modelled, primary data will need to be collected and analysed to assign a risk premium value or WTP metric. In the case of disruption events, there is also the challenge that the cause-effect chains from an initial triggering event through to the impacts on society are often very complex. Typically, individuals will not even understand

[25] In recent literature rank dependent utility theory and prospect theory have been proposed as a better underlying basis upon which to explain and predict people's choices under risk (cf. Botzen and van den Bergh, 2006).

or have available information on the full range of outcomes for the event, let alone have turned their mind to determining how much they are willing to pay to avoid it occurring.

Role of Government/ Public Decision Makers

One of the core pillars of risk management (ISO 31000) is to embed risk management and risk-based decisions within the decision makers' own context, including risk tolerance and financial position. Also, according to the CBA approach, decision makers should choose policies after having considered the value of *all consequences* to *all members of society*. In these regards several points are worth considering:

- *Risk Preferences* - to account for all consequences on all individuals of society necessarily entails having due regard to the risk preferences of those individuals.
- *Government must inevitably choose winners and losers* - although there is a well-established criterion in welfare economics that any decision "should make at least one person better off and no person worse off", in practice this standard can rarely be satisfied. In the case of fuel supply resilience, for example, a decision to invest public funds in storage provision may be highly beneficial for a risk averse individual, but for a risk-taking individual this may be seen as an overall worse outcome because they would prefer to accept the risk and instead spend the funds on other activities (e.g. improved roading or healthcare). In the end, public decision makers are tasked with making decisions that best reflect the spectrum (and often conflicting) preferences of their communities, while also maintaining general principles of equity and justice, and taking into consideration any other objectives that have been laid-out to guide their decisions.
- *Risk perceptions* – many models of public decision making simply assume that individuals have available and act upon perfect information. However, as has been noted above, subjective perceptions of risk have been shown as important in explaining how individuals make decisions. Thus there is an argument to be made that, where individuals are not acting rationally with regards to risks due to poor risk perception (for example treating two risks entirely differently despite having similar consequences), it is acceptable for government to ignore, discount or substitute for the preferences of those individuals.

As a final part of this discussion we should acknowledge that it is sometimes argued that the correct role of a public decision maker is to assume a risk neutral position and not include allowance for 'risk premiums' when making decisions. The rationale behind this argument seems to rest on the idea that since government is responsible for selecting many different actions/policies, all with varying risks, it can spread risks geographically as well as intertemporally. This creates a pooling of risk over a collection of policies and/or a collection of individuals so that, on average, the realised values of costs and benefits will be close to their expected values – in other words, government acts like an insurance agency. This argument only holds, however, when government fully intends to act in a type of insurance provision role. This would require not only the collection of 'premiums' from individuals that are differentiated by income/wealth to account for the variation in impacts that would be experienced (due to marginal utility of income)[26], but also the payment of 'compensation' should the adverse event occur. However, there are a variety of reasons (e.g. transaction costs, complexity, risks of creating moral hazards) why it may not be possible or desirable for government to take on this role across all societal risks. The argument also does not hold

[26] While the tax system has some of these features, we can also note that where insurance schemes are voluntary, individuals have the option to choose a level of cover based not only on their income/wealth positions but also their individual risk preferences.

where policy options involve risks that cannot be pooled across individuals (e.g. policies aimed at mitigating large events where almost everyone is impacted). In these cases, the realised value of costs may be very far from their expected value. The article by Kind *et al.,* (2017), written in the context of flood risk management, provides a helpful summary of these topics. [27]

Other Considerations in Interpreting/Applying Results

In addition to the discussion above regarding the challenges of taking into account risk preferences in a CBA, it is also worthwhile to note that a CBA (and any other decision evaluation tool) would need to, in theory, comprehensively evaluate all the benefits of a mitigation. Such a task would involve examining a full range of probability events, as well as assessing business-as-usual benefits. Given the information and resources required, this is not always practical. Research is ongoing to enable tools like MERIT to more easily conduct these integrated, probabilistic assessments. In the near-term, however, the best practice appears to be to consider a range of 'representative' scenarios that enable decisions makers to understand the full range of potential values at stake. We note that over nearly the last decade MBIE has been putting in place such processes, particularly through the scenario-based work commissioned by Twomey and West (2017) and NZIER (2012).

A final limitation of decision analysis (including CBA and other tools) that is worth noting is that when applied to high impact, low probability events, you are often assessing benefits that could occur 10, 20, 50 years into the future. There is a high likelihood that the assumptions made (including parameters and model structure) will be different when the mitigation benefit is actually realised. For example, the technological structure of the economy may have changed, new infrastructure interdependencies may exist, more people may live in New Zealand, and so on. Modelling of high impact, low probability events, such as the modelling in this report, are more concerned with understanding the relative benefits of different mitigation approaches, rather than providing absolute values upon which to base decisions.

7.3 Further Modelling

Through the modelling process and consideration of the impacts of and likely responses to fuel disruption, several areas for further modelling have been identified.

The probability for the long-term refinery outage scenario was estimated based on consideration of both a refinery outage and a tsunami scenario. Here we have assumed that it is a refinery only disruption. If the scenario was a tsunami event, the economic disruption would be significantly larger; not only because of the additional (non-fuel) related damage, but because fuel is a key enabler in recovery activities (e.g. it is required by earth-moving machinery needed to create new or re-establish transportation networks, it is used in back-up generators for communication infrastructure, and so on). A disruption to fuel supply would therefore hamper recovery efforts, and impact the speed at which critical infrastructure and economic activity would return to normal (Grace, 2017; Smith *et al.*, 2017). When considering investments in mitigation options, it will generally be worthwhile to consider whether any available options will also

[27] The author also discusses that in the accounting for risk premiums in CBA, costs that involve intangible damages such as loss of life, injuries or inconvenience are a special case. These types of costs are incorporated into a CBA through values of statistical life, value of statistical injury and similar, which are based on direct inquiry of individual's WTP and already incorporate risk premiums.

provide improved resilience through faster recovery of other critical infrastructure during a natural hazard event (or other major disruption).

We also note that the role of petroleum-based energy in the New Zealand economy is likely to change over the next decades, with the introduction of electric and alternative-energy vehicles, advances in cycling infrastructure and public transport systems, electrified production process, and changes to working practices including increased availability of remote working. Correspondingly, the economic impacts of the scenarios considered here are likely to change. Further sensitivity analysis around future energy dependence scenarios would be valuable. This line of modelling would also be useful for evaluating policies that reduce petroleum dependency.

More detailed analysis around the nature of the proposed mitigations would be useful. The current analysis assumes that the distribution of fuel types stored is the same as the current distribution of fuel use in the economy. The size and spatial distribution of storage would need to be investigated and modelled further to ensure a robust arrangement that provides benefits across multiple disruption scenarios as well as potentially providing additional benefits under normal operating conditions.

As already alluded to above, a useful extension of this modelling would be to look at the impacts of potential mitigation efforts/policies in the event of other disruptions, or disruptions that involve a full range of direct impacts (i.e. more than just fuel outages). While credible scenarios have been identified here, there is always the potential for a 'black swan' event. Preparedness for these events centres around developing the ability to adapt to the unknown – through capability building and strategy development. This modelling approach could be used to explore the relative benefits of different fuel disruption response strategies, for example, industry specific prioritisation, freight movement prioritisation, private transportation policies and split of fuel types between available fuel tankers. It could also explore potential tipping points in behavioural responses. That is, if a significant disruption is sustained for a long period, more dramatic changes (temporary or even permanent) may eventuate that drive larger economic impacts, e.g. through population relocation, permanent changes to supply chains, etc. (Akehurst and Gordon, 2014).

As discussed, the current assessment of welfare impacts is an aggregate measure that does not incorporate the distributional effects of welfare impacts across society. Other studies, such as a recent study of the impact of a regional road tax in Auckland (Fairgray, 2014), have demonstrated that the effects of petrol, transportation and commodity price increases can have dramatically different impacts on different socio-economic groups. While extending MERIT to report welfare impacts across multiple household types will take considerable resources, the benefit of more nuanced analysis will help to improve the information available to decision makers.

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Appendix A: Notes on Elasticity-Based Analyses for Short-Run Disruptions

One option that is sometimes used for estimating welfare impacts associated with the loss of a good or service (e.g. petroleum in the case of our study) is to use price elasticities to estimate an increase in the implied 'shadow price' of the good/service. In the case of short-term disruptions in supply, this may produce unreliable estimates of welfare loss. We identify two limitations; each are discussed below.

(1) Price Elasticities of Demand (PEDs) are typically estimated for changes at the margin. That is, the percentage change in the quantity demanded for a good is estimated given a small, marginal increase in the price of the good. However, the demand response to a small price change might be radically different to the demand response to a much larger price change. This is likely to be the case with fuel and the expected price spike following a supply disruption. Fuel is also (arguably) an essential good, and the demand for it is therefore likely to be inelastic. This means that a marginal increase in the price of fuel is expected to have little effect on demand. However, it is reasonable to assume that demand becomes more elastic as the price nears the consumer's choke price. Therefore, estimating the increase in the implied shadow price using elasticities that only consider demand response to marginal changes may bias results.

(2) The estimation of PEDs are made assuming all other conditions are held constant. However, this ceteris paribus assumption ignores the reality that economic variables are largely interdependent. It is very likely that there are several other factors, such as income levels and the price of related goods, that are changing simultaneously. The change in demand therefore might not be due solely to a change in the price of the good, but rather a composite of changes including fluctuations in confounding variables.

Appendix B: Industry Response to Fuel Supply Disruption

B.1 Introduction

At the beginning of 2019, Research Consultants at Resilient Organisations (www.resorgs.org.nz) interviewed representatives from different industry groups to better understand how they would respond in the event of a fuel shortage. Interviewees were asked questions relating to how a shortage of fuel would affect their ability to produce goods and services. In particular, questions were centred around disruption to:

- Production of goods;
- Freight disruption;
- Work related travel; and
- Staff travel.

Interviewees were also asked questions related to demand for their goods and services, and the potential for post-disruption re-capture of this demand. The interview questions are included at the end of this document. Where possible, we tried to ascertain an estimation of the extent of disruption (in numerical terms). However, many interviewees were either unable or unwilling to estimate the impact.

A total of eight organisations representing seven industry groups were interviewed for this study, outlined in Table 17. This report describes how each of these industry groupings is affected by and responds to fuel disruptions.

Table 17: Summary of Interviewees and the Industry Groupings they represent.

Industry group	Example industries	Interviewee*
Information services	Professional services, insurance and financial services, government services	Business Continuity Manager from a large Wellington-based government organisation
Destination services	Hospital, Accommodation, Hospitality	Steve Martin, General Manager, James Cook Hotel
Freight reliant – fast turnover	Fast Moving Consumer Goods, milk production	Robb Macbeth, Dairy Farmer Kris Lancaster, Supply Chain Development Manager, Foodstuffs
Freight reliant – slow turnover	Retail, some manufacturing	Greg Harford, Retail NZ Owner of medium-sized manufacturing company
Freight transport services	Road freight, rail freight, coastal shipping	Employee of Road Transport Forum NZ
Transport Services	International air, domestic air	Airline representative
Oil-dependent production	Agriculture, forestry, some construction	Owner of medium-sized construction company
** note that some interviewees wished that they and/or the organisations they represented remain anonymous.*		

B.2 Information Services

For the information services sector, the main disruption would be related to staff travel. The representative from this sector was from a large government organisation that predominantly provides online services. The interviewee noted that many staff are equipped with laptops to allow increased flexibility and mobility around work hours and location. Although this may not be typical of the sector as a whole, this interviewee also mentioned that their core business systems were able to be accessed remotely. As a result, the representative felt that there generally wouldn't be extreme disruption to their organisation.

Some government organisations, however, depend on workers being physically present in the office (e.g., contact centres for government agencies, telecommunications etc.). If fewer staff are able to physically travel to work, some tasks may be delayed internally. The representative felt that this would not have a visible impact on the day-to-day operations from a customer viewpoint. It was also felt that government organisations would increase the ability to cope with the disruption over time as businesses found more efficient ways of working.

With regard to demand, the industry representative felt that there would only be a slight impact on demand as people will still require information services. Due to this, they would be able to recover a large proportion of demand post-disruption.

Following the disruption, the representative noted that they would recapture all their lost production due to the critical nature of the services they provide.

Key Messages for Modelling – Information Services

Main source of disruption	Extent of disruption on operability	Impact on demand	Production recapture
Staff travel	Little initial disruption, with efficiency gains over time	Little change	Government organisations will recapture all lost production

B.3 Destination Services

The representative from the accommodation industry was from a large hotel. This representative felt that for their organisation impacts on both freight and staff travel would be equally disruptive.

In terms of freight, the interviewee noted that the industry is largely reliant on being able to receive goods and services (e.g., linen, food and beverage supplies). On average, stock inventory could delay the onset of disruption by four or five days. However, once half of regular freight services were lost, there would be an extreme level of disruption to operability.

In terms of staff travel, the representative felt there would be a similar buffer period of four to five days while staff drew down personal fuel supplies (i.e. in private vehicles). The industry representative felt that once half of staff were unable to work, they would cease ability to operate.

The representative felt that a sustained reduction in fuel supply would have a large impact on demand for destination services (proportionately higher than fuel shortage). Many of these services are dependent on the functionality of airlines. The industry representative felt that only around 10% of this lost demand could be recaptured post-disruption, with a small surge of travel expected following the disruption.

Key Messages for Modelling – Destination Services

Main source of disruption	Extent of disruption on operability	Impact on demand	Production recapture
Freight disruption (for large hotels and hospitality organisations). Staff travel for smaller organisations.	Disruption approximately proportional to freight availability (with an initial buffer as existing supplies are drawn down)	Significant due to airline service disruption	Estimated 10%
Note that smaller accommodation and hospitality services will likely be more disrupted by staff travel.			

B.4 Freight Reliant Goods – Milk Production

Milk production is heavily dependent on freight, and the loss of any freight will have an impact on the operability of milk production, almost immediately. Milk needs to be collected within a 24-hour window and constitutes 85% to 90% of a dairy farm sales. A loss of 25% or more of regular freight services would cause serious disruption to farmers.

The production of milk also relies indirectly on the supply of fuel to feed stock, particularly in the winter and spring. The dairy farmer we interviewed noted that they could absorb up to a 10% reduction in fuel supply before operability would be impacted. Following the loss of 50% of fuel, there would be a reduction in operability of about 50%. However, the length of time that milk producers could sustain a disruption before it affected the operability of the business depends both on the availability of fuel in storage, and on the time of year that the disruption was experienced. Dairy farmers typically store up to a month's worth of fuel at a time, so on average have between 12 – 15 days of fuel stored. The actual amount, of course, depends on when the last delivery of fuel was. Farmers also need more fuel in spring and winter (to feed stock) and less in summer.

The inability for workers to travel would also impact dairy farmers in the event of a fuel disruption. Our interviewee noted that in the milk production industry some staff live on site, but others commute 5 – 10km to work each day. In general, a farm will always be able to operate to some degree as they are often family owned. However, if off-site staff are not able to travel to work then part of the operations of the industry would be suspended for the duration of the fuel shortage. In the event of a shortage of fuel there is no ability to recapture milk production.

Key Messages for Modelling – Freight Reliant – Perishable Goods

Main source of disruption	Extent of disruption on operability	Impact on demand	Production recapture
Freight disruption	Proportionate to available fuel supplies	Little (or slight increase due to shortage)	Low to no ability to recapture lost production.

B.5 Freight Reliant Goods – Fast-Moving Consumer Goods

Similar to milk production, the fast-moving consumer goods (FMCG) sector relies heavily on freight. Retail stores hold around one to two days of stock. Due to improvements in technology, and a drive for greater efficiencies, the sector now uses a 'just in time' model, and stock is held in distribution centres before being deployed as needed. In the event of a fuel shortage, reduction in operability would be proportional to the loss of normal freight services. Our interviewee noted that if a fuel shortage occurred, the industry would prioritise the types of goods sent out to retail stores, ensuring that essentials were shipped before luxuries. They would also look for efficiencies including truck route rationalisation.

Disruption to the ability for staff to travel to work would also have a major impact on their operability, as the sector is heavily reliant on manual labour, particularly at their distribution centres. The particular operator that we interviewed for this study mentioned that between 90% to 95% of their distribution staff use a private vehicle to drive to work.

Loss of supply would dictate changes in demand for the FMCG sector. Using the demand changes following the Canterbury earthquakes as a reference, our interviewee noted that retailers would restrict the number of units available to purchase per transaction, as a result of the industry rationing product at distribution. People may shop less often due to private vehicle fuel shortages (at present most people shop three to four times per week). Our interviewee also noted that impact on demand may be affected by media portrayal. For example, media portrayal of potential shortages post-earthquake resulted in "frenzy" shopping in supermarkets as people worried that supplies may not be available for an extended period of time.

Although there would be some demand recapture once fuel supplies returned to normal, any recapture would be minimal. Our interviewee mentioned that consumers do not tend to spend more once goods are available again, and that new habits around shopping tend to occur during times of shortage.

Key Messages for Modelling – Freight Reliant – Fast-Moving Consumer Goods

Main source of disruption	Extent of disruption on operability	Impact on demand	Production recapture
Freight disruption	Proportional to freight availability	Proportional to stock availability	Little

B.6 Freight Reliant Goods – Slow Turnover

Like the fast-moving consumer goods and milk production sectors, the slow turnover goods sector is heavily reliant on freight, using the 'just in time' model. Most retailers hold about a week's worth of stock but, similar to milk production, the extent to which this stock would delay the impacts of a fuel disruption depends on where in their stock cycle the business was when the disruption to freight began. However, after one to two weeks there would be serious shortage of stock, smaller businesses may be heavily impacted, and would have compromised viability.

Similarly, a medium-sized manufacturing company indicated that their production would be most impacted by freight availability. They could continue operating to some extent during a fuel disruption but would be limited where 'just in time' supplies were needed (e.g. concrete deliveries). Generally, their production would be impacted proportionately to freight availability.

Disruption to staff travel would also have a notable impact on this industry group. A retail representative noted that the level of disruption would depend on where people work and live. It was also noted that even if public transport was given priority fuel, the public transport system may still struggle to cope with the increased number of users.

Our retail industry representative felt that demand for retail goods would decline if there was a prolonged disruption to fuel supply. They also mentioned the time of year as being important – during the summer people may be more open to alternative ways of traveling to spend money, but felt that this was less likely if it was raining or if the disruption occurred during the colder months. Post-disruption, there may be some ability to regain lost sales, but this would only occur very quickly after fuel supply was restored and normal spending habits would return to normal shortly afterwards.

For manufacturing, there was a higher ability to recapture lost production through an increase in labour hours.

Key Messages for Modelling – Freight Reliant – Slow Turnover

Main source of disruption	Extent of disruption on operability	Impact on demand	Production recapture
Freight disruption	Proportional to freight availability, with a 2-week buffer before notable disruption is felt.	Slight decline in non-discretionary spending	Little recapture expected for retail. Higher recapture expected for manufacturing.

B.7 Freight Transport Services

Freight transport services are reliant on fuel for their day to day operational processes. The level of disruption experienced in the event of a fuel shortage would be relative to the size of the fleet. Prior work has assessed what essential services (e.g., food and medical supplies) would be prioritised in such an event. This prioritisation would then determine use of the allocated fuel for freight services. Our industry representative also noted that the level of disruption would depend on how the shortage is communicated so that operators are able to plan for any fuel shortage, including route rationalisation and industry collaboration. Our interviewee noted that some larger companies store fuel at depots around the country, while other smaller operators do not. However, as it is considered competitive knowledge, companies may not be forthcoming with the volume of fuel they have stored that may be able to be utilised in the event of a disruption.

Our interviewee believed that impact on staff travel would vary across companies. For example, companies that are not based in major cities would likely fare better, as many staff live locally and would be able to travel to work via alternate modes of transport. Depending on the role, some office staff may be able to work from home. However, not all companies are well set up to achieve this. In the freight transport industry, there is a minimum number of staff needed to be physically present to be able to load trucks. Our interviewee noted that logistics depends on the ability to communicate effectively and efficiently, and that smaller companies with fewer staff to manage may manage better in this regard.

Our interviewee believed there was limited ability to recapture production, as the industry would not have the extra capacity due to limits on driver availability, working hours, and vehicle size.

Key Messages for Modelling – Freight

Main source of disruption	Extent of disruption on operability	Impact on demand	Production recapture
Production (fuel as key input to core service delivery)	Proportionate to available fuel	Reduction in demand due to disruption in other sectors	Little due to constraints in driver availability, working hours and vehicle size.

B.8 Air Transport Services

Air transport services are reliant on jet fuel for a large portion of their operations. In the event of a fuel shortage, air transport services would experience a relatively major disruption. A representative from this industry noted that they would use route prioritisation to determine where these services could be more efficient. Additionally, where possible, planes would also tanker fuel from overseas.

The sector is also reliant on staff moving between airports to ensure planes are appropriately staffed. Cabin crew often travel as passengers to specific locations to make their shifts. In the event of a shortage, staff would be rostered as best as possible based on their home locations.

Our interviewee noted that services would need to be cut if staff were unable to travel to the airport to make shifts. However, they also noted that staff disruptions are a regular occurrence, and during business-as-usual staff often swap shifts if there are external factors that prevent cabin crew from arriving at the airport when needed.

Our representative from the air transport sector believed that there was unlikely to be a reduction in demand for air transport services in the event of a fuel shortage. Following the full return of fuel supply there will be a slight surge in demand.

Key Messages for Modelling – Air Transport Services

Main source of disruption	Extent of disruption on operability	Impact on demand	Production recapture
Production (fuel as key input to core service delivery)	Disruption would be less than fuel availability due to the ability to rationalise routes and tanker fuel.	Little or no	Some production recapture

B.9 Oil-Dependent Production

There are a variety of organisations that rely on oil for production of core services.

As noted above for milk producing organisations, agricultural services have a reliance on fuel for farm activities, and disruption to fuel can significantly disrupt operations. Typically, rural fuel deliveries are monthly, so on average there would be 12-15 days' worth of fuel available that would delay the onset of the disruption. Staff travel and freight for moving stock on- and off-site also contribute to production, but this is seasonal for many operations.

The construction company owner we spoke to indicated that diesel is essential for on-site operations. Fuel is also required to move staff to site but this is easier to manage than a lack of fuel for on-site activities. Some on-site plant could be converted to electric, but this would be unlikely during a short duration event. Over time more construction plants may become electrified.

Generally, any costs associated with delays due to a fuel shortage would be borne by the contractor (as fixed sum contracts are the current standard for the industry). Therefore, any lost production time will have to be recaptured to meet contractual obligations.

Key Messages for Modelling – Oil-Dependent Production

Main source of disruption	Extent of disruption on operability	Impact on demand	Production recapture
Production	Proportional to available fuel	None	Yes as far as possible

Fuel Security Project

Industry Interview Questions

Some definitions:

- *Operability – your ability to meet demand for your services*
- *Production – the making or creation of goods or services*
- *Fuel – this includes petrol, diesel, and aviation/jet fuel (take a note if they speak about different levels of reliance on types of fuel, otherwise covering generically is fine as we have data on typical fuel use by industry)*

A. Production

1. Do you use fuel directly in your operations / production processes (other than for work related travel, covered below)? Yes / No
2. If yes, how would an ongoing fuel supply disruption affect your operability/production? (assume a disruption of 1 week or more)

Percentage loss of your normal fuel supply	Level of disruption				Approximate % reduction in operability/production
	Not disruptive	Slightly disruptive	Moderately disruptive	Very disruptive	
5%					
10%					
25%					
50%					
75%					
100%					

3. How would this level of disruption change over time?
   a. How long could you sustain a fuel disruption before it affected operability?
   b. If the fuel disruption went on for an extended period, would your ability to operate increase or decrease over time?
4. Do you have your own fuel supplies/stores? If so, how many days worth of fuel do you typically store? And/or how quickly would you draw down on those stores during a fuel shortage?

B. Freight *(n/a for freight services themselves, they are covered under production, above)*

1. Does your organisation or industry's core business depend on freight services? Yes / No
2. If yes, how does loss of freight services affect your productivity? (assume a disruption of 1 week or more)

Disruption to your normal freight services	Level of disruption				Approximate % reduction in operability (or production)
	Not disruptive	Slightly disruptive	Moderately disruptive	Very disruptive	
5%					
10%					
25%					

50%					
75%					
100%					

3. Do you hold stock inventory that can mitigate the impact of freight disruption? If yes,
    a. How many days worth of stock? (input goods)
    b. Would this delay the onset of freight disruption? If so, by how many days?
4. Can you hold produced goods on site if there is disruption to freight services? If so, how long can you hold outbound goods?
5. How would this level of freight disruption change over time?
    a. How long could you sustain a fuel disruption before it affected operability?
    b. If the fuel disruption went on for an extended period, would your ability to operate increase or decrease over time?

C. Work travel *(n/a for freight services)*

1. Is travel part of your day to day operations (i.e. do you need to travel to deliver your core services)? Yes / No
2. If yes, how would an ongoing fuel supply disruption affect your operability? (assume a disruption of 1 week or more)

Percentage loss of normal fuel supply	Level of disruption				Approximate % reduction in operability (or production)
	Not disruptive	Slightly disruptive	Moderately disruptive	Very disruptive	
5%					
10%					
25%					
50%					
75%					
100%					

1. How would this level of disruption change over time?
    a. How long could you sustain a fuel disruption before it affected operability?
    b. If the fuel disruption went on for an extended period, would your ability to operate increase or decrease over time?

D. Staff travel

1. If some staff could not physically travel to work – how would this affect your organisation's or industry's operability? (assume a disruption of 1 week or more)

Percentage of staff not able to get to work	Level of disruption				Approximate % reduction in operability
	Not disruptive	Slightly disruptive	Moderately disruptive	Very disruptive	
5%					
10%					
25%					

50%					
75%					
100%					

2. How would this level of disruption change over time?
   a. How long could you sustain a fuel disruption before it affected operability?
   b. If the fuel disruption went on for an extended period, would your ability to operate increase or decrease over time?
3. If there was a fuel shortage, how many staff do you think would not physically travel to work?

Percentage loss of normal fuel supply	Approximate % staff that would not physically come to work
5%	
10%	
25%	
50%	
75%	
100%	

E. Demand

1. How do you think a reduction in national fuel supply would impact demand for your goods/services? (assume a disruption of 1 week or more)

Percentage loss of normal fuel supply	Level of disruption to demand				Approximate % reduction in demand
	Not disruptive	Slightly disruptive	Moderately disruptive	Very disruptive	
5%					
10%					
25%					
50%					
75%					
100%					

2. How would this level of demand disruption change over time?
   a. How long would it be before you would see a change in demand?
   b. If the fuel disruption went on for an extended period, would demand increase or decrease over time?

F. Post-disruption

1. Once fuel is restored to full supply, would you be able to re-capture lost production?
   a) What percentage of lost production do you think you could recover?
   b) How quickly could you recover this lost production?
2. Once fuel is restored to full supply, would you see any demand 're-capture'?
   a) What percentage of lost demand do you think you would recover?
   b) How quickly would you recover that lost demand?

G. Other

1. Do you rely on any fuel dependent services/industries (apart from freight)? How would you be impacted by a disruption to their service?
2. What would you do to reduce the impact of a fuel supply disruption?
3. If your organisation/industry is affected by more than one of the above impacts (staff travel, work travel, freight or production) which is the dominant disruption?
4. Do you have any other thoughts about how your industry woud respond to a fuel shortage?

H. General

1. Are you (as an individual or as a representative of your organisation) happy to be identified as a contributor to this study? Yes / No
   If yes, please be aware that we are only speaking to one or two people from each industry group so it will not be possible to keep your responses confidential. If requested, we can provide a copy of any material relating to this interview to you prior to inclusion in our report to MBIE.

Appendix C: Options for Welfare Analysis in Multi-Sectoral Economic Simulation Models

In many (but not all) standard CGE models used for policy analysis, households are aggregated into a single representative household, implying that these households have homogenous needs and tastes, and exhibit the same behaviours. However, households do, in fact, differ in several aspects ranging from income to employment to number of household members. Consequently, the implications of policy decisions can vary widely across household groups. For policy evaluation, particularly where changes in welfare are a key reporting metric, it is therefore appropriate to build a model that explicitly represents households as heterogeneous economic agents so that the distributional implications of proposed policies can be evaluated.

Below is a brief summary of how CGE models can be adjusted to account for distributional effects.

Multiple Household CGE Model

The simplest approach is to build a multiple household CGE model. This method involves expanding the number of households from a single representative household to multiple household types. Apart from increasing the number of households in the model, the structure of the CGE model remains the same.

Moving away from the single representative household assumption can be achieved in two ways. First, the household types incorporated in the model can be disaggregated by specific characteristics. For instance, Ojha *et al.,* (2013) modelled nine households classified by type of employment (urban/rural, agricultural/non-agricultural and wage/self-employed) and level of education in a recursive dynamic CGE framework to analyse the implications of several different economic growth strategies for India. The most commonly used criteria to disaggregate households are geographical location, factor endowments and occupation of household head (Estrades, 2013). Other aspects include heterogeneity in wage rates, rates of return to capital as well as preferences and savings (i.e. different consumption budgets across households) (van Ruijven, O'Neil and Chateau, 2015). If income level is an endogenous variable in the model, then disaggregation by income levels is typically avoided. The resulting disaggregation should seek to reproduce the existing socioeconomic differences across household types as this would then allow an analysis of the distributional implications of policy alternatives on different household types.

The second approach involves wholly integrating household survey data into the CGE model so that the model includes the same number of households as in the survey. For instance, Cockburn (2001) examined the effects of trade liberalisation on the poor in Nepal, integrating 3,373 households from the Nepalese Living Standards Survey in a national CGE model. Similarly, Tarr (2012) integrated all 55,098 households from the Russian Household Budget Survey as agents in a static CGE model to investigate the impacts of liberalising the barriers to foreign direct investment.

Once the level of disaggregation is decided, each household type is assigned a utility function and the labour supply, consumption preferences and substitution elasticities of each type is specified.

From the description of the model, it should be clear that this approach is rather data intensive. Reconciling the data from the household survey with the data in the CGE model, which are based on SAM, may prove to be an arduous task. van Ruijven *et al.,* (2015) warn that data on consumption levels, income and assets can deviate substantially between household survey data and national accounts. To reconcile the two datasets, either the household survey or SAM (or both) can be adjusted; however, in any case, some original information may be lost in the process.

Another drawback of the model is the limited results that are generated. That is, while this approach produces distributional implications for between groups, the model does not account for changes within groups, which may be even more important. Increasing the number of households in the model can minimise the problem; however, the integration of multiple household types significantly multiples the number of equations necessary for solving the model. Because of this, the model is known for being complex and cumbersome to operate (Estrades, 2013).

A final limitation of this methodology is that heterogeneity across households is only captured in structural characteristics (e.g. income, occupation, location etc.), not behaviour. Because of this, many of the studies that have incorporated multiple household types use a static CGE model.

Macro-Micro Synthesis: Micro-simulation Models

Another common approach is macro-micro syntheses which involves combining macro (typically, CGE and GTAP) models with micro models. Macro models account for the impacts of policies or shocks on macroeconomic variables and are linked to micro models which incorporate detailed information at the household level. This approach captures the channels through which policies and shocks affect the economy at the macro level, while simultaneously integrating micro data that account for distributional impacts at the micro (household) level.

A subset of macro-micro syntheses are micro-simulation models. These models differ from the multiple household CGE models in that the latter replaces the single representative household with multiple households within the macro model itself, whereas the former uses the results of the macro model as inputs to simulate outcomes with a higher degree of heterogeneity.

Micro-simulation models can be used sequentially following the CGE model simulations (i.e. top-down) or in iteration between the micro-simulation and CGE model (i.e. top-down/bottom-up) which allows a bi-directional feedback until the models converge on a solution. The simplest of these two methods appears to be the top-down sequential micro-simulation model. This approach involves first quantifying the changes in labour markets, capital markets and aggregated consumption. These outputs are then transposed as exogenous variables in the micro-simulation model which determines the impacts on different households.

In all micro-simulation models a first set of equations is constructed which determines income, taxes, savings and expenditure for all household types based on survey data. A second set of equations is constructed which consists of a series of econometric functions that determine household behaviour based on characteristics of households observed in the survey data. Theoretically, it is possible to model a wide range of behavioural choices of households; although, occupation-related behavioural choices of households are generally modelled in the literature (van Ruijven *et al*., 2015).

Since a welfare analysis ultimately seeks to answer how much better- or worse-off households are as a consequence of policy, a behavioural sequential micro-simulation model as an appendage to a CGE model is potentially useful. The main advantage of this approach is that it explicitly models the behavioural responses of households and accounts for changes in employment status which have been found to have the greatest weight in changes in income distribution. Most applications of behavioural micro-simulation models are used in conjunction with static CGE models and focus on macroeconomic crises or shocks. For instance, Bussolo and Lay (2003) built a behavioural micro-simulation model for Colombia which included individual occupational choice between four alternatives (inactive, wage-worker, self-employed, rural wage/self-employed) to analyse the impacts of trade liberalisation on income distribution.

Similar to the multiple household CGE model, behavioural micro-simulation models are data intensive as these require detailed background data pertaining to households in order to model behavioural choice. Data reconciliation therefore is also the main drawback of this methodology. Estrades (2013) notes that adjusting the data may compromise its integrity such that it creates doubt regarding the robustness of the parameters estimated. Moreover, while this method permits greater flexible modelling of household behaviour, it does not however guarantee that the CGE and micro-simulation model will be compatible.

Welfare Weights

If the model used does not have the capacity to incorporate distinct household types, it may be worth exploring the idea of assigning welfare weights to the different household types as a way to measure social welfare. This approach involves first specifying the number to be used as weights and then assigning the weight to the different household types. It is typical for social welfare to be measured as the weighted sum of household income. The change in social welfare therefore is measured as the weighted average of changes in the incomes (y) of all n households, as shown in the following equation.

$$\Delta W = \sum_{i=1}^{n} \omega_i \Delta y_i \qquad (1)$$

The difficulty in implementing this approach is justifying the number and assignment of the welfare weights, ω_i, which is likely to involve a normative judgement. The problem with this is that introducing subjective analysis can minimise the credibility of the results.

Cowell and Gardiner (1999) address this issue from a utilitarian perspective. Their social welfare function takes the following form

$$W = \sum_{i=1}^{n} v_i(y_i) \qquad (2)$$

where v_i denotes the utility of household i which is expressed as a function of income. Differentiation of (2) gives

$$dW = \sum_{i=1}^{n} v_i'(y_i) dy_i \qquad (3)$$

Relating this back to (1) shows that weight ω_i is simply the marginal utility of income, $v_i'(y_i)$. Drawing on the classical assumption of decreasing marginal utility, this result implicates that higher incomes lead to lower weights. From this, the authors provide the following policy rule: "In evaluating the change in welfare associated with a policy, assign lower weights to people on higher incomes" (Cowell and Gardiner, 1999, p.3). However, this rather simple rule relies on the assumption that there are no significant differences between the utilities of different households. Homogeneity across households therefore justifies the use of income as the objective measure of utility. In reality, however, households do differ in terms of needs and tastes, and thus, distributional weights should not be determined solely on the basis of income.

Welfare-Specific Reporting Metrics

Once the CGE model has been transformed so that it accounts for multiple household types, welfare-specific reporting metrics that measure the social benefits and costs of policy alternatives can be included. A measure often used is the willingness-to-pay measure known as Equivalent Variation (EV). EV reflects the additional income that a household would need (at initial prices and income) to make it as well-off with the new policy. In other words, the EV measures the amount of income that would have to be given (if positive economic change occurs) or taken away (if negative economic change occurs) from an economy before the policy is implemented to leave the economy as well-off as it would be after the policy has been implemented (Research Triangle Institute International, 2010). The functional form of the standard EV analysis is the following:

$$EV = u(p^o; p', m') - u(p^o; p^o, m^o)$$

$$= u(p^o; p', m') - m^o$$

where p^o and m^o denote the baseline prices and income, respectively, and p' and m' denote the prices and income resulting from the policy, respectively.

This reporting metric was used by Siriwardana and Yang (2008) in a GTAP model whereby households were disaggregated by geographical location, with each region represented by a single household. The authors found that both Australia and China experienced positive EVs which indicates an improvement in welfare due to greater trade resulting from the trade agreement. For non-member countries, negative EVs were recorded, implicating the creation of a trade division.

For further welfare analysis, often the estimated EV is decomposed into a number of sub-effects to determine the contributions of each to the overall change in welfare. In the Siriwardana and Yang (2008) study, the estimated EV was decomposed into four sub-effects: (1) allocative efficiency; (2) endowment; (3) change in terms of trade; and (4) change in capital stock.