

Estimating the Economic Effects of the Canterbury  
Earthquakes Sequence using Synthetic Control  
Methods

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## **Abstract**

Since, 2010, New Zealand, Japan and Haiti have suffered from large scale damages as the result of earthquakes. Along with the devastating immediate losses associated with such disasters, particularly the loss of lives, those exposed to such events may in addition suffer from prolonged negative effects on the wider economy.

This thesis examines the economic effects of the Canterbury earthquakes, with a focus on the impacts on the tourism and trade sectors. Specifically, the synthetic control methodology pioneered by Abadie and Gardeazabal (2003) is used to estimate the effects of the earthquakes on regional GDP and its derivatives, tourism and international trade. The effect of the earthquake on tourism is investigated by looking at regional guest nights and regional international flight arrivals, while the effect of the event on trade is investigated through regional gross imports and regional gross exports. The synthetic control methodology is a data driven procedure that uses regions throughout New Zealand to generate a counter-factual which represents the Canterbury region if it were relatively unaffected by the earthquake. The difference between Canterbury and its counter-factual estimates the causal effect of the earthquake events for the region.

The effect of the earthquake on Canterbury's tourism is significant, while the effects on regional GDP, international arrivals and exports are inconclusive with regards to statistical significance. As at 2012Q4, the average effect of the earthquakes on Canterbury (the difference between Synthetic Canterbury and Treated Canterbury) indicate that regional GDP fell by 4.9% and regional regional guest nights fell by 22.9%. International arrivals fell by 17.7% reductions in imports were seen to be negligible and exports fell by 13.3%. Placebo tests and regression based techniques are used to verify the robustness of these results.

## Acknowledgements

For one time in this thesis I get to shrug off the sometimes stifling prose of academic writing to pay homage to those who have been instrumental in this thesis (in no particular order).

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*“I ain’t the coolest but I know I’ve got passion, I’ve got passion!”*

Evan Miller, 16/11/2013

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# 1 Introduction

*“ Today I want Christchurch to hear this message: You will get through this.*

*This proud country is right behind you with all our might . . .*

*Christchurch, today is the day your great comeback begins ”*

*John Key, February 22nd<sup>1</sup>*

The Canterbury earthquake caused a large amount of damage and had repercussions for not only Canterbury, but for all of New Zealand. Events of this size have occurred frequently over the last decade, with earthquake events of similar magnitude affecting Japan (2011) and Haiti (2010). Estimating the economic effects of the Canterbury earthquake sequence is essential to understand the full magnitude of these events, thus ensuring policy makers, politicians and citizens all understand and prepare for the true cost of an earthquake event of this size.

However, understanding of the economic effects of natural disasters as a whole is still undeveloped (Cavallo and Noy, 2009) due to the effects of natural disasters depending on a number of factors, such as the magnitude of the event and the level of economic development in the affected country (Toya and Skidmore, 2007). Some researchers have even found that natural disasters only affect economic growth due to political instability and subsequent revolutions after the event (Cavallo et al., 2010a).

Estimating the economic effects of any natural disaster event is difficult, as the researcher must not only investigate the damages (direct losses), but also must understand the economic repercussions of these damages (indirect losses) (Hallegatte and Przyluski, 2010).<sup>2</sup> Indirect losses arise through damages to lifeline utilities, which disrupt businesses and households causing reduced production and consump-

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<sup>1</sup>See Key (2011) for transcript.

<sup>2</sup>“Indirect losses include all losses that are not provoked by the disaster itself, but by its consequences” (Hallegatte and Przyluski, 2010).

tion, with many economists believing that these losses are a large multiple of direct losses due to flow on effects throughout the economy (Rose, 2004). Furthermore, depending on the severity of the event and aftershocks, productive human and physical capital may exit the affected area and relocate to a safer environment, which can be the difference between the affected region recovering or not. This thesis investigates the economic effects of the Canterbury earthquake sequence, focusing on regional GDP, tourism and international trade. The regional effects are investigated by examining regional guest nights and regional international arrivals, while the regional effects on international trade are investigated by examining regional gross imports and exports by port. We use the synthetic control group methodology developed by Abadie et al. (2010) to examine the economic effects of the Canterbury earthquakes. This technique enables us to estimate the Canterbury region without the earthquake (“Synthetic” Canterbury) and compare it to Canterbury with the earthquake (“Treated” Canterbury).

This analysis compares “Treated” Canterbury to “Synthetic” Canterbury to get an estimate of total losses due to the earthquake events, calculating an estimate of the total losses due to the event. Recently, applications of synthetic control groups has become popular with a wide range of topics examined, such as the effects of stricter employment regulations on illegal immigrants in Arizona (Bohn, Lofstrom, and Raphael, 2011) and the economic long run effects of the Kōbe earthquake (DuPont and Noy, 2012). However as with all statistical approaches there are certain caveats. Due to the reliance of the approach on donor regions, positive and negative spill overs have the ability to contaminate the synthetic control region, causing unreliable estimates of economic effects. To test the statistical significance of synthetic control group results, placebo tests and difference in difference estimators are used.

Doyle and Noy (2013) use Structural Vector Autoregressive (VAR) models to estimate the effects of the Canterbury earthquakes at the national level, and find that

there was no significant effect on real GDP growth. In investigating the regional effects using comparisons of aggregate and regional trends, Parker and Steenkamp (2012) find the presence of economic effects on most of the variables that they consider. Additionally, results from questionnaires gathered by Orchiston et al. (2011) indicate that, due to the Canterbury earthquakes, international tourists have decreased significantly, with different types of accommodation providers made either better or worse off due to the earthquake events.

The analysis in this thesis differs from previous approaches by Doyle and Noy (2013) as it employs regional level data to estimate the effect of the earthquakes on the Canterbury region. Parker and Steenkamp (2012) use regional level data to estimate the effects of the earthquakes on Canterbury using trend comparisons, while this thesis uses a different methodology allowing control of other macroeconomic fluctuations and providing a more precise estimation of the causal effects of the earthquakes through the creation of more adequate comparison groups.

In previous literature, the economic effects of earthquakes are predominantly estimated using either Computable General Equilibrium models or Input-Output models, as their mathematical set-up enable accurate and robust estimates of direct and indirect economic losses of natural disasters (see Selcuk and Yeldan, 2001). Moreover, these models lend themselves to estimating how economic losses of an earthquake event are transmitted geographically, as well as the effects of disruptions to lifeline utilities on consumers and firms due the event.<sup>3</sup>

Despite these advantages, these approaches require extensive and detailed data on the structure of the economy being considered.<sup>4</sup> Due to this, an econometric approach was chosen. The synthetic control group methodology is adopted due to its previous applications in the economics of natural disaster literature, as well as

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<sup>3</sup>See Shibusawa and Miyata (2011) & Cho et al. (2001) for related literature.

<sup>4</sup>Both CGE and I-O models were found to be infeasible due to a lack of sufficiently detailed and available New Zealand-specific CGE and I-O models, as for this project to create either of these from scratch would have required considerable time and resources.

the methodology’s ability to estimate synthetic control groups close to the date of incidence.

Results from this thesis indicate that as a result of the Canterbury earthquakes, regional GDP in Canterbury fell by 4.9%, with reductions in tourism causing guest nights stayed to fall by 22.9% and international arrivals to fall by 17.7%. Furthermore, as a result of the earthquake events international trade was affected, with imports by port experiencing a modest increase of 0.72%, while exports by port fell 13.34%.

The structure for this thesis is as follows. Chapter 2 presents and discusses relevant literature to this thesis. Chapter 3 summarizes the methodological approaches used for both estimation and statistical significance. Chapter 4 presents the results of estimation and statistical significance. Chapter 5 discusses the results and draws comparisons to findings in previous literature. Finally, Chapter 6 concludes this thesis.

## 2 Literature Review

Many economists initially believed that the effects of any natural disaster event should be modelled as a negative shock to a county’s capital and labour stocks using models common in growth literature such as the Solow Model or the AK Model. However, Dacy and Kunreuther (1969) investigated the economic effects of the 1964 Alaskan Earthquake and indicated that conventional economic theory represented in previous applications does not apply strictly to natural disaster situations due to unique effects on demand and supply, necessitating further research on the economic effects of natural disasters<sup>5</sup>.

Since this initial investigation of natural disasters and their economic effects by Dacy and Kunreuther (1969), the literature surrounding the economic effects of nat-

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<sup>5</sup>See Solow (1956) and Aghion, Howitt, and Peñalosa (1998) for related growth literature.

ural disasters has expanded substantially with empirical research approaches split into three categories; Input-Output (I-O), Computable General Equilibrium (CGE) and Econometric models.

I-O models are linear in nature, allowing for easy computation while adequately representing of the current state of the economy as they are calibrated from input-output tables. Notable applications include Cochrane (1974) and Cochrane (1997). CGE models are highly detailed General Equilibrium models as they are programmed and solved in mathematical optimising software such as MATLAB or GAMS. The number of applications of these models in the natural disaster literature is increasing, with influential applications by Selcuk and Yeldan (2001) and Shibusawa and Miyata (2011). Finally, Econometric models use either time series or panel data to estimate the effects of a given natural disaster event, often using regression based approaches. These applications are becoming more popular as the number as techniques become more developed (such as synthetic control groups) and data sources become more comprehensive (such as EM-DAT). Due to the large number of high intensity disasters recently, the applications of Econometric models has increased as of late, with notable contributions to this literature seen in Cavallo, Powell, and Becerra (2010b) and Coffman and Noy (2012).<sup>6</sup> The literature surrounding each of these applications is critically reviewed in the rest of the section.

## **2.1 Input-Output Models:**

Input-Output models were pioneered by Leontief (1936) who built on previous work by François Quesnay and Léon Walras to produce a model of interlinked industries representing the structure of an economy, which was both empirically testable and computationally feasible. Input-Output models are very flexible and can be aug-

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<sup>6</sup>The EM-DAT database is maintained by World Health Organisation (WHO) Collaborating Centre for Research on the Epidemiology of Disasters (CRED) and the Belgian Government.

mented with numerous methodological innovations directly applicable to natural disasters events, making usage of this technique popular in estimating the economic effects of natural disasters.

To estimate the potential economic effects if the 1906 San Francisco earthquake would occur in modern times, Cochrane (1974) represents one of the first applications of I-O model in the estimation of the economic effects of natural disaster events. A primary motivation for this application of the I-O technique was to emphasize the model's potential application in cost-benefit analyses of disaster mitigation techniques. The author used county level data to supplement a broad categorization of industries in the San Francisco area, superimposing earthquake intensity data to estimate how significantly each county was affected by the earthquake.<sup>7</sup> Cochrane (1974) estimated the combined direct and indirect cost of the earthquake to be USD 13 billion, of which USD 7 billion was attributed to direct damages to the public, industrial & commercial and residential sectors.<sup>8</sup> The remaining effect of the earthquake was attributed to indirect losses on reduced economic activity of USD 6 billion, one of the first applications of indirect losses to earthquake loss estimation, with the author further supplying examples of policies usable to reduce total economic losses due to the earthquake.

In a later study, Cochrane (1997) uses the HAZUS model to estimate the economic losses of an earthquake that would cause USD 50 million in direct damages to Memphis, Tennessee.<sup>9</sup> The author simulates substantial reductions in lifeline services effect on Memphis, with 30% of lifeline services destroyed.<sup>10</sup> Due to the

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<sup>7</sup>County level data used in this paper includes estimates of number of residences, number of persons employed in basic industry and the local service industry.

<sup>8</sup>Indirect losses are the consequences of direct damages on economic activity, due to shortages of goods and services or lifeline disruptions.

<sup>9</sup>The HAZUS model is a Federal Emergency Management Agency (FEMA) developed Input-Output model.

<sup>10</sup>Lifeline services are services such as electricity, gas, sewage, communication and transportation

earthquake event output, household payments and employment in Memphis all substantially decrease due to the earthquake, but the indirect losses due to the reduction in lifeline services are many multiples of these direct effects.<sup>11</sup> As a result of the earthquake, income in the affected area increases by USD 14.32 billion due to increased transfers to fund the rebuild. The unaffected area of the region exports a larger amount of construction supplies to the affected region, increasing income by USD 8.67 billion, resulting in a regional increase in income of USD 22.99 billion. However, national income would decrease by USD 2.57 billion from government spending cuts needed to finance the rebuild.

Input-Output models have both significant benefits, as well as significant drawbacks, requiring the exercise of caution. These models lend themselves well to the estimation of the effects of natural disasters due to their simplicity and the ability to calculate both direct and indirect costs of natural disaster events. However, Input-Output models are rigid with regards to input and import substitutions, and cannot model explicit resource constraints or responses to price changes (Rose, 2004). As Computable General Equilibrium models solve most of the problems highlighted above, while incorporating the same benefits of Input-Output models, Computable General Equilibrium models are becoming increasingly popular in the natural disaster literature.

## 2.2 Computable General Equilibrium models

Computable General Equilibrium (CGE) models are extensions of General Equilibrium models, which are descended from Input-Output models pioneered by Leontief (1936). These models are loosely related to General Equilibrium, with the additional

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<sup>11</sup>This application assumes the Memphis economy is fully constrained and cannot avoid backwards or forwards moving losses, no excess capacity is available and other regions cannot help the affected region. After the event all costs of the rebuild are paid by the government.

ability to model disequilibria such as persistent unemployment or perfectly inelastic demand (government demand). Due to the mathematical framework associated with these models data requirements are small, but greater than I-O models. Due to these benefits, applications of this technique are common in either estimating of the effects of occurred natural disaster events or to the estimation of the damages of hypothetical disasters.

Selcuk and Yeldan (2001) investigate the economic effects of the 17th August 1999 earthquake, a 7.4 richter scale earthquake that occurred in Izmit, Turkey. The authors estimate the short, medium and long run effects of the event using a CGE model of the Turkish economy. They find that the earthquake may have caused damage amounting to between -4.5% to +0.8% reductions in Turkish GDP, depending on the government response to the earthquake. Selcuk and Yeldan (2001) conclude that using an increase in the indirect tax rate to recover the loss in capital stock deepens the recession caused by the earthquake, and that foreign aid used to recover capital causes a stimulatory result on GDP due to the earthquake.

Shibusawa and Miyata (2011) estimate the effect of an earthquake occurring in the Tōkai region of Japan.<sup>12</sup> The authors use a Dynamic, Spatial Computable General Equilibrium model to determine the effects of three scenarios specifically on Ōsaka and Shizuoka. The scenarios examined are (i) a Business As Usual (BAU) scenario with no earthquake, (ii) an unpredicted earthquake occurs (Case 1), and (iii) a fully predicted earthquake (Case 2). Shibusawa and Miyata (2011) find that the Tōkai earthquake causes the value of capital in Ōsaka and Shizuoka to increase in both Case 1 and Case 2 as part of the capital stock is destroyed, making it more scarce. In Case 1, Gross Regional Product (GRP) in regions geographically distant from Tōkai increase, with the earthquakes resulting in aggregate reductions in na-

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<sup>12</sup>The Tōkai region experiences large earthquakes every 100-150 years.

tional output. Due to anticipation of the earthquake in Case 2, Tōkai regional GRP increases.<sup>13</sup> Shibusawa and Miyata (2011) find that due to large increases in investment in the Tōkai region intra-regional trade increases to Tōkai and other regions, with geographically proximate regions also benefitting.

CGE models are moving towards the forefront of the economics of the natural disaster literature due to their superior handling of many methodological problems that are associated with I-O models, and stemming from the complexity allowed through their computational formulation. However CGE models also have numerous limitations, mainly due to restrictive underlying assumptions of General Equilibrium models, from which CGE models are based from. For instance, the assumption of optimizing behaviour is questionable under post-disaster situations due to large amounts of uncertainty (Okuyama, 2007). In the following section econometric models are discussed with their lack of theoretical assumptions aiding in the estimation of short run effects of natural disaster events.

## 2.3 Econometric Models of Natural Disasters

Econometric models used to estimate the effects of natural disasters can be split into two categories; time series/panel regression models and synthetic control groups. Time series and panel regression models focus on the effects of natural disasters globally, or on individual disaster events using regression based techniques<sup>14</sup> such as event studies.<sup>15</sup> Synthetic control groups are suited for the estimation of the economic effects of specific disaster events, in which comparison regions are used to recreate the affected region without the intervention, to estimate the causal effect

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<sup>13</sup>The earthquake is perfectly predicted in Case 2 and, as the region prepares for the earthquake, regional income increases.

<sup>14</sup>As shown in (Okuyama, 2002).

<sup>15</sup>Event study methodology is a financial regression based methodology used to estimate the effects of a specific intervention on variables, used in Mazzocchi and Montini (2001).

of the event.

Cavallo, Powell, and Becerra (2010b) investigate the short term effects of the Haiti earthquake, while Okuyama (2002) models the long term effect of the Kōbe earthquake, highlighting the flexibility of regression based techniques. Cavallo, Powell, and Becerra (2010b) use out of sample predictions from pooled regression models to estimate the effect of the 2010 Haiti earthquake.<sup>16</sup> Using aggregate damages (in USD) as the dependent variable and a range of independent variables to describe the severity of the disaster, Cavallo, Powell, and Becerra (2010b) infer that the Haiti earthquake has caused USD 8.1 Billion in direct damages, which was validated by robustness checking with different pooled sample regressions. Okuyama (2002) use a Auto-Regressive Distributed Lag Model (see Hendry, 1995) in a linear general linear form to estimate the effects of the earthquake at national, regional and city levels. The author concludes that the effects of the earthquake are only significant for the city of Kobe, due to the Kōbe earthquake changing the economic structure of Kōbe, while there are negligible regional and national level effects.

While the literature surveyed above suggests that the aggregate effects of earthquakes can be large, it is reasonable to expect that some sectors of the economy and types of economic activity will be disproportionately affected. For example, Tourism is particularly adversely affected because the hospitality industry is particularly capital intensive (hotels, public transportation and infrastructure) and because the potential threat to lives deter potential visitors from travelling following a large natural disaster. One article that focuses on the impact on Tourism in particular is Mazzocchi and Montini (2001), which uses the event study methodology to estimate the effects of the 1997 Umbria earthquake on tourist arrivals.<sup>17</sup> To estimate the ef-

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<sup>16</sup>Natural disaster events data used in this paper is from the EM-DAT database.

<sup>17</sup>In a previous paper, tourist arrivals were found to be particularly vulnerable to seismic risk (see Mazzocchi, Montini, and Zoboli, 1999).

fect of the earthquake on regional tourist arrivals as compared to regions before the earthquake event, the authors use a simple Partial Adjustment model, using total inbound tourism in Italy and monthly dummy variables to estimate regional tourism arrivals.<sup>18</sup> Mazzocchi and Montini (2001) find that the main tourist destination in Umbria, Assisi experienced substantial decreases in tourist arrivals resulting in monetary losses of 61% as a result of the earthquake event. Interestingly, these monetary losses in arrivals were predominantly due to reductions in domestic tourists numbers (-73.8%) as opposed to reductions in international domestic tourists numbers (-42.5%). In aggregate, Mazzocchi and Montini (2001) estimate that the 40% reduction in tourist arrivals (between July 1997 and October 1998) had an estimated dollar loss to the tourism industry of USD 71 million.

As New Zealand is a small open economy, it participates in a large amount of international trade with the rest of the world. A large amount of consumption, production and personal income is derived from industries that participate in either importing or exporting, causing New Zealand to be particularly vulnerable to changes in international demand and supply of goods. There is evidence that the recovery of transportation systems play large roles in determining the long term effects of earthquake events (Chang, 2000). Chang (2000) analyzes the effect of the Kōbe earthquake on the Port of Kōbe, investigating whether the Kōbe earthquake affected international cargo through the port. The author finds that in the immediate aftermath of the earthquake, Kōbe experienced a significant reduction in Twenty-foot Equivalent Units (TEU).<sup>19</sup> As a result of the earthquake a large number of buildings at the Port of Kōbe were damaged, reducing capacity and causing traffic destined for Kōbe to be redistributed to ports either domestically or internationally. Chang (2000) finds that the redistributed tonnage to Japanese ports was returned to Kōbe

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<sup>18</sup>Total inbound tourism to Italy was used to proxy for variables such as exchange rates, incomes and changes in the tastes of international tourists which would affect all regions equally.

<sup>19</sup>Twenty-foot Equivalent Units are a standardized measure of traffic through any given port.

once the port had been repaired (after 2 years), but the international redistribution never returned to Kōbe, resulting in a persistent reduction in traffic due to the earthquake.

An alternate approach to estimating the effects of individual disaster events is to use databases on natural disasters such as EM-DAT to estimate the average effect across all countries. Toya and Skidmore (2007) use data from the EM-DAT database to investigate the effects of economic growth on fatalities and damages from natural disasters.<sup>20</sup> The authors use panel data analysis to estimate two regressions, one explaining the number of fatalities and the second regression explaining the damage to GDP ratio using a range of variables and drawing from a sub-sample of OECD countries, then extending the analysis to all countries in the database. The authors find that as a country grows their risk of mortality and of economic damages due to a natural disaster event decrease. Interestingly, Toya and Skidmore (2007) find that when income is controlled for, education, openness of trade, more advanced financial systems and smaller governments reduce the amount of economic and human losses due to a disaster event.

In contrast to these regression based techniques, Abadie and Gardeazabal (2003) develop the synthetic control methodology, a data driven procedure to estimate the causal effect of an intervention by comparing the treated region to a similar untreated comparison group. This approach also controls for macroeconomic effects such as businesses cycles, allowing for a more accurate estimate of the causal effect of the intervention than a standard time series comparison approach.

Initially, Abadie and Gardeazabal (2003) used this methodology to estimate the effects of terrorism in Basque Country, Spain by the ETA who, in order to gain

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<sup>20</sup>The EM-DAT database classifies natural disasters to five categories of geophysical, meteorological, hydrological, climatological and biological disasters.

funds for their terrorist activities, kidnapped and ransomed several entrepreneurs.<sup>21</sup> As a result, this caused an exodus of entrepreneurial skill from Basque Country, decreasing production and innovation in the region. To estimate the effects of the ETA terrorism, the authors create a “Synthetic” Basque country under the counterfactual of no terrorism and compare it to the “Treated” Basque country, which was affected by terrorism. “Synthetic” Basque Country is estimated by constructing a weighted average of unaffected regions that best matches Basque Country for various variables of interest before terrorism began. Abadie and Gardeazabal (2003) find that compared to Basque Country without terrorism, ETA terrorism reduced regional GDP by 10% as well as causing significantly reducing regional population.<sup>22</sup> The methodology presented in Abadie and Gardeazabal (2003) is extended in Abadie et al. (2010) with the addition of a more detailed mathematical treatment of the synthetic control methodology, and the introduction of placebo tests to determine statistical significance for synthetic control groups.<sup>23</sup>

Coffman and Noy (2012) and Lynham, Noy, and Page (2012) employ this methodology in investigating the effects of natural disasters on the Hawaiian islands, using the unaffected islands as synthetic controls to estimate the causal effects of the 1960 tsunami on Hawaii (Lynham et al., 2012), as well as the effect of Hurricane Iniki on Kauai (Coffman and Noy, 2012). Coffman and Noy (2012) look at the long term effects of Hurricane Iniki on Kauai on various macroeconomic indicators such as tourist arrivals, private sector employment, resident population, personal income, transfer payments and hotel accommodations. They find that as a result of the hurricane, private sector employment reduced by 15%, resident population decreased by 12%, and transfers to Kauai significantly increased, while employment, population

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<sup>21</sup>Euskadi Ta Askatasuna (ETA) were a pro-Basque independence group, which murdered around 800 people between 1970 and 2000.

<sup>22</sup>The effect of terrorism on regional GDP in Basque Country increases as terrorist activity becomes more frequent.

<sup>23</sup>A detailed discussion will be given in Section 3.

and tourism took numerous years to return to pre-Iniki levels. The authors conclude that that personal income rose, with no effect on income per capita.

Lynham, Noy, and Page (2012) focus on the economic effect of the tsunami that affected Hilo in 1960, and find that the tsunami had significant effects in the long run. As a result of the tsunami migration off the island increased, population fell by 9%. The number of employers also fell and sugarcane production fell. The after effects of the tsunami caused the local labour market to severely weaken with unemployment increasing significantly by 33%, while wage levels remained flat.

Due to conflicting literature on the long run effects of natural disasters, DuPont and Noy (2012) re-estimate the effects of the Kōbe earthquake using the synthetic control group methodology. The authors find that as a result of the earthquake the population of Kōbe increases above the pre earthquake trend, with GDP per capita decreasing, indicating significant reductions in Kōbe’s production 15 years after the event. As wages remained flat, workers were not moving to Kōbe in response to price signals. Furthermore, GDP per capita fell in Kōbe even though there was a significant increase in fiscal spending, either questioning the effectiveness of increases in fiscal spending in this situation to mitigate disaster losses, or indicating that the initial earthquake event had such substantial effects that even substantial increases in government spending could not mitigate its effect.

Cavallo, Galiani, Noy, and Pantano (2010a) dispute the conclusion that natural disasters have zero effect on growth in the long run, as proposed by Horwich (2000) and many other economists. Cavallo, Galiani, Noy, and Pantano (2010a) stratify the EM-DAT database by event fatalities as a proportion population to define a “large” disaster, and then estimate whether the these events had an effect on economic growth. The authors find that only a small number of disasters (Nicaragua and Iran) had economic effects and this is due to both countries experiencing political

revolutions after the disaster events. After excluding revolutions post disaster, the authors conclude that not even the most destructive disasters have an effect on economic growth, supporting conclusions by Horwich (2000) that natural disaster have no effects on economic growth.

## 2.4 Econometric Analysis of the Canterbury Earthquakes

Due to the recent occurrence of the Canterbury earthquakes, very little research has been done to estimate their economic impacts. Examinations of the Canterbury Earthquakes include estimates on the effect on the national economy (Doyle and Noy, 2013), regional effects (Parker and Steenkamp, 2012) and the effects on tourism (Orchiston, Vargo, and Seville, 2011).

Doyle and Noy (2013) use both graphical and VAR approaches to investigate the effects on many macroeconomic variables due to the Canterbury earthquakes.<sup>24</sup> The authors initially use graphical analysis to estimate the effects of the earthquakes and find a moderate decrease in real GDP growth, which is nevertheless within the baseline bounds, with expanding production as measured by the Performance Manufacturing Index (PMI). The Performance Manufacturing Index is a proxy for regional production and is released monthly by BusinessNZ, a result of above 50 indicates an expanding production sector. Doyle and Noy (2013) find a moderate increase in inflation after the first earthquake, with no effect on inflation after the second earthquake. They also find that consumers reduce consumption (a result which falls outside benchmark bounds).<sup>25</sup> The authors indicate that as a result of the earthquake there were no effects on international trade, or on New Zealand's Net international investment position (NIIP). The authors use Structural vector Autoregressions (VAR) to estimate the direct and indirect effects of the earthquakes

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<sup>24</sup>The authors used data from between 2000Q1 and 2007Q4 to generate upper and lower estimates of 1.5 standard deviations from the average value of a variable, referred to as the baseline bounds.

<sup>25</sup>The authors account for the two both goods and services tax and cigarette taxation increase in estimating the effect of the earthquake on inflation.

on the New Zealand economy. They conclude that the Canterbury earthquakes had no statistically significant effect at a national level. However, to supplement this research, a regional focus would be informative. As shown in previous research by DuPont and Noy (2012), as regional effects of earthquakes can persist over large periods of time (15 years for the Kōbe earthquake), while in aggregate the effects of earthquake events may seem negligible.

Parker and Steenkamp (2012) use regional and national level data to look at the effects on the Canterbury region by comparing regional time series to New Zealand averages and selected regions. After the February 2011 earthquake, the authors indicate that as a result of the Canterbury earthquakes, regional working age population in Canterbury has decreased by between 2% and 6%. Furthermore, construction appears to be strongly performing with the number of EQC funded repairs, building consents and ready-made concrete produced all increasing. Furthermore, the authors find that average total hourly earnings have increased as measured by the Quarterly Employment Survey (QES), as well as the Canterbury house price index increasing above national averages and rental contracts becoming more common.

Parker and Steenkamp (2012) also find that after the earthquakes, business activity was resilient, with the exception of retail and tourism. The large effect on retail businesses is due to disruptions in supply chains and lower numbers of electronic payments after the earthquakes.<sup>26</sup> The authors also find that there is a substantial reduction in both international guest nights (reduced by more than 30%) and domestic guest nights (reduced by 8%). Interestingly, exports and investment intentions have marginally increased since the earthquakes. Additionally, as re-insurance claims are counted as overseas assets, New Zealand's Net International Investment Position (NIIP) has improved. The authors use a regional focus as opposed to an aggregate view shown in Doyle and Noy (2013) to demonstrate the effect

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<sup>26</sup>The Reserve Bank of New Zealand attempted to reduce this negative effect by ensuring an ample amount of cash was available for Canterbury residents and businesses.

of the Canterbury earthquakes on economic indicators. Various indicators sectors of Canterbury’s regional economy are examined, such as tourism as considered in Orchiston et al. (2011), and compared to nationwide averages or to selected regions in New Zealand. This thesis builds on the results presented here by implementing the synthetic control methodology, which is aimed at creating more reliable comparison groups while also controlling for exogenous events such as the Global Financial Crisis.

As discussed above, the tourism industry is specifically vulnerable to seismic risk. Due to this vulnerability, Orchiston, Vargo, and Seville (2011) investigate the effects of the Canterbury earthquakes on tourism.<sup>27</sup> The authors find that reductions in international visitor numbers are substantial, with 67% of Rest of Canterbury businesses experiencing reductions and 75% of Impact Zone businesses experiencing reductions. However, the authors find that half of accommodation businesses in the Impact Zone were in a better situation after the earthquakes.<sup>28</sup> Of the firms surveyed, Orchiston, Vargo, and Seville (2011) found very few businesses permanently shut down due to the earthquakes (1% of Impact Zone businesses closed permanently after the September 4th earthquake and 3% closing after the 11th February earthquake).<sup>29</sup> This indicates that both demand and supply for accommodation in the Canterbury region has decreased due to the earthquake events. This paper has a very specific focus on the tourism industry with the findings proposed in this paper to be further examined in this thesis.

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<sup>27</sup>Research was done by distributing questionnaires to businesses that were greatly affected by the earthquake, “Impact Zone” businesses (affected by Modified Mercalli intensities of 6 or greater) and to other relatively unaffected “Rest of Canterbury” businesses.

<sup>28</sup>The authors found that 75% of motels experiencing increased revenues after the earthquakes.

<sup>29</sup>15% of questionnaires sent to Christchurch were marked “return to sender” indicating that the firm had shut down or moved premises, making previous estimates of permanent closure a lower bound estimate.

## 3 Methodology and Data

### 3.1 Methodology

For the analysis of the economic effects of the Christchurch earthquake I will be employing synthetic control methodology is a regional approach that attempts to identify the effects of a treatment or event on the affected region relative to a set of control regions. From the Statistical Matching literature, we will refer to the set of potential control regions as the “donor pool”. The affected region is called the treated region.

By using non-treated regions, this methodology calculates a weighted average which recreates the affected region before the treatment occurs. In this application Canterbury is the treated region and the treatment is the earthquake sequence that begun on the 4th of September with the Canterbury earthquake and also includes the Christchurch earthquake of February the 22nd.

The use of the synthetic control methodology to answer the question posed by this thesis is appropriate for the following reasons: (1) The initial September earthquake was unexpected and the February earthquake was not expected in terms of size and the strength, allowing causal effects to be identified, (2) as the damage was associated with a geographically compact region, regions outside of the directly impacted area should serve as adequate control groups.

### 3.2 Implementation

The methodology is outlined in detail in the original application by Abadie and Gardeazabal (2003) and in the further development by Abadie, Diamond, and Hainmueller (2010). A useful summary is described in Bohn, Lofstrom, and Raphael (2011). In describing the estimation procedure in this section, the discussion will

follow closely Bohn et al. (2011), and the reader is referred to their paper for further details.

Before explaining the methodological approach it is useful to summarise the data and time periods used in empirical estimation. This thesis will primarily focus on the impact on GDP, which is measured in 1995/1996 prices in millions of dollars, between 2002Q1 to 2012Q4. In addition to regional GDP, regional tourism and international trade will be examined. Regional tourism effects will be estimated from regional guest nights, which is measured in thousands of guest nights stayed (2000Q1 and 2012Q4), and through international airport arrivals in thousands of passengers (2000Q1 to 2012Q4). Finally international trade will be examined through gross imports and gross exports by port, measured in thousands of tonnes (2000Q1 and 2012Q4).

For each of the outcome variables above, the synthetic control methodology will be applied in order to estimate the causal effect of the Canterbury earthquake on the specific variable of interest. Suppose that we observe  $k$  regions indexed by  $k = 0, \dots, K$ , where  $k = 0$  corresponds to Canterbury, and all other  $K$  regions corresponding to potential synthetic controls. For all 42 quarterly time periods since the intervention date (2010Q3), define a  $F_0$  as a  $(42 \times 1)$  vector equal to the outcome variable of interest for Canterbury before the intervention period (between 2000Q1 and 2010Q3) and  $F_1$  as a  $(42 \times K)$  vector equal to the variable for all other regions in the donor pool before the intervention period.<sup>30</sup> The synthetic control methodology identifies a convex combination of the  $K$  states in the donor pool that best approximates the pre-intervention time series for a specified region.

Define the  $(K \times 1)$  weighting vector  $W = (w_1, w_2, \dots, w_K)'$  such that  $\sum_{k=1}^K w_k = 1$

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<sup>30</sup>As regional GDP has a shorter time series, it covers between 2002Q1 and 2010Q3.

and  $w_k \geq 0$  for  $k = (1, \dots, K)$ . The product  $F_1 W$  then gives a weighted average of the pre-intervention time series for all regions omitting Canterbury, with the difference between Canterbury and the average given by  $F_0 - F_1 W$ . The synthetic control method chooses a value for the weighting vector,  $W$ , that yields a synthetic comparison group (constructed from donor pool observations only) that best approximates the pre-intervention path for Canterbury.  $W$  is chosen by solving the constrained quadratic minimisation problem:

$$W^* = \arg \min_W (F_0 - F_1 W)' V (F_0 - F_1 W) \quad \text{s.t} \quad (1)$$

$$W' i = 1, \quad w_k \geq 0 \text{ for } k = (1, \dots, K)$$

where  $V$  is a  $(42 \times 42)$  diagonal positive-definite matrix with diagonal elements providing the relative weights for the contribution of the square elements in the vector  $F_0 - F_1 W$  relative to the objective function being minimised and  $i$  is a  $(K \times 1)$  vector of ones. Once an optimal weighting vector  $W^*$  is chosen, by using  $W^*$ , the pre-intervention and post intervention values can be calculated for “synthetic” Canterbury by using a weighted average of the non-zero weighted regions in the donor pool for each time period. The post intervention values for the synthetic control group serve as our counter-factual outcomes for Canterbury.<sup>31</sup> However due to only a small number of geographically proximate regions available for this thesis, the risk of having positive or negative spill overs contaminating the synthetic control group is likely, indicating that adequate safeguards should be put in place. Positive spill overs may be identified by an unexplained upward trend in the synthetic control group after the intervention date.

The accuracy of the Synthetic Control Region accurately measuring the Treated

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<sup>31</sup>This procedure is automated using the SYNTH package available for R, Stata and Matlab from <http://www.mit.edu/~jhainm/synthpage.html>

region is defined as the Mean Squared Prediction Error (MSPE). This is the squared difference between the Treated Variable and the Synthetic Variable. Abadie et al. (2010) uses this as a measure of how accurately the synthetic region approximates the treated region. A more detailed, formal explanation of the methodology of synthetic control groups is provided in Abadie et al. (2010), and essential details are reproduced in Appendix A.

### 3.3 Placebo Tests

To measure the statistical validity of the estimated treated effects using the synthetic control group method, we employ the placebo test outlined in Abadie et al. (2010). (For similar applications, see Auld and Grootendorst, 2004; DiNardo and Pischke, 1997). This entails applying the same intervention date to other regions in the donor pool to the affected region. This testing methodology is similar to hypothesis testing from statistical distributions with the following hypotheses;

- $H_0$  = no effect of the intervention,
- $H_1$  = effect of the intervention.

With extreme effects of the intervention on the affected region as compared to unaffected regions,  $H_0$  can be rejected. To create a distribution from which the above hypothesis can be tested, the same intervention date is used for all other regions to estimate the impact on those regions. Each effect of the intervention on all regions in the donor pool (applied to every region, regardless of affected or unaffected) is used to create a distribution describing the effect of the intervention on all regions in the donor pool. Once the distribution of unaffected regions has been calculated, then the intervention effect for the affected region is compared to these “placebo disasters”. If the intervention effect on the affected region is the most extreme out of the distribution of placebo disasters, this indicates that we should reject  $H_0$ . This methodology produces classical randomisation inference for the case

where the intervention is randomized across regions.

This inference examines whether or not the estimated effect of the actual intervention is large relative to the distribution of the effects estimated for the regions not exposed to the intervention. This inference is informative as under the hypothesis of no intervention effect, and we can test whether the intervention of the earthquake on Canterbury would produce extreme outcomes according to the distribution of placebo disasters, indicating significance of the synthetic control findings.

Due to both a small number of regions in total and the need to reduce spill overs between Canterbury and non-affected regions, the number of regions allowed in the donor pool is small (8 regions is the maximum number of regions in any donor pool). Because of this, if Canterbury has the most significant effect due to the earthquake, the probability of this occurring under random circumstances would be  $1/8$  (12.5%), which is above the conventional level of significance (5%). Even though the small number of comparison regions implies that significance of any effects cannot be evaluated at conventional levels, we find that inspections of the effects in Canterbury compared to other regions provide both a sense of the economic importance and potential statistical significance of the effects. This approach follows Lynham, Noy, and Page (2012) who also evaluate the effects of a natural disaster by drawing comparisons with a small number of control groups.

In order to more accurately evaluate the statistical significance of the results, the placebo distributions are expanded by randomizing not only through the affected region but also by intervention date. (This approach is in the spirit of the Monte Carlo simulations in Bertrand, Duflo, and Mullainathan (2004).) This provides a larger number of comparison “treatment” observations, and will permit rejections of the null hypothesis, that the deviations in outcomes for Canterbury following the particular event date (the date of the first major earthquake) are unrelated to the

event itself, at conventional significance levels<sup>32</sup>.

### 3.4 Policy Analysis with Pooled Cross Sections

Further testing of statistical validity is conducted using the difference in difference based approach used in Saiz (2003) and Wooldridge (2009). They estimate the effect of an intervention on a specific region using cross-sectional data. This approach estimates:

$$R_{it} = \alpha_i + \beta D_{after} + \gamma D_{after} \cdot D_{Canterbury} + \theta \cdot other\ factors + \varepsilon_{it} \quad (2)$$

In the above equation,  $R_{it}$  represents the outcome variable of interest and  $\alpha_i$  is the the unit fixed effect of regression equation.  $D_{after}$  is a dummy variable which takes a value of one if the time period is after 2010Q3, while  $D_{Canterbury}$  is a dummy variable which is equal to one if the selected region is Canterbury.  $\gamma$  gives the average effect of the earthquake on the variable of interest.  $\theta$  is the  $(K \times 1)$  vector point estimates for K explanatory variables included in the *other factor* variable. If  $\gamma$  is statistically significant, this is indicative of the earthquake event having a significant effect on the variable of interest. Moreover, Wooldridge (2009) indicates that controlling for other relevant factors is necessary to minimize the standard errors of  $\gamma$ .

Unlike in the SCG methodology where the weights are restricted to be in the range  $[0,1]$ , which limits the estimated counterfactual to lie within the support of the control region data, the DiD is not restricted in this way, and the counterfactual can be extrapolated using available data for all control regions. The estimators for SCG and DiD estimators are also different with the SCG estimator being dynamic

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<sup>32</sup>Observations with poor fits will be omitted from the placebo distribution (as measured by a MSPE exceeding twice that of Canterbury with an intervention date of 2010Q3) and the earliest intervention date used will be 2005Q2 giving a minimum of 3 years of pre-intervention data.

as it changes over time and the DiD estimator producing an average estimate over time for the effect.

From this point onwards the above procedure will be referred to as the Difference in Difference (DiD) estimator.

### 3.5 Data

As the synthetic control methodology requires regional time series data on the variable of interest, as well as data on relevant control variables to calculate optimal weighting  $W^*$ , this methodology is relatively data-intensive. This section will describe the data used in this thesis.

Most of the data is from Statistics New Zealand which are freely available through the Infoshare portal at [www.stats.govt.nz](http://www.stats.govt.nz). Due to the irregularity in release of Regional Gross Domestic Product (GDP) data from Statistics New Zealand, Infoshare kindly allowed me to use their real Regional Gross Domestic Product cross sectional time series. The series has a quarterly frequency and runs from 2002Q1 to 2012Q4, giving a snapshot of the regional income both before and after the earthquake. The regional GDP is measured in prices which average the price levels of the four quarters to March 1996, in millions of dollars. Henceforth, real regional GDP will be referred to as regional GDP.

For this thesis, New Zealand was divided into the following regions to ensure that all regional coding was consistent; (1) Northland, (2) Auckland, (3) Waikato, (4) Bay of Plenty, (5) Hawke's Bay & Gisborne, (6) Taranaki, Manawatu & Wanganui, (7) Wellington, (8) Tasman, Nelson & Marlborough, (9) Canterbury, (10) West Coast, (11) Otago and (12) Southland.<sup>33</sup>

To investigate the effect of the earthquake events on tourism in Canterbury, regional guest nights stayed and international arrivals were used. Ideally tourist ex-

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<sup>33</sup>Due to some variables aggregating geographically proximate regions, the above coding was the most efficient way to ensure that all variables were measured consistently.

penditure data would have been used (as seen in Coffman and Noy, 2012), however this was unavailable. Furthermore, as domestic and international guest night data does not have enough observations, international arrivals data was used in conjunction with guest night data to estimate the effect of the earthquake on tourism (as employed in Mazzocchi and Montini, 2001). International arrival data is supplied by airport of entrance, necessitating this data to be aggregated in to regional format through the geographic region the airport was situated in. Both regional guest nights and international arrivals are measured in thousands of people.

To investigate the effects of the earthquake events on trade, both regional imports and exports by port are used. Regional data for imports and exports by port was supplied in port of arrival/exit format, aggregated to regional through the region in which the port is located in. As both imports and exports by port are used as explanatory variables for regional trade, Waikato must be omitted from the donor pool as it has no ports. All import and export figures by region are quoted in gross thousands of tonnes.

Data for a number of independent variables are employed for constructing the synthetic control groups, as well as regression based measures of statistical significance. Male and female employment data was taken from the Household Labour Force (HLF) survey labour status by regional council, measured in thousands of people. However, in the HLF survey, West Coast (region 10) and Nelson, Tasman and Marlborough (region 8) are combined into one large region. To separate these regions in accordance with the regional format discussed above, the population for the larger region was estimated using the 2006 census, allowing the population of the the larger region attributable to the West Coast and Nelson, Tasman and Marlborough to be calculated. This weighted average was then used to decompose both West Coast and Nelson, Tasman and Marlborough employment from total employment

of the larger region.<sup>34</sup>

Estimated Resident Population for Regional Councils were used to estimate regional population. This data ran annually from 1996 to 2012, with quarterly regional population equal to the regional population for that given year. These population estimates were used along with Regional GDP data in order to estimate regional income per capita. The population estimates were also combined with Regional Council Size in order to generate population density (population per  $km^2$ ).

Business demography data by Territorial Authority is from Statistics New Zealand. This data tracks the broad industry a business operates in for all businesses in a Territorial Authority. This data was consolidated from Territorial Authority to Regional Council aggregation using the Territorial Authority outline, summing regional businesses according to broad industry groups. Due to the large number of detailed industry classifications present in business demography data, to aid in inference in these regressions, the following aggregations have been used;

- TotalBusiness: The total number of businesses in a given region,
- Primary: The summation of all primary production related industries (Mining and Agriculture),
- Production: The summation of all production related industries (Manufacturing, Utilities and Construction),
- Services: The summation of all service related industries (Health, Education, Administration (Public and Private), Scientific research, Financial/Insurance, IT, Real Estate and other classified businesses).

As some of the variables of interest were not available in a seasonally adjusted format, International Arrivals, Regional GDP and Imports/Exports, these series'

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<sup>34</sup>Due to these data restrictions, I had to assume that regional employment was distributed in a similar manner to population.

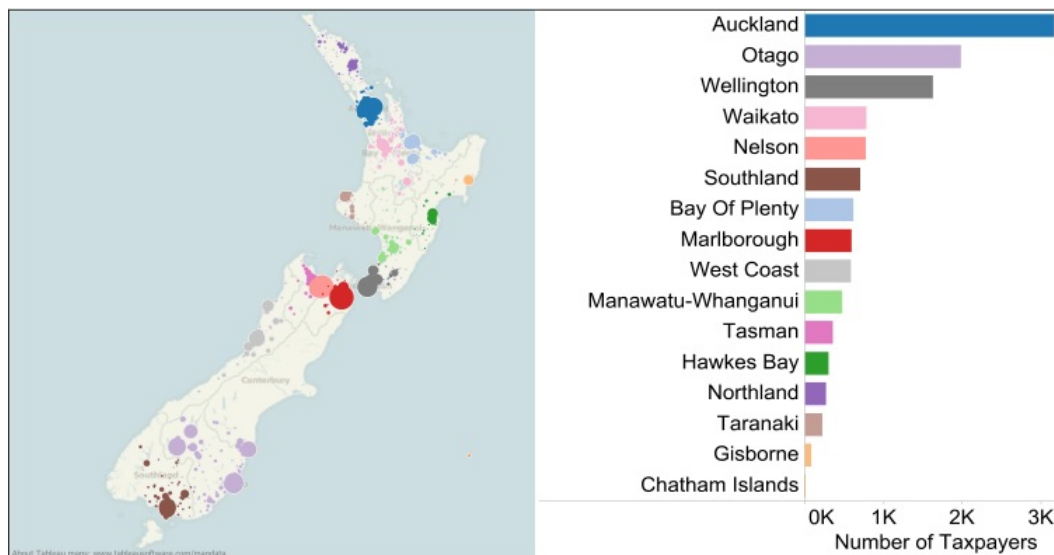
were seasonally adjusted using the X-11 program, developed at the United States Department of the Census which is similar to Statistics New Zealand's seasonal adjustment procedure.

## 4 Results

### 4.1 Synthetic Control Groups

Natural Disaster events have significant repercussions, which can persist for long periods of time. However due to the large number of after-shocks as a result of the September 2010 earthquake, a substantial amount of Canterbury residents have moved to other regions throughout New Zealand, having implications on estimation techniques presented in this thesis.

Figure 1: Regional tax pay emigration (gross outflow) from Canterbury: September 2010 - January 2012



<sup>1</sup>Source: Euqab (2012).

Figure 1 is taken from Euqab (2012) who uses Inland Revenue tax payer data to show which regions migrants from Canterbury move to. The figure shows that there is a large amount of migration from Canterbury to regions throughout New Zealand since 2010. Also, as the Figure 1 measures only tax paying residents (children and students will not be included), making this a lower bound estimate. As people migrate out of Canterbury for other regions, the stock of human capital will decrease, reducing productive capacity in the region. If large amounts of workers emigrate from Canterbury, firms may choose to invest in other regions in New Zealand, reducing the amount of capital in Canterbury to below pre-earthquake levels.

Due to the migration between regions, there may be some spillover effects due to the earthquake, causing variables examined in regions weighted in “Synthetic” Canterbury to change, as the variable decreases in “Treated” Canterbury, overstating the estimated effect of the earthquake. Figure 1 indicates that the number of migrants from Canterbury depends on the destination region, with only small regions experiencing large migration movements from Canterbury being likely to experience spillover effects. Due to a large amount of migration occurring from Canterbury to other regions in the South Island with relatively small populations, spillovers could occur. As a result, South Island regions will be excluded from the donor pool to address this potential issue.<sup>35</sup>

The fit of the synthetic control groups is calculated by the Mean Squared Prediction Error (MSPE), which is a measure of the difference between the treated and synthetic control group in the pre-intervention outcomes unless stated differently, the MPSE will be minimised between 2000Q1 and 2010Q3 for each series, in order to accurately estimate the treated region (Canterbury) without the effect of the treatment (the earthquake events).<sup>36</sup>

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<sup>35</sup>However, inclusion of South Island to the donor pool has little bearing on the synthetic control estimates for Canterbury in the variables examined in this thesis.

<sup>36</sup>This methodology disallows extreme counter-factuals as only regions which are similar to the affected region before the intervention can be included in “Synthetic Canterbury”.

The following section will investigate the effects of the Canterbury earthquake events on regional GDP, regional guest nights stayed, international arrivals, gross imports and exports by port. For each of these variables the synthetic control results will be presented and discussed followed by consideration of the statistical significance of the findings. To examine statistical significance, Placebo test results will be illustrated in both graphical and table based formats, accompanied by difference in difference regression estimates.

## 4.2 Regional Gross Domestic Product

Regional GDP is an important variable to investigate after an earthquake event as it holistically represents economic activity in a given region. Through understanding the effects of the earthquake events on regional GDP, the focus can be tightened to understand which sectors of the economy are most adversely affected by the earthquake event.

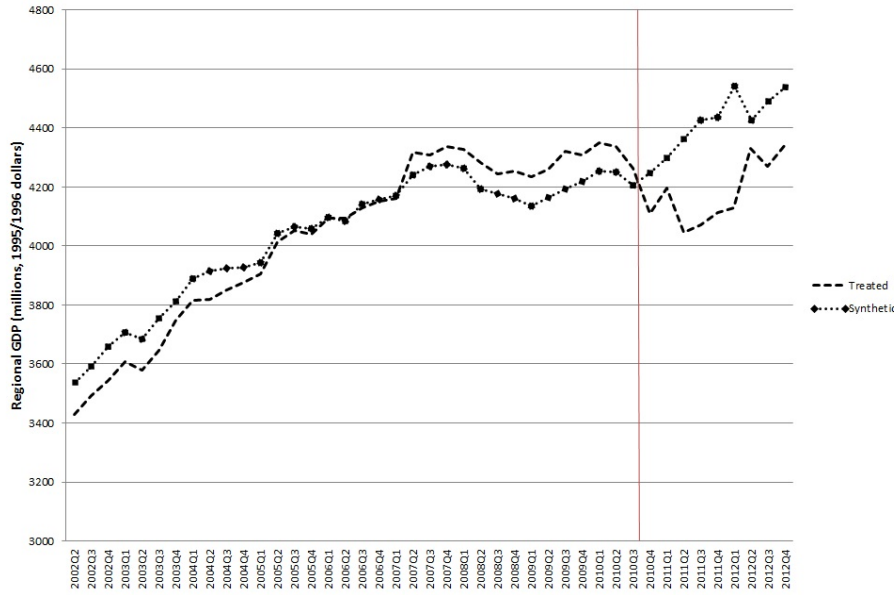
To estimate the synthetic control group for regional GDP, variables to model the production base of Canterbury prior to the earthquake were included<sup>37</sup> as well as consents for new buildings, regional male and female labour force participation rates, population per  $km^2$  and lagged variables for the dependent variable in the time periods 2002Q1, 2007Q1 and 2010Q3.<sup>38</sup>

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<sup>37</sup>To estimate the production base of the region, the number of businesses in each industry as a proportion of all businesses in the region was included.

<sup>38</sup>In following with estimation techniques presented in Abadie et al. (2010), lagged dependent variables for specific years will be included in estimating synthetic control groups.

Figure 2: Canterbury Regional GDP



MSPE : 77.22. Synthetic Canterbury is comprised of Waikato (81.6%), Auckland (12.7%) and Wellington (5.7%).

Figure 2 compares regional GDP for the Canterbury region and Synthetic Canterbury. From 2002 to 2008 the regional income per capita increased consistently, while after 2008 the regional income per capita decreased in Canterbury. The difference between the treated and synthetic Canterbury after the intervention date (2010Q3) indicates that regional GDP on average fell \$211,000,000 per quarter, a reduction of Canterbury's regional GDP of 4.9%, due to the earthquakes.

The largest gap between treated Canterbury and Synthetic Canterbury occurring between 2011Q2 and 2012Q1, a period over which numerous aftershocks hampered the rebuild Christchurch. As the rebuild began in earnest post-2012Q1, the two series converge. However, after 2012Q2 the distance between Synthetic and Treated Canterbury increases further, an indication of a persistent reduction in regional GDP and business activity in the Canterbury region. As it is possible that these reductions in regional business activity may affect industries unevenly, the effects on tourism and international trade are to be examined in the following sections.

Before and after the earthquake events, the Canterbury region faced adverse economic events affecting regional production capacity. Between spring 2007 and autumn 2008, one of the most severe droughts in record occurred in New Zealand, with aggregate effects estimated to reduce national GDP by 0.5% (The Treasury, 2008). This drought predominantly affected Waikato and Canterbury regions due to their respective dependence on agricultural production, disrupting future livestock production and harming crops. Even though Waikato and Canterbury were the most adversely affected regions due to the drought, as Waikato comprises of a majority of Synthetic Canterbury (81.6%) the drought severely affects both Synthetic and Treated Canterbury, causing little divergence between the two series' as a result.

After the intervention date, a large amount of damage occurred to the Canterbury regions capital stock. Statistics NZ (2012) estimates that damage due to the Canterbury earthquakes equals 0.77% of New Zealand's total net capital (\$4.6 billion of the 2011 net capital stock). This reduction in net capital stock as caused by the earthquake events is estimated to reduce New Zealand's gross domestic income per capita by 0.25% alone.<sup>39</sup> Due to these significant reductions in production capacity for the Canterbury region as a result of the earthquake events, a relatively persistent effect of the earthquake event on regional GDP is likely. To ascertain whether the effect of the earthquake on regional GDP is significant, I run a placebo test and compare the average treatment effects between the regions with a treatment period of 2010Q3.

The results of the placebo test are shown in Figure 3. This depicts the variation between treated and synthetic estimations of regions in the donor pool, with a treatment period of 2010Q3. As the earthquake events are centralized to the Canterbury region, the difference between treated and synthetic regions in the donor pool should

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<sup>39</sup>This estimate is calculated by a back of the envelope calculation using  $y = Ak^\alpha$  with  $\alpha = 0.33$ .

be small as there are no further asymmetric shocks affecting individual regions in the donor pool. In the absence of further asymmetric shocks to individual regions (excluding the Canterbury earthquake sequence), the major form of economic fluctuation will be due to macroeconomic pressures, which will affect all regions in similar fashions, causing both treated and synthetic regions in the donor pool to have comparable effects. To conclude on whether the results presented in Figure 2 are statistically significant the difference between treated and synthetic Canterbury should be larger than the difference between treated and synthetic regions in the donor pool. Placebo tests will be covered in two formats. Firstly a graphical examination of the test results will be presented to explain the differences between treated and synthetic regions in the donor pool. Secondly, a table containing the difference (in percentage terms) between treated and synthetic regions in the donor pool are presented to aid in the comparison of the treatment effects with the placebo effects.

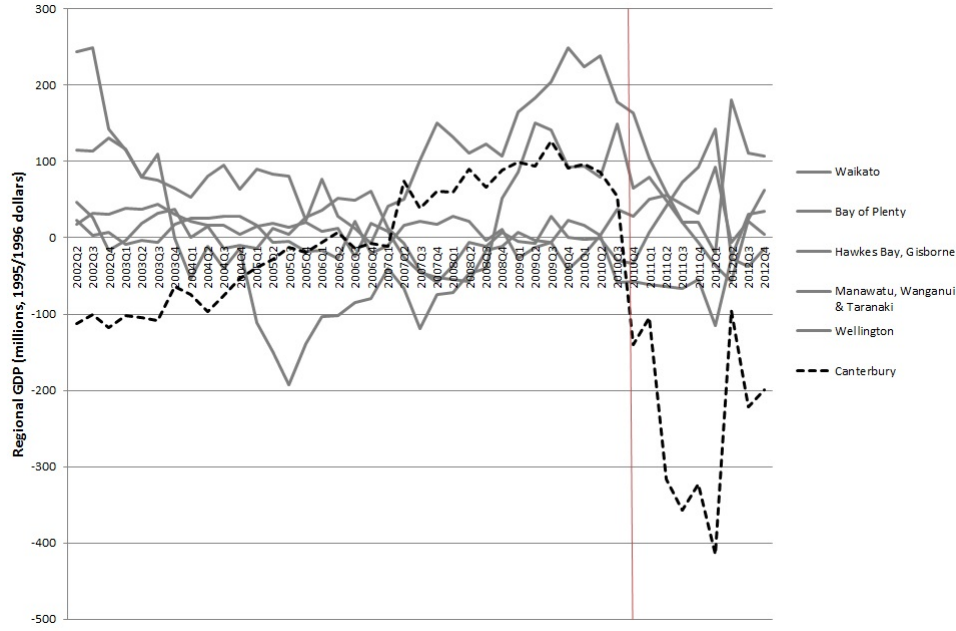
In the Synthetic Control Methodology, once the synthetic region is calculated the difference between the synthetic and the treated region is the causal effect of the intervention. However, there are certain regions in my analysis that are never truly approximated by this methodology due to estimation problems.

As shown in Figure 17, the difference between treated Auckland and synthetic Auckland is significantly positive and widens over time, causing the large positive divergence seen in Figure 17, indicative of estimation problems. The large difference between treated and synthetic Auckland is due to Auckland having no regions in the donor pool which are comparable to itself in terms of regional GDP. This causes treated Auckland to significantly exceed synthetic Auckland for all time periods examined.<sup>40</sup> The estimation problems also include the Northland region so both Northland and Auckland will be omitted in Figure 3.

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<sup>40</sup>On average regional GDP per quarter in treated Auckland is \$12,905,760,000 as compared to regional GDP in synthetic Auckland of \$4,762,315,000.

Figure 3: Placebo Test for Regional GDP



Measuring the difference between actual GDP and synthetic region GDP in millions of 1995/1996 dollars.

Table 1: Percent Difference between Treated and Synthetic Regions, Post 2010Q3

|             | Northland | Auckland | Waikato | Bay of<br>Plenty | Hawkes Bay,<br>Gisborne | Manawatu,<br>Wanganui<br>& Taranaki | Wellington | Canterbury |
|-------------|-----------|----------|---------|------------------|-------------------------|-------------------------------------|------------|------------|
| 2010Q2      | -43.76    | 165.23   | -0.02   | 0.15             | 0.24                    | 8.85                                | 1.60       | 2.01       |
| 2010Q3      | -41.64    | 163.96   | -1.15   | 1.99             | -4.62                   | 5.70                                | 3.07       | 1.55       |
| 2010Q4      | -41.56    | 171.93   | -1.27   | 1.48             | -4.37                   | 5.20                                | 1.34       | -3.08      |
| 2011Q1      | -41.97    | 169.42   | 0.20    | 2.76             | -2.90                   | 2.73                                | 1.60       | -2.36      |
| 2011Q2      | -42.30    | 174.16   | 1.41    | 3.00             | -2.35                   | 1.10                                | 0.99       | -7.38      |
| 2011Q3      | -41.33    | 176.23   | 2.49    | 2.28             | -2.60                   | -0.42                               | 0.41       | -8.40      |
| 2011Q4      | -41.47    | 176.83   | 3.16    | 1.64             | -2.56                   | -0.44                               | -0.11      | -7.77      |
| 2012Q1      | -40.24    | 180.00   | 4.77    | 4.92             | -4.73                   | -1.85                               | -0.71      | -9.79      |
| 2012Q2      | -41.59    | 177.17   | -0.93   | -0.45            | -3.66                   | 5.54                                | -1.13      | -2.08      |
| 2012Q3      | -41.96    | 173.45   | 1.00    | 1.02             | -2.64                   | 2.91                                | 0.48       | -5.11      |
| 2012Q4      | -42.25    | 170.25   | 1.10    | 0.08             | -1.44                   | 2.68                                | 1.19       | -4.59      |
| Average Gap | -41.63    | 173.34   | 1.08    | 1.87             | -3.19                   | 2.32                                | 0.71       | -4.90      |

Average Gap indicates the average difference between treated and synthetic regions from 2010Q3 to 2012Q4

By excluding Auckland from Figure 3 and comparing regions closer to the national average, graphical analysis becomes feasible. However estimation problems with Northland become apparent. As Northland is the smallest region in terms of regional GDP, all possible comparison groups in the donor pool are significantly larger than Northland in terms of regional GDP.<sup>41</sup> Due to this, synthetic Northland will exceed treated Northland for all time periods examined causing a persistent negative difference between treated Northland and synthetic Northland. Results in Figure 3 indicate that after the earthquake, there is a large decrease in treated Canterbury's GDP, as compared to synthetic Canterbury.

It is important to note that as a result of the earthquakes, there may have been effects to other regions that could possibly violate the assumptions for the synthetic control group. For instance, due to the earthquake large manufacturers may choose to move their Canterbury production operations to other manufacturing centres. This would cause manufacturing specifically in other regions to increase, violating the unit treatment assumption. Results shown in Figure 3 illustrate that as a result of the downturn in Canterbury due to the earthquake, none of the regions shown experience consistent growth, indicating that the assumptions regarding estimation still hold.

Table 1 describes the deviation between the treated region and the synthetic region in terms of percentages throughout the time period. Canterbury has the largest percentage deviation between treated and synthetic with an intervention date of 2010Q3, indicative of statistical significance of findings in Figure 2. As both Figure 3 and Table 1 indicate that the effects of the intervention on Canterbury are large in comparison to effects on members of the donor pool indicating statistical

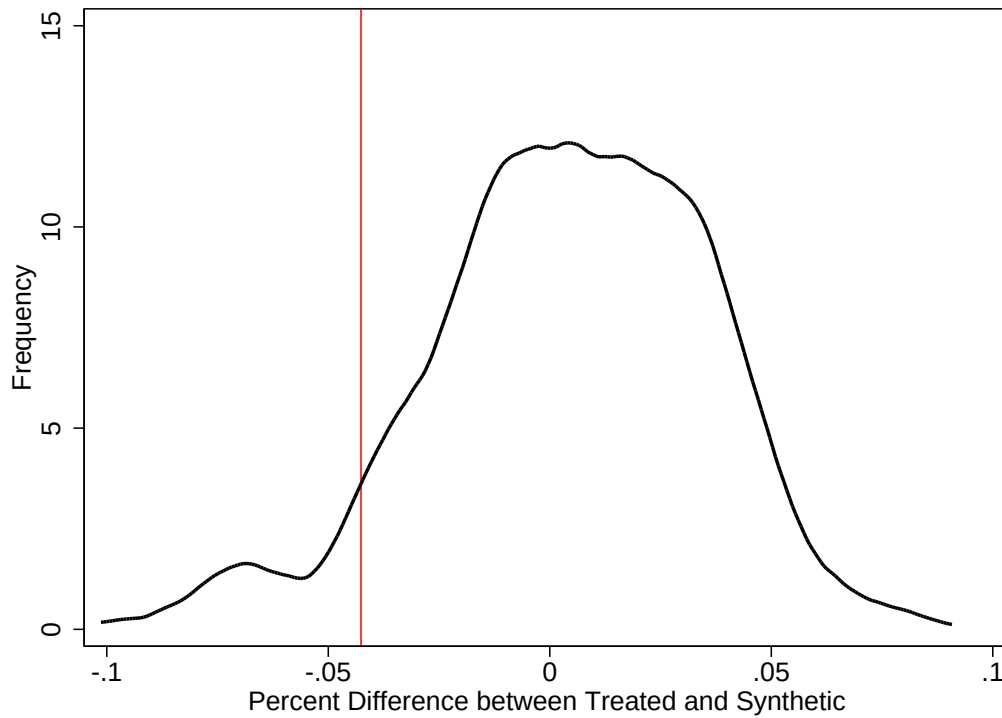
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<sup>41</sup>Over the period examined average regional GDP in Northland is \$790,160,000, while synthetic Northland GDP is \$1,384,716,000.

significance of the findings in Figure 2.<sup>42</sup>

As the findings of Figure 3 are indicative of an effect of the earthquakes on Canterbury's regional GDP, a placebo distribution will be used. The expanded placebo distribution (with randomized intervention dates) is used to test whether the effect of the earthquake is significant as compared to all regional level economic fluctuations since 2005Q2. Figure 4 shows the kernel distribution for the placebo distribution<sup>43</sup>.

Figure 4: Placebo Distribution for regional GDP



Red line represents the average aggregate effect of the earthquake on Canterbury

For the placebo distribution shown in Figure 4, 1825 observations meet the selection criteria to be included in the placebo distribution. Out of these observations,

<sup>42</sup>These conclusions shown here are based on the exclusion of regions which experience estimation problems such as Auckland and Northland.

<sup>43</sup>Regions with exceptionally large MSPE figures as compared to the MSPE for Canterbury 2010Q3 will be omitted.

117 observations exceed the post earthquake effect on Canterbury. This indicates a 117/1825 (6.4%) probability of exceeding the effect of the earthquakes on Canterbury regional GDP, a more convincing rejection of the null hypothesis of no earthquake effect than Figure 3.

Due to the large amount of graphical analysis used in synthetic control methodology, regression based techniques can also be used to take advantage of the time series data available, gaining useful insights to statistical significance. In their paper, Abadie et al. (2010) present a simplified synthetic control group estimator, which can be simplified and stated in the terms used in Section 3.5 as:

$$R_{it} = \alpha_i + \delta_t + \gamma_t \cdot D_{after} \cdot D_{Canterbury} + \theta \cdot other\ factors + \varepsilon_{it} \quad (3)$$

Where  $\delta_t$  is unknown common factor with constant factor loadings across units and  $\gamma_t$  representing the point estimate for the effect of the intervention on the variable of interest in a given year. *other factors* is a vector of explanatory variables associated with explaining  $R_{it}$  while  $\theta$  represents the point estimates of these explanatory variables on  $R_{it}$ . Explanatory variables included in the “other factor” vector explain regional business composition, male and female employment rates, building consents for new construction and population per  $km^2$ . To ease collinearity concerns in this section, the number of businesses in a given industry categorization as a proportion of total businesses in a region is used as an explanatory variable for regional GDP.<sup>44</sup> In later sections the logged number of businesses in a given industry will be used as an explanatory variable instead. The main difference between the difference in difference estimator presented in Section 3.5 and the simplified synthetic

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<sup>44</sup>Collinearity concerns are due to regional GDP being the sum of the number of businesses in a given region multiplied by their output in current price terms.

control estimator is that difference in difference estimator calculates the average effect of the intervention post-treatment, while the simplified synthetic control estimator estimates the effect of the earthquake on the variable of interest in any given year. Furthermore it should be noted that as a result of a "recovery" phase after the event the two approaches will differ as the DID estimator will exhibit a downwards bias. Due to the similarities between these two measures, the difference in difference estimator will be used as a regression based technique to estimate the effect of the earthquake on the variable of interest, with the ability to explicitly model statistical significance of findings shown in Figures 2 and 3. Table 11 presents the difference in difference results of estimating the effects of the earthquakes on regional GDP.

Table 2: Difference in Difference Analysis using Interaction Variables

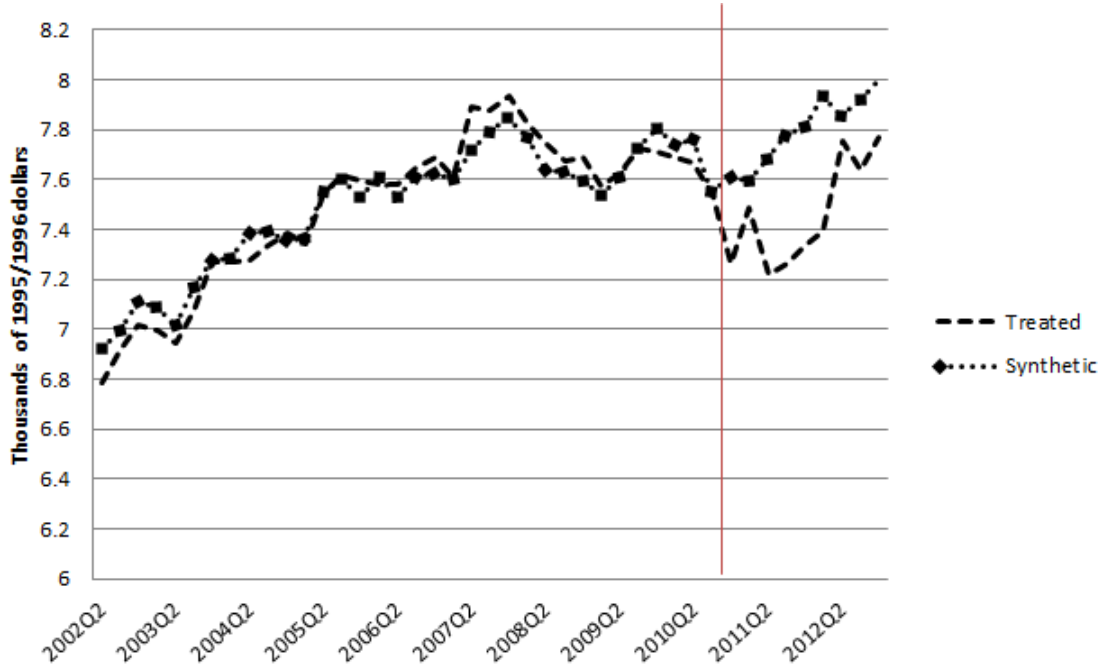
|                                            | (1)          | (2)           | (3)            |
|--------------------------------------------|--------------|---------------|----------------|
|                                            | region_gdpSA | region_gdpSA  | region_gdpSA   |
|                                            | $\beta$ / SE | $\beta$ / SE  | $\beta$ / SE   |
| <i>Time Dummy Variables</i>                |              |               |                |
| Canterbury * Post 2010Q3                   | -221.620     | -13911.844*** | -6291.815***   |
|                                            | (253.708)    | (1541.340)    | (690.053)      |
| Post 2010Q3                                | 327.967***   | 327.967***    | 327.967***     |
|                                            | (119.599)    | (108.664)     | (107.927)      |
| <i>Earthquake Interaction Variables</i>    |              |               |                |
| Canterbury * Percent(Accommodation & Food) |              | 385233.697*** |                |
|                                            |              | (42884.493)   |                |
| Canterbury * Percent(IT)                   |              |               | 1281812.636*** |
|                                            |              |               | (137461.145)   |
| Observations                               | 387          | 387           | 387            |
| $R^2$                                      | 0.020        | 0.193         | 0.204          |
| Year Dummy Variables                       | Yes          | Yes           |                |

Table 2 column (1) shows the most basic difference in difference estimate of the effect of the earthquakes on regional GDP. The interaction variable between Canterbury and the Post 2010Q3 variable indicates that there is a insignificant negative

effect of the Canterbury earthquake on regional GDP. In accordance to observations by Wooldridge (2009) adding explanatory variables will reduce the standard errors associated with the intervention effect estimate, with Table 11 in Appendix B using a full set of explanatory variables. Results shown in Table 11 indicate that as a result of the earthquakes regional GDP significantly increases (at the 5% level), opposing earlier conclusions and being indicative of variables acting as channels by which to influence regional GDP. To identify the variables acting as a channel for regional GDP, each explanatory variable was included to the regression presented in Table 2 column (1) and the effect of their inclusion noted. As shown in Table 10 in Appendix B the inclusion of accommodation & food and IT businesses as a proportion of total businesses causes the effect of the earthquakes on Canterbury's regional GDP becomes positive and significant (at the 1% and 10% levels respectively). Furthermore, these were included in Table 2 columns (2) and (3) as interaction variables with the effect of the earthquakes. Both of the interaction variables presented in Table 2 are significant (at the 1% level) while causing the effect of the earthquake to become negative statistically significant (both at the 1%), indicating that these variables are channels by which the earthquake events affect regional GDP. However due to difference in difference estimates indicating a positive effect of the earthquake events we cannot conclude on the statistical significance of findings in Figure 2.

While this analysis provides some perspective on the effects of overall economic activity in the region, an important related question is what do these effects imply for average income and welfare for Canterbury residents. In order to shed some light on this question and do complement our analysis of the overall economic effects, the effects on GDP per capita are estimated.

Figure 5: Canterbury Regional GDP per Capita



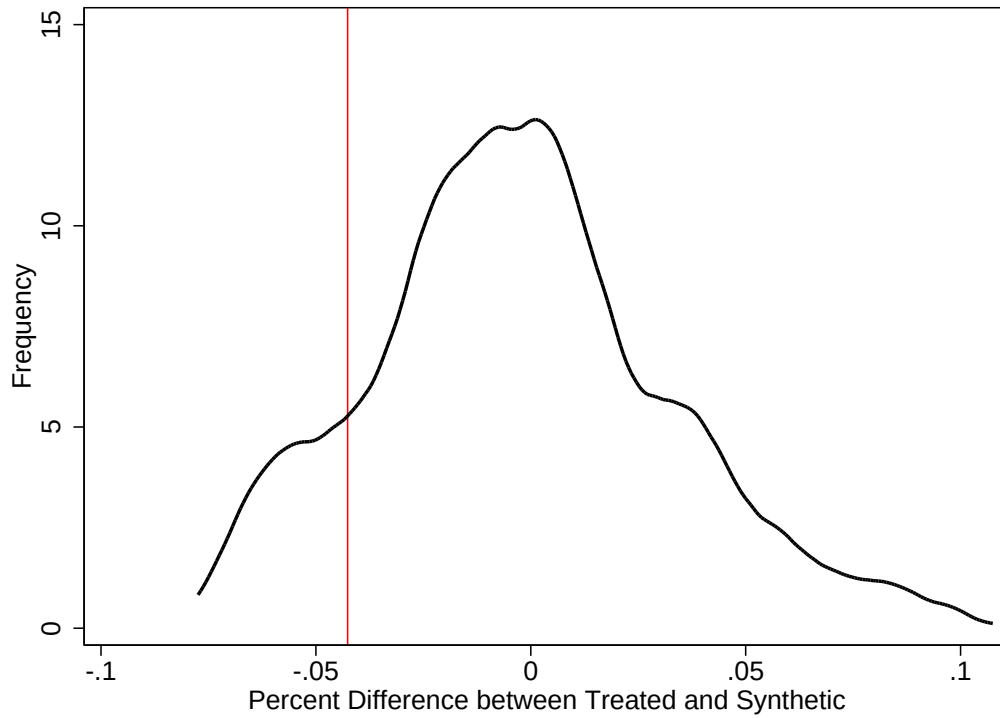
MSPE : 0.15. Synthetic Canterbury is comprised of Auckland (21.3%), Waikato (34.3%), Bay of Plenty (2.6%) and Manawatu, Wanganui and Taranaki (41.8%).

To estimate the synthetic control group for regional GDP per capita in Figure 5 the same explanatory variables were used as in estimating Figure 2. Figure 5 compares regional GDP per capita for the Canterbury region and Synthetic Canterbury. From 2002 to 2008 the regional income per capita increased in steps, while after 2008 the regional income per capita decreased in both treated and synthetic Canterbury. The difference between the treated and synthetic Canterbury after the intervention date (2010Q3) indicates that regional GDP per Capita on average fell by \$310.10 per quarter, a reduction of Canterbury's regional GDP per Capita of 4.2% due to the earthquakes.

As the findings of Figure 5 are indicative of an effect of the earthquakes on Canterbury's regional GDP per Capita, a placebo distribution will be used. The expanded placebo distribution (with randomized intervention dates) is used to test

whether the effect of the earthquake is significant as compared to all regional level economic fluctuations since 2005Q2. Figure 6 shows the kernel distribution for the placebo distribution<sup>45</sup>.

Figure 6: Placebo Distribution for regional GDP per capita



Red line represents the average aggregate effect of the earthquake on Canterbury

For the placebo distribution shown in Figure 6, 2187 observations meet the selection criteria to be included in the placebo distribution. Out of these observations, 283 observations exceed the post earthquake effect on Canterbury. This indicates a 283/2187 (12.9%) probability of exceeding the effect of the earthquakes on Canterbury regional GDP, indicating that at conventional levels of statistical significance, the effect of the Canterbury earthquake on regional GDP per capita is not statistically significant.

<sup>45</sup>Regions with exceptionally large MSPE figures as compared to the MSPE for Canterbury 2010Q3 will be omitted.

Table 3 presents the difference in difference estimates for regional GDP per capita. The estimated effect of the earthquake on Canterbury regional GDP per capita is reported in column (1). Various independent variables are used to estimate regional GDP per capita such as number of business in each industry, gender employment rates, population density and dummy variables associated with the earthquake events and the RWC. As shown in Table 3 the effect of the Canterbury earthquakes on regional GDP per capita is not significant at the 10% significance level, coinciding with conclusions made in Figure 6.

Table 3: Difference in Difference Analysis using Interaction Variables

|                                          | (1)                                                                                                                   |
|------------------------------------------|-----------------------------------------------------------------------------------------------------------------------|
|                                          | Regional GDP per Capita                                                                                               |
|                                          | $\beta$ / SE                                                                                                          |
| <i>Regional Production Decomposition</i> |                                                                                                                       |
| log(Primary Industry)                    | -0.285**                                                                                                              |
|                                          | (0.138)                                                                                                               |
| log(Wholesale Trade)                     | 0.117                                                                                                                 |
|                                          | (0.448)                                                                                                               |
| log(Retail)                              | 3.572***                                                                                                              |
|                                          | (0.693)                                                                                                               |
| log(Accommodation & Food)                | 0.213                                                                                                                 |
|                                          | (0.502)                                                                                                               |
| log(IT)                                  | 0.105                                                                                                                 |
|                                          | (0.171)                                                                                                               |
| log(Admin)                               | -0.645**                                                                                                              |
|                                          | (0.320)                                                                                                               |
| log(Education)                           | -1.257**                                                                                                              |
|                                          | (0.489)                                                                                                               |
| log(Health)                              | -2.695***                                                                                                             |
|                                          | (0.516)                                                                                                               |
| <i>Labour Market</i>                     |                                                                                                                       |
| Male Employment Rate                     | 0.174                                                                                                                 |
|                                          | (0.511)                                                                                                               |
| Female Employment Rate                   | 0.762                                                                                                                 |
|                                          | (0.499)                                                                                                               |
| <i>Urbanisation</i>                      |                                                                                                                       |
| Population per $km^2$                    | -0.013***                                                                                                             |
|                                          | (0.004)                                                                                                               |
| <i>Time Dummy Variables</i>              |                                                                                                                       |
| Canterbury * Post 2010Q3                 | -0.072                                                                                                                |
|                                          | (0.054)                                                                                                               |
| Post 2010Q3                              | -0.081                                                                                                                |
|                                          | (0.055)                                                                                                               |
| Observations                             | 387                                                                                                                   |
| $R^2$                                    | 0.802                                                                                                                 |
| Year Dummy Variables                     | Yes                                                                                                                   |
| Variables Omitted:                       | New Building Consents, Production, Transportation,<br>Accommodation & Food, IT,<br>Rugby World Cup & Canterbury * RWC |

### 4.3 Tourism

Reductions in regional GDP shown above may represent disproportionate effects across industries. And while I do not have regional data on production/income across different sectors to compare, data is available that allows me to examine the effects on one very important sector of the New Zealand economy, tourism.<sup>46</sup>

Initially, regional guest night data will be used to estimate the effect on the number of tourists staying in Canterbury due to the earthquake event. Furthermore, we will estimate the effect of the earthquakes on international traveller arrivals using data collected throughout New Zealand airports. The time series data has large periods in which international airlines find it unprofitable to fly into certain smaller international airports (such as Palmerston North and Tauranga). Due to this, only a small group of airports have consistent data in order to be included into the donor pool when constructing our synthetic control group. The members of the donor pool are Auckland, Waikato and Wellington.

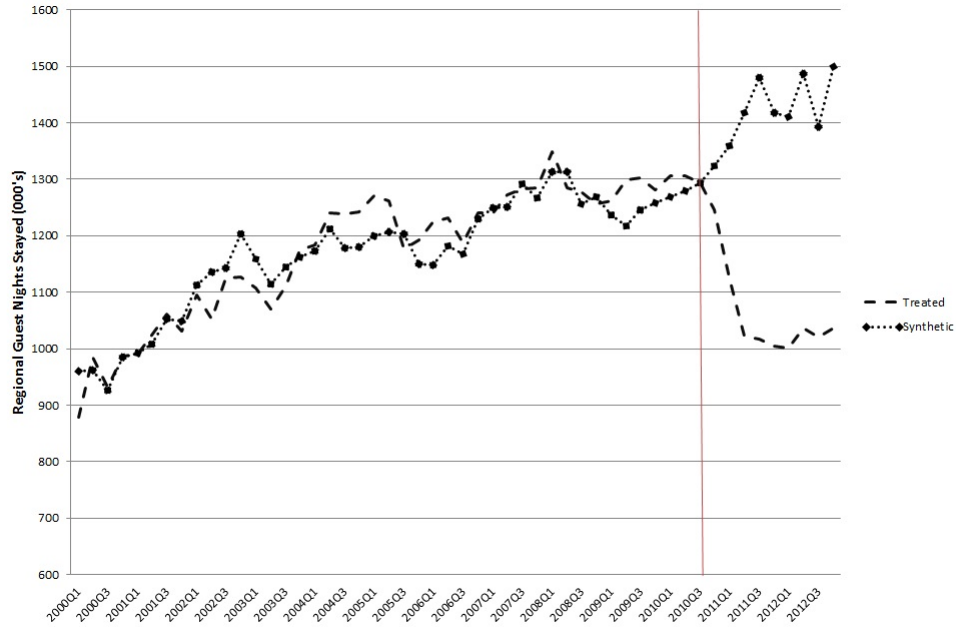
To estimate the effects of the earthquake events on tourism, numerous explanatory variables will be used. To estimate the synthetic control Canterbury for regional guest nights, the proportion of recreational, accommodation and food and retail businesses of total businesses, regional income per capita (logged), population per kilometre and lagged variables for the dependent variable in the time periods 2000Q1, 2007Q1 and 2010Q3 will be used. To estimate the synthetic control Canterbury for international arrivals the proportion of businesses that can be classified as recreational, accommodation and food and retail as a proportion of all industry in the region, the number of total businesses in the region, regional income per capita (logged), population per kilometer and lagged variables for the dependent variable

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<sup>46</sup>The tourism sector contributed 3.7% to total New Zealand GDP in 2013.

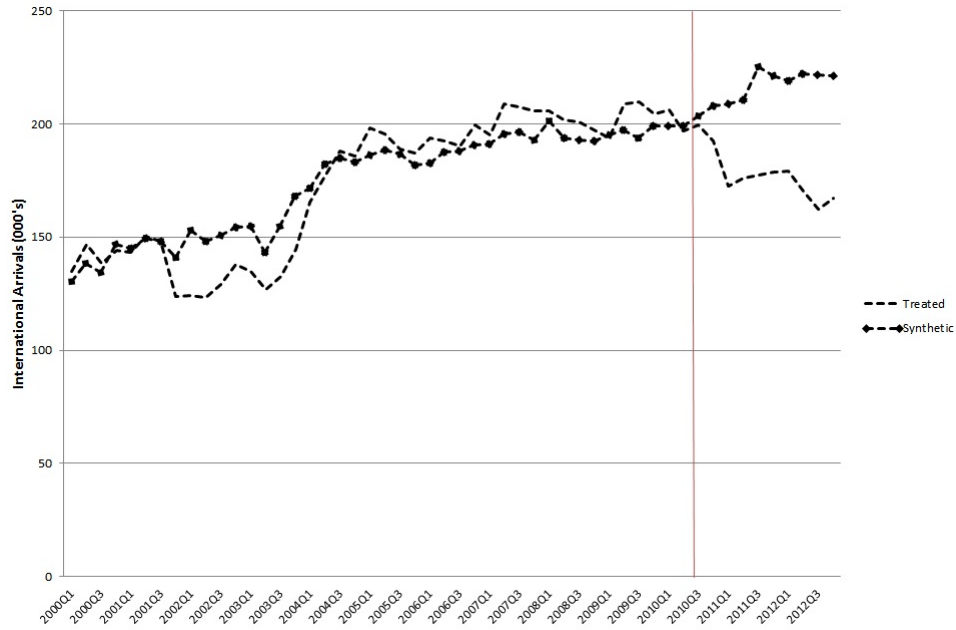
in the time periods 2000Q1, 2007Q1 and 2010Q3, as well as the first lag of the regional arrivals variable will be used as explanatory variables.

Figure 7: Canterbury Regional Guest Nights



MSPE : 35.59. Synthetic Canterbury is comprised of Auckland (83.1%), Wellington (16.1%) and Bay of Plenty (0.8%).

Figure 8: Canterbury International Arrivals



MSPE : 11.95. Synthetic Canterbury is comprised of Wellington (83.6%) and Auckland (16.4%).

Figure 7 depicts the synthetic control for Canterbury's regional guest nights. After the earthquake event (2010Q3) Figure 7 shows a decrease in the regional guest nights, indicative of a negative effect of the earthquakes. The decrease in regional guest nights persists until the final period of investigation, 2012Q4. The difference between treated Canterbury and synthetic Canterbury yields a reduction in regional guest nights stayed of 328,000 per quarter, a reduction of 22.9% due to the earthquake.

Figure 8 depicts the synthetic control for Canterbury's international passenger arrivals. After the intervention there is a very noticeable divergence between the two series in Figure 8, indicating a significant reduction in international tourist arrivals for the Canterbury region. The difference between the two series, indicates a reduction in international arrivals into Canterbury of 38,000, 17.7%, due to the earthquake. Orchiston et al. (2011) found that international tourist numbers fell more significantly for Impact Zone businesses than for businesses in the rest of Can-

terbury, indicating the reduction displayed in Figure 8 was predominantly centered in businesses in central Christchurch.

However, due to severe damage to Christchurch's Central Business District (CBD) as a result of the February 2011 earthquake, the reduction in Canterbury regional guest nights stayed could be misconstrued as a reduction in capacity. In their examination of Canterbury businesses, Orchiston et al. (2011) found that of the Accommodation businesses in the Impact Zone, only 2% closed permanently after the September 4th earthquake and 4% closed permanently after the February 22nd earthquake. However the effect of these closures will have differing effects on the Canterbury's accommodation capacity depending on which accommodation businesses closed.<sup>47</sup> If closures are consolidated in hotel or hostel accommodation businesses (which are most likely to be situated inside the Red-Zone), then their closure could significantly reduce capacity and thus regional guest nights in Canterbury.<sup>48</sup> However, if the closures are mostly in motel or bed and breakfasts type businesses, then their closures may not affect accommodation capacity in Canterbury, implying that Figure 7 indicates reductions in tourism demand due to the earthquakes.

As shown in Figures 7 and 8 there is a divergence between treated and synthetic Canterbury shown in Figures for both regional guest nights and international arrivals, indicating negative effects of the Canterbury earthquake. However as the time differential between arriving in Auckland or Canterbury is relatively small compared to the flight time to New Zealand, international tourists may choose another port of arrival instead of Christchurch airport creating spill overs between the treated and un-treated regions. In addition, Auckland has recently put in place several initia-

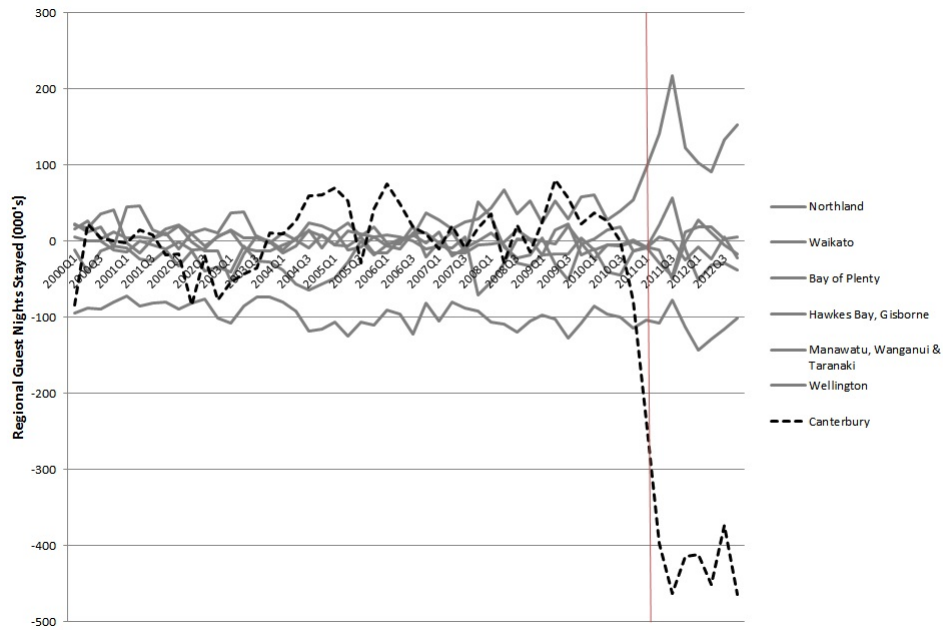
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<sup>47</sup>Impact Zone businesses are businesses that experienced modified Mercalli intensities of greater than 6.

<sup>48</sup>The Red-Zone is a portion of the Christchurch CBD that has been cordoned off due to major structural damage in the surrounding buildings. No entrance is permitted to the Red-Zone under any circumstances.

tives to boost incoming tourists by targeting Asian destinations specifically<sup>49</sup>. Due to this there has been a significant increase both in international arrivals and regional guest nights for the Auckland region independent of both the RWC and the Canterbury earthquakes (See Figure 18), violating the stable unit treatment assumption necessitating Auckland's removal from Figures 9 and 10. To indicate whether the effect of the earthquake on regional guest nights and international tourist arrivals is statistically significant, placebo tests will be run.

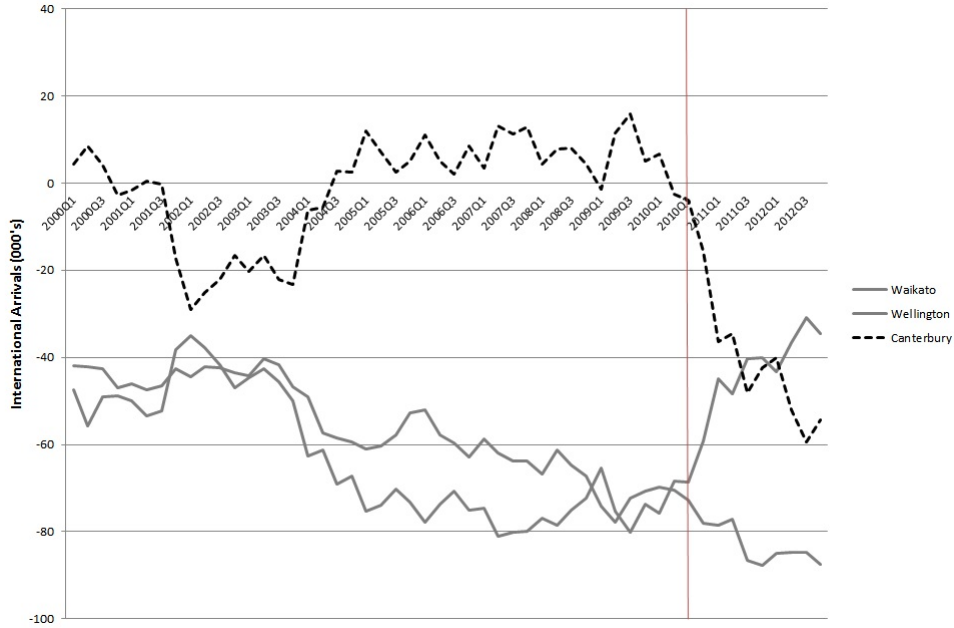
Figure 9: Placebo Test for Regional Guest Nights, excluding Auckland



Measures the difference between actual and synthetic regional guest nights in thousands of guests.

<sup>49</sup>For full details on Auckland Airport's strategy to boost international arrivals, see "Auckland Airport announces new tourism ambitions of 4 million visitor arrivals by 2020", Auckland Airport, <http://www.aucklandairport.co.nz>

Figure 10: Placebo Test for Regional International Arrivals, excluding Auckland



Measures the difference between actual and synthetic region international arrivals in thousands of people.

Figures 9 and Figure 10 plots the difference between actual and synthetic for region regional guest nights and international arrivals (in thousands of people) for all regions in the donor pool. Figure 9 illustrates a significant reduction in regional guest nights after the intervention date for Canterbury, as compared to other regions in the donor pool. This result is indicative of significance in the reductions in regional guest nights shown in Figure 7.

As shown in Figure 10, both Wellington and Waikato have large negative differences between treated and synthetic regions. This is a problem associated with the small donor pool, meaning that both of these regions are approximated by regions significantly larger than themselves causing synthetic versions of the region to greatly exceed values for the treated region. Due to this the synthetic control group methodology cannot properly recreate synthetic either of these regions, limiting the number of regions applicable for analysis and making Figure 10 an unsuitable measure of statistical significance for Figure 8. Tables 4 and 5 represent the percent

difference between treated and synthetic regions in the donor pool for both regional guest nights and international arrivals.

Table 4: Percent Difference between Treated and Synthetic Regions for regional guest nights, Post 2010Q

|             | Northland | Auckland | Waikato | Bay of<br>Plenty | Hawkes Bay,<br>Gisborne | Manawatu,<br>Wanganui<br>& Taranaki | Wellington | Canterbury |
|-------------|-----------|----------|---------|------------------|-------------------------|-------------------------------------|------------|------------|
| 2010Q2      | -1.64     | 9.26     | -6.43   | 2.45             | -24.37                  | -1.08                               | 6.74       | -0.02      |
| 2010Q3      | -1.64     | 9.26     | -6.43   | 2.45             | -24.37                  | -1.08                               | 6.74       | -0.02      |
| 2010Q4      | -0.21     | 14.68    | -1.76   | -1.62            | -27.14                  | 0.51                                | 9.13       | -5.95      |
| 2011Q1      | -2.09     | 25.08    | -1.05   | -1.18            | -25.31                  | -1.81                               | 17.03      | -17.33     |
| 2011Q2      | 1.43      | 34.80    | -3.92   | 2.80             | -26.01                  | -2.73                               | 26.00      | -28.00     |
| 2011Q3      | 0.13      | 37.46    | -5.99   | 7.07             | -18.92                  | -10.78                              | 40.22      | -31.29     |
| 2011Q4      | -5.80     | 36.02    | 1.70    | -1.25            | -26.68                  | -0.26                               | 22.29      | -29.22     |
| 2012Q1      | -1.75     | 35.98    | 2.91    | -6.70            | -32.75                  | 6.83                                | 18.50      | -29.10     |
| 2012Q2      | -5.97     | 37.52    | 2.82    | -4.01            | -31.12                  | 2.80                                | 16.70      | -30.32     |
| 2012Q3      | 1.53      | 33.89    | 0.50    | -3.84            | -29.79                  | -1.25                               | 25.29      | -26.83     |
| 2012Q4      | -5.34     | 37.65    | 0.81    | -4.92            | -24.61                  | -3.84                               | 28.09      | -30.90     |
| Average Gap | -1.97     | 30.23    | -1.04   | -1.12            | -26.67                  | -1.16                               | 21.00      | -22.90     |

Average Gap indicates the average difference between treated and synthetic regions from 2010Q3 to 2012Q4

Table 5: Percent Difference between Treated and Synthetic Regions for international arrivals, Post 2010Q3

|             | Auckland | Waikato | Wellington | Canterbury |
|-------------|----------|---------|------------|------------|
| 2010Q2      | 635.22   | −90.04  | −46.66     | −1.29      |
| 2010Q3      | 636.00   | −90.93  | −46.17     | −1.89      |
| 2010Q4      | 638.89   | −92.97  | −41.41     | −7.50      |
| 2011Q1      | 686.68   | −94.34  | −35.00     | −17.40     |
| 2011Q2      | 696.52   | −93.53  | −36.96     | −16.38     |
| 2011Q3      | 691.03   | −94.93  | −30.69     | −21.36     |
| 2011Q4      | 653.41   | −94.73  | −30.24     | −19.20     |
| 2012Q1      | 670.78   | −95.03  | −32.66     | −18.30     |
| 2012Q2      | 699.55   | −94.19  | −28.91     | −23.41     |
| 2012Q3      | 715.00   | −94.51  | −25.63     | −26.81     |
| 2012Q4      | 714.14   | −98.55  | −28.00     | −24.57     |
| Average Lag | 680.20   | −94.37  | −33.57     | −17.68     |

Average Gap indicates the average difference between treated and synthetic regions from 2010Q3 to 2012Q4

Table 4 reports the differences between the treated and synthetic regions for regional guest nights stayed. The table shows that, after the Canterbury earthquakes, the difference between the treated and the synthetic control groups is the largest for the Canterbury region (barring the difference between treated and synthetic Auckland). Wellington exceeds its synthetic control group, suggesting that since the intervention date, it was made better off in terms of regional guest nights stayed. By contrast, Hawke’s Bay and Gisborne region is made worse off as compared to its synthetic control group in terms of regional guest nights stayed.

Table 5 describes the deviation of the treated unit from the synthetic control group during the treatment period. Table 5 does not give much credence to the statistical significance of results indicated in Figure 8, however. The distance between

synthetic Wellington and treated Wellington decreases since the intervention, while the distance between synthetic and treated Waikato increases over time. Similarly, the difference between treated Canterbury and synthetic Canterbury increases over time, highlighting that over time, the effect of the Canterbury earthquakes on international tourist arrivals into Canterbury is becoming more severe.

However, as effects in Canterbury after the intervention date are similar effects in Waikato after the intervention date, there is no evidence from these tests that the effects on international arrivals are statistically significant. Percent differences between treated and synthetic Waikato increase markedly in 2012Q4 due to Wellington international arrivals increasing significantly, while Waikato international arrivals decrease further.<sup>50</sup>

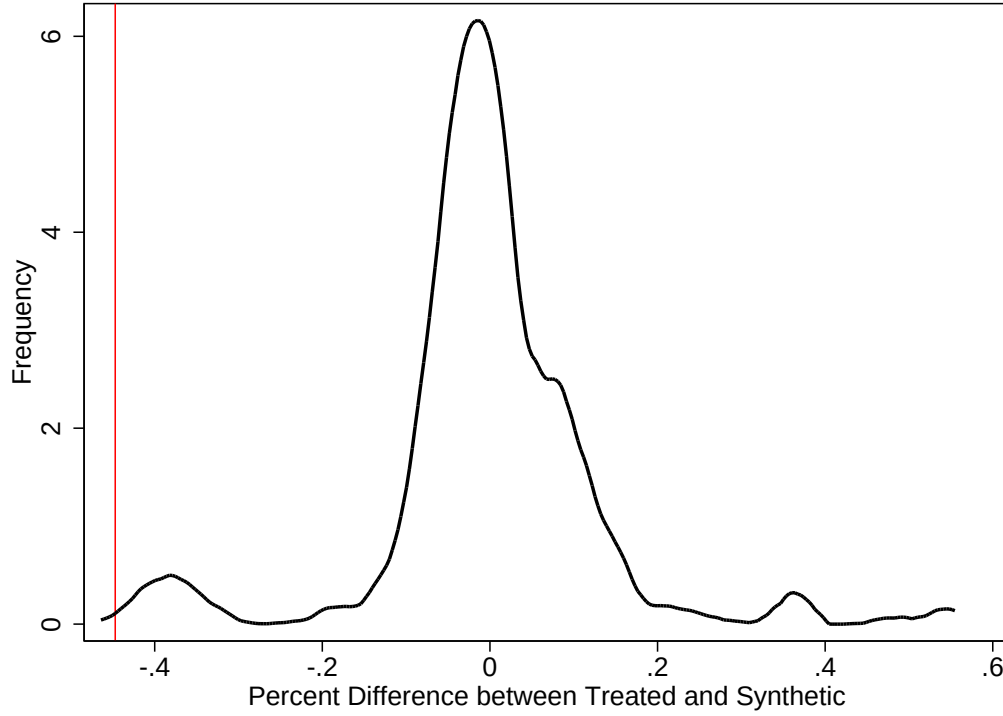
As the findings of Figure 9 are indicative of an effect of the earthquakes on Canterbury's regional guest nights, a placebo distribution will be used. The expanded placebo distribution (with randomized intervention dates) is used to test whether the effect of the earthquake is significant as compared to all regional level economic fluctuations in guest nights stayed since 2005Q2. Figure 11 shows the kernel distribution for the placebo distribution.<sup>51</sup>

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<sup>50</sup>Wellington has a 100% weighting in synthetic Waikato.

<sup>51</sup>Regions with exceptionally large MSPE figures as compared to the MSPE for Canterbury 2010Q3 will be omitted.

Figure 11: Placebo Distribution for regional guest nights



Red line represents the average aggregate effect of the earthquake on Canterbury

For the placebo distribution shown in Figure 11, 3104 observations meet the selection criteria to be included in the placebo distribution. Out of these observations, 4 observations exceed the post earthquake effect on Canterbury. This indicates a  $4/3104$  (0.13%) probability of exceeding the effect of the earthquakes on Canterbury regional guest nights, a more convincing rejection of the null hypothesis of no earthquake effect than Figure 9.

Table 6 presents the difference in difference estimates. The estimated effect of the earthquake on Canterbury regional guest nights is reported in column (1), with the effect of the earthquake on international arrivals reported in column (2). Various independent variables are used to estimate regional tourism in New Zealand. log Regional income per capita, population per  $km^2$ , Rugby World Cup and Rugby World Cup and Canterbury interaction and lagged arrivals as well as the log recre-

ation, accommodation & food, retail businesses were all included as explanatory variables. This result further indicates that results of the placebo test illustrated in Figure 9 are not due to the effect of Auckland guest night increases, instead due to a persistent reduction in guest nights as a result of the earthquakes.

Most interestingly, the negative effect on regional guest nights in Canterbury due to the earthquake on Canterbury regional guest nights has a statistically significant effect at the 1% level of significance, in keeping with results shown in Figure 7 and Table 4. These estimates reveal that, since the occurrence of the initial earthquake, regional guest nights have decreased by 89,000 (-0.8%) nights stayed in Canterbury. This reduction is compounded due to damages to Canterbury regional infrastructure causing Rugby World Cup games to be moved to other regions, further decreasing regional guest nights stayed in Canterbury during the RWC, as compared to all other regions by 51,000 (significant at the 10% level). The coefficient representing the effect of the earthquake events on international arrivals is insignificant at the 10% level, indicating that there is no statistically significant difference between international arrivals in Canterbury after the earthquake event and the untreated regions, mirroring earlier conclusions of Figure 10.

Table 6: Difference in Difference Analysis for Regional Guest Nights and International Arrivals

|                                          | (1)                     | (2)                    |
|------------------------------------------|-------------------------|------------------------|
|                                          | Guest Nights Stayed     | International Arrivals |
|                                          | $\beta$ / SE            | $\beta$ / SE           |
| <i>Income</i>                            |                         |                        |
| log(Regional Income per Capita)          | 726.068***<br>(90.027)  | 404.606***<br>(49.997) |
| <i>Regional Production Decomposition</i> |                         |                        |
| log(Recreation)                          | -39.258<br>(98.384)     | -44.366<br>(94.891)    |
| log(Accommodation & Food)                | 230.177**<br>(101.649)  | -192.040**<br>(96.735) |
| log(Retail)                              | 412.078***<br>(132.451) | 179.932<br>(143.036)   |
| log(Total Business)                      | -94.901<br>(123.278)    | 74.471<br>(72.292)     |
| <i>Urbanisation</i>                      |                         |                        |
| Population per $km^2$                    | 5.665***<br>(0.509)     | 5.456***<br>(0.296)    |
| <i>Time Dummy Variables</i>              |                         |                        |
| Canterbury * Post 2010Q3                 | -88.757***<br>(11.971)  | -2.214<br>(8.605)      |
| Post 2010Q3                              | 26.525*<br>(13.704)     | 10.338<br>(8.634)      |
| Rugby World Cup                          | -13.695<br>(14.983)     | -4.923<br>(9.509)      |
| Canterbury * RWC                         | -50.618*<br>(29.703)    | 14.240<br>(17.971)     |
| <i>Lagged Variables</i>                  |                         |                        |
| Arrivals (-1)                            |                         | 0.047*<br>(0.025)      |
| Observations                             | 387                     | 204                    |
| $R^2$                                    | 0.980                   | 0.935                  |
| Year Dummy Variables                     | Yes                     | Yes                    |

## 4.4 Trade

Due to reliance of trade on key port and distribution infrastructure, this sector is potentially vulnerable as a result of earthquake events. This section will be analysing the effects of the Canterbury earthquakes on Imports and Exports in the Canterbury region.

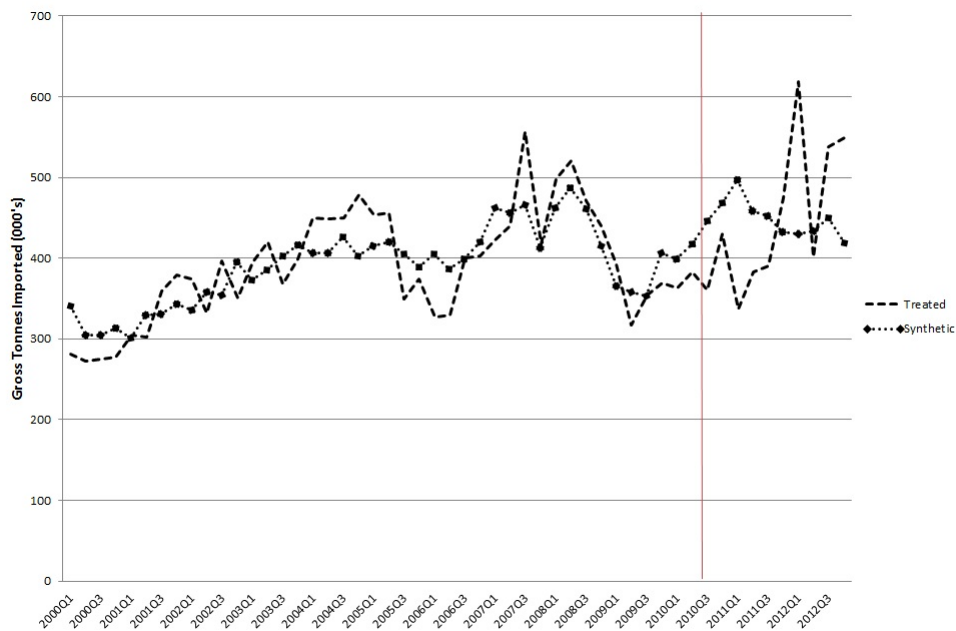
The main port in Canterbury, Lyttleton port, opened in a limited capacity very quickly after the February earthquake after experiencing substantial damages. Wood (2013) illustrate that around 500 wharf assets, including the main offices, have been damaged, with an estimated cost to insurers of around \$500 million and reconstruction planned to begin at the end of 2013. The large amount of damage to port facilities, and the strength of the earthquake events, are very similar to the effects of the Kōbe earthquake on port facilities, which is examined by Chang (2000). Chang (2000) finds that as a result of significant damages to the Port of Kōbe, there was a large amount of disruption to the port services and as a result, cargo volumes decreased. Some traffic returned to the Port of Kōbe once rebuilding finished, but overall the earthquake event reduced traffic through the port.

As the level of disruption occurring in the Lyttleton port is similar to the disruption to the Port of Kōbe after the earthquake, it is possible that the earthquake events will have persistent effects on imports and exports for the Canterbury region due to service disruption. However Pugh (2011) indicates that due to the closure of the Lyttleton port, ships have been redirected to Timaru port, which is situated in the Canterbury region, which could potentially smooth out the effects of the earthquake on imports and exports for the Canterbury region.

For all synthetic control estimations on regional gross imports and exports by

sea, Waikato will be excluded from the donor pool as it has no port. The independent variables used to estimate the synthetic control groups include the number of firms employed in primary industries, production based businesses and service based industries, each as a proportion of all businesses in the given region. Also included is regional male and female labour force participation rates, population per  $km^2$ , as well as lagged regional imports by port for years 2000Q1, 2003Q1 and 2010Q3.<sup>52</sup>

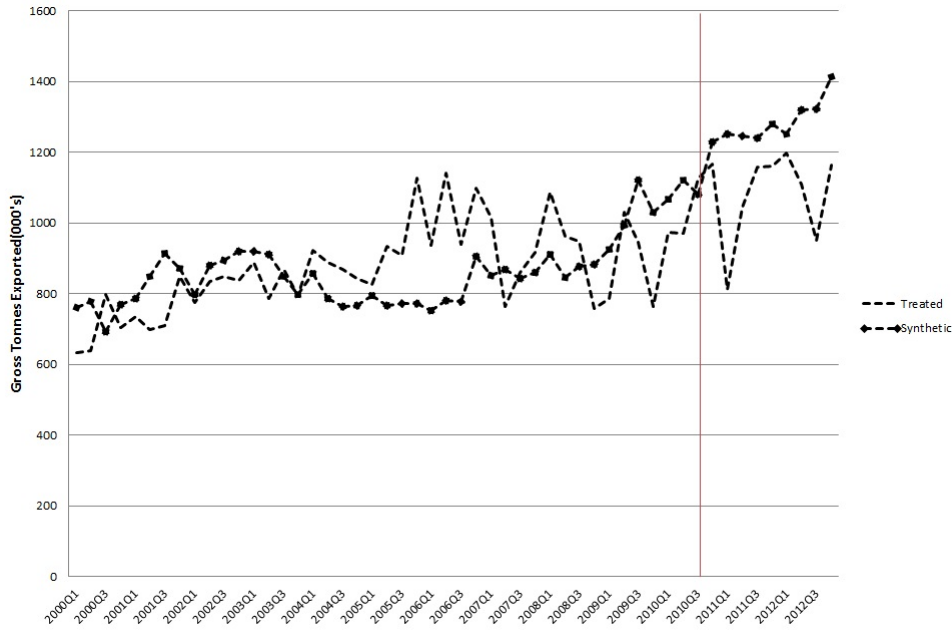
Figure 12: Canterbury Regional Imports by Port



MSPE : 39.02. Synthetic Canterbury is comprised of Manawatu, Wanganui & Taranaki (63.4%), Auckland (30.9%) and Bay of Plenty (5.7%).

<sup>52</sup>These specific periods were used with the synthetic control methods to estimate the level of imports initially and subsequent to the intervention date, as well as a period between these two dates.

Figure 13: Canterbury Regional Exports by Port



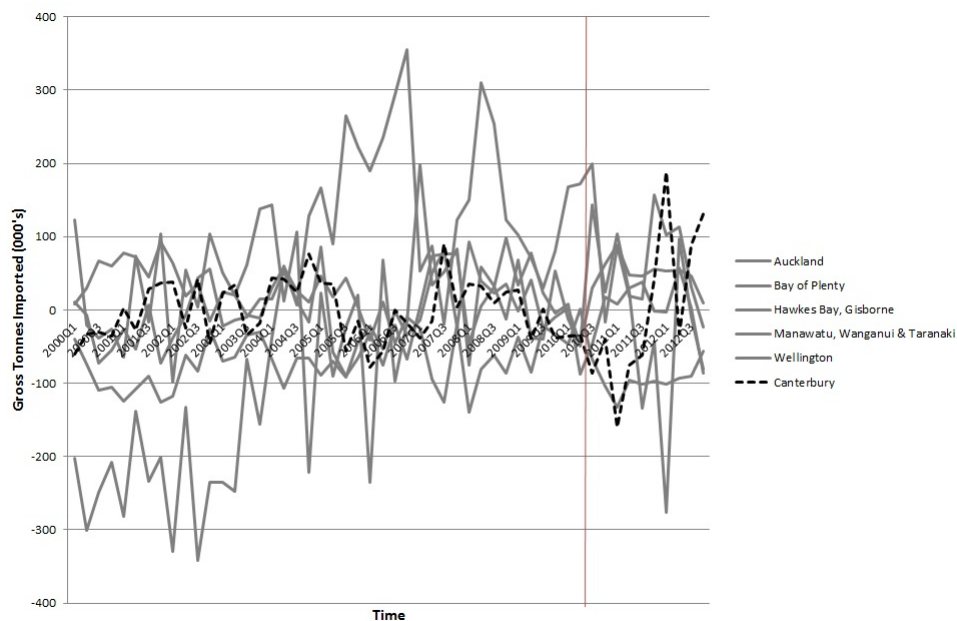
MSPE : 141.513. Synthetic Canterbury is comprised of Hawke's Bay, Gisborne (48.3%), Auckland (28.4%), Bay of Plenty (23.4%) and Manawatu,Wanganui & Taranaki (0.1%).

As seen in Figure 12, synthetic Canterbury loosely tracks treated Canterbury. After the intervention date synthetic Canterbury exceeds treated Canterbury until 2011Q4, when treated Canterbury imports by port exceeds synthetic Canterbury imports by port, indicating an ambiguous effect of the earthquake events, as Canterbury's gross imports by ports both increase and decrease as a result of the earthquake events. As a result of the earthquake event, Canterbury's gross imports by sea have on average increased by 473 tonnes per quarter, an insignificant amount.

The MSPE for Figure 13 is the largest MSPE for all synthetic control regions presented. As the large MSPE in Figure 13 indicates, previous to the intervention date there is a large amount of variation that synthetic Canterbury does not capture. Problems associated with this estimation are exacerbated when possible positive spill overs to other regional goods are accounted for. For instance, if an overseas customer cannot get their preferred Canterbury milk, they may choose to

purchase milk produced in the Waikato, increasing exports as a result of the earthquake events.<sup>53</sup> After the intervention date, synthetic Canterbury exceeds treated Canterbury, indicating a negative effect of the Canterbury earthquakes on regional exports by port, with an average reduction in Canterbury's gross exports by sea of 173,000 tonnes per quarter. Figures 12 and 13 show the results of the Placebo Test on Imports and Exports:

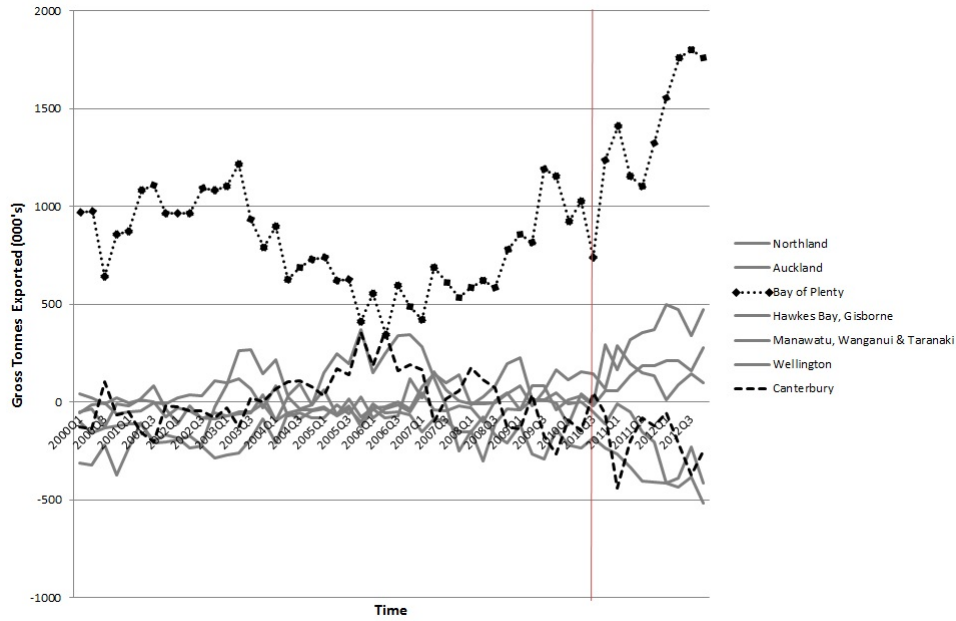
Figure 14: Placebo Test for Imports by Port



Measures the difference between actual and synthetic regional imports by port in gross tonnes.

<sup>53</sup>Abadie et al. (2010) indicates that synthetic control groups with large MSPE values may not be approximated by the technique adequately.

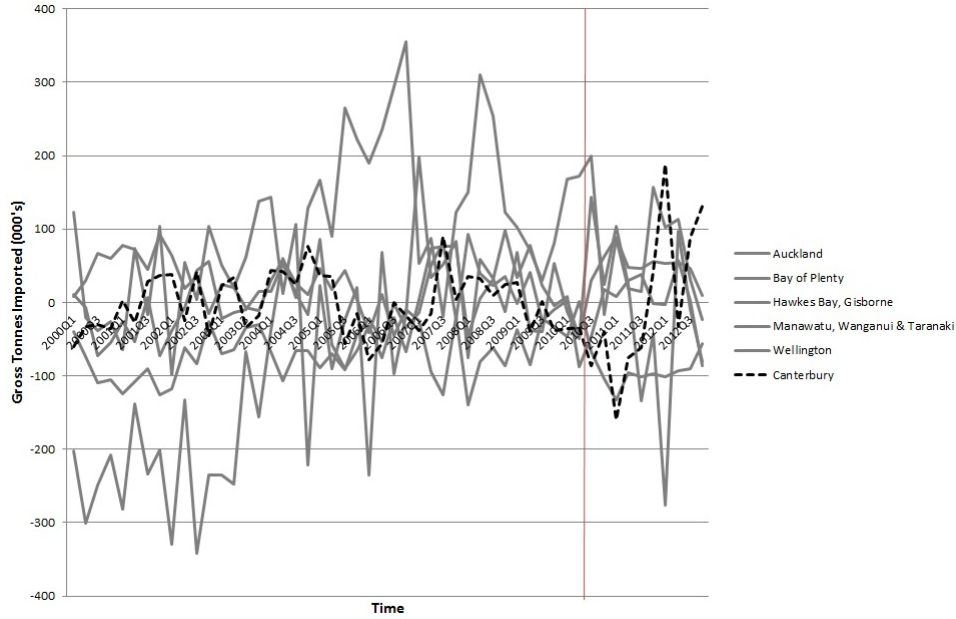
Figure 15: Placebo Test for Imports by Port



Measures the difference between actual and synthetic regional exports by port in gross tonnes.

Figure 14 shows the results of the placebo test for gross imports by sea, for all regions in the donor pool. We see that, Northland is not easily recreated by the synthetic control methodology, as it is the largest region in terms of tonnes of imports by sea, and any weighted average of the donor pool regions never exceed the treated Northland. By excluding Northland from Figure 14 and comparing regions with observations closer to the national average, it becomes feasible to identify the effects of the earthquake.

Figure 16: Placebo Test for Regional Imports by Port, excluding Northland



Measuring the difference between actual tonnes imported and synthetic region tonnes imported.

Both figures use seasonally adjusted data on gross imports/exports by port, however there appears to be some unexplained variation in estimating the synthetic control group for the Northland region. Figure 15 shows the results of the placebo test for all regions in the donor pool. In Figure 15 treated Bay of Plenty exports by port consistently exceed the synthetic Bay of Plenty exports.<sup>54</sup> However, as this difference is not largely different to regional variation in exports by port for other regions in the donor pool, Bay of Plenty will be included in the graphical analysis. Tables 7 and 8 describe the deviation of the synthetic control group from the treated unit during the treatment period.

<sup>54</sup>As the Port of Tauranga is the largest exporting port in New Zealand

Table 7: Percent Difference between Treated and Synthetic Regions, Post 2010Q3, as measured in thousands of tonnes

|             | Northland | Auckland | Bay of<br>Plenty | Hawkes Bay,<br>Gisborne | Manawatu,<br>Wanganui<br>& Taranaki | Wellington | Canterbury |
|-------------|-----------|----------|------------------|-------------------------|-------------------------------------|------------|------------|
| 2010Q2      | 85.33     | -5.07    | 23.16            | 0.92                    | -27.28                              | -26.10     | -8.33      |
| 2010Q3      | 48.23     | 16.84    | 27.53            | -38.69                  | 28.47                               | -16.24     | -19.25     |
| 2010Q4      | 86.05     | 2.60     | -2.17            | -43.35                  | 45.56                               | 6.43       | -8.40      |
| 2011Q1      | 76.86     | 10.86    | 11.28            | -57.14                  | 88.92                               | 3.04       | -32.25     |
| 2011Q2      | 93.30     | 2.42     | 2.33             | -47.27                  | 44.68                               | 11.65      | -16.48     |
| 2011Q3      | 126.80    | -12.33   | 1.83             | -44.02                  | 36.20                               | 13.78      | -13.50     |
| 2011Q4      | 74.93     | -4.54    | 20.66            | -48.25                  | 54.46                               | -0.48      | 9.87       |
| 2012Q1      | 115.17    | -24.84   | 12.21            | -43.27                  | 40.04                               | -0.90      | 43.89      |
| 2012Q2      | 60.63     | 11.17    | 15.36            | -52.48                  | 64.35                               | 22.80      | -7.65      |
| 2012Q3      | 78.45     | -1.01    | 3.74             | -46.80                  | 45.10                               | 0.87       | 19.75      |
| 2012Q4      | 95.60     | -7.96    | -2.79            | -31.58                  | 8.14                                | -31.60     | 31.27      |
| Average Gap | 85.60     | -0.68    | 9.00             | -45.28                  | 45.59                               | 0.93       | 0.72       |

Average Gap indicates the average difference between treated and synthetic regions from 2010Q3 to 2012Q4

Table 8: Percent Difference between Treated and Synthetic Regions, Post 2010Q3, as measured in thousands of tonnes

|             | Northland | Auckland | Bay of<br>Plenty | Hawkes Bay,<br>Gisborne | Manawatu,<br>Wanganui<br>& Taranaki | Wellington | Canterbury |
|-------------|-----------|----------|------------------|-------------------------|-------------------------------------|------------|------------|
| 2010Q2      | 7.27      | 0.13     | 105.80           | 19.60                   | -4.66                               | -47.04     | -13.37     |
| 2010Q3      | -3.68     | -7.20    | 65.76            | 18.06                   | 1.37                                | -41.43     | 4.30       |
| 2010Q4      | 11.87     | -13.68   | 105.94           | 7.37                    | -28.46                              | -44.41     | -4.82      |
| 2011Q1      | 10.60     | -0.90    | 173.71           | 34.85                   | -16.11                              | -44.59     | -34.97     |
| 2011Q2      | 26.37     | -6.49    | 110.91           | 21.46                   | -30.13                              | -51.94     | -16.14     |
| 2011Q3      | 39.00     | -19.98   | 95.53            | 15.66                   | -32.34                              | -60.23     | -6.60      |
| 2011Q4      | 39.24     | -26.04   | 114.09           | 13.62                   | -32.38                              | -62.47     | -9.32      |
| 2012Q1      | 47.94     | -50.65   | 129.99           | 1.37                    | -41.16                              | -63.46     | -4.21      |
| 2012Q2      | 44.50     | -47.55   | 158.92           | 8.52                    | -37.39                              | -63.69     | -15.90     |
| 2012Q3      | 32.07     | -29.65   | 189.85           | 15.36                   | -28.05                              | -58.30     | -28.06     |
| 2012Q4      | 47.72     | -46.59   | 151.25           | 8.84                    | -33.57                              | -59.88     | -17.71     |
| Average Gap | 29.56     | -24.87   | 129.59           | 14.51                   | -27.82                              | -55.04     | -13.34     |

Average Gap indicates the average difference between treated and synthetic regions from 2010Q3 to 2012Q4

Figure 16 and Table 7 illustrate the placebo test for imports as well as the percent deviation between treated and synthetic regions in the donor pool. Both of these indicate that the effect of the earthquake on Canterbury imports is negligible in comparison to other regions in the donor pool, implying that the reduction in imports shown in Figure 12 is not statistically significant. Moreover, the effect on exports due to the earthquake events shown in Figure 13 is indicated to be statistically insignificant. This is a result of both Figure 15 and Table 8 indicating that the effects of the earthquakes on Canterbury exports is not extreme in to macroeconomic variation occurring in other regions in the donor pool.

Table 9 estimates the effect of the earthquake events on gross imports in exports by port using a difference in difference estimator. Both regressions use log income

per capita, log of the number of primary, production and service related businesses, male and female employment rates, population per  $km^2$  and variables related to the earthquake and Rugby World Cup events. Table 9 column (2) estimates the effect of the earthquake on imports.

The Canterbury Post 2010Q3 interaction variable in Table 9 column (2) is insignificant at conventional levels, mirroring earlier conclusions that the effect of the earthquakes on imports in Canterbury is insignificant. Interestingly, Table 9 column (1) indicates that as a result of the earthquake regional exports reduced significantly by 151,000 tonnes since the initial earthquake. This result has large implications, possibly implying that the synthetic control groups may not have adequately estimated synthetic regions in the donor pool, causing the true effect of the earthquake to be understated.<sup>55</sup> At this point however we cannot conclude as to whether the reduction in exports is statistically significant, only to indicate that it is a possibility.

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<sup>55</sup>The high MSPE of Figure 13 indicates a poor fit of actual region to the synthetic version.

Table 9: Difference in Difference Analysis for Imports and Exports by Port

|                                          | (1)                       | (2)                      |
|------------------------------------------|---------------------------|--------------------------|
|                                          | Gross Exports by Port     | Gross Imports by Port    |
|                                          | $\beta$ / SE              | $\beta$ / SE             |
| <i>Income</i>                            |                           |                          |
| log(Regional Income per Capita)          | 299.897<br>(396.799)      | 70.595<br>(228.486)      |
| <i>Regional Production Decomposition</i> |                           |                          |
| log(Primary)                             | 7.753<br>(111.648)        | -9.265<br>(64.290)       |
| log(Production)                          | -1925.208***<br>(338.589) | -355.701*<br>(194.968)   |
| log(Services)                            | 2654.774***<br>(374.961)  | 464.221**<br>(215.911)   |
| <i>Labour Market</i>                     |                           |                          |
| Male Employment Rate                     | -1028.753**<br>(489.498)  | 1089.335***<br>(281.865) |
| Female Employment Rate                   | -688.623<br>(523.109)     | -576.170*<br>(301.219)   |
| <i>Urbanisation</i>                      |                           |                          |
| Population per $km^2$                    | -16.905***<br>(2.615)     | -1.606<br>(1.506)        |
| <i>Time Dummy Variables</i>              |                           |                          |
| Canterbury * Post 2010Q3                 | -151.137***<br>(45.316)   | 27.961<br>(26.094)       |
| Post 2010Q3                              | 128.834**<br>(59.338)     | 14.280<br>(34.168)       |
| Rugby World Cup                          | 33.464<br>(58.496)        | -24.078<br>(33.684)      |
| Observations                             | 344                       | 344                      |
| $R^2$                                    | 0.760                     | 0.301                    |
| Year Dummy Variables                     | Yes                       | Yes                      |

## 5 Discussion

The previous section presented the main results of this thesis, identifying the economic effects of the earthquakes on the Canterbury region based on key indicators. In this section we will discuss the results presented in this thesis and their statistical significance. Furthermore, these results will be compared to previous literature highlighting important results and their implications.

Due to the earthquake events, Canterbury regional GDP fell by \$211,000,000 (\$310.10 in regional GDP per capita terms) per quarter (1995/1996 dollars), suggestive of reductions in regional GDP in excess of initial direct losses due to the earthquake event, culminating in widespread reductions in economic activity. This could represent a change in regional GDP of -4.9% (-4.2% in regional GDP per capita terms), and a reduction of New Zealand GDP per capita by 0.55%, a 2.2% reduction in the post intervention real GDP growth rate.<sup>56</sup> VAR estimates presented in Doyle and Noy (2013) indicate that the first earthquake caused reductions in the real GDP growth rate of between 1.19% and 1.60%, while the February earthquake was associated with reductions in the real GDP growth rate of between 0.3% and 0.91%, which is inline with estimates presented above.<sup>57</sup>

Furthermore, Canterbury international arrivals were suggested to have fallen by 38,000 (-17.68%) per quarter due to the effects of the earthquakes, with a number of international flights into Christchurch airport constrained by limited accommodation options proximate to the airport (Becken, 2012). The resulting reduction in international arrivals into Christchurch airport will affect South Island tourism, as the Christchurch airport is used as an entrance to the South Island. Orchiston et al. (2011) indicate that Canterbury international visitor arrivals fell by 6.7% between

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<sup>56</sup>This is a back of envelope calculation, as Canterbury comprises 11.5% of New Zealand's total GDP (Statistics New Zealand, 2006). The Post intervention real GDP growth rate is 1.7%.

<sup>57</sup>The dummy variables associated with earthquake events are infrequently statistically significant.

2010 and 2011, with Becken (2012) suggesting that between March 2010 and March 2011, international arrivals into Christchurch reduced by approximately 30%. This thesis finds similar results, indicating that between March 2010 and March 2011 international arrivals fell by 9.88%.<sup>58</sup> However, results of this thesis are inconclusive on whether reductions in international arrivals are statistically significant, as placebo tests cannot conclusively indicate statistical significance and the difference in difference estimates are not statistically significant. The placebo tests for international tourist arrivals are severely reduced in power due to the small number of donor pool regions. With outlier regions omitted, the lowest probability of the most extreme situation occurring randomly is 1/4 (25%).

As a result of the earthquake events it is suggested regional guest nights stayed fell in Canterbury by 328,000 (-22.90%) per quarter. Previous research on the effects of the earthquake on tourism are shown in Parker and Steenkamp (2012) who find that international guest nights stayed fell by 6% after the September 2010 event, and fell by 33% after the February 2011 earthquake. Moreover, they find that domestic guest nights fell by 8% as a result of both earthquake events.<sup>59</sup> Becken (2012) estimates that Christchurch's accommodation capacity fell by approximately 60%, with an estimated reduction in national capacity of approximately 5% (Euqab, 2011). Such a substantial reduction in capacity will not only reduce the supply of accommodation for tourists, but will also reduce demand as tour groups will change destinations to areas with adequate accommodation facilities (Becken, 2012). The results reported in this thesis support the conclusions formed in Parker and Steenkamp (2012) and Becken (2012), indicating that these reductions indicated in these papers are statistically significant and robust to macroeconomic effects associated with events such as the Global Financial Crisis.

The earthquake events are suggested to have caused gross imports by port to

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<sup>58</sup>Becken (2012) does not report data from 2012.

<sup>59</sup>Decreases in Canterbury guest nights stayed are supported by primary evidence from Orchiston et al. (2011) and Becken (2012).

rise by 473 (0.72%) tonnes per quarter and exports to fall by 173,000 (-13.34%) tonnes per quarter. Effects of the earthquake event on Canterbury exports presented in Parker and Steenkamp (2012) find positive effects of the earthquake on exports, contrasting results presented in this thesis.<sup>60</sup> While in comparison to regional effects on trade, Doyle and Noy (2013) estimate the aggregate effects of the earthquakes on trade and finds that imports per quarter fell by 0.43% and 3.75% for each earthquake event, while exports per quarter fell by 1.08% and 0.55%.<sup>61</sup>

In this thesis, the synthetic control methodology measures the persistent effect of the initial earthquake, from the intervention date until the current period. The treatment period includes not only the initial earthquake event, but also a number of aftershocks. Due to the presence of large, significant earthquake events after the initial intervention date, the estimated magnitude of the economic impact of the Canterbury earthquake is not directly comparable to the estimated effects of singular earthquakes/events estimated in the literature (see, for example, DuPont and Noy (2012)) as Canterbury earthquake sequence will incur larger economic effects, due to the presence of two large earthquake events in the treatment period.

Most researchers have found that the effects of earthquake events, especially in developed countries, had no significant effects on GDP. Previous literature has shown that earthquake events only have negative effects due to political stability after the disaster (Cavallo, Galiani, Noy, and Pantano, 2010a). Doyle and Noy (2013) draw similar conclusions with respect to the effects of the Canterbury earthquake on the New Zealand real GDP growth rate. However, regional analyses have differing conclusions as to the effects of earthquakes. Horwich (2000) indicates that the Kōbe earthquake has no effect due to the earthquake, but further research by DuPont and Noy (2012) reaches the opposite conclusion. Using the synthetic control group

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<sup>60</sup>Imports are not considered in the paper by Parker and Steenkamp (2012).

<sup>61</sup>Estimates of the earthquakes on imports or exports are scarcely statistically significant.

methodology, DuPont and Noy (2012) find persistent effects on regional GDP per capita, 15 years after the Kōbe earthquake. The results from the synthetic control analysis in this thesis indicate the regional effects of the earthquake are significant for the relatively short period examined. Previously, reductions in regional GDP due to the Canterbury earthquakes have not been found, contrasting results found in Parker and Steenkamp (2012)<sup>62</sup> which indicate that production levels in Canterbury remained resilient after the earthquake events.<sup>63</sup>

When using a full set of explanatory variables the difference in difference estimate effect of the earthquake on regional GDP indicated a positive and statistically significant effect. Further investigation into these results indicated that accommodation and IT businesses as a proportion of all businesses caused the effects of the earthquake on regional GDP to become positive and significant. As a result these variables were included as interaction terms with the earthquake effect variable, causing the effect of the earthquake to become negative and significant. This indicates that these variables are indirect channels by which the earthquake reduces regional GDP, a result not found in the literature previously.

The combined effect of the Global Financial Crisis (GFC) and sovereign debt crisis caused world-wide recessions, with large adverse effects on financial markets. As a result of the GFC and the sovereign debt crisis, New Zealand real GDP fell sharply between 2007 and 2009, with real GDP increasing marginally between 2009 and 2010.<sup>64</sup> Recessions have been found to reduce economic damages associated with natural disasters due to idle capacity and low factor price inflation (Hallegatte and Ghil, 2008). As New Zealand was only just beginning to recover from a large recession, the number of idle factors of production would have been beneficial in

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<sup>62</sup>As this paper was published in September 2012, conclusions formed in Parker and Steenkamp (2012) do not extend for the full period investigated in this thesis.

<sup>63</sup>As measured by the Performance of Manufacturing Index (PMI).

<sup>64</sup>Source: [http://www.rbnz.govt.nz/statistics/key\\_graphs/real\\_gdp/](http://www.rbnz.govt.nz/statistics/key_graphs/real_gdp/).

mitigating some of the losses due to the earthquake events.

Stricter building codes, shortages of skilled labour and after-shocks will also have significant effects on Canterbury, making the effects of the earthquake more persistent.<sup>65</sup> Due to stricter building codes following the earthquake events, some businesses that were previously up to current building codes may need to close or to reduce capacity in order to comply with building codes<sup>66</sup>, with policy submissions to increase earthquake strengthening required in the Building Code Act 2004 being accepted currently (Williamson, 2013). Over the longer term, these stricter building codes will mitigate the effects of earthquakes, allowing earthquake affected regions throughout New Zealand to return to pre-earthquake levels of production and income earlier. In addition, the number of skilled engineers and construction specialists available will directly affect how quickly capacity is restored in Canterbury. Labour shortages have become so severe in Canterbury that foreign workers are migrating to Canterbury to satisfy demand (Parker and Steenkamp, 2012), with longer periods of labour shortages contributing to Canterbury taking longer to recovery to pre-earthquake levels of production and income.

As a result of the earthquakes entrepreneurial, human and physical capital have migrated to other regions throughout New Zealand, with the persistence of this migration affecting Canterbury in the long term. If migration of the mentioned factors of production are only temporary, then once these factors of production migrate back to Canterbury the region will begin to grow, and the adverse economic effects of the earthquake events may reduce. However if this migration is permanent, production in Canterbury may never again reach pre-earthquake levels. DuPont and

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<sup>65</sup>Other regions with large amounts of historical buildings will be affected, but due to earthquake damage the effect on Canterbury will be significant.

<sup>66</sup>See “220 buildings urgently closed since quakes”, The Press, <http://www.stuff.co.nz/the-press/business/the-rebuild/9200180/220-buildings-urgently-closed-since-quakes>

Noy (2012) found that as a result of the Kōbe earthquake initially population in Kōbe decreased, with migration back to Kōbe causing population to increase above the pre-earthquake trend. However, observed by Euqab (2012), migration out of Canterbury has already begun and it is unclear whether this migration will be reversed in the future. DuPont and Noy (2012) found that Kōbe also experienced a large number of business migrations out of the city as a result of the earthquake, resulting in long term reductions of business activity in Kōbe. Due to the significant fixed costs associated with relocating and starting new businesses, such a migration of businesses is expected to result in more persistent reductions in economic activity than the migration of productive factors alone.

Several limitations of this methodology warrant discussion. A lack of applicable and timely data resulted in an inability to estimate the most accurate synthetic control groups. Due to a lack of regional data for variables that would be useful in estimating regional GDP, tourism and international trade synthetic control groups are not as accurate as they could have been.<sup>67</sup> Also a longer, more consistent time series (especially with regards to regional international arrivals) would have been interesting to examine. However, even with a small time period, significant results have been found. Methodologically, time placebos would have been interesting to add to my distribution of placebo disasters. Time placebos are used in addition to placebo tests, using differing intervention dates to ascertain whether the event is the most significant result in recent periods throughout all regions, creating a larger distribution of placebo disasters. Larger placebo distributions also allow further applications of statistical significance to be applied such as using a p-value for estimated disaster impact as illustrated in Cavallo, Galiani, Noy, and Pantano (2010a). Instead of this, difference in difference estimators were used as an alternative method of testing statistical significance, utilizing time series data through a

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<sup>67</sup>Variables such as regional foreign direct investment by region and regional CPI would have been very useful in estimating synthetic control groups.

regression based technique while aiding in interpretation of placebo test results.

## 6 Conclusions

The key for ensuring that additional disaster events are adequately prepared for is to understand the breadth and significance of the losses that these events cause. This thesis uses synthetic control groups to estimate the effect of the Canterbury earthquakes on regional GDP, tourism and international trade. A majority of damages occurred in the Canterbury region, with other regions being relatively untreated by the earthquake event. This implies that the unaffected regions form an ideal donor pool from which to estimate a “Synthetic” Canterbury for each of the outcomes of interest.

As the earthquake events are recent, the literature covering the economic ramifications of the Canterbury earthquakes is small. Doyle and Noy (2013) investigate the short term macroeconomic implications of the earthquakes using a VAR based approach with dummy variables used to capture the effect of the earthquakes, similar in spirit to the difference in difference estimator presented in this thesis. Parker and Steenkamp (2012) investigate the regional effects of the earthquake on Canterbury by regional time series for a set of outcome variables, several which are examined in this thesis.

This thesis combines a larger time period than used in Parker and Steenkamp (2012), while also employing the synthetic control methodology to more accurately estimate the effects of the earthquake events. In doing so, this thesis also adds to the literature that employs the Synthetic Control Methodology to applications natural disaster events. Results presented in this thesis are suggestive of persistent reductions in regional GDP over the period 2010Q3 - 2012Q4 and potentially beyond, this conclusion is not supported by regional GDP per capita figures however.

However, whether these effects are statistically significant is not clear, as placebo tests are merely suggestive of significant reductions, while difference in difference analysis indicates a positive effect due to the earthquake events.

This thesis examines the effects of the earthquakes on international arrivals, a component of economic activity not previously examined in the literature. From synthetic control results, the earthquake events reduced international arrivals. However, we were unable to find conclusive evidence that this effect is statistically significant. Moreover, there has been a statistically significant reduction in guest nights stayed, concluded by both placebo tests and the difference in difference estimator. Lastly, the effect on imports due to the earthquake is not statistically significant, while pooled sample regressions indicate that the reduction in exports may be significant.

Although our empirical results support several previous findings in the literature, there are also many differences. The reductions in regional GDP found in this thesis contrast Parker and Steenkamp (2012), who find that production remained flat after the earthquake event. Guest nights were found to reduce by -22.90% due to the earthquake. This result is in agreement with conclusions presented in Parker and Steenkamp (2012) and primary evidence reported in Orchiston et al. (2011), indicating their findings are significant, while controlling for macroeconomic factors. As a result of the earthquake, international arrivals fell by 17.68%, in accordance with initial observations by Becken (2012) and Orchiston et al. (2011). Moreover, we find that exports reduced by -13.34% due to the earthquake events, contrasting results found in Parker and Steenkamp (2012) which indicate that exports in Canterbury increased. Lastly, results in this thesis indicate that the earthquakes have had negligible effects on gross imports by port of +0.72%, a topic yet to be considered by the literature on a regional level.

As New Zealand is situated between the Australian and Pacific Tectonic Plates, earthquakes are relatively frequent in New Zealand. As there is a lack of research on the economic effects of earthquakes in New Zealand, estimates of earthquake

damages will be downwards biased as wider economic costs will not be included. This may result in an under-allocation of funding for prevention and preparation, and there more research is needed. This thesis is aimed to help fill this gap.

Although the empirical analysis of this thesis provides many insights into the regional effects of the Canterbury earthquake, further research will be useful as more data becomes available. A longer time series will enable an analysis of the long term consequences. Moreover, should regional data become available for more economic variables, a better fit of the control groups to actual data would be possible, contributing to more accurate estimates. Time placebo tests could also be used as they add observations to the placebo disaster distribution, increasing the strength of placebo test inference presented in this thesis. Also, as more data becomes available, a long term study could be done on the effects on the Canterbury region, with a focus on whether the economic effects found in this thesis persist in the longer term.

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## 7 Appendices

### 7.A Mathematical Appendix

Without loss of generality suppose that only the first region is exposed to the intervention of interest, so we have  $j$  remaining potential controls.<sup>68</sup> These  $j$  regions are called the donor pool. Let  $W$  be a  $(J \times 1)$  vector of positive weights that sum to one. That is,  $W = (w_2, \dots, w_{j+1})'$  with  $w_j \geq 0$  for  $j = 2, \dots, J + 1$  and  $w_2 + \dots + w_{J+1} = 1$ . Each value of  $W$  represents a weighted average of the available control regions and, therefore, a synthetic control. Notice that, although we define our synthetic controls as convex combinations of unexposed units, negative weights or weights larger than one can be used at the cost of allowing extrapolation.

The outcome variable of interest is observed for  $T$  periods for the region affected by the intervention  $Y_{it}$ , ( $t = 1, \dots, T$ ) and unaffected regions  $Y_{jt}$ , ( $j = 2, \dots, J + 1, t = 1, \dots, T$ ). Let  $T_1 = T - T_0$  be the number of post-intervention periods. Let  $Y_1$  be the  $(T_1 \times 1)$  vector of post-intervention outcomes for the exposed region, and  $Y_0$  be the  $(T_1 \times J)$  matrix of post-intervention outcomes for potential control regions. Let the  $(T_0 \times 1)$  vector  $K = (k_1, \dots, k_{T_0})'$  define a linear combination of pre-intervention outcomes:  $Y_i^{\bar{K}} = \sum_{s=1}^{T_0} k_s Y_{is}$ . For example, if  $k_1 = k_2 = \dots = k_{T_0-1} = 0$  and  $k_{T_0} = 1$ , then  $Y_i^{\bar{K}} = Y_{iT_0}$ , the value of the outcome variable in the period immediately prior to the intervention. If  $k_1 = k_2 = \dots = k_{T_0} = 1/T_0$ , then  $Y_i^{\bar{K}} = T_0^{-1} \sum_{s=1}^{T_0} Y_{is}$ , the simple average of the outcome variable for the pre-intervention periods.

Consider  $M$  of such linear combinations defined by the vectors,  $K_1, \dots, K_M$ . Let  $X_1 = (Z_1', \bar{Y}_1^{K_1}, \dots, \bar{Y}_1^{K_M})'$  be a  $(k \times 1)$  vector of pre-intervention characteristics for the exposed region, with  $k = r + M$ . Similarly,  $X_0$  is a  $(k \times J)$  matrix that contains

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<sup>68</sup>For a more technical explanation, see Abadie and Gardeazabal (2003) and Abadie et al. (2010)

the same variables for the unaffected regions. That is, the  $j$ -th column of  $X_0$  is  $(Z'_j, \bar{Y}_1^{K_1}, \dots, \bar{Y}_1^{K_M})'$ . The vector  $W^*$  is chosen to minimise some distance (or psuedo-distance),  $\|X_1 - X_0W\|$ , between  $X_1$  and  $X_0W$ , subject to  $w_2 \geq 0, \dots, w_{J+1} \geq 0$ ,  $w_2 + \dots + w_{J+1} = 1$ .

In practise however, the computation of the weights  $w_2^*, \dots, w_{J+1}^*$  can be simplified by considering only a few linear combinations or pre-intervention outcomes and checking whether the following equation holds approximately for the resulting weights:

$$\sum_{j=2}^{J+1} w_j^* Y_{j1} = Y_{11}, \dots, \sum_{j=2}^{J+1} w_j^* Y_{jT_0} = Y_{1T_0}, \quad \text{and} \quad \sum_{j=2}^{J+1} w_j^* Z_j = Z_1.$$

To measure the discrepancy between  $X_1$  and  $X_0W$ , we will employ  $\|X_1 - X_0W\| = \sqrt{(X_1 - X_0W)'V(X_1 - X_0W)}$ , where  $V$  is some  $(k \times k)$  symmetric and positive semi-definite matrix, although other choices are also possible. If the relationship between the outcome variable and the explanatory variable in  $X_1$  and  $X_0$  is highly non-linear and a support of of explanatory variables is large, interpolation biases may be severe.

Following Abadie and Gardeazabal (2003)  $V$  is chosen among positive definite and diagonal matrices such that the mean squared prediction error of the outcome variable is minimised for the pre-intervention period.

## 7.B Figures and Tables

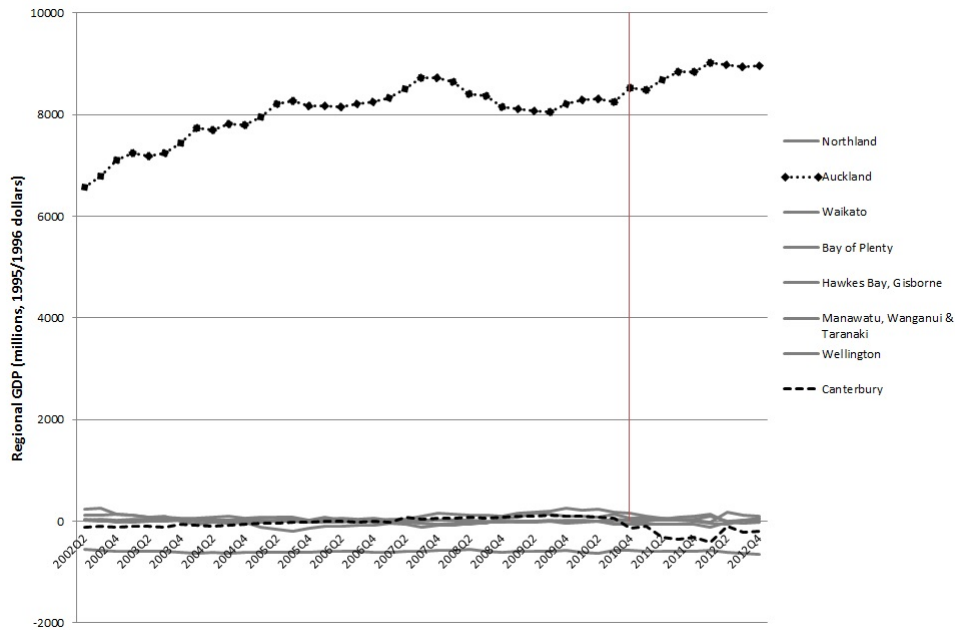
Table 10: Difference in Difference Regression with Control Variable

|                                                                   | (1)                     | (2)                         | (3)                          |
|-------------------------------------------------------------------|-------------------------|-----------------------------|------------------------------|
|                                                                   | region_gdpSA            | region_gdpSA                | region_gdpSA                 |
|                                                                   | $\beta$ / SE            | $\beta$ / SE                | $\beta$ / SE                 |
| <i>Time Dummy Variables</i>                                       |                         |                             |                              |
| Canterbury * Post 2010Q3                                          | −221.620<br>(253.708)   | 347.693***<br>(114.890)     | 277.717*<br>(146.672)        |
| Post 2010Q3                                                       | 327.967***<br>(119.599) | 140.219***<br>(53.932)      | −121.248*<br>(70.504)        |
| <i>Businesses in industry as a proportion of total businesses</i> |                         |                             |                              |
| Accommodation & Food                                              |                         | 318264.191***<br>(8236.389) |                              |
| IT                                                                |                         |                             | 752330.503***<br>(27124.902) |
| Observations                                                      | 387                     | 387                         | 387                          |
| $R^2$                                                             | 0.020                   | 0.803                       | 0.678                        |
| Year Dummy Variables                                              | Yes                     | Yes                         |                              |

Table 11: Difference in Difference regression for Regional GDP

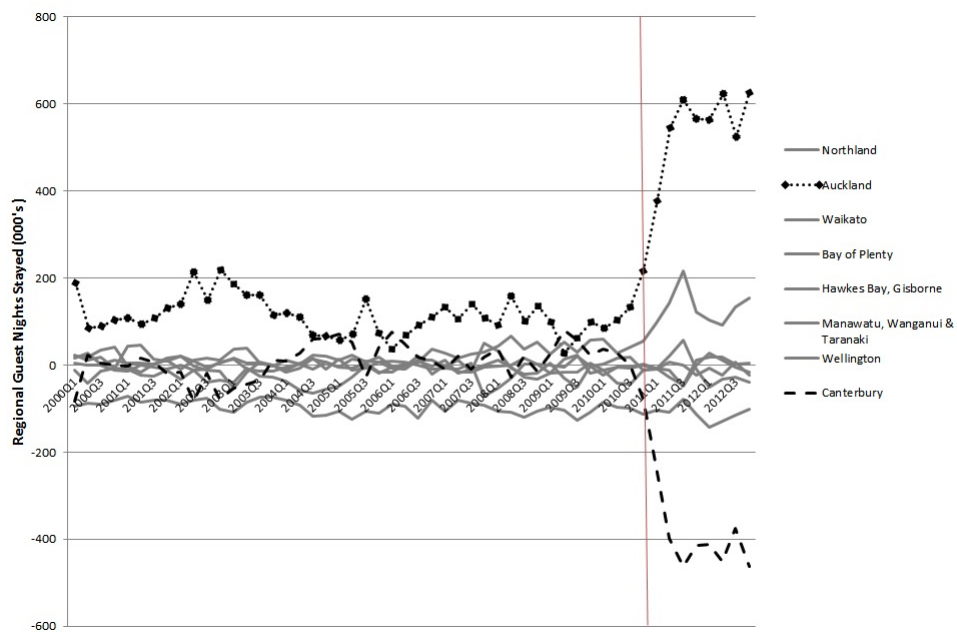
|                                                          | (1)                                                                    |
|----------------------------------------------------------|------------------------------------------------------------------------|
|                                                          | Regional GDP                                                           |
|                                                          | $\beta$ / SE                                                           |
| <i>Number of firms as a proportion of all businesses</i> |                                                                        |
| Production                                               | 8671.150**<br>(4183.259)                                               |
| Wholesale trade                                          | −68823.137***<br>(12717.140)                                           |
| Retail                                                   | 45240.884***<br>(13762.760)                                            |
| Accommodation & Food                                     | 80264.703***<br>(15446.087)                                            |
| Administration                                           | 76296.636***<br>(14325.163)                                            |
| Health                                                   | 43711.035***<br>(15819.073)                                            |
| <i>Labour Market</i>                                     |                                                                        |
| Male Employment Rate                                     | 1477.888**<br>(594.393)                                                |
| Female Employment Rate                                   | −10.874<br>(590.605)                                                   |
| <i>Construction Industry</i>                             |                                                                        |
| New Building Consents                                    | 0.339***<br>(0.052)                                                    |
| <i>Urbanisation</i>                                      |                                                                        |
| Population per $km^2$                                    | 64.478***<br>(4.607)                                                   |
| <i>Time Dummy Variables</i>                              |                                                                        |
| Canterbury * Post 2010Q3                                 | 136.671**<br>(63.630)                                                  |
| Post 2010Q3                                              | −47.964<br>(65.407)                                                    |
| Canterbury * RWC                                         | −158.417<br>(144.037)                                                  |
| Observations                                             | 387                                                                    |
| $R^2$                                                    | 0.965                                                                  |
| Year Dummy Variables                                     | Yes                                                                    |
| Variables Omitted:                                       | Primary, Transportation, IT, Education Industries<br>& Rugby World Cup |

Figure 17: Placebo Test for Regional GDP



Measuring the difference between actual GDP and synthetic region GDP in millions of 1995/1996 dollars.

Figure 18: Placebo Test for Regional Guest Nights



Measures the difference between actual and synthetic regional guest nights in thousands of guests.

Table 12: Guest Nights Stayed: Difference between Treated and Synthetic Regions, Post 2010Q3

| Time Period | Northland | Auckland | Waikato | Bay of Plenty | Hawke's Bay, Gisborne | Manawatu, Wanganui & Taranaki | Wellington | Canterbury |
|-------------|-----------|----------|---------|---------------|-----------------------|-------------------------------|------------|------------|
| 2010Q3      | −6.55     | 132.04   | −44.54  | 18.77         | −99.12                | −4.45                         | 40.42      | −0.26      |
| 2010Q4      | −0.84     | 214.36   | −12.18  | −12.71        | −113.69               | 2.14                          | 54.63      | −78.85     |
| 2011Q1      | −8.55     | 376.43   | −7.22   | −9.08         | −104.26               | −7.61                         | 96.50      | −235.64    |
| 2011Q2      | 5.83      | 545.53   | −28.04  | 21.60         | −107.20               | −11.56                        | 141.56     | −397.39    |
| 2011Q3      | 0.54      | 609.22   | −45.64  | 56.32         | −77.20                | −49.30                        | 217.24     | −463.16    |
| 2011Q4      | −24.26    | 565.33   | 11.76   | −9.71         | −113.25               | −1.12                         | 122.68     | −414.57    |
| 2012Q1      | −6.98     | 562.82   | 19.08   | −50.74        | −143.47               | 28.00                         | 103.63     | −411.03    |
| 2012Q2      | −23.79    | 622.08   | 19.34   | −31.53        | −128.32               | 11.22                         | 91.47      | −450.79    |
| 2012Q3      | 5.83      | 522.88   | 3.33    | −28.81        | −116.05               | −4.95                         | 133.15     | −374.06    |
| 2012Q4      | −22.04    | 626.25   | 5.53    | −38.31        | −101.03               | −16.41                        | 153.51     | −463.75    |
| Average Gap | −8.08     | 477.69   | −7.86   | −8.42         | −110.36               | −5.40                         | 115.48     | −328.95    |

Table 13: International Arrivals: Difference between Treated and Synthetic Regions, Post 2010Q3

| Time Period | Auckland | Waikato | Wellington | Canterbury |
|-------------|----------|---------|------------|------------|
| 2010Q3      | 720.11   | −72.80  | −68.68     | −3.84      |
| 2010Q4      | 728.50   | −77.99  | −59.29     | −15.63     |
| 2011Q1      | 741.84   | −78.57  | −44.85     | −36.37     |
| 2011Q2      | 755.35   | −77.17  | −48.37     | −34.50     |
| 2011Q3      | 795.61   | −86.63  | −40.40     | −48.20     |
| 2011Q4      | 760.91   | −87.69  | −40.13     | −42.49     |
| 2012Q1      | 766.64   | −85.01  | −43.38     | −40.13     |
| 2012Q2      | 785.67   | −84.81  | −36.62     | −52.11     |
| 2012Q3      | 785.72   | −84.83  | −30.93     | −59.49     |
| 2012Q4      | 788.67   | −87.42  | −34.50     | −54.45     |
| Average Lag | 762.90   | −82.29  | −44.72     | −38.72     |

Table 14: Regional GDP: Difference between Treated and Synthetic Regions, Post 2010Q3

| Time Period | Northland | Auckland | Waikato | Bay of<br>Plenty | Hawke's Bay,<br>Gisborne | Manawatu, Wanganui<br>& Taranaki | Wellington | Canterbury |
|-------------|-----------|----------|---------|------------------|--------------------------|----------------------------------|------------|------------|
| 2010Q3      | -567.47   | 8 237.49 | -29.91  | 36.98            | -58.94                   | 178.31                           | 149.61     | 54.21      |
| 2010Q4      | -570.41   | 8 516.71 | -33.53  | 28.45            | -57.57                   | 163.27                           | 65.53      | -140.59    |
| 2011Q1      | -586.61   | 8 481.64 | 7.33    | 51.12            | -61.31                   | 104.51                           | 78.85      | -104.28    |
| 2011Q2      | -595.79   | 8 680.76 | 41.84   | 55.86            | -63.53                   | 59.67                            | 48.89      | -316.63    |
| 2011Q3      | -587.95   | 8 826.68 | 73.23   | 43.66            | -66.04                   | 20.00                            | 20.42      | -357.11    |
| 2011Q4      | -593.39   | 8 837.47 | 92.71   | 32.32            | -54.80                   | 20.00                            | -5.41      | -323.43    |
| 2012Q1      | -571.41   | 9 022.95 | 141.99  | 92.11            | -114.69                  | -20.37                           | -35.67     | -415.58    |
| 2012Q2      | -607.81   | 8 973.35 | -25.18  | -5.44            | -26.91                   | 180.44                           | -57.71     | -94.76     |
| 2012Q3      | -620.18   | 8 930.23 | 31.26   | 21.63            | -37.27                   | 111.50                           | 24.39      | -221.86    |
| 2012Q4      | -642.45   | 8 946.28 | 34.55   | 4.29             | -14.42                   | 107.33                           | 62.02      | -199.40    |
| Average Gap | -594.35   | 8 745.36 | 33.43   | 36.10            | -55.55                   | 92.47                            | 35.09      | -211.94    |

Table 15: Imports: Difference between Treated and Synthetic Regions, Post 2010Q3, as measured in thousands of tonnes

| Time Period | Northland | Auckland | Bay of<br>Plenty | Hawke's Bay,<br>Gisborne | Manawatu, Wanganui<br>& Taranaki | Wellington | Canterbury |
|-------------|-----------|----------|------------------|--------------------------|----------------------------------|------------|------------|
| 2010Q3      | 381.42    | 143.27   | 199.40           | -67.31                   | 30.37                            | -46.18     | -86.00     |
| 2010Q4      | 641.54    | 24.59    | -16.89           | -104.39                  | 62.15                            | 17.56      | -39.43     |
| 2011Q1      | 625.81    | 104.13   | 87.94            | -133.27                  | 88.87                            | 8.13       | -160.53    |
| 2011Q2      | 724.27    | 24.01    | 18.45            | -95.81                   | 47.74                            | 30.36      | -75.56     |
| 2011Q3      | 948.16    | -134.25  | 14.69            | -100.53                  | 46.27                            | 38.27      | -61.01     |
| 2011Q4      | 551.80    | -42.78   | 156.71           | -96.91                   | 56.62                            | -1.36      | 42.65      |
| 2012Q1      | 822.34    | -276.73  | 102.33           | -101.25                  | 53.15                            | -2.77      | 188.79     |
| 2012Q2      | 456.29    | 96.95    | 113.28           | -92.67                   | 54.00                            | 57.19      | -33.23     |
| 2012Q3      | 607.14    | -10.13   | 31.29            | -90.27                   | 46.29                            | 2.35       | 88.78      |
| 2012Q4      | 702.19    | -81.05   | -23.14           | -55.94                   | 9.87                             | -85.49     | 130.90     |
| Average Gap | 646.10    | -15.20   | 68.41            | -93.84                   | 49.53                            | 1.81       | -0.46      |

Table 16: Exports: Difference between Treated and Synthetic Regions, Post 2010Q3, as measured in thousands of tonnes

| Time Period | Northland | Auckland | Bay of<br>Plenty | Hawke's Bay,<br>Gisborne | Manawatu, Wanganui<br>& Taranaki | Wellington | Canterbury |
|-------------|-----------|----------|------------------|--------------------------|----------------------------------|------------|------------|
| 2010Q3      | −16.79    | −50.74   | 740.80           | 145.75                   | −11.27                           | −182.16    | 46.49      |
| 2010Q4      | 56.39     | −109.79  | 1 237.00         | 66.97                    | 293.54                           | −236.00    | −59.15     |
| 2011Q1      | 57.34     | −6.29    | 1 412.55         | 287.24                   | 166.34                           | −266.70    | −437.25    |
| 2011Q2      | 133.85    | −48.60   | 1 157.16         | 195.30                   | 318.66                           | −333.20    | −200.86    |
| 2011Q3      | 187.34    | −152.98  | 1 105.78         | 151.25                   | 353.71                           | −402.10    | −81.82     |
| 2011Q4      | 184.54    | −203.29  | 1 323.63         | 133.61                   | 370.14                           | −409.11    | −119.22    |
| 2012Q1      | 212.01    | −415.23  | 1 556.59         | 13.82                    | 500.07                           | −415.15    | −52.58     |
| 2012Q2      | 209.38    | −386.00  | 1 761.96         | 86.25                    | 472.98                           | −433.08    | −209.67    |
| 2012Q3      | 160.29    | −227.66  | 1 803.99         | 145.42                   | 341.96                           | −384.83    | −370.63    |
| 2012Q4      | 278.40    | −415.75  | 1 759.88         | 100.78                   | 474.05                           | −515.99    | −250.41    |
| Average Lag | 146.28    | −218.40  | 1 457.62         | 131.18                   | 365.72                           | −377.35    | −197.95    |