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Can Zoning Reform Increase Housing Construction? Evidence from Auckland

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Abstract

In 2016, Auckland, New Zealand upzoned approximately three-quarters of its residential land. Permits for the construction of new dwellings subsequently reached record highs. In this paper we use a synthetic control method to evaluate the impact of this zoning reform on housing permits. The method compares Auckland to a weighted average of other urban areas that exhibit similar housing market outcomes prior to the policy change. The weighted average, or "synthetic control", provides an estimate of outcomes under the counterfactual of no zoning reform. The synthetic control implies that the zoning reform approximately doubled new dwelling permits per capita within five years of the reform becoming operational. Six years on from the reform, cumulative permits issued exceed those of the synthetic control by approximately 43,500 – forty-five percent of the 97,000 permits issued in Auckland since 2016. These findings add to extant evidence that large-scale zoning reform in Auckland increased new housing starts.

Keywords: Upzoning, Land Use Regulations, Redevelopment, Housing Costs, Permits, Synthetic Controls.

JEL Classification Codes: R14, R31, R52.

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1 Introduction

Zoning reform is increasingly advocated to address housing shortages and unaffordable housing (Glaeser and Gyourko, 2003; Freeman and Schuetz, 2017; Manville et al., 2020). Proponents argue that overly restrictive land use regulations (LURs) in many cities around the world have restrained housing supply and increased housing costs. Relaxing those regulations would consequently enable housing supply through the redevelopment of existing residential parcels into more intensive housing, including plexes, rowhouses and apartments. Many municipal and gubernatorial governments are now implementing zoning reforms to redress housing shortages. Between 2019 and 2023, the states of California, Oregon and Maine, and the cities of Minneapolis, Charlotte and Arlington passed laws to abolish single-family zoning, and a similar bill currently sits before the Washington State Senate.

However, there remains skepticism of the ability of zoning reform to meet stated goals (Rodríguez-Pose and Storper, 2020a; Wetzstein, 2021). Studies on localized upzonings often find muted or no housing supply response (Freemark, 2020; Dong, 2021; Peng, 2023; Stacy et al., 2023), contravening outcomes anticipated by the supply-side argument for reforms (Rodríguez-Pose and Storper, 2020a). Meanwhile, our understanding of the effects of large-scale zoning reforms is presently limited by a lack of empirical research on the subject (Schill, 2005; Freeman and Schuetz, 2017; Freemark, 2019), which is due, in part, to the fact that, until very recently, no city has systematically upzoned large shares of land as a mechanism to promote affordability (Freeman and Schuetz, 2017, p. 229).

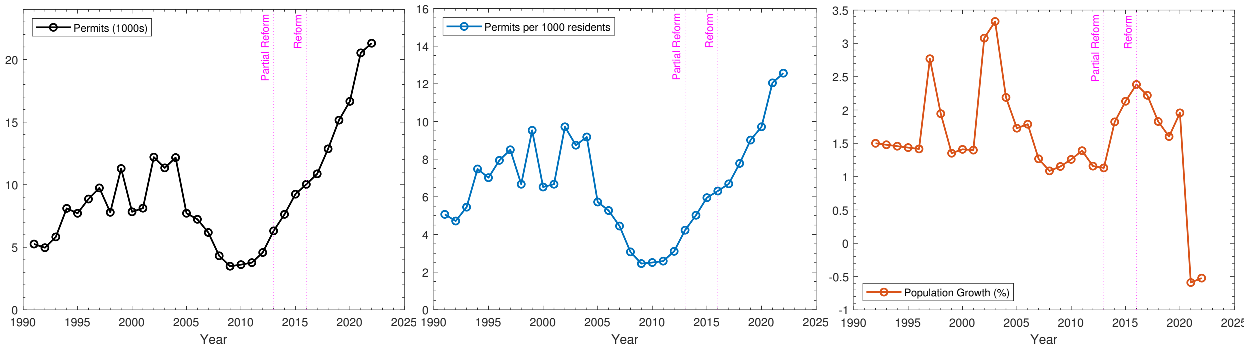
However, in 2016, Auckland, New Zealand, upzoned approximately three-quarters of its residential land under the Auckland Unitary Plan (AUP) (Greenaway-McGrevy and Jones, 2023). Building permits for new dwellings subsequently reached record highs, in both absolute and per capita terms. As illustrated in figure 1, permits increased from approximately 9,200 in 2015, the year prior to the AUP becoming operational, to 21,000 by 2022. Over the same period, permits per thousand residents more than doubled, increasing from 5.95 to 12.57. In total, approximately 97,000 new dwelling permits have been issued over the six years subsequent to the reform. To contextualize the magnitude of this figure, Statistics New Zealand (the nation's statistical agency) estimates that there were 530,000 dwellings in Auckland in 2016, when the reform was implemented.[1]

While new dwelling permits have reached record highs, it remains unknown how various outcomes of interest would have changed under the counterfactual of no policy intervention. In this paper, we assess the impact of the reform by adopting the synthetic control method to specify the counterfactual scenario. The synthetic control is constructed from a donor pool comprised of other commuting zones in New Zealand, and matched to a variety of observed housing market outcomes, including dwellings per capita, personal income, population growth, and the proportion of developable land, which acts as an exogenous mediator of housing supply (Saiz, 2010).

The synthetic control suggests that the reform doubled the rate that new dwelling permits are issued within five years of the policy change. Permits per thousand residents in Auckland

[1]See Table 8 of the experimental dwelling estimates, available at https://www.stats.govt.nz/experimental/experimental-dwelling-estimates/ [accessed 2 September 2023].

Figure 1: New dwelling permits and population in the Auckland region, 1991 to 2022



Source: Author's calculations based on Statistics New Zealand data. Population is estimated resident population, 1996 to 2022. Population figures for 1991 to 1995 imputed using a linear spline on census 1991 and 1996 Auckland region population, obtained from `https://teara.govt.nz/files/g-23512-data.txt`. Notes: Zoning reform was implemented in Auckland in November 2016, with a partial reform operating between September 2013 and November 2016. Refer to section 2 for additional details.

reached 12.1 in 2022, while permits per thousand residents in the synthetic control were 5.9 – approximately the same level in Auckland immediately prior to the reform. Differences between actual and synthetic permits per capita imply that the reform increased the number of permits by 43,500 over six subsequent years. This means that about forty-five percent of the 97,000 permits issued since 2016 are attributable to the reform, or equivalently that the reform increased permits by 82% over this period.

To assess the statistical significance of these increases, we apply the conventional rank permutation test to the ratios of post- to pre- intervention root mean square errors (RMSEs, Abadie et al. 2010). Auckland has the largest ratio among all 52 placebos. Thus, if one were to assign the intervention at random, the probability of obtaining a ratio as large as Auckland's is 0.019 (= 1/52).

The finding that large-scale zoning reform can enable housing supply is important. While researchers have advocated for large-scale zoning reform as a means to redress housing shortages, studies that focus on localized (or "spot") upzonings typically show muted effects on housing supply (Dong, 2021; Peng, 2023), or no effect at all (Freemark, 2020), casting doubt on the ability of zoning reform to meet intended objectives (Rodríguez-Pose and Storper, 2020b). Recently, Stacy et al. (2023) examine over fifty upzonings in various cities in the U.S., finding small effects on housing construction and costs. Meanwhile, early research indicates that some of the recent large-scale reforms in the United States have not enabled significant housing supply (Garcia and Alameldin, 2023).[2] Results from the present synthetic control approach indicate that the large-scale zoning reform undertaken as part of the Auckland Unitary Plan did enable a substantial amount of housing

[2]Also see the "Minneapolis Housing Indicators Dashboard" at `https://minneapolisfed.shinyapps.io/Minneapolis-Indicators/` [accessed 7 September 2023]. To evaluate the 2019 Minneapolis zoning reform, the Federal Reserve Bank of Minneapolis compares multifamily housing permits to a synthetic control, finding no statistically significant increase as of 2022.

construction, suggesting that such reforms can succeed, and thereby play a role in redressing housing shortages and unresponsive housing supply.

Our measure of construction is based on new dwelling permits issued, and it is important to note that this is not a measure of completed dwellings. However, Statistics New Zealand produces experimental estimates based on administrative data that indicate completion rates in the country are typically in excess of 90%, depending on how a completed dwelling is defined. New dwellings are also not a measure of the change in the housing stock. Redevelopment of parcels often requires an existing dwelling to be demolished or relocated. Further details are provided in section 3 below.

The synthetic control method has been applied to evaluate policies in a variety of contexts (see Abadie (2021) for a comprehensive review), and was recently described by Susan Athey and Guido Imbens as "arguably the most important innovation in the policy evaluation literature in the last 15 years" (Athey and Imbens, 2017). We take several steps to ensure that our research design and implementation is robust to common pathologies. First, we use the longest possible times series on outcomes prior to intervention in order to minimize bias in the synthetic unit (Abadie et al., 2010). Our time series on new dwelling permits spans 1991, when the available permit data begin, to 2022, with the intervention occurring in 2016. Second, we consider whether inter-regional displacement from the synthetic control to Auckland as result of the reform is biasing estimated policy impacts upwards. To so, we estimate a set of auxiliary synthetic controls for the selected donors that constitute Auckland's synthetic control. This allows us to see whether there is any evidence that the zoning reform in Auckland caused a sustained reduction in the permitting rate of the donors. Based on the results of this exercise, we argue that displacement effects are negligible, if present. Third, the directional impacts of our findings are robust to various permutations of our modeling choices, including the incorporation of Australian regions in the donor set, although there is variation in the magnitude of the estimated impacts in terms of the number of new dwelling permits created by the policy. Fourth, our findings are largely unaffected by the "leave one out" robustness check (Abadie et al., 2010), whereby units from the donor pool are iteratively removed from the sample while the procedure is repeated.

The effects of zoning reform on housing and urban development remains an important but regrettably understudied topic, with only a handful of studies focusing on what happens after land use regulations (LURs) are relaxed. Freemark (2020) shows that transit-oriented upzoning in Chicago failed to stimulate construction, while Peng (2023) shows that housing supply responded slowly to a sequence of localized upzonings in New York. Dong (2021) finds that localized upzonings in Portland approximately doubled the long-term probability of parcel development, but the number of new units constructed remains small. Buechler and Lutz (2021) examine a sequence of spot upzonings in Zurich, and find that a 10% increase in zoned capacity leads to a 1.2% increase in housing supply after five years. In recent work, Stacy et al. (2023) show that various reforms in US cities between 2000 and 2019 generated negligible increases in housing supply, on average. Studies on large-scale zoning reforms are more rare. Gray and Millsap (2020) show that the city-wide reduction in minimum lot sizes in Houston preceded an increased concentration of development activity in middle-income, less dense, under-built neighborhoods. Houston now issues building permits at a much higher per capita rate than other US cities (Gray, 2022). Anagol et al. (2021) examine a large-scale increase in built-area-ratios in São Paulo, and find that the reform led to a 2.2 percent increase in the housing stock. In work related to the present paper, Greenaway-McGrevy and Phillips (2023) show that the AUP generated a significant increase in housing construction using a modified difference-in-differences approach that compares changes in permits in upzoned and non-upzoned residential areas within Auckland. The salient feature of their framework is that it accounts for displacement from control (non-upzoned) to treatment (upzoned) areas, which would otherwise generate an overstatement of policy effects if unaccounted for. This is achieved by specifying a set of counterfactual outcomes around an extrapolated pre-treatment trend in the control group. Causal inference then proceeds via set identification of treatment effects that compares observed outcomes in the treatment group (upzoned areas) to the counterfactual sets. One drawback of this approach is that point estimates of the net impact of the policy can only be obtained by restricting the counterfactual sets to a linear sequence of points. The linear counterfactual is highly restrictive (Greenaway-McGrevy and Phillips, 2023, pp.13–14), and is likely to be inaccurate at longer time horizons, particularly as the construction cycle begins to slow down. The synthetic control offers a substantially more flexible counterfactual scenario that is informed by construction activity in similar donor units. By adopting a between-city quasi-experimental framework, the method employed herein can account for within-city displacement effects and provide a more credible point-estimated counterfactual scenario.

The remainder of the paper is organized as follows. The following section provides the institutional details of Auckland's zoning reform. Section three describes the data. In section four presents the method and results. Section five concludes.

2 Institutional Background

Auckland in the largest city in New Zealand, with rapidly growing population that increased from 1.16 million in 2001 to of 1.57 million in 2018 (source: New Zealand census). Centered on an isthmus between two harbors, the entire metropolitan region, as well as large amounts of outlying rural land and offshore islands fall under under the jurisdiction of a single local government, the Auckland Council.

Prior to 2010, the region comprised seven different city and district councils, each with their own planning regulations. The councils were amalgamated through an Act of Parliament,[3] and the newly-formed Auckland Council required to create a consistent set of planning rules for the region.[4] In March 2013, Auckland Council announced the first version of the "Auckland Unitary Plan" (AUP), which introduced a standardized set of planning zones for the jurisdiction. After several rounds of reviews and consultation, the plan was functionally operationalized in November 2016. Approximately three-quarters of residential land was upzoned under the final version of the

[3] *The Local Government (Auckland Council) Act 2009.* https://www.legislation.govt.nz/act/public/2009/0032/latest/DLM2044909.html [accessed 14/03/2023]

[4] *The Local Government (Auckland Transitional Provisions) Act 2010.* https://www.legislation.govt.nz/act/public/2010/0037/latest/DLM3016607.html [accessed 22/03/2023]

plan, in the sense that the FAR restrictions implied by height and site coverage limits on housing development were relaxed (Greenaway-McGrevy and Jones, 2023). Figure 2 illustrates the spatial distribution of upzoned and non-upzoned residential areas of the city, with the upzoned residential areas decomposed into zones that differ in permissible site development. A detailed timeline of key events leading up to the reform can be found in the Appendix. For additional details on the implementation of the plan and information on the spatial distribution of upzoning, see Greenaway-McGrevy and Jones (2023).

The AUP introduced four new residential zones to the city. Listed in declining levels of permissible site development, these were: Terrace Housing and Apartment Buildings (THA); Mixed Housing Urban (MHU); Mixed Housing Suburban (MHS); and Single House (SH).[5] Table 3 in the Appendix summarizes the various land use regulations (LURs) that apply in each zone, including site coverage ratios, height restrictions, setbacks, and building envelopes, among others. For example, five to seven storeys and a maximum site coverage of 50% is allowed in THA, whereas only two storeys and 35% site coverage is allowed in SH. Prior to the AUP, the planning rules for the Auckland region were governed by the seven different city and district councils that were amalgamated to form the single jurisdiction in 2010. Although most of the seven different plans allocated some residential land to medium density housing, the aggregate area covered was severely limited. Over 95% of residential land in the Auckland region was zoned for site development that was similar to what the SH zone now allows (Greenaway-McGrevy and Jones, 2023). Under the AUP, the SH zone only covers about twenty five percent of residential land, mainly at the periphery and the inner suburbs (with the latter often under character neighborhood protection).

Although the AUP was implemented in 2016, an interim agreement between the Auckland Council and the central government allowed developers to build to the rules of the "Proposed Auckland Unitary Plan" (PAUP), notified in September 2013.[6] This agreement modified a national inclusionary zoning program called "Special Housing Areas" (SpHAs, also launched in September 2013) that offered developers an accelerated permitting process in exchange for a ten percent affordable housing provision in the development.[7] The program ended once the AUP was implemented. Thus, while the AUP was formally operationalized in 2016, it began to have a limited effect from September 2013 onwards because SpHA developments fell under the more relaxed LURs of the PAUP. Outside of Auckland, the SpHA program operated until November 2019, and was not implemented in conjunction with zoning reform.

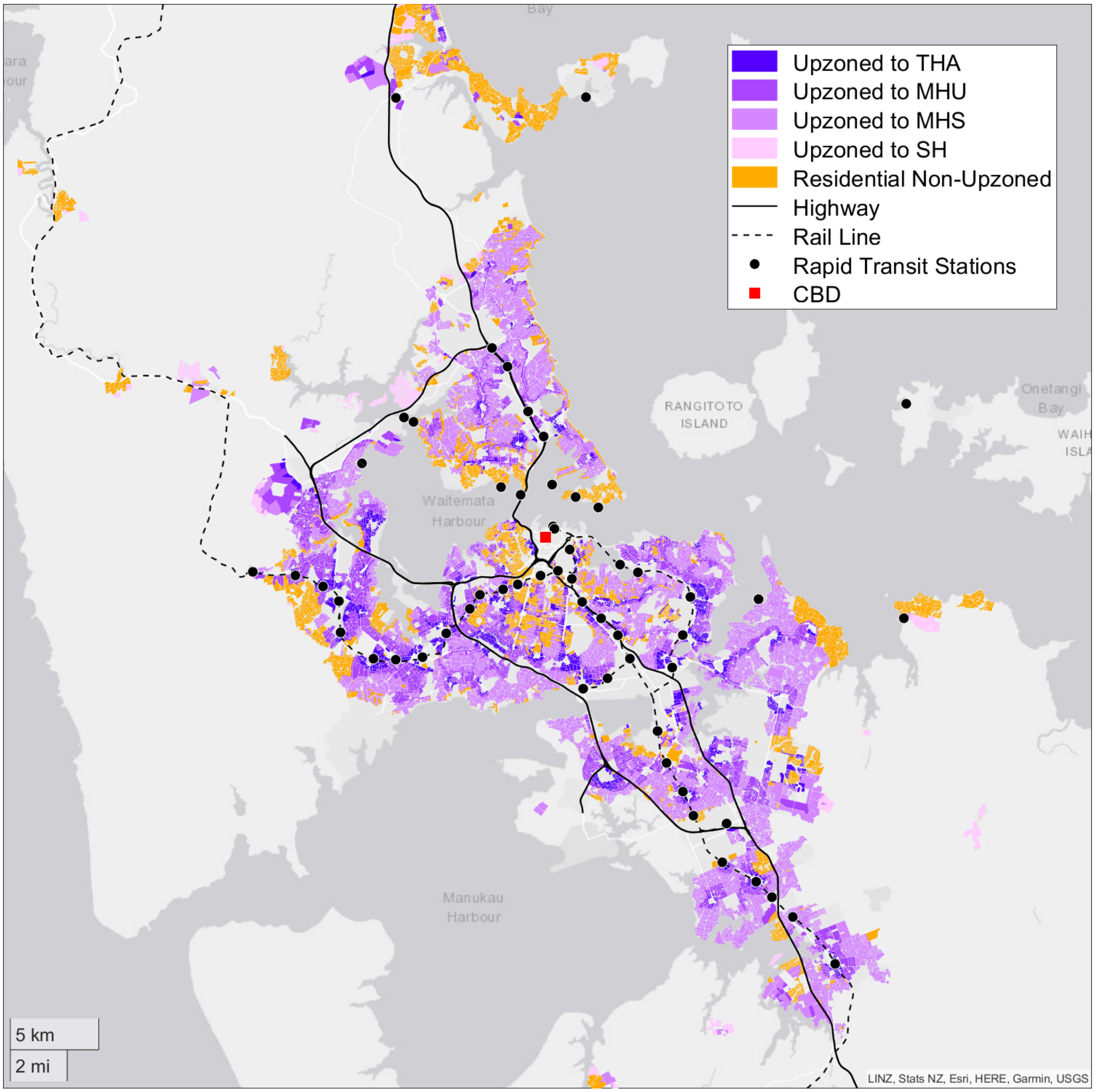
Data on new dwelling permits suggests that housing supply quickly responded to the reform. Figure 3 exhibits annual permits issued per year, decomposed into permits issued in upzoned and non-upzoned areas (including business and rural areas). Permits for new dwellings significantly increased year-on-year from 2016 onwards, with all of the new construction occurring in upzoned

[5] There are two additional zones in the AUP that are classified as "Residential": "Large Lot" and "Rural and Coastal Settlement". These areas are an intermediate, semi-rural zone between outright rural and urban housing areas. Residential land on inhabited islands have their own unique zoning.

[6] The Auckland Housing Accord (AHA). See https://www.beehive.govt.nz/sites/default/files/Auckland_Housing_Accord.pdf

[7] The "Housing Accords and Special Housing Areas Act 2013" (HASHAA). See https://www.legislation.govt.nz/act/public/2013/0072/latest/DLM5369001.html

Figure 2: Upzoned and non-upzoned residential areas in Auckland



Source: Greenaway-McGrevy and Jones (2023). Notes: Rapid Transit stations include heavy rail stations, dedicated busway stations, and ferry terminals. The CBD marker is centered on Auckland's iconic 'Sky Tower' skyscraper. Water in grey. Business and rural areas not depicted, including business areas rezoned from residential or rural. Areas upzoned to Single House (SH) were previously zoned as rural or semi-rural.

areas. There is some evidence of policy "leakage" as developers took advantage of the relaxed regulations under the PAUP from 2013 onwards. Figure 20 in the Appendix exhibits permits issued in SpHA areas that were upzoned and not upzoned, and shows that PAUP-SpHA permits were disproportionately located in upzoned areas.

For the purposes of the synthetic control exercise, we use 2016 as the date of the policy intervention. Although developers could access the upzoned land use regulations through the special housing area program from September 2013, figure 3 suggests that the zoning reform began to have a significant impact after 2016, as evidenced by the dramatic divergence in permitting activity in upzoned and non-upzoned areas from this point in time. However, 2012 or 2013 could also feasibly be used as the intervention date. We use 2013 in a set of robustness checks. Specifications with an earlier intervention date generally result in larger estimated policy impacts, although there is a greater variance across different model specifications. These results are discussed in section 4.4.2.

3 Data

Our outcome of interest is new dwelling permits per thousand residents, which we refer to as the "permitting rate". Normalizing the flow variable (permits) by a measure of stock (population) facilitates comparability between different urban areas.[8]

We use Functional Urban Areas (FUAs) as the geographic units of analysis. These areas are delineated by Statistics New Zealand on the basis of commuting patterns, and are analogous to commuting zones as defined by the OECD.[9] There are 53 FUAs in New Zealand, including Auckland. We omit Christchurch from the donor set due to the effects of the 2011 Christchurch earthquake, which generated a substantial idiosyncratic shock to the housing market as a substantial proportion of the housing stock was demolished and subsequently rebuilt. As noted by Abadie (2021), donor units subjected to large idiosyncratic shocks to the outcome variable during the study period should be omitted (p. 409). This leaves 52 FUAs.[10] For clarity, we henceforth drop the "functional" descriptor and refer to "urban areas" (UAs).

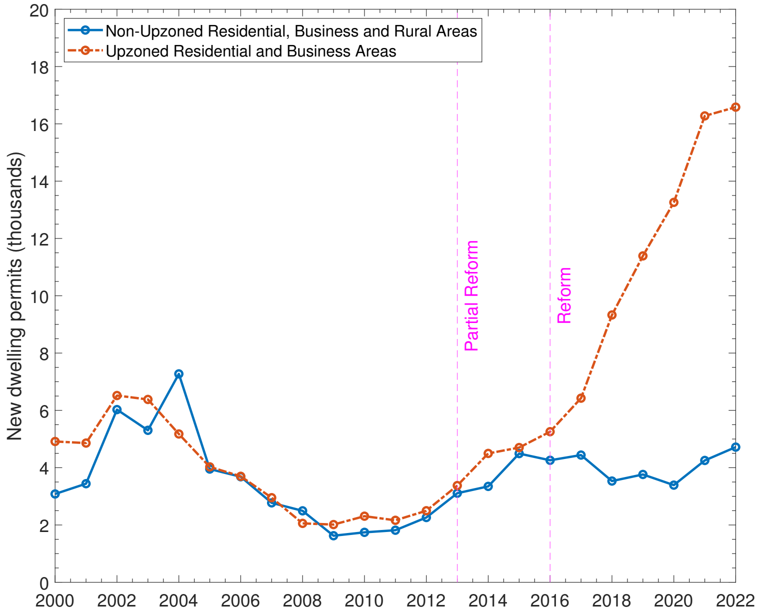
New residential dwelling permits and estimated population by UA were obtained from Statistics New Zealand. Population estimates are as of June of the reference year. Permit data begin in 1991 and end in 2022. Estimated population data begin in 1996. We backcast and linearly interpolate estimated population data using the growth rate in the resident population of the UAs between

[8]Permits per existing dwelling could also be used as a measure of the permitting rate. Unfortunately Statistics New Zealand does not produce estimates of dwellings between census years. Censuses usually occur every five years. The 2011 census was delayed until 2013 due to earthquakes in Christchurch in 2011.

[9]See https://www.stats.govt.nz/assets/Methods/Functional-urban-areas-methodology-and-classification.pdf [accessed 05/09/2023]

[10]Lower Hutt, which is a city council that sits within the Wellington urban area, upzoned under "district plan change 43", which became operative in part on 9 April 2020, and fully operative from 23 February 2021. See https://www.huttcity.govt.nz/council/district-plan/district-plan-changes/completed-district-plan-changes/residential-and-suburban-mixed-use [accessed 5 September 2023]. We keep Wellington in the donor pool since Lower Hutt constitutes a small proportion of the greater Wellington region, and the zoning reform occurs rather late in the sample period. In future updates of this work it may become important to remove Wellington from the donor pool.

Figure 3: New dwelling permits in Auckland region by 2016 zoning change



Notes: New dwelling permits in areas that were upzoned and were not upzoned in 2016 under the AUP. The first, "draft", version of the AUP was announced in March 2013, while the "Proposed" AUP (PAUP) was notified in September 2013. Partial zoning reform were implemented in September 2013 under the Auckland Housing Accords. Between September 2013 and November 2016, Special Housing Area (SpHA) developments could build to the regulations of the PAUP in exchange for affordable housing provisions. Full reform occurred in November 2016 when the final version of the AUP became operative. Source: Author's calculations based on individual permits matched to planning zones. See the Appendix for a description of the geomatching algorithm. Upzoning classification is based on comparing floor-to-area (FAR) ratios implied by height and site coverage restrictions before and after the policy change. See Greenaway-McGrevy and Jones (2023) for additional details.

the 1991 and 1996 censuses.

Permits are not a measure of completed dwellings. However, unless there is a substantial systematic difference in completions between Auckland and its weighted average of donor units, relative (as opposed to absolute) estimates of policy impacts will reflect changes in completed dwellings. For example, suppose that 7,500 dwelling permits are issued in Auckland, while 5,000 are issued in the synthetic control. If completion rates are the same in Auckland and its donor units, then there has been a 50% increase in both permits and completed dwellings (relative to the counterfactual of no reform). Completion rates are, however, important for measuring policy impacts in absolute terms. Unfortunately the institutional features of data collection in New Zealand make it difficult to measure completions. Aggregate data on completions at the regional level, including Auckland, are unavailable. Statistics New Zealand (SNZ) publishes experimental estimates of completions for the country as a whole, however many areas of the country are not covered. Currently SNZ uses the issuance of a "code of compliance certificate" (CCC) as an indicator of completion. For the subset of areas covered, SNZ experimental estimates show that the proportion of permits that received a CCC over the ten years to December 2018 was 91.2%, on average.[11] However, using CCC issuance understates completions to a habitable standard since dwellings can be occupied without a CCC. Using the final building inspection as a measure of completion results in a rate of 92.9% over the ten years to December 2018. Legacy surveys typically imply higher completion rates. Until 2017, SNZ surveyed developers to measure completions, resulting in a completion rate above 95% in recent years.[12] [13]

3.1 Comparing Auckland's Permitting Rate to Other Urban Areas

Figure 4 exhibits the permitting rate in the Auckland urban area between 1991 and 2022. For comparative purposes, in the top panel of the figure we include the average and range of the permitting rates for all other "metropolitan" and "large" urban areas of the country.[14] As described below in section 4.1, this group of urban areas comprises the set of donors used to construct the synthetic control for Auckland. As such, we refer to it as the "donor pool".

Auckland's permitting rate varies between six and ten permits per thousand residents from the

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[11]See `https://www.stats.govt.nz/experimental/experimental-building-indicators-march-2022-quarter/` [accessed 05/09/2023].

[12]See `https://www.stats.govt.nz/experimental/experimental-dwelling-estimates/` [accessed 5 September 2023].

[13]New dwellings are also not a measure of the change in the housing stock, as parcel redevelopment often requires an existing dwelling to be demolished or relocated. Unfortunately, assessing the impact of the reform directly on the dwelling stock is difficult, because New Zealand lacks accurate measures of the number of dwellings demolished or removed from redeveloped sites. There is no administrative record of demolitions, as dwellings less than three storeys do not require a permit in Auckland. Relocations require a new dwelling permit at the new site, but not from the local council where the dwelling originated.

[14]See figure 19 in the Appendix for the location of these urban areas. Statistics NZ classifies FUAs as either "metropolitan", "large", "medium" or "small" according the population of the "urban core". FUAs that have more than 100,000 residents living in their urban core are known as metropolitan areas, while smaller FUAs are divided into large (core population 30,000–99,999), medium (core population 10,000–29,999), and small regional centers (core population 5,000–9,999). See https://www.stats.govt.nz/methods/functional-urban-areas-methodology-and-classification#appendix-3 [accessed 5 September 2023].

mid-nineties through to the early-2000s. It's high permitting rate in the early 2000s is driven, in part, by a construction boom in business areas and the central business district (see figure 21 in the Appendix). Auckland's permitting rate was above average but in the middle of the range of donor pool over this period. Its permitting rate then declines dramatically from 2004 onwards, falling below the average in 2005, and attaining a low of approximately two-and-a-half between 2009 and 2011.[15] Over this period, Auckland's permitting rate sits near the bottom of the donor pool. From 2011 onwards there is a sustained increase each year. From 2020 to 2022, Auckland's permitting rate altogether exceeds the range of the donor pool. By 2022, its permitting rate of 12.7 is approximately 30% more than the highest permitting rate of 9.7 in the donor pool, held by Whangārei, a city 131 km north of Auckland (as the crow flies) with a population of 87,000 in the urban area.

The bottom panel of figure 4 exhibits Auckland alongside the other metropolitan urban areas of the North Island of New Zealand, namely Hamilton, Tauranga and Wellington. These cities are selected purely for expositional purposes: In the analysis to follow we use the synthetic control method to select donors. By 2020, Auckland's permitting rate had increased to the point where is exceeded that of Tauranga, which had been the fastest growing metropolitan area over the previous three decades.

3.2 Matching Variables

As we discuss in more detail in section 4.1, the synthetic control method selects comparable donors for the control by matching outcomes prior to the policy intervention. These outcomes can include the outcome of interest (in our application, permits per thousand residents), but typically also include other outcomes related to the policy of interest. Here we describe the additional matching variables used in our application, all of which are related to housing market outcomes.

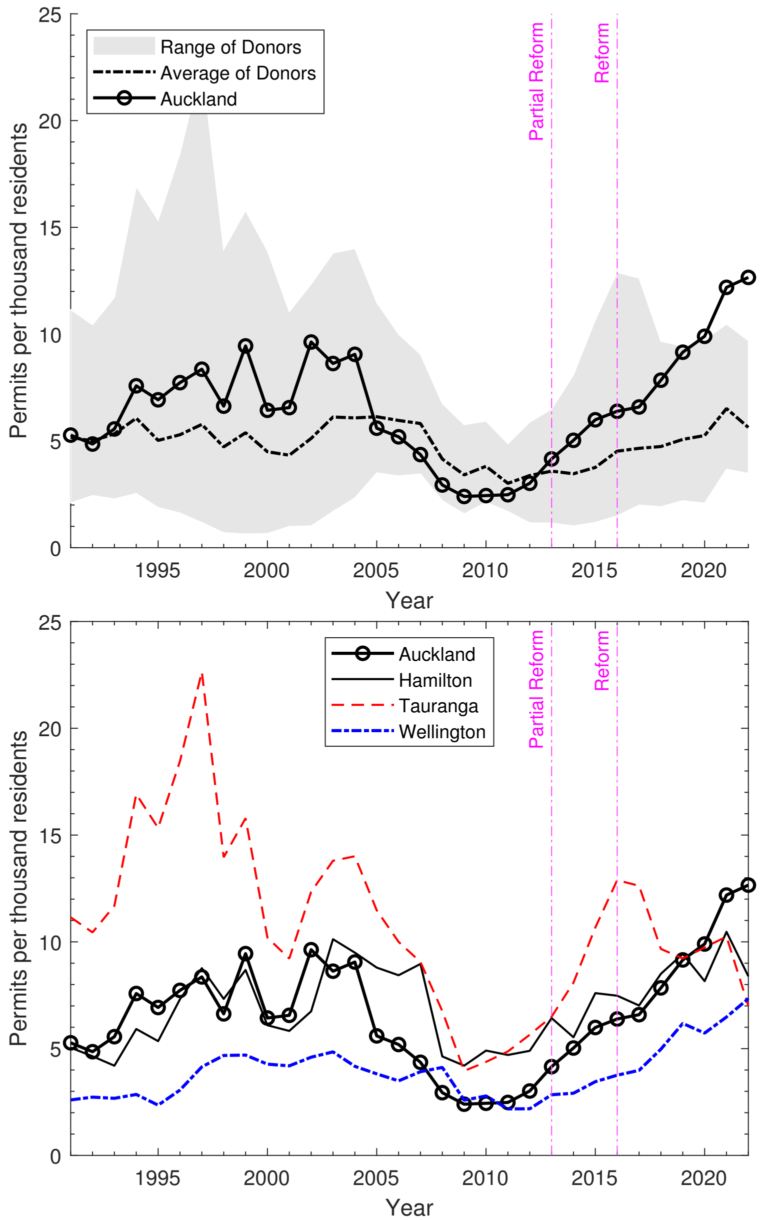
Population growth. This is the log difference of the urban area's estimated population in census years. Censuses occur in 1991, 1996, 2001, 2006, 2013 in the pre-reform period of the sample. There is also a census in 2018.

Dwellings per capita. This is the number of occupied dwellings in the urban area divided by the usually resident population of the urban area. Both measures are obtained from census data. The measure is obtained for the pre-reform census years (1991, 1996, 2001, 2006, 2013).

Household income. We obtain the average personal income (from all sources) for the census years of 2001, 2006 and 2013 by urban area from Statistics New Zealand. Personal income data for earlier census years is unavailable.

[15] Figure 21 in the Appendix shows that a large proportion of the permits issued in the early 2000s were in business areas, reaching a high of 36% in 2004.

Figure 4: New dwelling permits per thousand residents in Auckland and other urban areas, 1991–2022



Source: Author's calculations based on Statistics New Zealand (SNZ) data. Notes: Urban areas are commuting zones as defined by Statistics New Zealand. Average of donors taken across all urban areas in the donor pool as described in section 4.1. Shaded region denotes the range between the minimum and maximum permits per thousand residents among the donor pool. "Partial Reform" refers to the Proposed Auckland Unitary Plan (PAUP), notified in September 2013. Developments that qualified as "Special Housing Areas" could build to the regulations under the PAUP in exchange for ten percent of the development to qualify as affordable housing. "Reform" refers to the Auckland Unitary Plan, which became operational in November 2016.

Developable land. We calculate the proportion of the area within 25 kilometers of the center of the urban area that is land under a 10 degree slope. We take the location of the local council office as the center. This variable acts as an exogenous restriction on housing supply. Saiz (2010) uses land under a 15% slope as an exogenous instrument for housing supply as such land can be easily developed. Ten degrees corresponds to 17.6% slope.

4 Synthetic Control Method and Results

This section outlines the synthetic control method, including details on the selection of comparable donors for Auckland. It then presents results.

4.1 Synthetic Control Method

We have time series data on an outcome of interest for $N+1$ units indexed by $i = 1, ..., N+1$, where $i = 1$ corresponds to the unit receiving the policy intervention, and $i = 2, ..., N+1$ indexes the "donor pool", a collection of untreated units that is unaffected by the intervention. Observations on the outcome of interest span $t = 1, ..., T$, where the observations prior to intervention span $t = 1, ..., T_0$ and $T_0 < T - 1$. Outcomes and matching variables are logged prior to analysis.

$y_{i,t}$ denotes the observed outcome of interest for unit i in period t. A synthetic control is defined as a weighted average of the units in the donor pool. Given a set of weights $w = (w_2, ..., w_{N+1})$, the synthetic control estimator of $y^N_{1,t}$ is $\hat{y}^N_{1,t} = \sum_{i=2}^{N+1} w_i y_{i,t}$. Let $y^N_{i,t}$ be the outcome without intervention for each i, while $y^I_{1,t}$ is the outcome under the intervention for the affected unit in period $t > T_0$. The effect of the intervention is then $y^I_{1,t} - \hat{y}^N_{1,t}$.

Abadie and Gardeazabal (2003) and Abadie et al. (2010) choose $\boldsymbol{w}$ so that the resulting synthetic control best resembles a set of pre-intervention "predictors" for the treated unit. (In section 3.2 we referred to these as "matching variables".) For each i, there is a set of k observed predictors of $y_{i,t}$ contained in the vector $X_i = (x_{1,i}, ..., x_{k,i})$, which can include pre-intervention values of $y_{i,t}$ unaffected by the intervention. The $k \times N$ matrix $\boldsymbol{X}_0 = [X_2 \cdots X_{N+1}]$ collects the values of the predictors for the N untreated units. Abadie and Gardeazabal (2003) and Abadie et al. (2010) select weights $w^* = (w^*_2, ..., w^*_{N+1})$ that minimize

$$\|X_1 - \boldsymbol{X}_0\boldsymbol{w}\|_{\boldsymbol{v}} = \left(\sum_{h=1}^{k} v_h \left(x_{h,1} - w_2 x_{h,2} - ... - w_{N+1} x_{h,N+1}\right)^2\right)^{1/2} \tag{1}$$

subject to the restrictions $w_i \in [0, 1]$ and $\sum_{i=2}^{N+1} w_i = 1$, and where $\boldsymbol{v} = (v_1, ..., v_k)$ is a set of non-negative constants. Following Abadie et al. (2010), we choose $\boldsymbol{v}$ to assign weights to linear combinations of the variables in $\boldsymbol{X}_0$ and X_1 that minimize the root mean square error (RMSE) between the synthetic control and the outcomes of the treated unit over the pre-treatment period. This helps ensure that the synthetic control time series tracks outcomes in the outcome variable prior to the intervention. Then, the estimated treatment effect for the treated unit at time $t = T_0 \ldots, T$ is $\hat{y}^N_{1,t} = \sum_{i=2}^{N+1} w^*_i y_{i,t}$.

Weights $\boldsymbol{w}$ that minimize (1) can found using standard quadratic programming solvers. To select $\boldsymbol{v}$ in the nested RMSE-minimization problem, we use Evolution Strategy with Covariance Matrix Adaptation (CMA-ES), which is a stochastic optimization algorithm for solving difficult optimization problems (Hansen, 2016). It exhibits strong invariance properties (Hansen et al., 2011), is robust to highly non-linear, non-quadratic, non-convex, non-smooth and/or noisy objective problems (Hansen, 2006), and can tackle ill-conditioned optimization problems (Jones, 2021).[16] It is considered a state of the art evolutionary optimizer (Li et al., 2020).[17]

We employ a "hierarchical" restriction of the donor pool for each urban area based on Statistics New Zealand categories of the size of the commuting zone. Statistics New Zealand categorizes urban areas as either "metropolitan", "large", "medium" or "small", depending on size (see footnote 14). "Metropolitan" consists of six urban areas; "large" consists of eleven; and "medium" a further fourteen. The remainder are "small". Under hierarchical selection, major areas have their donor pool restricted to other metropolitan and large urban areas. This means that Auckland's donor pool incorporates the four other metropolitan areas (Hamilton, Tauranga, Wellington and Dunedin, since Christchurch is excluded), as well as proximate large urban areas such as Whangārei and Rotorua. For placebo tests (see section 4.3), large urban areas have their donor pool restricted to metropolitan, large and medium urban areas. Medium and small urban areas do not have their donor sets restricted. Figure 19 in the Appendix presents the location of the metropolitan and large urban areas, while Table 4 presents their key statistics.

In our baseline empirical specification, we include all pre-treatment realizations of the outcome variable, permits per thousand residents, in the set of matching variables. As discussed in Abadie et al. (2010) and Abadie (2021), increasing the pre-intervention time period T_0 reduces the bias in the synthetic control. We also subtract the pre-treatment average from the time series of outcomes prior to implementation (Ferman and Pinto, 2021). We do this for two reasons. First, Abadie (2021) emphasizes that the validity of the synthetic control hinges on its ability to replicate the treated unit's outcome prior to the intervention. De-meaning the outcome variable can allow the comparison group to reproduce the changes in outcomes for the treated unit even if the level of the outcome variable cannot be reproduced (Abadie, 2021, pp. 411–412). As we show in the Appendix, this de-meaning normalization results in substantial reductions in pre-treatment RMSE, suggesting that it is useful in our application. This is due, in part, to Auckland exhibiting the near-lowest permitting rate among donors between 2009 and 2011: In 2009, its permitting rate of 2.40 permits per thousand residents is only larger than that of Dunedin; while in 2010, its permitting rate of 2.44 is only larger than that of Whanganui. Second, our method for identifying displacement effects is based on whether the intervention in Auckland has a clear and persistent impact on its selected

[16] Ill-conditioning refers to when there is a large change in the objective function in response to a small change in arguments. This is possible in the current application because the weights are selected via a quadratic programming problem that sets weights to zero on the majority of donor units.

[17] We adapt the Matlab version of the Synth package provided by Jens Hainmueller (available from `https://web.stanford.edu/~jhain/synthpage.html`) to incorporate CMA-ES minimization of nested RMSE objective function, using the cmaes.m matlab code provided by Nikolaus Hansen (available from `http://cma.gforge.inria.fr/cmaes.m`) CMA-ES generated reductions in the nested RMSE objective function. It also improved the RMSE of Hainmueller's synth STATA package, though the obtained weights for our baseline models were similar under both approaches.

donor units (see section 4.4.1). This requires the synthetic control method to satisfactorily fit pre-treatment outcomes in Auckland's donor units as well. One the selected donors for Auckland – Tauranga – has the highest permitting rate among donors over the 1991 to 2020 period (see figure 4 above), making it difficult for the synthetic control to match these outcomes without de-meaning. Pre-treatment model fit for this and other donors is substantially improved when the de-meaning normalization is employed.[18]

4.2 Results and Policy Impacts

Table 1 exhibits the selected weights for the donor units. Our preferred empirical specification places a weight of 0.574 on Tauranga, 0.211 on Kāpiti Coast, 0.118 on Wellington, and 0.098 on Hamilton. Tauranga is a major urban area 150 km south east of Auckland (as the crow flies) with an estimated population of 156,666 within the urban area as of the 2018 census. Wellington is a major urban area located 800 km south of Auckland with a population of 422,427 in the urban area. It also contains the capital of the nation, Wellington City. Hamilton is another major urban area 140 km south of Auckland with an estimated population of 209,970. Finally, Kāpiti Coast is a large urban area 750 km south of Auckland with an estimated population of 46,839 in 2018. It is contiguous to the Wellington urban area, but constitutes its own commuting zone as approximately 70% of employed residents work within the urban area.

Table 2 exhibits Auckland's matching variables and those of synthetic Auckland. We include the average of the donor pool for comparison. Population growth and personal income are matched reasonably well. Dwelling per capita are lower in Auckland than its synthetic counterpart. This may reflect regional differences in preferences over family sizes, as Auckland is more ethnically diverse than the rest of the country. Finally, the proportion of developable land is somewhat well matched, with Auckland's figure exceeding that of its synthetic counterpart by approximately 14

[18]Section 6.5.1 in the Appendix presents results when the de-meaning normalization is not employed, and shows that results are similar to when the normalization is employed.

Table 1: Selected weights

Urban Area	Weight	Urban Area	Weight
Hamilton	0.098	Napier	0
Tauranga	0.574	Hastings	0
Wellington	0.118	Whanganui	0
Dunedin	0	Palmerston North	0
Whangārei	0	Kāpiti Coast	0.211
Rotorua	0	Nelson	0
Gisborne	0	Invercargill	0
New Plymouth	0		

percentage points. Because the inner loop of the synthetic control method minimizes RMSE prior to the intervention, dwellings per capita and the proportion of developable land are not useful in explaining variation in permitting rates prior to the reform.

Figure 5 exhibits the actual and synthetic permitting rate (i.e., permits per thousand residents) for Auckland over the 1991 to 2022 period. The model fits well prior to intervention, apart from a period in the early 2000s, when the permitting rate exceeds its synthetic counterpart for four consecutive years. This period is characterized by unusually high levels of dwellings constructed in business areas and the central business district (see figure 21 in the Appendix), and may prove difficult for donors to match this construction boom. Also, the synthetic permitting rate permanently falls below the actual rate from 2014 onwards, prior to intervention, perhaps reflecting "policy leakage" of the SpHA-PAUP program (see section 2).

There is a notable divergence from 2016 onwards, when the reform is implemented, with permits per thousand residents growing very quickly, while its synthetic counterpart remains at pre-intervention levels. Within five years of the zoning reform, the permitting rate is more than double what they would have been in the absence of the policy. Permits per thousand residents reach 12.1 in 2021, while synthetic permits per thousand residents is 5.9. There is also a noticeable decrease in the synthetic permitting rate between 2021 and 2022, from 5.9 to 4.4. Over this period, the nation's central bank swiftly increased interest rates from record lows to combat emergent inflation, and the economy entered a technical recession in the first two quarters of 2023. While the rate of growth in the permitting rate for Auckland slows down significantly, there is still a mild increase from 12.1 permits per thousand residents in 2021, to 12.7 in 2022.

Next we consider the impact of the policy on new building permits (as opposed to permits per thousand residents). To calculate the counterfactual change in permits, we multiply the synthetic permits per capita by population implied by synthetic population growth after the policy intervention. That is, synthetic permits are

$$\hat{c}_{1,t}^N = \hat{y}_{1,t}^N + \hat{\mu}_1 - \hat{p}_{1,t}^N \tag{2}$$

where c denotes (log) permits, p denotes (log) population, $\hat{\mu}_1$ is the pre-treatment mean of outcomes (permits per thousand residents) for the treated unit, and

$$\hat{p}_{1,t}^N = \hat{p}_{1,t}^N - \hat{p}_{1,T_0}^N + p_{1,T_0}^N$$

where $\hat{p}_{1,t}^N = \sum_{i=2}^N w_i p_{i,t}$ for $t > T_0$ and $\hat{p}_{1,t}^N = p_{1,t}$ for $t \leq T_0$.[19]

Figure 6 exhibits actual and synthetic permits. A total of 96,842 new dwelling permits were issued in Auckland between 2017 and 2022 (inclusive), while 53,330 new dwelling permits were issued in the synthetic Auckland. The difference of 43,512 is attributable to the policy interven-

[19] We obtain very similar time series of synthetic permits when actual population $p_{1,t}$ is used in place of $\hat{p}_{1,t}^N$ in (2) or when weights are applied directly to de-meaned permits, i.e. $\hat{c}_{1,t}^N = \sum_{i=2}^N w_i c_{i,t} + \hat{\mu}_{c,1}$, where $\hat{\mu}_{c,1}$ is the pre-treatment mean of permits for the treated unit.

Table 2: Matched variables

Variable	Auckland	Synthetic Auckland	Average of Donors
Personal Income ($), 2013	30,200	28,872.88	27,744.26
Personal Income ($), 2006	27,200	24,504.96	23,417.84
Personal Income ($), 2001	21,500	18,433.63	17,595.20
Dwellings per capita, 2013	0.332	0.396	0.389
Dwellings per capita, 2006	0.338	0.397	0.385
Dwellings per capita, 2001	0.343	0.395	0.384
Dwellings per capita, 1996	0.334	0.383	0.368
Dwellings per capita, 1991	0.345	0.381	0.365
Population growth, 2006 to 2013	0.084	0.093	0.054
Population growth, 2001 to 2006	0.121	0.116	0.056
Population growth, 1996 to 2001	0.087	0.124	0.026
Population growth, 1991 to 1996	0.134	0.143	0.066
Proportion of developable land	0.453	0.309	0.372

Notes: Matching variables include permits per thousand residents, 1991 to 2016. These are not tabulated for the sake of brevity. Population growth is log difference of estimated population.

Figure 5: Synthetic and actual permits per thousand residents

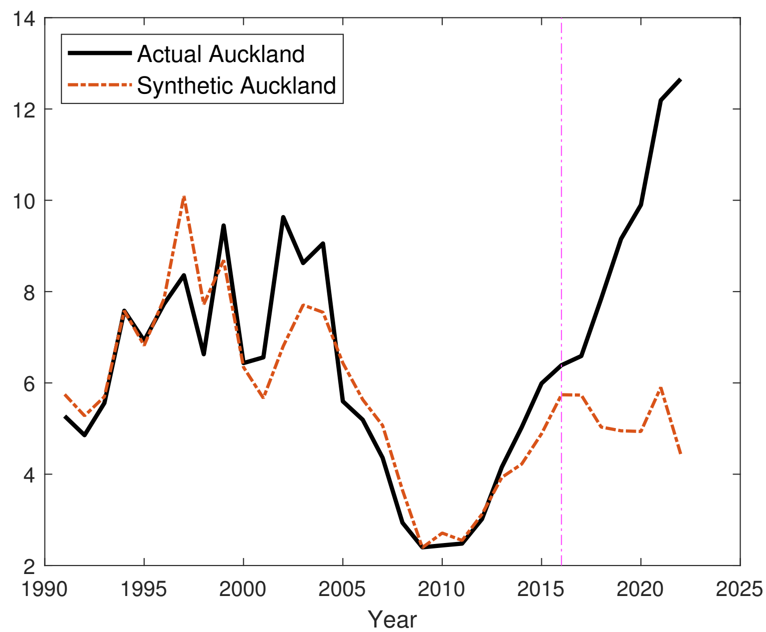
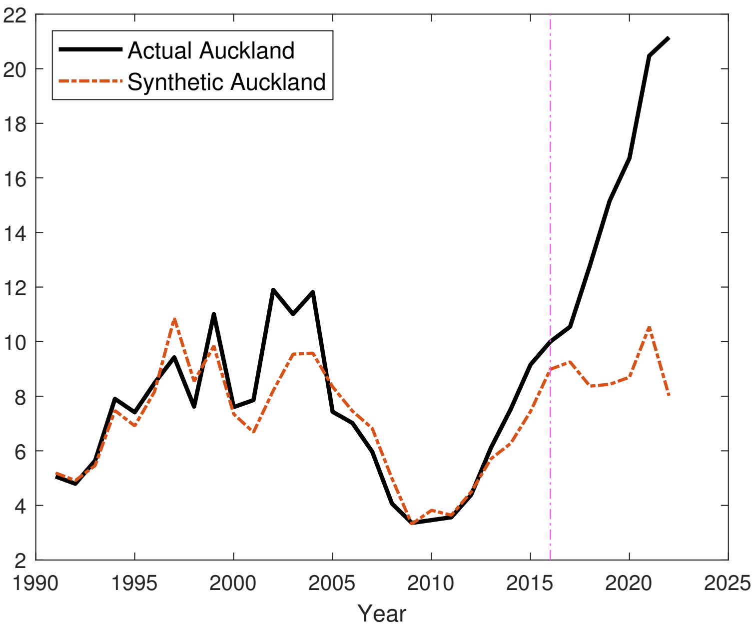


Figure 6: Synthetic and actual permits (thousands)



tion.[20] Thus, approximately forty-five percent of all permits issued in the six years subsequent to the zoning reform are attributable to the policy. Equivalently, the zoning reform increased new dwelling permits by 82% (= 0.45/(1–0.45)) over the six years subsequent to the reform.

4.3 Inference

We run placebo interventions on the other donor units to assess whether the decrease relative to the counterfactual is large. Figure 7 plots the difference between the actual outcomes of each donor and its synthetic control. Evidently there is a large increase in Auckland's prediction error over the post-intervention period, indicating that the zoning reform had a substantive positive impact.

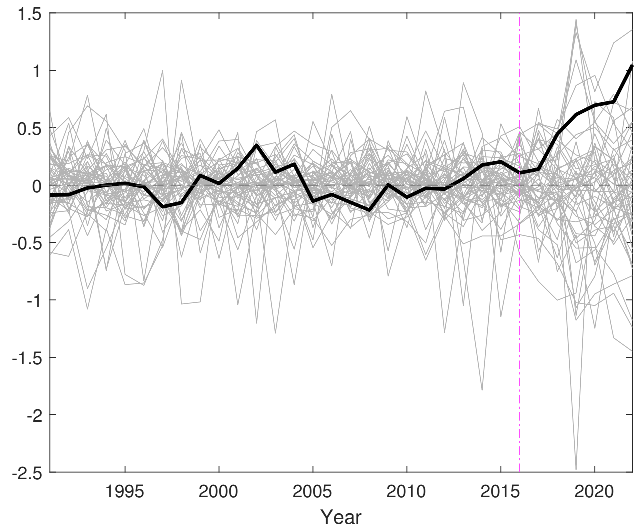
However, many of the placebo runs exhibit a larger positive error than Auckland. To assess whether this is simply due to poor model fit, we construct RMSE ratios. Let

$$R_i\left(t_1, t_2\right) = \sqrt{\frac{1}{t_2 - t_1} \sum_{t=t_1}^{t_2} \left(Y_{i,t} - \hat{Y}_{i,t}^N\right)^2}$$

such that the RMSE in the post-intervention period is $R_i\left(T_0 + 1, T\right)$, and the RMSE in the pre-intervention period is $R_i\left(1, T_0\right)$. Following Abadie et al. (2010), we use the ratio of pre- to post-

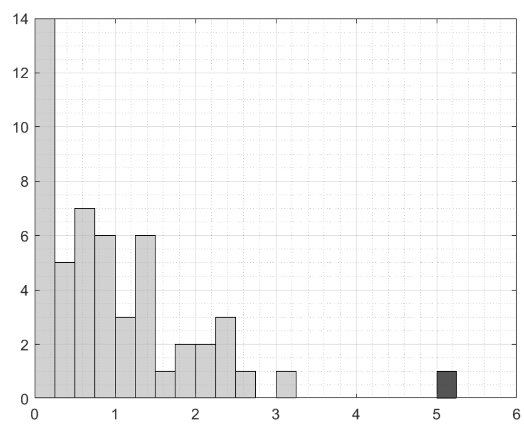
[20] Applying the synthetic control method directly to permits results in 44,235 additional permits attributed to the reform, with weights of 0.640, 0.238, 0.092 and 0.029 applied to Tauranga, Kāpiti Coast, Hamilton and Wellington. The de-meaning normalization (see section 4.1) is required because the number of permits issued in Auckland exceeds those of other urban areas.

Figure 7: Prediction errors



Notes: Difference between synthetic and actual outcomes for Auckland (black line) and placebos (grey line).

Figure 8: Positive-error RMSE ratios



Notes: Histogram of positive-error RMSE ratios for Auckland and placebo policy interventions. Auckland appears in black.

intervention RMSE as a basis for inference,

$$r_i = \frac{R_i\left(T_0+1, T\right)}{R_i\left(1, T_0\right)}$$

One drawback of the ratio is that it does not distinguish between positive and negative deviations from the synthetic unit, whereas many hypotheses posit a directional change from an intervention. For example, the relevant alternative hypothesis in our case is that zoning reform increased permits. Substantial increases in power can be obtained by testing for increases relative to the synthetic control, rather than differences (Abadie, 2021). To conduct a one-tailed test, we compute

$$r_i^+ = \frac{R_i^+\left(T_0+1, T\right)}{R_i\left(1, T_0\right)}$$

where

$$R_i^+\left(t_1, t_2\right) = \sqrt{\frac{1}{t_2-t_1} \sum_{t=t_1}^{t_2} \left(\left\lfloor Y_{i,t} - \hat{Y}_{i,t}^N \right\rfloor\right)^2}$$

where $\lfloor x \rfloor = 0$ iff $x > 0$ and $\lfloor x \rfloor = x$ otherwise. We refer to this as the "Positive Error RMSE ratio", or PE-RMSE-R.

Figure 8 depicts the histogram of the ratios. Auckland has the largest PE-RMSE-R, meaning that if one were to assign the intervention at random, the probability of obtaining a ratio as large as Auckland's is 0.019 ($= 1/52$). We conclude that the increase in the permitting rate in Auckland is statistically significant.

4.4 Robustness Checks

This subsection explores how sensitive our results are to changes in the our preferred empirical model.

4.4.1 Displacement Effects

In this subsection we investigate whether zoning reform in Auckland affected new dwelling permits in its selected donors. For example, the housing construction sector may shift capital and labor to Auckland from the selected donors, such that some of the new dwelling permits in Auckland displaced new dwelling permits in the donors (Tauranga, Kāpiti Coast, Wellington, or Hamilton). These "displacement effects" would manifest as a reduction in dwelling permits in the donors, causing the estimated treatment effect to be biased upwards because the difference between actual and synthetic outcomes in Auckland overstates the policy impact. It is also possible for the reform in Auckland to increase new dwelling permits in the selected donors if houses in Auckland that are removed for redevelopment are exported to the selected donors, as it is common for single-level houses on elevated foundations to be relocated when a parcel is redeveloped. This positive spillover effect would bias estimated treatment effects downwards.

In this subsection we investigate whether there is evidence of displacement effects or positive spillovers from the donor units to Auckland. We are particularly concerned with displacement from Hamilton and Tauranga. Research by the New Zealand Treasury shows that the Far North, Whangarei, Waikato and Bay of Plenty regions received net migrants from Auckland in the time period immediately preceding the reform,[21] indicating that these locations comparatively proximate to Auckland are potentially locational substitutes. Tauranga and Hamilton are located in the Bay of Plenty and Waikato region, respectively.

Our strategy is as follows.[22] Displacement effects would manifest as the policy intervention in the treated unit having an opposite, negative impact on outcomes in the selected donor units. Meanwhile, positive spillovers would manifest as the intervention having a positive impact. We therefore construct synthetic controls for each donor using the Auckland reform as the intervention, and consider whether the synthetic control implies that the permitting rate would have been persistently higher or lower in the donor unit under the counterfactual of no reform. (When constructing the counterfactual synthetic control for each urban area, we omit Auckland from the donor set since a weighting to Auckland will manifest as a large decrease by construction.) Then, if it appears that a given donor may have been affected by the Auckland reform, we can re-estimate the synthetic control for Auckland with the identified urban area omitted.

Figure 9 presents the prediction errors of the selected donors. Given our aforementioned concerns about locational substitutability, we first consider Hamilton and Tauranga, before moving on to Wellington and Kāpiti Coast.

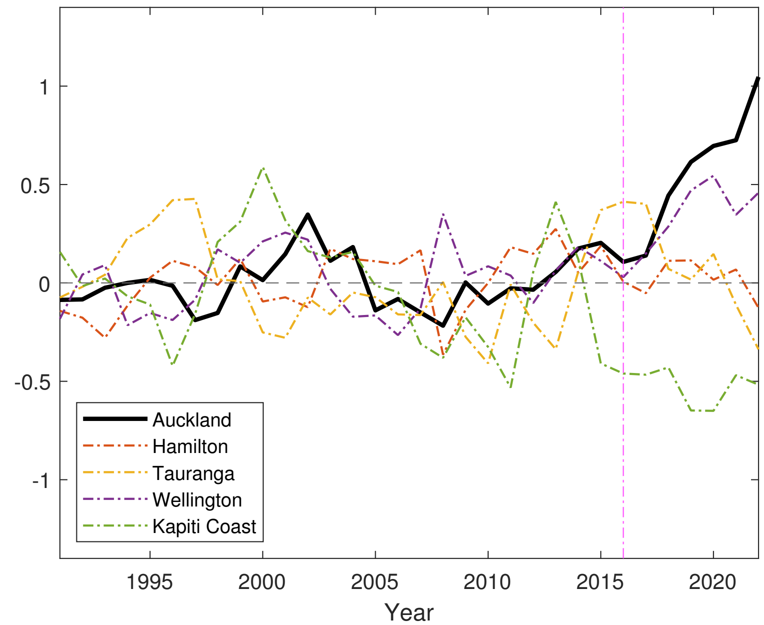
Tauranga and Hamilton. Interestingly, neither Tauranga nor Hamilton exhibit a persistent negative deviation from zero after the intervention, as would be expected if these areas were affected by displacement. This means that their respective synthetic controls fit well out-of-sample during the post intervention period, and, in particular, there is no persistent reduction in the permitting rate relative to the synthetic control after the reform in Auckland. Based on this, we conclude that there is little evidence of displacement from either Hamilton or Tauranga to Auckland.

Nonetheless, we present results when Tauranga and Hamilton are omitted from Auckland's donor set. Figures 10 and 11 present Auckland's synthetic permitting rates and number of permits under this restriction on the donor pool. Kāpiti Coast, Wellington and Nelson receive weights of 0.515, 0.340 and 0.125 in the re-estimated synthetic control. Estimated policy impacts are larger because synthetic permits per thousand residents are lower than when Hamilton and Tauranga are included in the donor set. The synthetic permitting rate is substantially lower than in the baseline specification until 2021, when it reaches 6.3 permits per thousand residents – a little more than half the actual permitting rate of 12.1. As shown in figure 12, Auckland's PE-RMSE-R ranks second, indicating the difference between the actual and synthetic permitting rates are statistically significant. Of the 96,842 permits issued in Auckland since 2016, 46,127 (or 47.6%) are attributed to the reform.

[21] See https://www.treasury.govt.nz/publications/ap/ap-18-02 [accessed 5 September 2023]

[22] I thank Matthew Maltman and Kade Sorensen for independently suggesting this approach.

Figure 9: Prediction errors, Auckland and selected donors



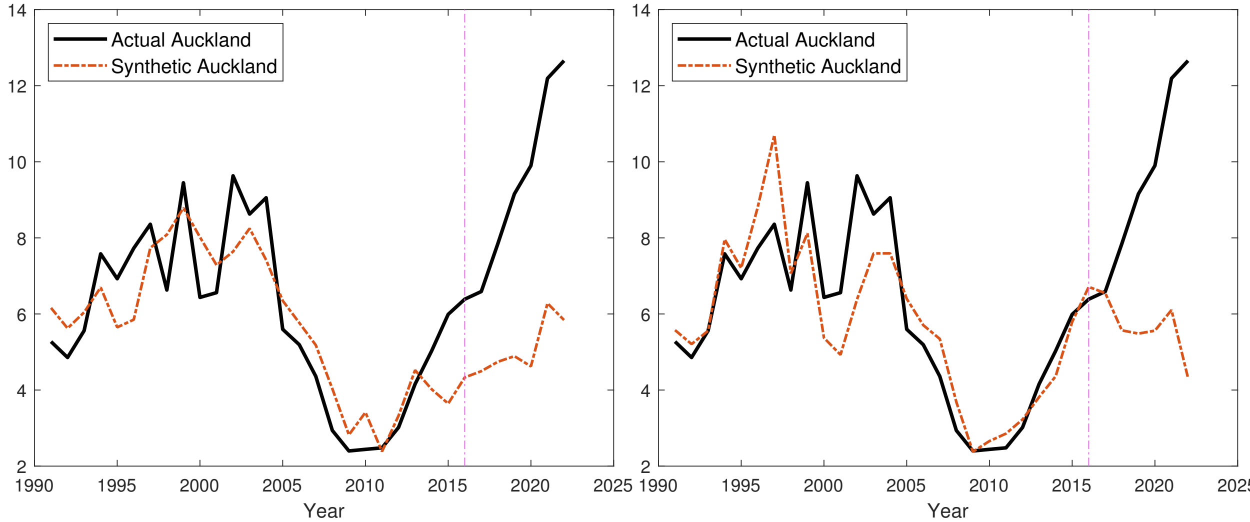
Notes: Prediction errors for selected donors are based on synthetic controls constructed with Auckland omitted from the donor set.

Wellington and Kāpiti Coast. Figure 9 shows there is a noticeable persistent increase in Wellington's prediction error after the intervention in Auckland. Lower Hutt (a local council within the Wellington urban area) upzoned in April 2020 (see footnote 10 for details), and thus the sustained deviation in the prediction error from 2020 until the end of the sample may be due to this policy. Note, however, that the increase in Wellington's prediction error begins prior the Lower Hutt upzoning, suggesting that the policy does not explain all of the deviation.

There is also a prolonged and persistent decrease in the prediction error of Kāpiti Coast, from 2015 until the end of the sample. Unlike Tauranga and Hamilton, Kāpiti Coast is comparatively distant to Auckland, and there is little other evidence to suggest that it is a locational substitute. Kāpiti Coast is however adjacent to Wellington, and thus more likely to be a locational substitute for the city. Displacement to Wellington, in part brought about by the Lower Hutt upzoning, might account for the sustained decrease in Kāpiti Coast.

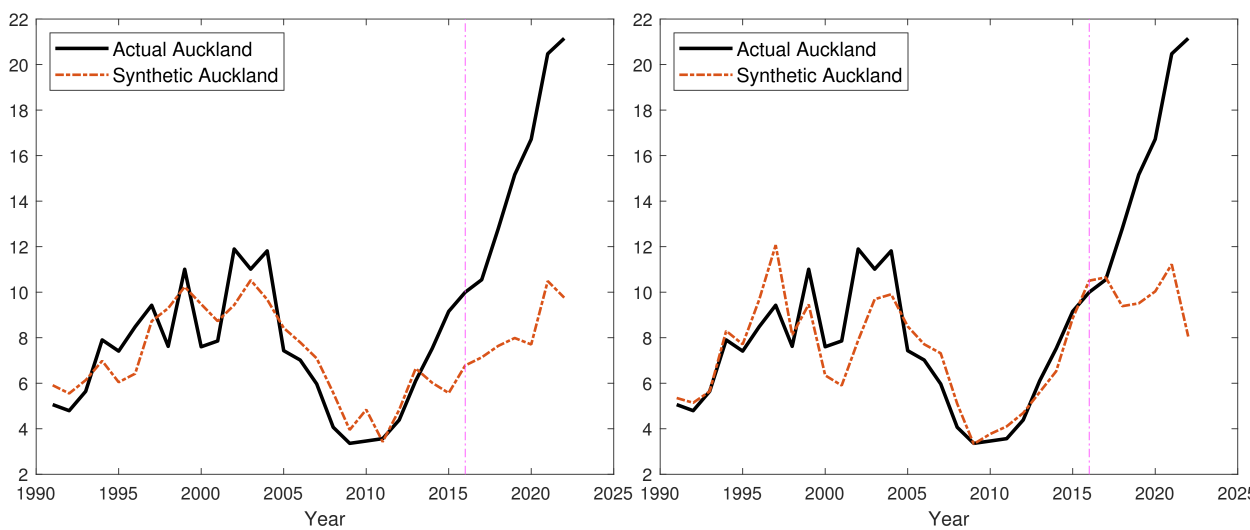
To guard against the possibility that Wellington and Kāpiti Coast are unsuitable donors, we also present results when these urban areas are omitted from Auckland's donor pool. Given their locational proximity to each other, we remove both donors from the pool since the Lower Hutt upzoning may have displaced construction in Kāpiti Coast, causing its permitting rate to also have been affected by a similar zoning reform to Auckland's. Tauranga, Hamilton and Palmerston North receive weights of 0.775, 0.208 and 0.018. Auckland's synthetic permitting rate is 6.1 in 2021, falling to 4.3 by 2022. As shown in figure 12, Auckland's PE-RMSE-R ranks first, indicating the difference between the actual and synthetic permitting rates are statistically significant. Of the

Figure 10: Synthetic and actual permits per thousand residents, displacement robustness check



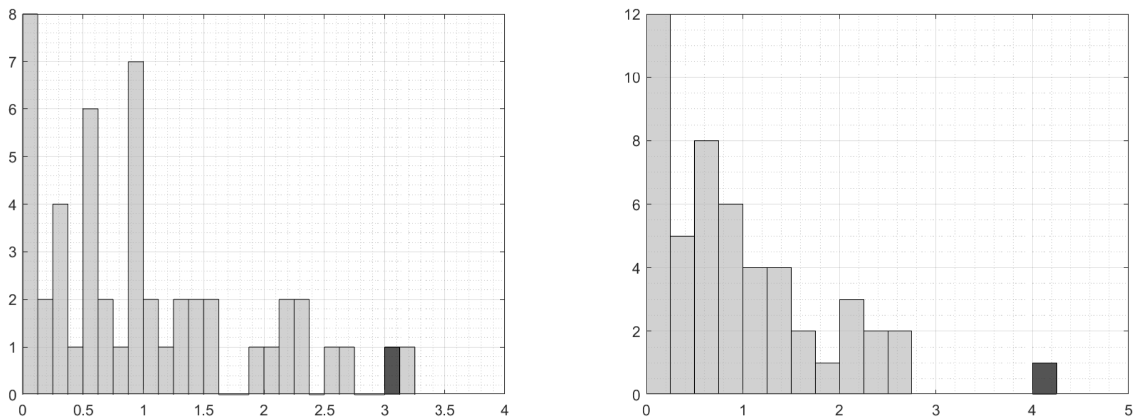
Notes: Left: Hamilton and Tauranga excluded from the donor pool. Right: Wellington and Kāpiti Coast excluded.

Figure 11: Synthetic and actual permits (thousands), displacement robustness check



Notes: Left: Hamilton and Tauranga excluded from the donor pool. Right: Wellington and Kāpiti Coast excluded.

Figure 12: Positive error RMSE ratios, displacement robustness check



Notes: Left: Hamilton and Tauranga excluded from the donor pool. Right: Wellington and Kāpiti Coast excluded.

96,842 permits issued since 2016, 37,983 (39.2%) are attributed to the policy.[23]

Based on these results, our view is that displacement effects, if present, are negligible. At most, the removal of Wellington and Kāpiti Coast due to potential concerns about their suitability as donors reduces the proportion on permits attributable to the reforms from 44.9% to 39.2%, and there remains a near doubling of the permitting rate by 2021.

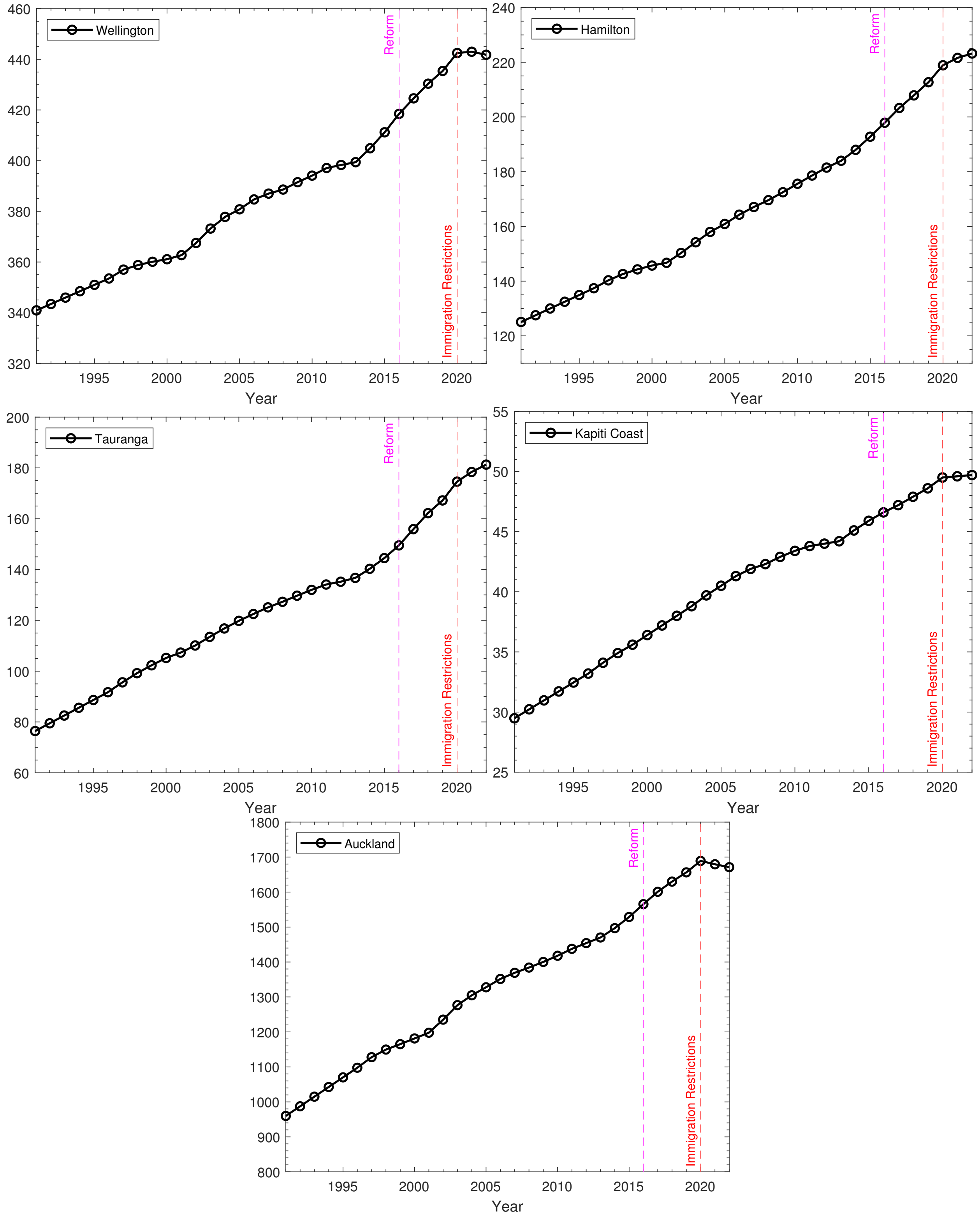
Our view is further reinforced by observed trends in population growth in each urban area's population after the reforms. Displacement effects would also manifest as a reduction in population in the donor units, as households that chose to locate in Auckland after the reform would have otherwise chosen to locate in one of the selected donor units under the counterfactual of no zoning reform. Because population growth is typically highly persistent, a clear reduction in the trend rate of growth in donor units after the reform would be consistent with a displacement effect to Auckland.

We plot estimated populations of the selected donor cities in figure 13. We include Auckland for comparison. In all four donors, there is a discrete increase in the trend rate of population growth in 2013, reflecting higher national immigration rates from 2013 onwards.[24] The higher rate of population growth is maintained until 2020, when the COVID-19 pandemic begins, and the New Zealand government imposes immigration restrictions. There is little, if any, discernible change in the trends in the years immediately after the zoning reform. In particular, there is no discernible

[23]If only Kāpiti Coast is omitted, Auckland's synthetic permitting rate is 6.4 in 2021, falling to 4.9 by 2022, and 35,300 of the 96,842 permits (36.5%) issued since 2016 are attributed to the policy. If only Wellington is omitted, Auckland's synthetic permitting rate is 5.7 in 2021, falling to 4.2 by 2022, and 45,471 of the 96,842 permits (47.0%) issued since 2016 are attributed to the policy.

[24]Between the 2013 and 2018 censuses, net migration increased by 339% relative to the five years prior to 2013. See https://www.stats.govt.nz/information-releases/2018-census-population-and-dwelling-counts#:~:text=2018%20Census%20data%20will%20be,the%202013%20Census%20(4%2C242%2C048). [accessed 5 September 2023]

Figure 13: Population of Auckland and selected donors



Source: Statistics New Zealand.

reduction in the trend rate of population growth in the donor units until 2020 – when Auckland experiences an even larger reduction in trend population growth. We conclude there is no reduction in population growth consistent with a displacement effect.

4.4.2 Alternative Empirical Specifications

We consider seven other variations to our baseline model as robustness checks. First, we consider a model in with fewer observations of the outcome variable, permits per thousand residents, included in the matching variable set. Specifically, we include observations in census years (1991, 1996, 2001, 2006, 2013). This timing matches most of the census-based variables. Second, we set the treatment date to 2013, since the special housing areas allowed developers to build to the relaxed LURs of the Proposed AUP between September 2013 and November 2016 (see section 2). Third, we consider non-hierarchical selection of donor units, such that Auckland's synthetic unit is constructed from all urban areas, not just the largest. Under non-hierarchical donor selection, all urban areas have their donor units selected from 50 other urban areas, excluding Warkworth and Christchurch. Warkworth is a small urban area in the north of the Auckland Council jurisdiction that was also affected by the reform. The various permutations of these different specification choices results in a total of eight different models (including our baseline specification). Section 6.5 in the Appendix presents the results.

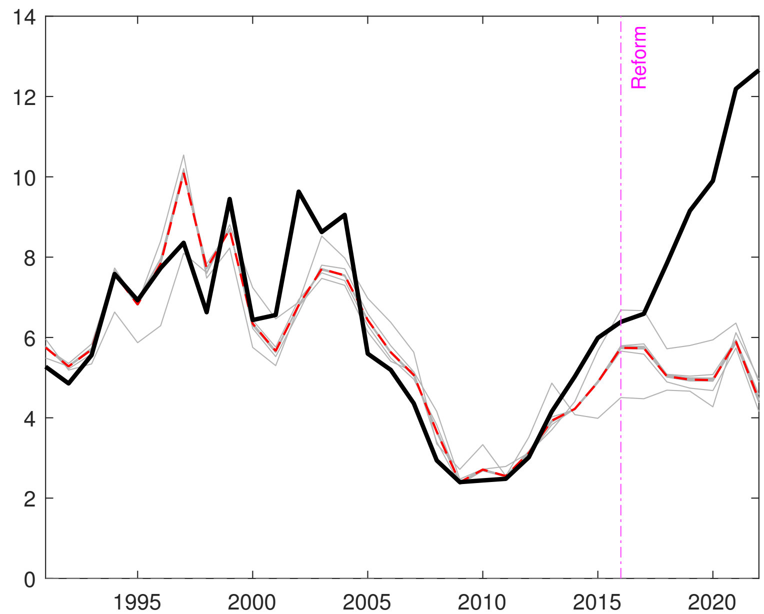
Table 5 shows that weights are broadly similar across the different permutations, with Tauranga and Kāpiti Coast featuring prominently. Hamilton features under hierarchical selection, but is replaced by "medium" and "small" urban areas under non-hierarchical selection. Figure 23 exhibits the synthetic and actual permits per thousand residents under the various permutations, while figure 24 exhibits the synthetic and actual permits. Post-intervention trends are broadly similar when 2016 is the treatment date. When 2013 is the treatment date, there generally is much less of a recovery in the permitting rate, meaning larger estimated policy impacts. The exception is the model with non-hierarchical donor selection, a treatment date of 2013, and the set of the outcome variables limited to census years in the matching set. For this specification, the post intervention permitting rate resembles that of the models when 2016 is used as the treatment date. Table 6 tabulates cumulative actual and synthetic permits when 2016 is used as the intervention date. Estimates of the permits attributable to the reform range between 40,100 to 46,200, or 41.4 to 47.7% of all permits issued.

4.4.3 Leave-One-Out

Under the "leave one out" robustness check units from the donor pool are iteratively removed from the sample while the procedure is repeated. The procedure provides an assessment of the extent to which the synthetic control may be dependent on any single given donor unit (Abadie et al., 2010).

Figure 14 exhibits the full-sample synthetic control (FS-SC red dashed line) alongside the 16 other leave-one-out synthetic controls (LOO-SCs, given by the grey lines). The sixteen synthetic

Figure 14: Synthetic and actual permits per thousand residents, leave-one-out robustness check



Notes: Leave-one-out replications in grey. The synthetic control for the full sample is the red dashed line.

controls follow a common trend over both the pre- and post- sample period, indicating that the results are not dependent on any single urban area being included in the donor set.

4.4.4 Including Australia in the Donor Set

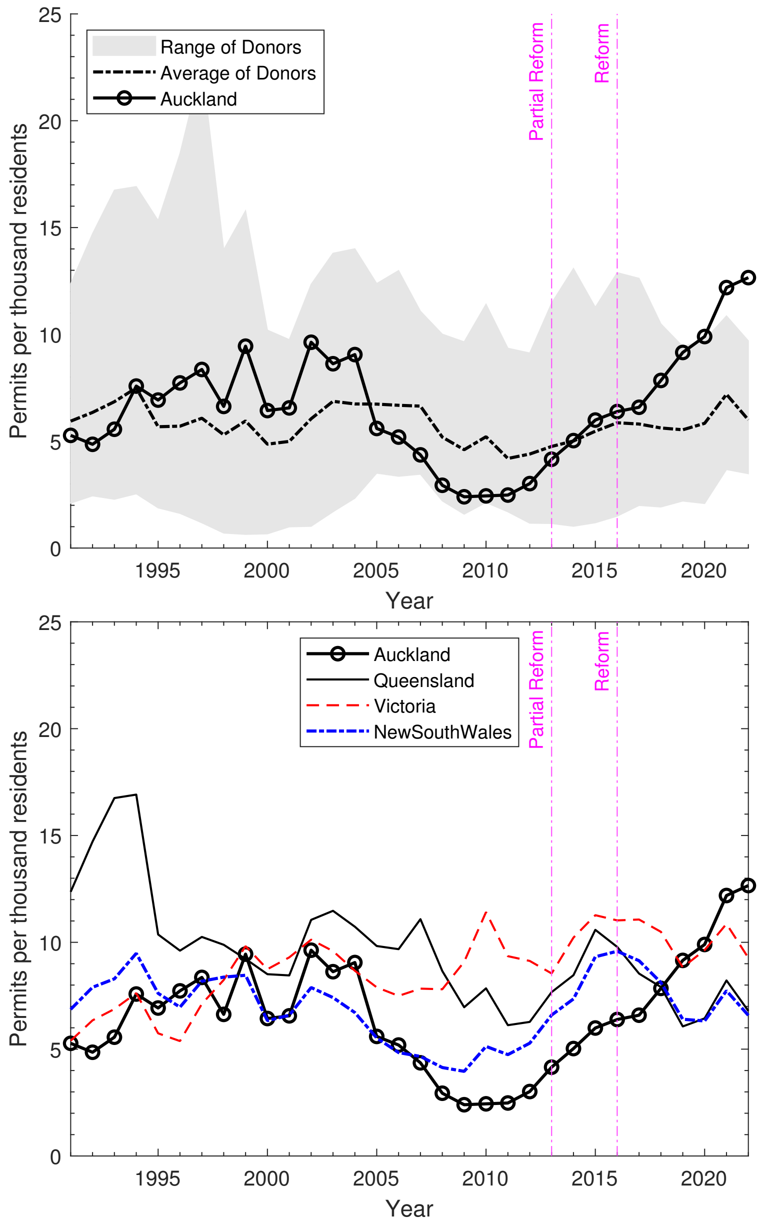
New Zealand is economically and socially integrated with Australia. The two countries share a comprehensive trade agreement (the Australia-New Zealand Closer Economic Relations Trade Agreement) and allow the free movement of workers across their border under the 1973 Trans Tasman Travel Arrangement. Australian regions may therefore provide suitable donor units for Auckland in the synthetic control procedure.

In this subsection we add Australian regions to the donor pool and repeat the analysis. While state data on permits and population for the five largest Australian states are available from the Australian Bureau of Statistics over the full time period of our analysis (1991 to 2022), city-level data are only available from 2002 onwards.[25] However, as illustrated in figure 22 in the Appendix, cyclicality and trends in the state and the state's capital city are very similar over the 2002 to 2022 period, suggesting that state time series on permits per thousand residents provide a reasonable approximation to city-level time series that are unavailable over the entire period.

State Data. We include the Australian states of New South Wales (NSW), Victoria, Queensland, South Australia, and Western Australia in the donor pool, as data for these five states are publicly

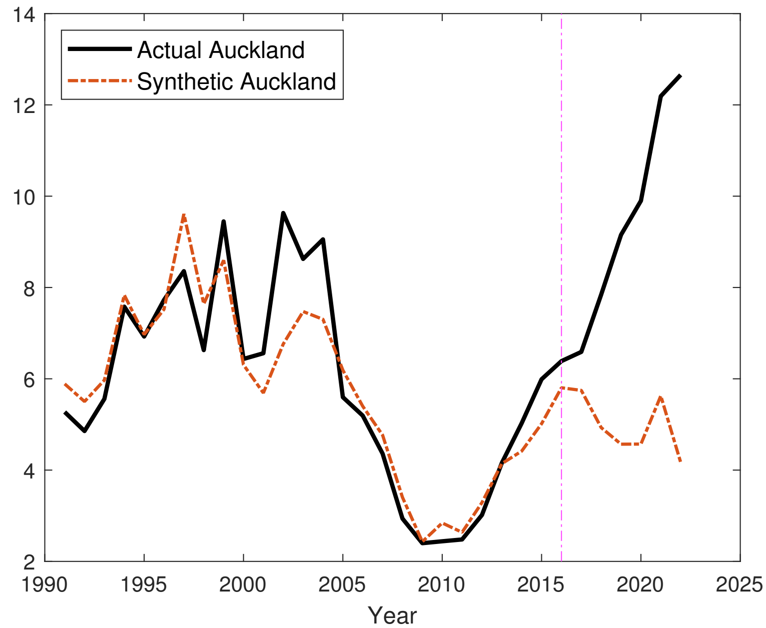
[25] Australian state capital city data on new residential dwelling approvals are available from July 2001, while annual population data are available from 2001.

Figure 15: Permits per thousand residents, Australian states included in donor pool



Source: Author's calculations based on Statistics New Zealand and Australian Bureau of Statistics data. Notes: Average of donors taken across all urban areas in the donor pool. Shaded region denotes the range between the minimum and maximum permits per thousand residents among the donor pool. Donor pool includes the states of New South Wales, Victoria, Queensland, South Australia and Western Australia.

Figure 16: Synthetic and actual permits per thousand residents, Australian states included in donor pool



Notes: Donor pool includes NSW, Victoria, Queensland, South Australia and Western Australia.

available from the Australian Bureau of Statistics over the time period of analysis. For matching variables, we collect Australian census data on private occupied dwellings and population from the 2001, 2006 and 2011 censuses, and median weekly personal income from the 2006 and 2011 censuses. We could not obtain population or occupied dwellings for the 1991 and 1996 Australian censuses, or personal incomes for the 1991, 1996 and 2001 censuses. From these, we are able to include dwellings per capita in 2001, 2006 and 2013; intercensal population growth from 2001 to 2006, and 2006 to 2013; and personal income for 2006 and 2013 in the set of matching variables.[26]

The inclusion of the five Australian states in the donor pool has a negligible impact on our results. NSW and Victoria receive weights of 0.132 and 0.031, while Hamilton, Tauranga, Wellington and Kāpiti Coast receive weights of 0.093, 0.489, 0.011 and 0.244, respectively. Figure 16 exhibits synthetic and actual permits per thousand residents. The synthetic permitting rate is 5.6 in 2021, less than half the actual rate of 12.1. Of the 96,842 permits issued since 2016, 46,352 (47.9%) are attributed to the reform, and Auckland's PE-RMSE-R ranks first out of sixty placebo runs (not depicted).[27]

[26]We use data from 2011 instead of 2013 for the Australian states. Matching variable data collected from https://www.abs.gov.au/census/find-census-data/quickstats [accessed 25 August 2023]. We multiply personal weekly incomes by 52 to accord with the annual personal income for NZ. We adjust Australian income using purchasing power parity exchange rates obtained from the OECD, obtained from: https://data.oecd.org/conversion/purchasing-power-parities-ppp.htm [accessed 25 August 2023]

[27]These results are largely unaffected when the displacement effects robustness check described in section 4.4.1 is implemented. When Hamilton and Tauranga are omitted from the donor set, Kāpiti Coast, New South Wales, Whangarei and Wellington receive weights of 0.458, 0.454, 0.076 and 0.012; synthetic permits per thousand residents

Figure 15 illustrates why the Australian states do not receive substantial weights. There are few similarities between Auckland and the Australian states (we show the three largest states for visual clarity). Auckland exhibits some comparability to NSW and Victoria from the early 1990s through to the early 2000s. Thereafter there is a decrease in NSW and Auckland, while Victoria continues on a mild upward trend. NSW begins its downturn in 2001, and recovers from 2009 onwards. Auckland's downturn begins in 2003 and lasts until 2011, but its downturn is significantly deeper, reaching a low of two-and-one-half permits per thousand residents between 2009 and 2011. Whereas Auckland and NSW exhibited similar levels in the 1990s, from 2008 onwards there is a noticeable level shift, with Auckland consistently lower than NSW from that point on until 2018, at which point Auckland exceeds NSW. Whereas NSW peaks in 2016, Auckland continuously increases between 2011 and 2022. By 2022, permits per thousand residents in NSW have fallen to 6.6, approximately half of the permitting rate of 12.7 in Auckland.[28]

City Data. We also run the analysis with the Australian city data instead of the state data. We are able to include a total of eight state capital cities for which permit data are available from the Australian Bureau of Statistics: Sydney, Melbourne, Brisbane, Adelaide, Perth, Hobart, Darwin, and the Australian Capital Territory (ACT). The sample period must be shortened to 2002 to 2022 to accommodate the Australian cities. The city dataset contains the same matching variables as the state dataset. Figure 17 shows that between 2009 and 2022, Auckland's permitting rate transitions from one of the lowest in the donor pool to the highest.

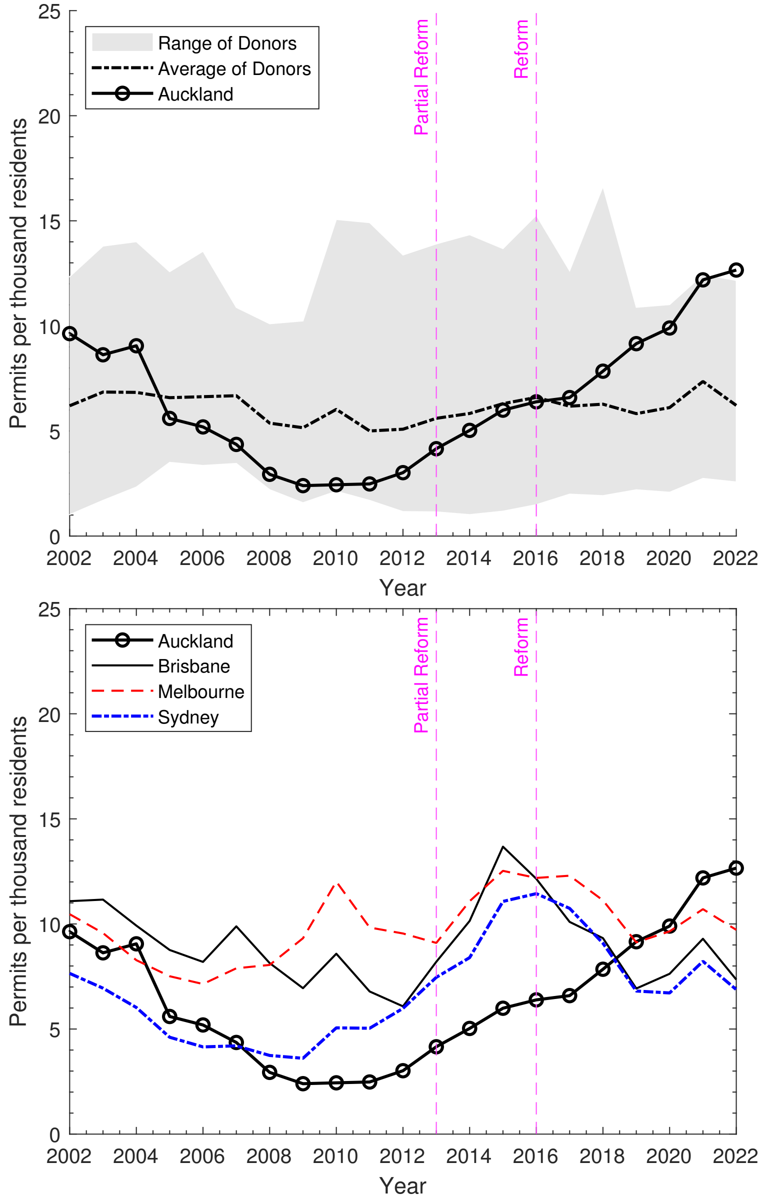
The inclusion of the Australian cities in the donor pool has a negligible impact. Sydney receives a weight of 0.127, while Tauranga and Kāpiti Coast receive weights of 0.601 and 0.272. Figure 18 illustrates actual and synthetic permits per thousand residents over the time period. Synthetic permits per thousand residents are 5.7 in 2021 – less than half the actual figure of 12.1. Of the 96,842 permits issued since 2016, 44,300 (45.7%) are attributed to the reform, while Auckland's PE-RMSE-R ranks fifth out of sixty placebo runs (not depicted).[29] Thus, if one were to assign the intervention at random to this sample, the probability of obtaining a ratio as large as Auckland's is 0.083 (= 5/60). However, we note that the in-sample fit of the synthetic control is likely to be affected by the relatively short training period of fifteen years.

is 5.51 in 2021; and 51,462 (53.1%) permits are attributed to the reform. If Wellington and Kāpiti Coast are omitted from the donor set, Tauranga, Hamilton, Victoria and New South Wales receive weights of 0.768, 0.096, 0.070 and 0.068; synthetic permits per thousand residents is 6.10 in 2021; and 39,307 (40.6%) permits are attributed to the reform.

[28] Lagging the Australian states by two years does not result is in any substantive changes. Victoria receives a weight of 0.073, 45,002 permits are attributed to the reform, and synthetic permits per thousand residents is 4.24 in 2022.

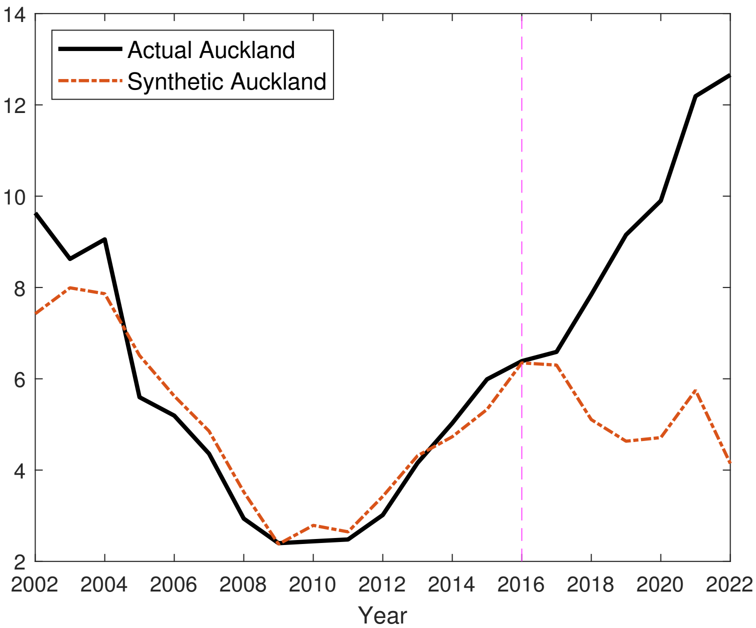
[29] These results are largely unaffected when the displacement effects robustness check described in section 4.4.1 is implemented. When Hamilton and Tauranga are omitted from the donor set, Kāpiti Coast and Sydney receive weights of 0.628 and 0.373; synthetic permits per thousand residents is 5.62 in 2021; and 51,643 (53.3%) permits are attributed to the reform. If Wellington and Kāpiti Coast are omitted from the donor set, Tauranga, Rotorua and Sydney receive weights of 0.372, 0.316 and 0.312; synthetic permits per thousand residents is 5.93 in 2021; and 37,187 (38.4%) permits are attributed to the reform.

Figure 17: Permits per thousand residents, Australian cities included in donor pool



Source: Author's calculations based on Statistics New Zealand and Australian Bureau of Statistics data. Notes: Average of donors taken across all urban areas in the donor pool. Shaded region denotes the range between the minimum and maximum permits per thousand residents among the donor pool. Donor pool includes Sydney, Melbourne, Brisbane, Adelaide, Perth, Hobart, Darwin and the Australian Capital Territory.

Figure 18: Synthetic and actual permits per thousand residents, Australian cities included in donor pool



Notes: Donor pool includes Australian state capital cities of Sydney, Melbourne, Brisbane, Adelaide, Perth, Hobart, Darwin and the Australian Capital Territory. Sample spans 2002 to 2022 to accommodate the Australian cities.

5 Concluding Remarks

This papers adopts a synthetic control method to assess the impact of a recent large-scale zoning reform on housing construction in Auckland. The outcome variable of interest is the rate of new dwelling permit issuance, measured by new dwelling permits per thousand residents. Weights on donor units are selected to match a variety of outcomes related to housing markets, including population growth, personal income, dwellings per capita and proportion of developable area.

The synthetic control indicates that the zoning reform had a substantial impact on new building permits. Relative to the counterfactual of no reform, the reform doubled the rate at which permits are issued within five years. The synthetic counterfactual implies that the reform accounts for 45% of permits issued over subsequent six years, or, equivalently, the reform increased the cumulative number of permits issued by 82%.

We conduct a battery of robustness checks that include alternative modeling decisions and the inclusion of Australian states and cities in the donor pool. The conclusion that the reforms had a substantial positive impact on new dwelling permits is robust to various permutations of the empirical specification. All specifications considered imply that the permitting rate approximately doubled within five years of the reform. Meanwhile, estimates of the proportion of permits issued that are attributable to the policy vary between 39 to 48%.

The success of Auckland's zoning reform in stimulating housing supply is particularly important given that other recent attempts to encourage housing construction through large-scale zoning reforms have, to date, met with limited success. For example, the California HOME Act of 2021 allows up to four dwellings per parcel, but one year on was found to have had only a small impact on new dwelling permits (Garcia and Alameldin, 2023). The Minneapolis 2040 plan, implemented in January 2020, allows up to three dwellings per parcel, but as yet has not increased dwelling permits for multifamily dwellings (see footnote 2). Further research on Auckland's reform can help us understand the factors that mediate the success or failure of zoning reform, thereby improving the design and implementation of upzoning policies in the future to redress burgeoning inequalities in housing access. We leave this task for future research.

6 Appendix

6.1 Auckland Unitary Plan Timeline

Prior to 2010, the greater Auckland metropolitan region comprised seven city and district councils: Auckland City Council, North Shore City Council, Waitākere City Council, Manukau City Council, Rodney District Council, Papakura District Council, and Franklin District Council. On 1 November 2010, Auckland Council (AC) was formed when the eight previous governing bodies in the region were amalgamated. Legislation was also passed by the central government requiring AC to develop a consistent set of planning rules for the whole region under the Local Government Act 2010. This set of planning rules is embodied in the Auckland Unitary Plan (AUP).

Key dates in the development and implementation of the AUP are as follows:

- 15 March 2013: AC releases the draft AUP. The next 11 weeks comprised a period of public consultation, during which AC held 249 public meetings and received 21,000 items of written feedback.
- 13 September 2013: Housing Accords and Special Housing Areas Act passed, offering developers accelerated permitting process in exchange for limited affordable housing in the development.
- 30 September 2013: AC released the Proposed AUP (PAUP) and notified the public that the PAUP was open for submissions. More than 13,000 submissions (from the public, government, and community groups) were made, with over 1.4 million separate points of submission.
- 3 October 2013: Mayor of Auckland and Minister of Housing sign the Auckland Housing Accord, allowing Special Housing Area developments to use the LURs from the PAUP. The agreement is stipulated to expire once the AUP becomes operational.
- April 2014 to May 2016: an Independent Hearings Panel (IHP) was appointed by the central government, which subsequently held 249 days of hearings across 60 topics and received more than 10,000 items of evidence.
- 22 July 2016: the IHP set out recommended changes to the PAUP. One of the primary recommendations was the abolition of minimum lot sizes for existing parcels. The AC considered and voted on the IHP recommendations over the next 20 working days. On 27 July the public could access and view the IHP's recommendations.
- 19 August 2016: AC released the 'decisions version' of the AUP, including the new zoning maps. Several of the IHP's recommendations were voted down, including a IHP recommendation to abolish minimum floor sizes on apartments. However, the abolition of minimum lot sizes for existing parcels was maintained. This was followed by a 20-day period for the public to lodge appeals on the 'decisions version' in the Environment Court. Appeals to the High Court were only permitted if based on points of law.
- 8 November 2016: A public notice was placed in the media notifying that the AUP would become operational on 15 November 2016.
- 15 November 2016: AUP becomes operational. There were two elements of the AUP that were not fully operational at this time: (i) any parts that remain subject to the Environment Court

and High Court under the Local Government Act 2010; and (ii) the regional coastal plan of the PAUP that required Minister of Conservation approval.

All versions of the AUP ('draft', 'proposed', 'decisions' and 'final') could be viewed online.

6.2 Land Use Regulations under the AUP

Table 3: Summary of land use regulations by residential zone under the Auckland Unitary Plan

Regulation	Terraced Housing Apartments	Mixed Housing Urban	Mixed Housing Suburban	Single House
Max. height	16m (five storeys)	11 to 12m (three storeys)	8 to 9m (two storeys)	8 to 9m (two storeys)
Height in relation to boundary	3m up + 45° recession plane	3m up + 45° recession plane	2.5m up + 45° recession plane	2.5m up + 45° recession plane
Setback (side and rear)	0m	1m	1m	1m
Setback (front)	1.5m	2.5m	3m	3m
Max. site coverage (%)	50%	45%	40%	35%
Max. impervious area (%)	70%	60%	60%	60%
Min. dwelling size (1 bedroom)	$45m^2$	$45m^2$	$45m^2$	n/a
Max. dwellings per site	does not apply	3	3	1
Min. Lot Size (subdivision)	$1200m^2$	$300m^2$	$400m^2$	$600m^2$

Notes: Restrictions are 'as of right' and can be exceeded through resource consent notification. Height in relation to boundary restrictions apply to side and rear boundaries. Less restrictive height in relation to boundary rules than those tabulated apply to side and rear boundaries within 20m of site frontage. Maximum dwellings per site are permitted as of right. Minimum lot sizes do not apply to extant residential parcels. Impervious area is the area under the dwelling and structures such as concrete driveways that prevent rainwater absorption into the soil.

6.3 Geomatching Algorithm

This subsection describes the geomatching procedure for the data depicted in figures 3, 20 and 21. Georeferenced data on individual permits were obtained from Auckland Council. Annual totals closely match SNZ data for the Auckland region. Permits are matched to GIS information on individual land parcels as at November 2016 that contains the AUP planning zone and the zone prior to the AUP. This enables the identification of upzoned parcels following the FAR classification used in Greenaway-McGrevy and Jones (2023).

Permits are matched to parcels through the following sequence of steps. 1. Find the parcel of the geo-coordinate of the permit and check whether the road number and first word of the road match. If these do not match: 2. Find all the parcels within 1250m of the geo-coordinate of the permit and search for a match based on the road number and first word of the road address. If no match is found: 3. Check whether the address contains a number or letter to indicate a subdivision or cross lease (such as "10B" or "2/10"). If not, proceed to step 5. If so, the remove the additional number of letter and check whether the road number and first word of the road match the address of the parcel corresponding to the geocoordinate of the permit. If there is no match: 4. Find all the parcels within 1250m of the geo-coordinate of the permit and search for a match based on the road number and first word of the modified road address. If no match is found: 5. Identify the parcel of the geo-coordinate of the permit. Check whether the name of the road in the address of the parcel matches the road name of the address given in the permit. If there is no match: 6. Identify the nearest parcel of the geo-coordinate of the permit and assign this parcel. Parcels coded to 'Water', 'Strategic Transport Corridor Zone', 'Road', 'Coastal - General Coastal Marine Zone', 'Coastal - Coastal Transition Zone', 'Green Infrastructure Corridor', or any of the 'Open Space ' zones are removed from the parcel dataset from this matching.

6.4 Additional Tables and Figures

Figure 19: Major and Large Urban Areas of New Zealand

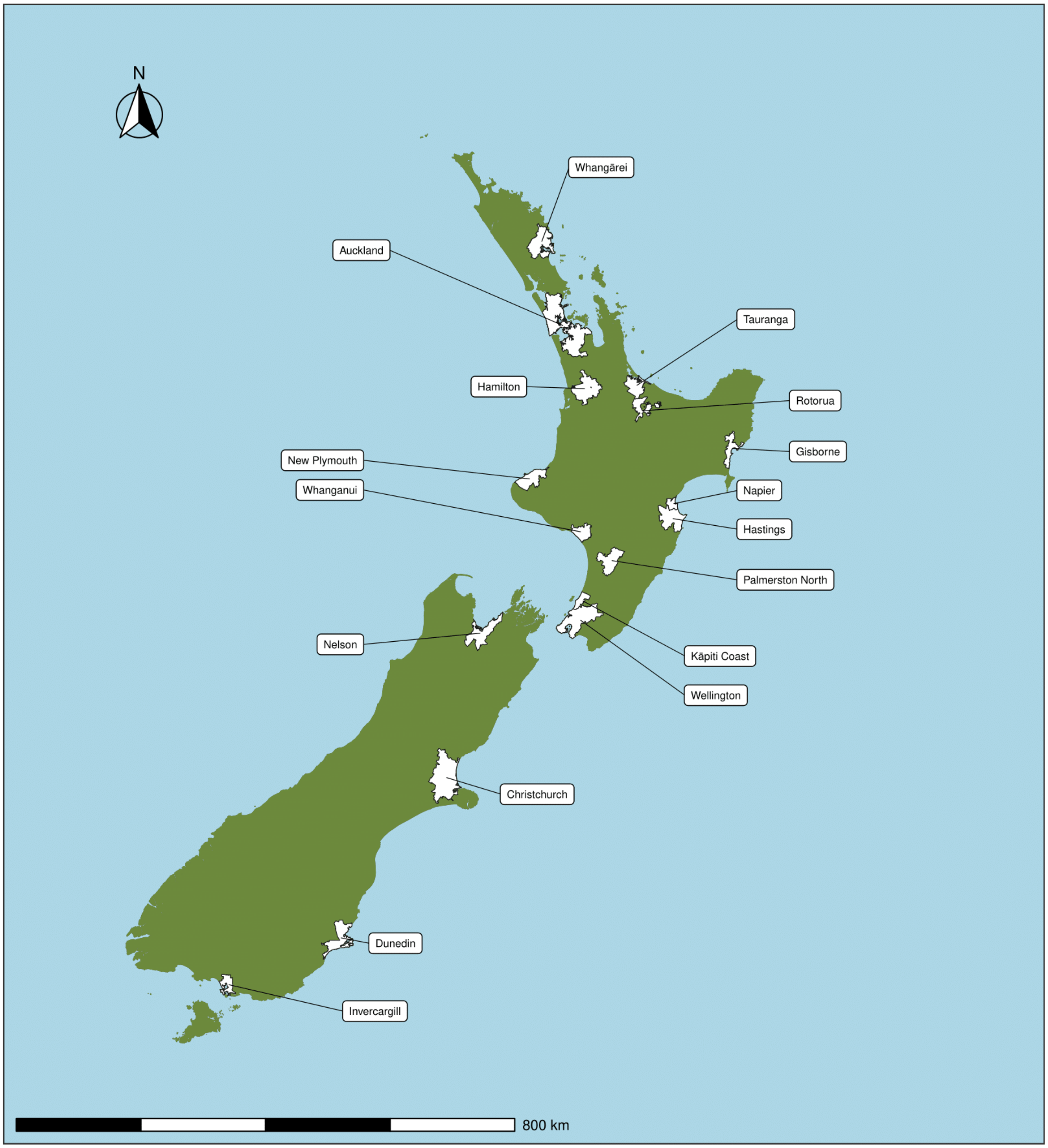
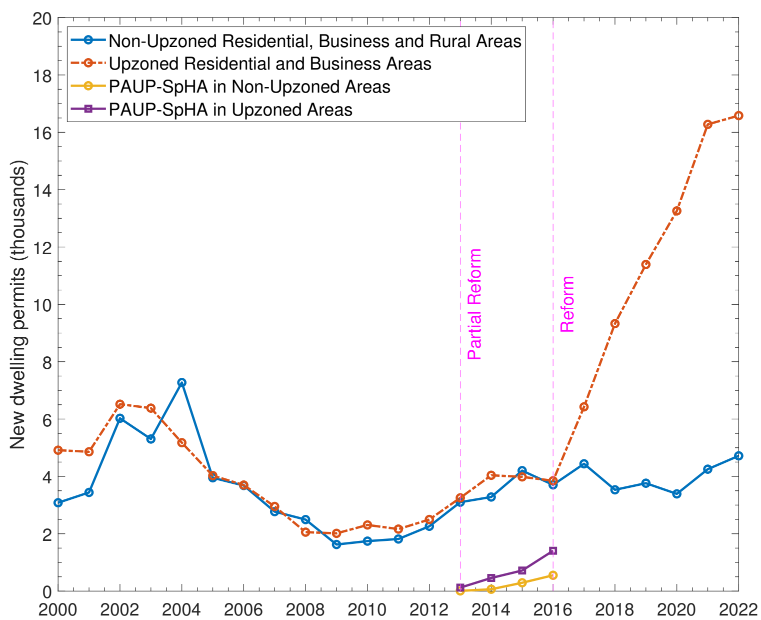


Table 4: Major and large urban areas

Urban Area	Population	Dwellings	Pers. Income ($)	Area (km^2)	Prop. develop. land	Dist. Auck. (km)
Auckland	1,567,038	490,695	36,000	3356.9	0.4532	-
Hamilton	209,970	70,596	33,700	1412.7	0.8217	114
Tauranga	156,666	57,690	33,300	789.9	0.3942	155
Wellington	422,427	149,820	39,700	1754.2	0.1212	493
Christchurch	482,088	177,135	35,400	2408.0	0.5797	764
Dunedin	132,006	49,533	27,400	1033.8	0.2278	1,064
Whangārei	86,538	31,407	29,000	1433.6	0.5402	131
Rotorua	74,028	24,795	29,100	649.2	0.5902	194
Gisborne	43,953	15,360	28,000	612.8	0.2432	350
Hastings	79,431	26,823	29,700	1160.4	0.5142	359
Napier	66,459	24,834	30,400	259.8	0.3496	348
New Plymouth	80,997	31,002	31,800	920.9	0.3967	253
Whanganui	45,747	18,249	25,400	598.1	0.3374	344
Palmerston North	96,552	34,737	32,000	978.3	0.7821	397
Kāpiti Coast	46,839	19,128	32,100	317.4	0.1705	452
Nelson	84,846	31,833	31,300	1177.2	0.1855	508
Invercargill	55,386	21,825	31,700	428.5	0.7148	1,188

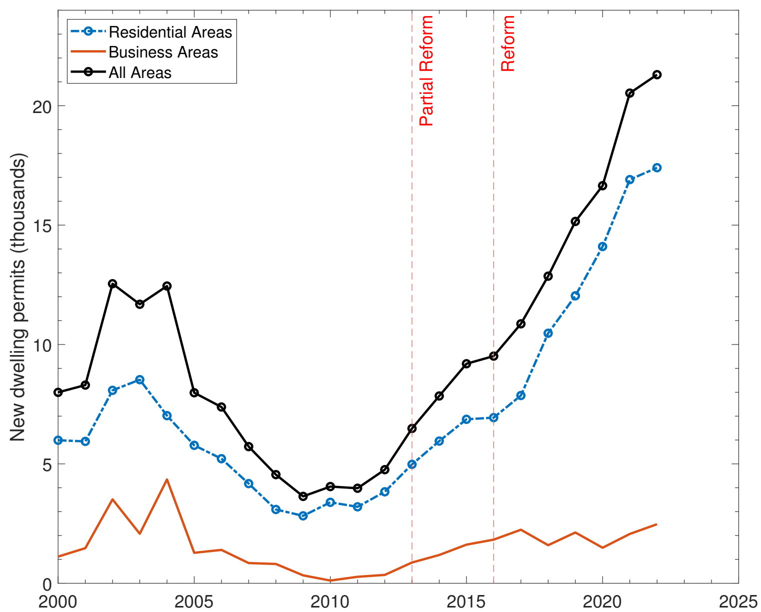
Source: Author's calculations based on 2018 Census. Notes: Dwellings are occupied dwellings. Note that Christchurch is omitted form the donor pool due to the effect of the 2011 earthquakes on the housing stock and subsequent rebuild. Tabulated distance is Haversine.

Figure 20: New dwelling permits in Auckland by location and including Special Housing Areas, 2000 to 2022



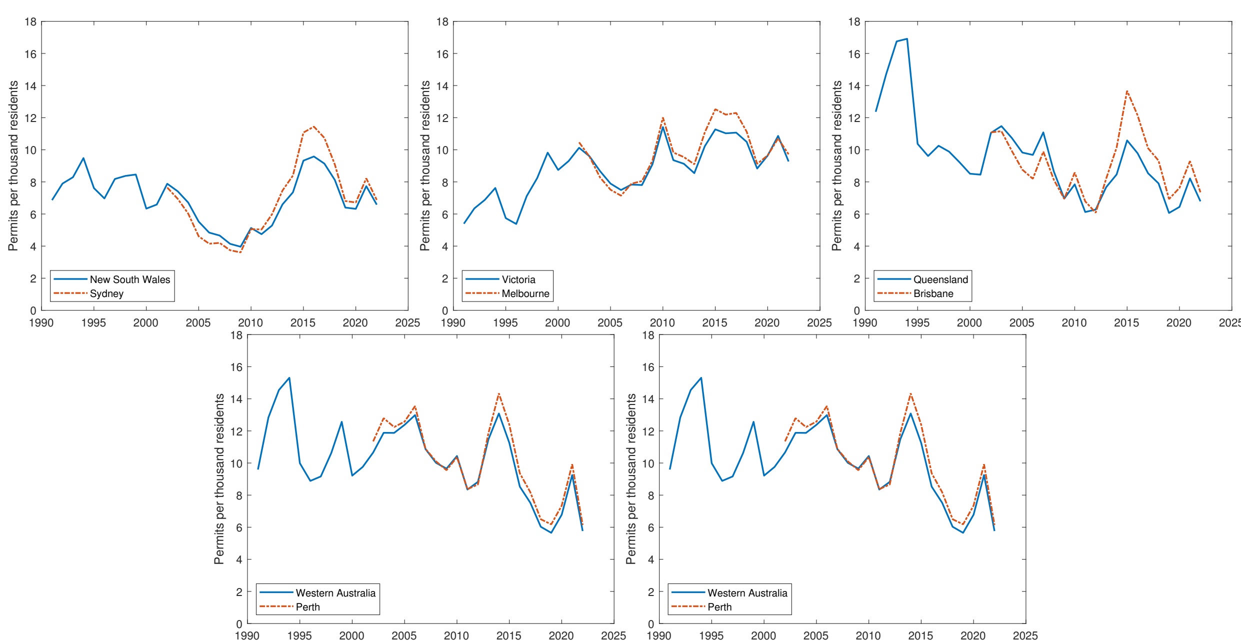
Notes: New dwelling permits in areas that were and were not upzoned in 2016 under the AUP. The first, "draft", version of the AUP was announced in March 2013, while the "Proposed" AUP (PAUP) was notified in September 2013. Partial zoning reform was implemented in September 2013 under the Auckland Housing Accords. Between September 2013 and November 2016, Special Housing Area (SpHA) developments could build to the regulations of the PAUP in exchange for affordable housing provisions. Full reform occurred in November 2016 when the final version of the AUP became operative. Source: Author's calculations based on permits matched to planning zones. Upzoning classification is based on comparing floor-to-area (FAR) ratios implied by height and site coverage restrictions before and after the policy change. See Greenaway-McGrevy and Jones (2023) for additional details.

Figure 21: New dwelling permits in Auckland by residential and business areas, 2000 to 2022



Source: Author's calculations based on permits matched to AUP planning zones. See Greenaway-McGrevy and Jones (2023) for additional details on the method.

Figure 22: New dwelling permits per thousand residents, Australian cities and states



Source: Author's calculations based on Australian Bureau of Statistics data.

6.5 Robustness Checks

Table 5: Donor weights under alternative specifications

	Treatment date: 2016				Treatment date: 2013			
	Hierarchical selection		Non-hierarchical		Hierarchical selection		Non-hierarchical	
Urban Area	Model A	Model B	Model A	Model B	Model A	Model B	Model A	Model B
Hamilton	0.098	0.098			0.095	0.169		
Tauranga	0.574	0.548	0.545	0.405	0.400	0.335	0.299	0.619
Wellington	0.118	0.131		0.212		0.019		0.131
Hastings					0.076			
Kāpiti Coast	0.211	0.224	0.224	0.242	0.429	0.435	0.422	
Nelson						0.041		
Tokoroa				0.040				
Taupo							0.102	0.171
Motueka			0.032				0.086	
Queenstown								0.075
Wanaka			0.142	0.168			0.069	0.004
Cambridge			0.057					
Cromwell							0.022	
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

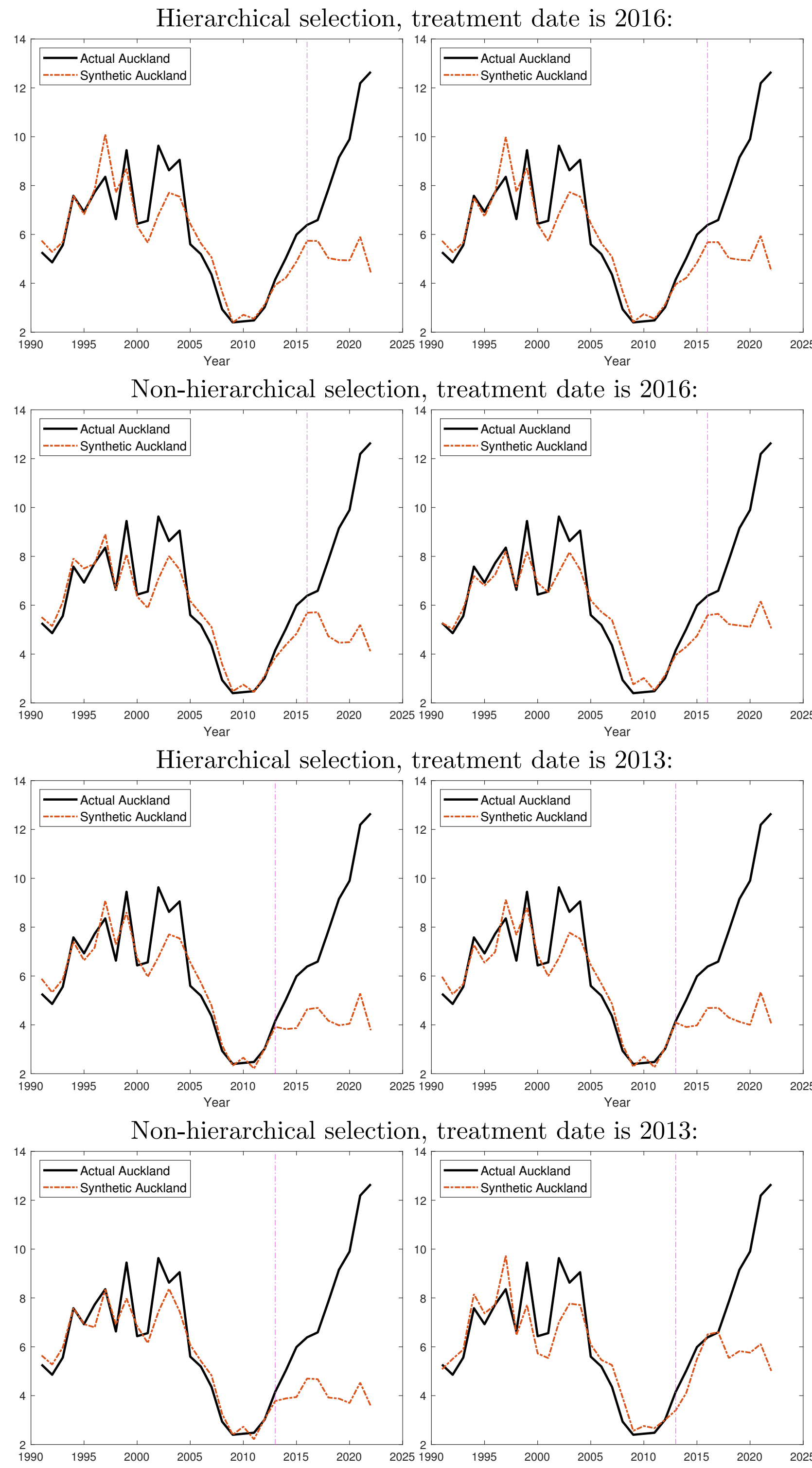
Notes: Model A includes the entire time series of outcomes in the set of matching variables; B only includes outcomes in pre-reform census years (1991, 1996, 2001, 2006, 2013) in the set. Baseline specification presented in the first column.

Table 6: Cumulative increase in permits under alternative specifications

	Hierarchical selection		Non-hierarchical selection	
	Model A	Model B	Model A	Model B
Permits issued, 2017–2022	96,842	96,842	96,842	96,842
Counterfactual permits	53,330	53,340	50,635	56,741
Difference	43,512	43,502	46,207	40,101
Proportion	0.449	0.450	0.477	0.414

Notes: Model A includes the entire time series of outcomes in the set of matching variables; B only includes outcomes in pre-reform census years (1991, 1996, 2001, 2006, 2013) in the set. Baseline specification presented in the main text is model A with hierarchical selection.

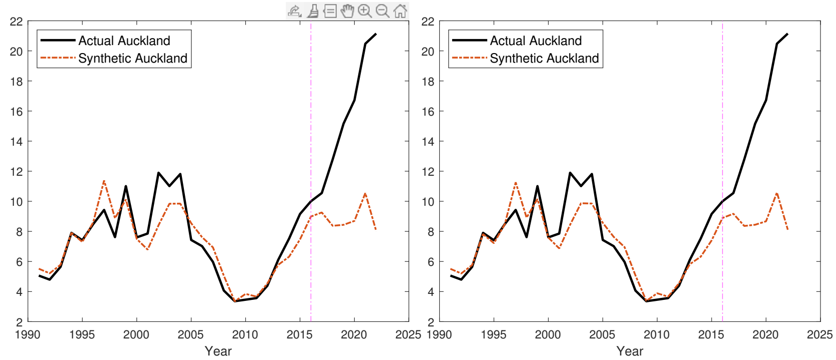
Figure 23: Synthetic and actual permits per thousand residents under alternative specifications



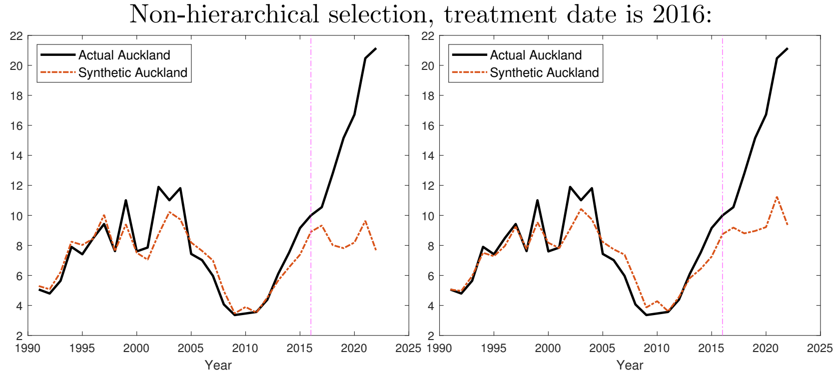
Notes: Left row depicts model A; right row, model B. Model A includes the entire time series of outcomes in the set of matching variables; B only includes outcomes in pre-reform census years (1991, 1996, 2001, 2006, 2013) in the set.Baseline specification presented in the main text is in the top left panel.

Figure 24: Synthetic and actual permits (thousands) under alternative specifications

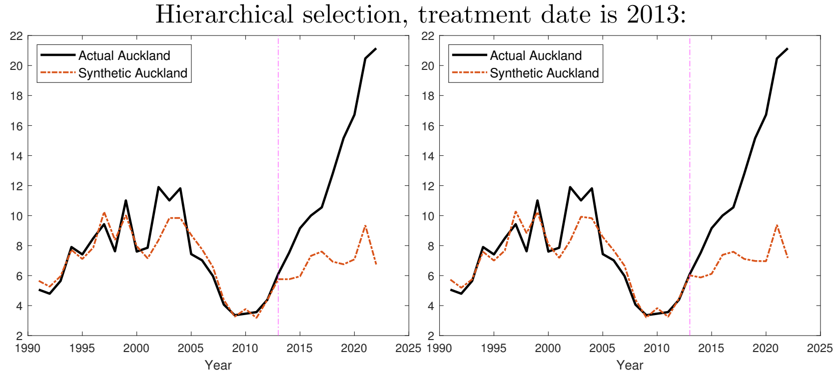
Hierarchical selection, treatment date is 2016:



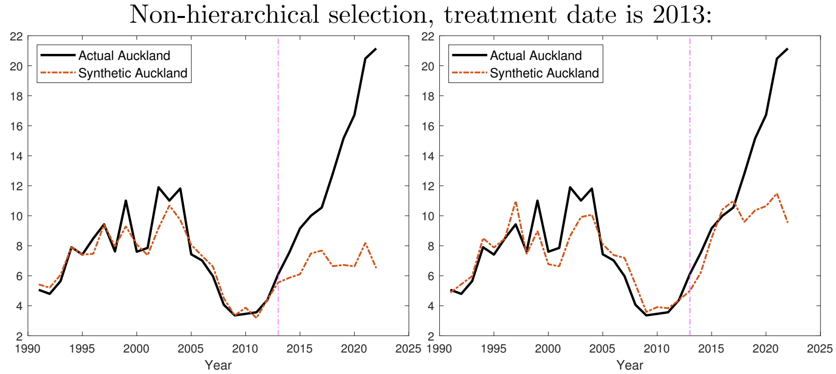
Non-hierarchical selection, treatment date is 2016:



Hierarchical selection, treatment date is 2013:

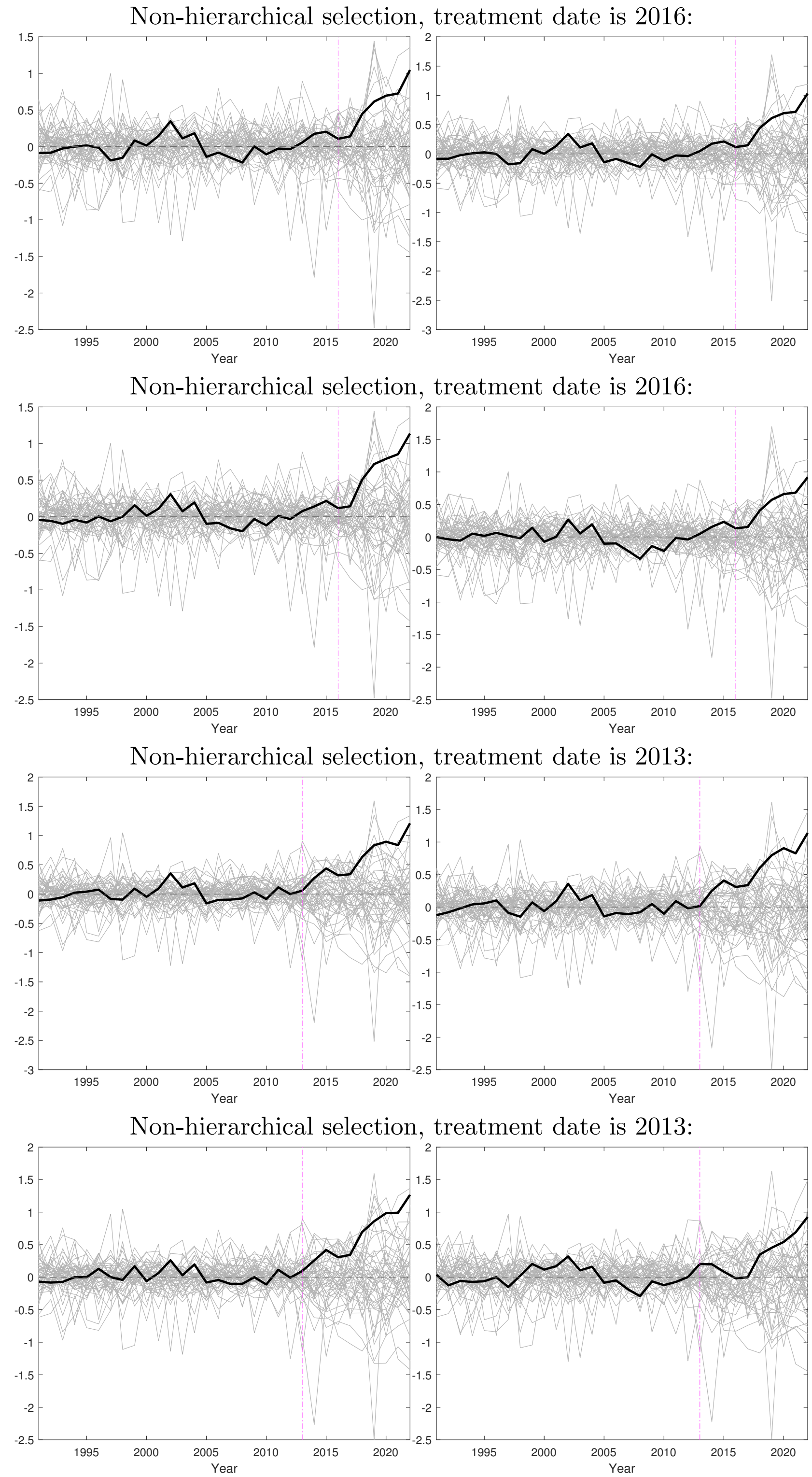


Non-hierarchical selection, treatment date is 2013:



Notes: Left row depicts model A; right row, model B. Model A includes the entire time series of outcomes in the set of matching variables; B only includes outcomes in pre-reform census years (1991, 1996, 2001, 2006, 2013) in the set. Baseline specification presented in the main text is in the top left panel.

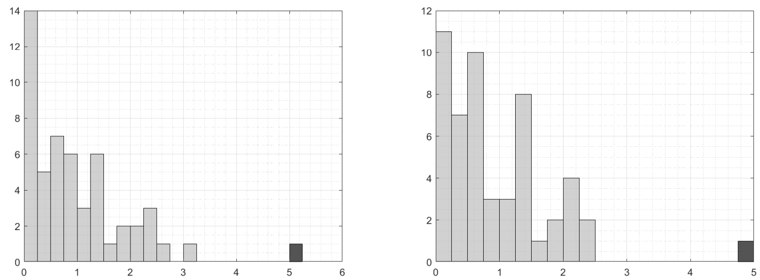
Figure 25: Prediction errors under alternative specifications



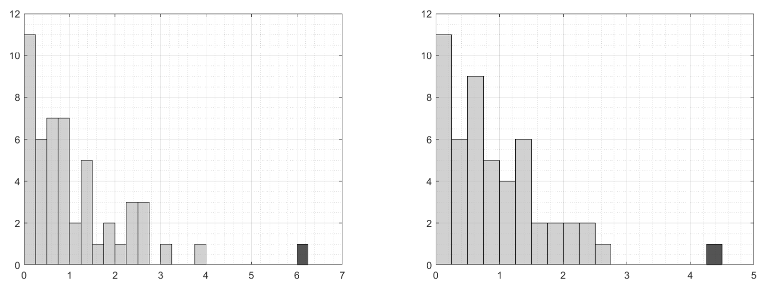
Notes: Difference between actual and synthetic log permits per thousand residents. Left row depicts model A; right row, model B. Model A includes the entire time series of outcomes in the set of matching variables; B only includes outcomes in pre-reform census years (1991, 1996, 2001, 2006, 2013) in the set. Baseline specification presented in the main text is in the top left panel.

Figure 26: Positive-error RMSE ratios under alternative specifications

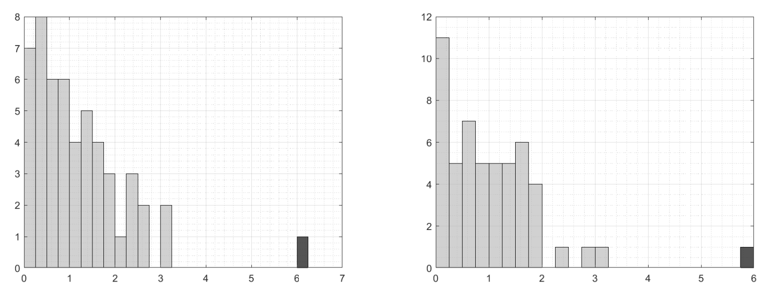
Hierarchical selection, treatment date is 2016:



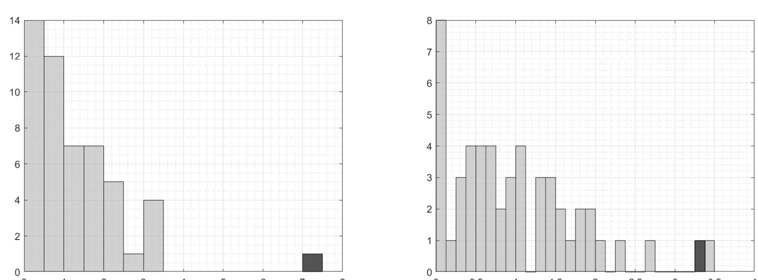
Non-hierarchical selection, treatment date is 2016:



Hierarchical selection, treatment date is 2013:



Non-hierarchical selection, treatment date is 2013:



Notes: Left row depicts model A; right row, model B. Model A includes the entire time series of outcomes in the set of matching variables; B only includes outcomes in pre-reform census years (1991, 1996, 2001, 2006, 2013) in the set. Baseline specification presented in the main text is in the top left panel.

6.5.1 Results without De-meaning Normalization

This subsection presents results when the times series of outcome variables for each urban area (log permits per thousand residents) does not have its pre-treatment mean subtracted. Table 7 shows that the de-meaning normalization reduces pre-treatment RMSE by between 22 and 28% when the treatment date is 2016, indicating significant gains in model fit from the normalization. Figure 27 exhibits synthetic permits per capita for the various permutations of the baseline model presented in section 6.5. Trends in the synthetic control are similar to those presented in figure 23, although it does a poorer job of matching the downturn from 2004 to 2010.

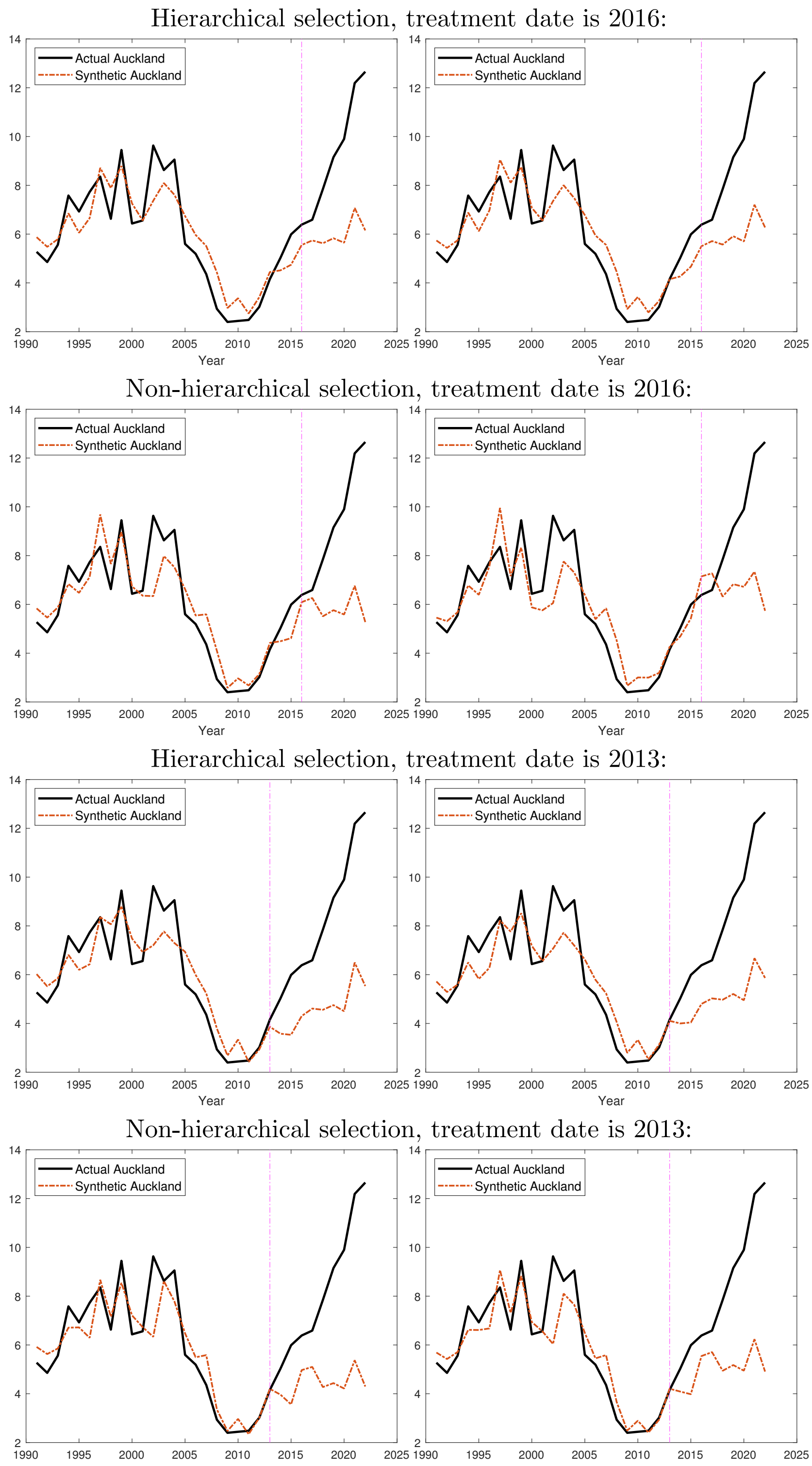
Table 7: Pre-intervention RMSEs

	Hierarchical donor selection			
	Treatment date: 2016		Treatment date: 2013	
Model	No normalization	De-meaning normalization	No normalization	De-meaning normalization
A	0.1731	0.1338	0.1601	0.1166
B	0.1761	0.1340	0.1642	0.1190

	Non-hierarchical donor selection			
	Treatment date: 2016		Treatment date: 2013	
Model	No normalization	De-meaning normalization	No normalization	De-meaning normalization
A	0.1589	0.1215	0.1747	0.1377
B	0.1432	0.1026	0.1481	0.1429

Notes: Model A includes the entire time series of outcomes in the set of matching variables; B only includes outcomes in pre-reform census years (1991, 1996, 2001, 2006, 2013) in the set.

Figure 27: Synthetic and actual permits per thousand residents without de-meaning normalization



Notes: Left row depicts model A; right row, model B. Model A includes the entire time series of outcomes in the set of matching variables; B only includes outcomes in pre-reform census years (1991, 1996, 2001, 2006, 2013) in the set.

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