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Can Zoning Reform Reduce Housing Costs? Evidence from Rents in Auckland

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Abstract

In 2016, Auckland, New Zealand upzoned approximately three-quarters of its residential land, precipitating a boom in housing construction. In this paper we investigate whether the increase in housing supply has generated a reduction in housing costs. To do so, we adopt a synthetic control method that compares rents in Auckland to a weighted average of rents from other urban areas that exhibit similar rental market outcomes to Auckland prior to the zoning reform. The weighted average, or "synthetic control", provides an estimate of Auckland rents under the counterfactual of no upzoning reform. Six years after the policy was fully implemented, rents for three bedroom dwellings in Auckland are between 26 and 33% less than those of the synthetic control, depending on model specification. These decreases are statistically significant at a five percent level under the conventional rank permutation method. Meanwhile, rents on two bedroom dwellings are between 21 and 24% less than the synthetic control, but these decreases are only statistically significant under some model specifications. These findings support the proposition that large-scale zoning reforms in Auckland enhanced the affordability of family-sized housing when evaluated by rents.

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

JEL Classification Codes: R14, R31, R52.

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1 Introduction

Housing has become increasingly expensive in many parts of the world, precipitating an affordability crisis (Wetzstein, 2017; Saiz, 2023). A wide range of economists and urban planners attribute high house costs, at least in part, to restrictive zoning (Gyourko and Molloy, 2015; Been, 2018; Hamilton, 2021). Zoning reform to relax restrictions on housing density is consequently advocated to reduce prices by relaxing regulatory restrictions on housing supply. (Glaeser and Gyourko, 2003; Freeman and Schuetz, 2017). However, up until very recently, few cities have pursued large-scale zoning reforms to enable affordability (Schill, 2005; Freeman and Schuetz, 2017), meaning there little empirical evidence to support the purported effects of zoning reforms.

However, in 2016 the city of Auckland, New Zealand, upzoned approximately three-quarters of its residential land (Greenaway-McGrevy and Jones, 2023), precipitating a construction boom in the city (Greenaway-McGrevy and Phillips, 2023), and affording us six years of data to examine the impact of the reforms on housing costs. In this paper, we assess the impact of the reforms on Auckland's housing costs, adopting a synthetic control approach to specify the counterfactual scenario to the policy change. The synthetic control is constructed from a donor pool comprising 51 commuting zones in New Zealand, and matched to a variety of observed housing market outcomes, including dwellings per capita and the average proportion of household income allocated to housing costs.

Depending on model specification, our measure of housing costs for family-sized (i.e., three bedroom) dwellings have decreased by between 26 and 33% relative to the synthetic control six years after the reforms. Housing costs for smaller (two bedroom) dwellings have decreased by 21 to 24% over the same period, depending on model specification. Put differently, the fitted models imply that housing costs for three bedroom dwellings in 2022 would be between 36 to 49 percent higher had Auckland not implemented zoning reforms. Housing costs for two bedroom dwellings would be 27 to 31% higher.

To assess the statistical significance of these decreases, we apply the conventional rank permutation test to the ratios of post- to pre- intervention mean square errors (MSEs, Abadie et al. 2010).[1] For three bedroom dwellings, Auckland has the largest ratio among all units in the donor pool across all model specifications. 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). Thus, the decrease in 3 bedroom rents is statistically significant at the conventional five percent level across various model specifications. For two bedroom dwellings, Auckland's ratio is ranked between second and eighth largest, depending on model specification, corresponding to p-values between 0.038 (= 2/52) and 0.115 (= 8/52).

We use prices on new rental tenancies (hereafter "rents") as our measure of housing costs. We use rents, rather than house prices, for two reasons. First, rents are not directly affected by enhanced redevelopment rights from zoning reform. The effects of upzoning on housing prices is mediated by the land endowment of affected properties. Land prices in desirable locations increase in value (Greenaway-McGrevy, 2023a), reflecting the increased capacity of the land to

[1] Abadie et al. (2010) rank root mean squared error, which is a monotonic transformation of MSE.

hold additional floorspace and the right to redevelop the property into capital intensive dwellings. Properties that are relatively land intensive, such as detached single family dwellings on large lots, are likely to appreciate in value. Both (Greenaway-McGrevy et al., 2021) and (Greenaway-McGrevy and Phillips, 2023) show evidence of this occurring in Auckland after the reforms. Rents, on the other hand, are not affected by the enhanced development rights, which accrue to the landowner. Second, rents potentially capture housing costs across a wider socioeconomic demographic, given that low income households are more likely to be tenants.

Rents are constructed from the Ministry of Housing and Urban Development (HUD) dataset on rental bonds, which reports the geometric mean of weekly rents on new tenancies in various regions of the country. From these data, we calculate the geometric mean of weekly rental prices on new tenancies within the commuting zone. Thus, our findings support the proposition that upzoning reduced average rents for larger, family-sized dwellings, but there is less statistical evidence that it decreased housing costs for smaller dwellings.

The differential effects between large and small homes is consistent with LUR changes under the reforms, which relaxed stringent restrictions on floorspace capacity. Prior to the reforms, the vast majority of residential land had an implied maximum floor to area ratio (FAR) restriction identical to that used for detached single family zoning under the reform (Greenaway-McGrevy and Jones, 2023). Minimum lot sizes (MLS) were comparatively low in some targeted locations, but were often paired with restrictive FARs.[2] The combination of stringent floorspace restrictions but comparatively relaxed MLS encourages smaller dwellings in these targeted areas. MLS on existing parcels were abolished under the zoning reforms, and FAR restrictions lifted on three-quarters of residential land.

The synthetic control method has been applied to evaluate policy 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 rental time series spans 1993, when the data begin, to 2022, with the intervention occurring in 2016. Second, we examine how robust our findings are to changes in modeling assumptions. Although the magnitude of implied rent decreases does vary some what between specifications, in all specifications we find that the decreases in three bedroom dwelling rents are statistically significant. Third, our findings are robust to conventional robustness exercises incorporated into study design that are used in the extant literature. Synthetic outcomes for the treated unit 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.

[2]For example, zones 3A, 4A, 4B, 6A, 6B and 6C under the former North Shore City Council plan had MLS between 350m^{2}and 450m^2, but also had site coverage ratios and height restrictions that implied a maximum FAR of 0.7. The "Single House" zone under the AUP also has an implied FAR of 0.7, and a MLS on new subdivisions of 600m^2.

Nonetheless, there are inherent limitations to the SC method. Donor units will be affected by the policy change if increased housing supply in Auckland affects inter-city migration. We note, however, that in-migration to Auckland from lower housing costs generates attenuation bias in estimates of the casual impact, since it reduces housing demand in other cities and increases it in Auckland, pushing up housing costs in Auckland. More problematic is a population decrease in Auckland from 2020 onwards, widely attributed to COVID-19 and policy responses thereto. Statistics New Zealand estimates that Auckland's population decreased by 1.1% between 2020 and 2022. Although media attention at the time focused mainly on Auckland, the same population estimates show that other cities experienced population decreases, including (but not limited to) Dunedin (1.79%), Wellington (0.14%) and Rotorua (0.4%). Notably, these cities experienced significant appreciation in rents between 2020 and 2022, despite population decreases. We address this problem in two ways. First, we end the sample in 2020, when the estimates of Auckland's population peak. Second, we include estimates of population decrease between 2020 and 2022 in the set of predictor variables, and drastically reduce the set of matching variables, so that the population decrease variable plays a prominent role in constructing the synthetic control for Auckland. Our conclusions remain unchanged: Rent decreases for three bedroom dwellings continue to be statistically significant.

There are also limitations to the rental tenancy dataset that forms the basis of our analysis. Geometric averages between regions and time periods can reflect differences in the quality of the transacted dwelling stock. Unfortunately, the reported attributes of dwellings in the dataset are limited, and rental statistics are aggregated to a regional level, making it difficult to quality-adjust rents. Nonetheless, we take several steps to control for quality differences given these limitations to the available data. First, we stratify the sample based on the number of bedrooms, examining three- and two- bedroom dwellings separately. Second, our results are largely unchanged when we further stratify the sample based on dwelling type, repeating the analyses on dwellings classified as "houses". Third, we normalize the rental time series relative to the intervention date, such that the outcome of interest is rental price changes. Much like a within-city fixed effect adjustment, this differencing transformation controls for pre-intervention rental dwelling characteristics at the city level, including differences in average quality of the housing stock. Nonetheless, differential changes in the quality of the rental dwelling stock between commuting zones is more difficult to control for, including quality changes due to the policy intervention itself. However, it is unclear whether the quality changes brought about by the zoning reforms would cause geometric averages to be higher or lower than quality-adjusted rents. As the reform stimulated construction, much of the housing stock in Auckland is new, and newer dwellings command higher rents, all else equal. Similarly, the housing stock is also closer to the CBD, job locations and transit network access points (Greenaway-McGrevy and Jones, 2023), which would increase rents, all else equal, if households prefer shorter commutes to work and other locations. These factors imply that quality-adjusted rents would be lower than reported averages. Conversely, much of the new dwellings are attached (Greenaway-McGrevy and Phillips, 2023), and may consequently command lower prices, all else equal, if there are disamenities associated with attached housing. It is also unclear whether the change in Auckland's housing stock to date is sufficiently large for these factors to significantly affect average rents. In any case, normalized geometric mean rents do reflect changes in average out-of-pocket expenses for households signing new tenancies on different dwelling types in the various urban areas.

The remainder of the paper is organized as follows. The following section provides the institutional details of the policy and backgrounds on Auckland and New Zealand. Section three describes the data. In section four presents the method and results. Section five concludes.

2 Institutional Background

Housing costs in New Zealand are among the most expensive in the developed world. Among renters and owner-occupiers with a mortgage, the median proportion of disposable income (i.e. after taxes and transfers) spent on housing costs was 22% in 2021, exceeded only by Australia, Greece and France among the OECD.[3] Among renting households, the median proportion is 28%. As of the 2018 census, over a third (35.5%) of households are tenants.[4] This figure is higher for Auckland, where more than two-fifths (40.6%) of households rent.

Auckland in the largest city in New Zealand, with a population of 1.57 million in 2018 (source: New Zealand census). In March 2013, the city announced the first version of the Auckland Unitary Plan (AUP), which introduced and applied a standardized set of planning zones across the jurisdiction, including four residential zones intended to encourage medium density housing. After several rounds of reviews and consultation, the plan was operationalized in November 2016. Approximately three-quarters of residential land was upzoned, in the sense that effective FAR restrictions on housing development were relaxed (Greenaway-McGrevy and Jones, 2023).

Although the plan was operationalized in 2016, an agreement between the Auckland Council and the central government allowed developers to build to the rules of the 'Proposed' Auckland Unitary Plan (PAUP), announced in September 2013. This was an inclusionary zoning program that required developers to offer a 10% proportion of affordable housing in exchange for accelerated permitting process and the ability to build to the more relaxed LURs under the PAUP. The program ended once the AUP was implemented. Thus, while the AUP was formally operationalized in 2016, it began to have a small effect from September 2013 onwards. For additional details on the implementation of the plan and the spatial distribution of upzoning, see Greenaway-McGrevy and Jones (2023).

Housing supply quickly responded to the reforms. Figure 1 exhibits annual consents issued per year, decomposed into consents issued in upzoned areas, non-upzoned areas (including business and rural areas). Consents for new dwellings significantly increased year-on-year from 2016 onwards, with all of the new construction occurring on upzoned areas. Note, however, that the divergence

[3] See Figure 10 here: https://www.msd.govt.nz/documents/about-msd-and-our-work/publications-resources/monitoring/household-income-report/2021/international-comparisons-of-housing-affordability.docx.

[4] Source: 2018 census https://www.stats.govt.nz/tools/2018-census-place-summaries/auckland-region#housing

between upzoned and other areas begins from 2013 onwards, reflecting policy "leakage" as some developers took advantage of the relaxed regulations under the PAUP. The PAUP-SpHA consents were disproportionately located in areas that were upzoned (see Figure 12 in the Appendix, which separately identifies PAUP-SpHA in the data). We use 2016 as the date of the policy intervention in the synthetic control approach, since this the date after which the divergence becomes most evident, although 2012 or 2013 could also feasibly be used as the treatment date.

3 Data

Data on new tenancies are compiled by the Ministry of Housing and Urban Development (HUD) on a quarterly basis and are available at the Statistical Area 2 (SA) level. HUD reports the geometric mean weekly rent for dwellings by the number of bedrooms (2, 3, 5 and 5+) and housing types ("Flats" and "Houses"). Because HUD reports the number of new tenancies, we can compute geometric mean rents for aggregations of the quarterly SA data. We aggregate the data into annual frequency for commuting zones.

We use Functional Urban Areas (FUAs) as the geographic units of analysis. FUAs are delineated by Statistics New Zealand on the basis of commuting patterns, and are analogous to commuting zones as defined by the OECD.[5] There are 53 FUAs in New Zealand, including Auckland. We omit Christchurch from the donor pool due to the impact of the 2011 earthquake on the housing stock and housing markets. As noted by Abadie (2021), potential donor units that are subject to large idiosyncratic shocks to the outcome variable should be withheld from the donor set. This leaves 51 units in the donor pool. FUAs are agglomerations of SA1s, which is a smaller geographic unit than the SA2s for which rent data are available. We assign an SA2 to a FUA if lies within or overlap the geographic boundary of the FUA.[6]

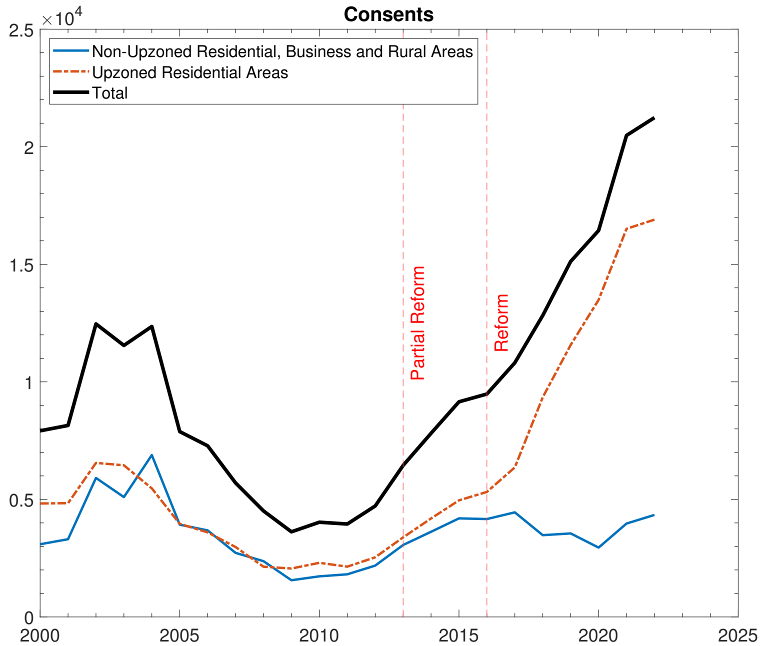
Rents for each FUA are calculated using data on rental bonds lodged by with central government agencies. Private sector landlords are legally required to lodge bonds at the origination of new tenancy contracts. The data contain information on the location and weekly rent, as well as some limited information on the characteristics of the dwelling, including the number of bedrooms. Each quarter, the Ministry of Housing and Urban Development (HUD) publishes the geometric mean of weekly rents on new rental contracts and the number of new bonds lodged.[7]These data are available

[5]See https://www.stats.govt.nz/assets/Methods/Functional-urban-areas-methodology-and-classification.pdf

[6]Thirteen of the SA2s appear in two FUAs that are typically contiguous. In such cases we assign the SA2 to the FUA that accounts for a greater proportion of the SA2's area.

[7]Statistics New Zealand also produces rental price indexes for five broad regions using a time dummy hedonic model that is fitted to individual rental bond data over an eight-year sample window (Bentley, 2022). Because the model includes individual dwelling fixed effects, rental inflation is inferred from price changes on repeated tenancies within the sample window. One drawback of measuring prices based on repeated observations is the "new goods" problem (Pakes, 2003), which refers to distortions in price measurement stemming from changes in the composition of differentiated products within the broader product class over time. Specifically, price differentials between different products do not contribute to measured inflation, which becomes problematic when new products are introduced and old products are retired. These problems are substantially more acute in housing markets, because each dwelling is a unique "product", and dwellings or rental contracts are infrequently transacted. Pakes (2003) advocates for hedonic methods to address the new goods problem, and recommends the use of hedonic imputation over the time dummy

Figure 1: Dwelling Consents in Auckland, 2000 to 2022



Notes: Consents issued per year in different areas of Auckland. The first, "draft", version of the AUP was announced in March 2013, while the "Proposed" AUP (PAUP) was notified in September 2013. 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. The final version of the AUP became operative in part in November 2016. Thus the first "partial" reform occurred in 2013, with the full reform following in 2016. Source: Greenaway-McGrevy (2023b).

for each statistical area (SAs), and are analogous to census tracts in the US. SAs are a geographic unit used by Statistics New Zealand for the census and cover approximately 2,000–4,000 residents in urban areas and are delineated to reflect communities that interact socially and economically.[8] We construct an annual geometric mean rent for each FUA using a mapping from SAs to FUAs and the number of new bonds lodged.[9]

HUD reports geometric mean rents by the number of bedrooms (2, 3, 4 and 5+) and housing types ("Flats", "Houses", and "Apartments"). In order to partially account for compositional differences in new rental housing between FUAs and time periods, we construct rents by number of bedrooms. For example, if the proportion of new contracts within a given quarter are for two bedroom dwellings, the average rent across all dwellings is likely to fall in that quarter because two bedroom homes typically rent for less that three or four bedroom homes. By conditioning on the number of bedrooms, we also reduce cross sectional variation due to persistent compositional differences in rental housing between different locations. For example, large metropolitan regions may have a higher proportion of two bedroom dwellings. Due to data sparsity, we do not compute rents for 4 bedroom or 5+ bedroom dwellings.

Figure 2 exhibits the average weekly rent for two- and three- bedroom dwellings in the "major" urban areas of the North Island of New Zealand: Auckland, Hamilton, Tauranga and Wellington.[10] We select these three cities as they are large cities comparatively proximate to Auckland. This comparison is purely for expositional purposes: In the analysis to follow we use the SC method to select controls. We also compare rents in Auckland to population-weighted averages across the 51 other FUAs.

Rents in Auckland trend upward between 2000 and 2018 or so, at which point they flatten out. Meanwhile rents in Hamilton, Tauranga and Wellington continue increase at a substantially faster rate over this period, such that rents in Wellington exceed those in Auckland for both 2- and 3-bedroom homes by the end of the sample, while rents on 3- bedroom homes in Tauranga exceed those in Auckland from 2020 onwards.

In 2016, the mean rent for a 3 Bedroom in Auckland was $528.14 per week. By 2022, this has increased in $587.42 – an increase of 11.2%. In Hamilton, 3 bedroom mean rent increased from $383.54 to $542.90, an increase of 41.6%. In Tauranga, 3 bedroom mean rent increased from $438.70 to $636.82, an increase of 45.16%. In Wellington, 3 bedroom mean rent increased from $483.08

method as it allows hedonic coefficients to change over time. Repeated transaction methods are also subject to the "Lemon's bias" when applied to housing, whereby measured prices are biased towards more frequently transacted properties (Clapp and Giaccotto, 1992).

[8]SAs were introduced in 2018, as the previous classification system had not been revised since 1992. The previous statistical geographies no longer reflect current land use and population patterns. The revision was also implemented in order to align the geographic unit standards with international best practice. Population data from the previous census (conducted in 2013) and associated projections were used in the design of the 2018 boundaries. For additional details, see https://www.stats.govt.nz/assets/Uploads/Retirement-of-archive-website-project-files/Methods/Statistical-standard-for-geographic-areas-2018/statistical-standard-for-geographic-areas-2018.pdf [Accessed 1 March 2023]

[9]Missing annual observations are linearly interpolated within each time series.

[10]Statistics NZ classifies FUAs into "Main", "Large", "Medium" and "Small" metropolitan areas.

to \$686.94, an increase of 42.2%. For 2 Bedroom dwellings, mean rents in Auckland increased by 14.8% over the same period, while those in Hamilton, Tauranga and Wellington increased by 56.2%, 59.3% and 48.0%, respectively. Thus, a rudimentary, subjective analysis that selected a combination of these other large, North Island cities as a counterfactual would imply that the zoning policy reduced three bedroom rents by at least 30%, and 2 bedroom rents by between 33 to 44%. Of course, the synthetic control method is motivated by a more objective selection of units as the relevant counterfactuals.

3.1 Matching Variables

As we demonstrate in more detail in the following section, the SC method selects comparable controls by matching outcomes prior to the policy intervention. These can include the outcome of interest (in our application, rents) as well as other related variables. Here we describe the additional matching variables, all of which are rental or housing market outcomes. First, we include the proportion of renting households within the FUA for the two census years prior to the intervention, 2006 and 2013. Second, we include dwellings per capita to capture demand for housing within the urban area. Dwellings are only available for census years. Dwellings and population by SAs are obtained from Statistics NZ and aggregated up to FUAs. We include data for the previous two censuses, 2006 and 2013. Third, we include the average proportion of household income spent of rental costs, for 2006 and 2013.

4 Synthetic Control Method and Results

This section outlines the SC method and applies it to our dataset.

4.1 Synthetic Control Method

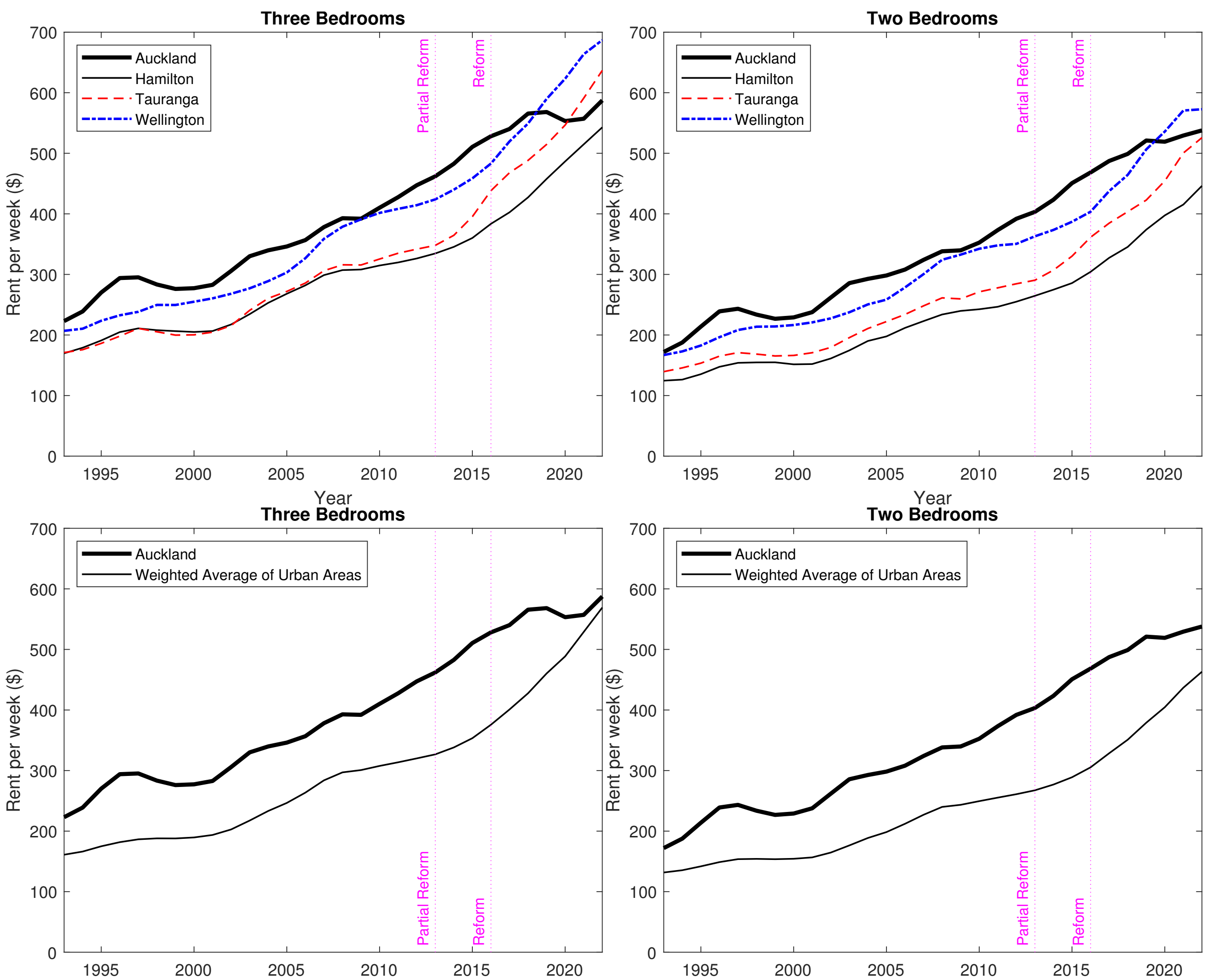
This section provides an overview of the SC method. Readers familiar with SC may wish to proceed to the next subsection.

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 $T_0 < T - 1$.

$y_{i,t}$ 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 SC 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. For each i, there

Figure 2: Weekly Rents in Metropolitan Areas, 1993–2022



Notes: Geometric mean rents for selected urban areas. Weights based on 2018 census populations.

is a set of k observed predictors of $y_{i,t}$ contained in the vector $X_i = (x_{1,i}, ..., x_{k,j})$, which can include pre-intervention values of $y_{i,t}$ unaffected by the intervention. The k matrix $\boldsymbol{X}_0 = [X_2 \cdots X_{J+1}]$ 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

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

subject to the restrictions $w_h \in [0,1]$ and $\sum_{h=1}^{k} w_h = 1$, and where $\boldsymbol{v} = (v_1, ..., v_k)$ is a set of nonnegative 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 mean square error of the synthetic control estimator in the pre-treatment period. Then, the estimated treatment effect for the treated unit at time $t = T_0 \ldots, T$ is $\hat{y}_{1,t}^N = \sum_{i=2}^{n+1} w_i^* y_{i,t}$.

Weights $\boldsymbol{w}$ that minimize (1) can found using standard quadratic programming solvers. To select $\boldsymbol{v}$ in the nested MSE-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).[11] It is considered a state of the art evolutionary optimizer (Li et al., 2020).[12]

In our application, we include all pre-treatment realizations of the outcome variable, rents. 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. In our baseline specification, we include rents between 1993 and 2016. As discussed above, we also include dwellings per capita, the proportion of renting households, and average proportion of household income spent on rent among the matching variables. See section three above for a discussion of the rationale for including these variables.

Conventional SC requires that the predictors of the treated unit must lie within the convex hull of the predictors of the donor pool. The convex hull assumption is necessary for the treated unit's predictors to be approximated by the donor pool's. However, rents in Auckland during the pre-intervention period were generally higher than those of other urban areas, meaning that the conventional convex hull requirement for construction of the synthetic control is unlikely to hold. Abadie (2021) suggests that the pre-treatment average can be subtracted from each outcome time series in such situations (Ferman and Pinto, 2021). However, the rent time series are non-stationary, meaning that the sample averages do not converge to a mean, and potentially making

[11] 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.

[12] 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 MSE objective function, using the cmaes.m matlab code provided by Nikolaus Hansen (available from `http://cma.gforge.inria.fr/cmaes.m`) CMA-ES generated significant reductions in the nested MSE objective function. It also improved the MSE of Hainmueller's synth STATA package, though the obtained weights for our baseline models were similar under both approaches.

results sensitive to the pre-intervention sample period selected.[13] We instead normalize log rents by subtracting the value for the treatment period, such that outcomes are log rents relative to the year of the treatment.

We employ a hierarchical restriction of the donor pool for each urban area based on Statistics New Zealand categories. Urban areas in New Zealand are categorized as "major", "large", "medium" and "small", depending on size. "Major" consists of six cities; "large" consists of eleven; and "medium" a further fourteen. The remainder are "small". Major UAs have their donor pool restricted to other major UAs and large UAs. This means that Auckland's donor pool incorporates the four other major UAs (Hamilton, Tauranga, Wellington, Dunedin), as well as nearby large UAs such as Whangarei and Rotorua. For the placebo tests, large UAs have their donor pool restricted to major, large and medium UAs. Medium and small UAs do not have their donor sets restricted.[14]

We refer to the model that includes the full time series of rents and matching variables in the set of predictors as "model A". We consider variations of the method to examine how sensitive our findings are to modeling assumptions. First, we restrict the predictor set to the matching variables and rents in 2013 and 2006. When the full time series of pre-intervention rents are included in the set of predictors, the selected weights are tilted towards matching Auckland's (normalized) rents in the pre-intervention sample period. By omitting the full time series of rents from the set of predictors we tilt the weights towards the matching variables. We include 2006 and 2013 observations on rents to match the timing of the census-based matching variables. Each set of variables (rents, dwellings per capita, rental costs as a proportion of income, and proportion of renting households) each have two observations in the donor pool. We refer to this as "model B". Second, we use an out of sample validation (OOSV) exercise to select the weights $\boldsymbol{v}$. This method is described on pp. 396–397 of Abadie (2021). We restrict the set of predictors to the time series of pre-intervention rents (i.e. we omit the matching variables), and divide the pre-treatment period into a training period and a validation period. Each sample period is the same length. The training period is used to select weights, as under (1). The weights$\boldsymbol{v}$ are selected to minimize the MSE in the validation period. We refer to this as "model C". Third, we perform the OOSV exercise but include the matching variables for 2006 in the set of predictors. The training period then ends in 2006. We refer to this as "model D".

4.2 Results

Table 1 exhibits the selected weights across the four methods considered.

The selected donor set for three bedroom homes comprises six urban areas (UAs) across all model specifications. For models based on in-sample selection of $\boldsymbol{v}$, Hamilton and Rotorua feature prominently, with nearly one-half on Hamilton and approximately one third on Rotorua. For models based on out-of-sample validation for selection of $\boldsymbol{v}$, Rotorua is more prominent. The donor set for 2 bedroom dwellings includes six UAs across all model specifications. Hamilton features prominently

[13]We obtained similar results to those reported when we normalize by subtracting the pre-intervention mean.

[14]An earlier version of the paper did not employ hierarchical restrictions on the donor pool. We report results from the unrestricted models as a robustness check.

among models based on in-sample selection of $\boldsymbol{v}$, while Tauranga features heavily among models based on out-of-sample validation.

Figures 3 and 4 exhibit rents and synthetic rents for Auckland over the 1993 to 2022 period. There is a notable divergence from 2016 onwards, with rents growing much more slowly than synthetic rents.

For instructive purposes, we begin by examining results from model A for three bedroom dwellings. By the end of the sample, log rents in Auckland are 0.306 less than the synthetic control, corresponding to a 26.3% decrease. Across all four specifications, log rents are between 0.306 and 0.397 less than the synthetic control, equating to a 26.3 to 32.8 percent decrease in rents relative to the counterfactual. For two bedroom dwellings, log rents are between 0.237 and 0.272 less than the synthetic control by 2022, corresponding to a 21.1 to 23.8 percent decrease. Notably, the range is lower to those obtained for of three bedroom dwellings.

4.3 Inference

We run placebo interventions on the other donor units to assess whether the decrease relative to the counterfactual is large. Figure 5 and 6 plot the difference between the actual outcomes of each donor and its synthetic control. Evidently the decrease in Auckland's prediction error in the greatest among all units over the post-intervention period, indicating that the zoning reform had a substantive negative impact on rents.

To conduct statistical inference we apply the rank permutation approach to the ratio of mean square prediction errors between the actual and synthetic units. Define the MSE over $t = t_1$ to $t = t_2$ as

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

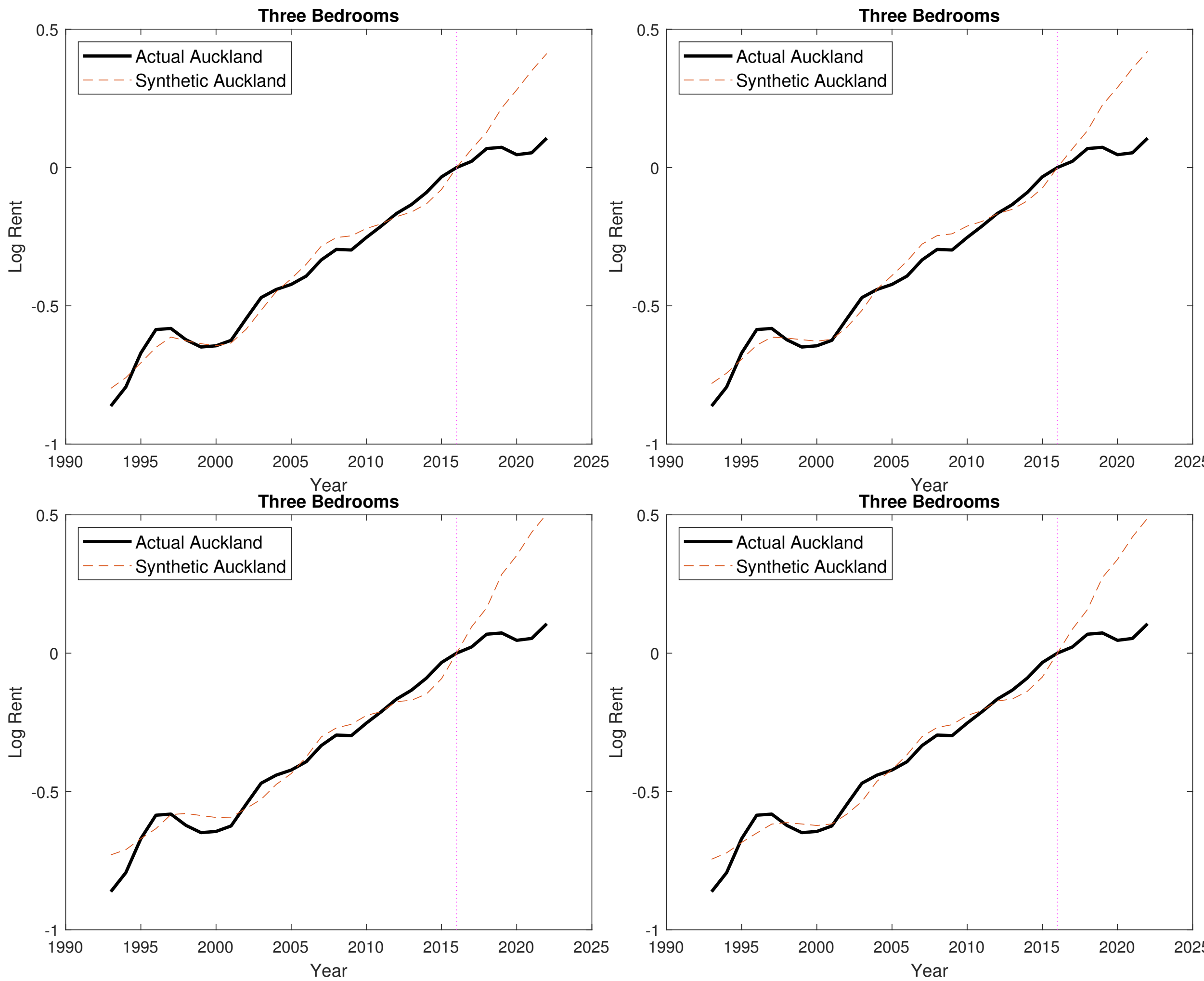
Following Abadie et al. (2010) suggest using the ratio of pre- to post- intervention MSE as a basis for inference,

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

The ratio is constructed for the treated unit and all placebo runs. The rank permutation test is then based on where the ratio for the treated unit ranks among all placebo runs. For example, if the ratio was ranked second among all 52 runs, then if one were to assign the intervention at random, the probability of obtaining a ratio that is second largest is 0.038 ($= 2/52$).

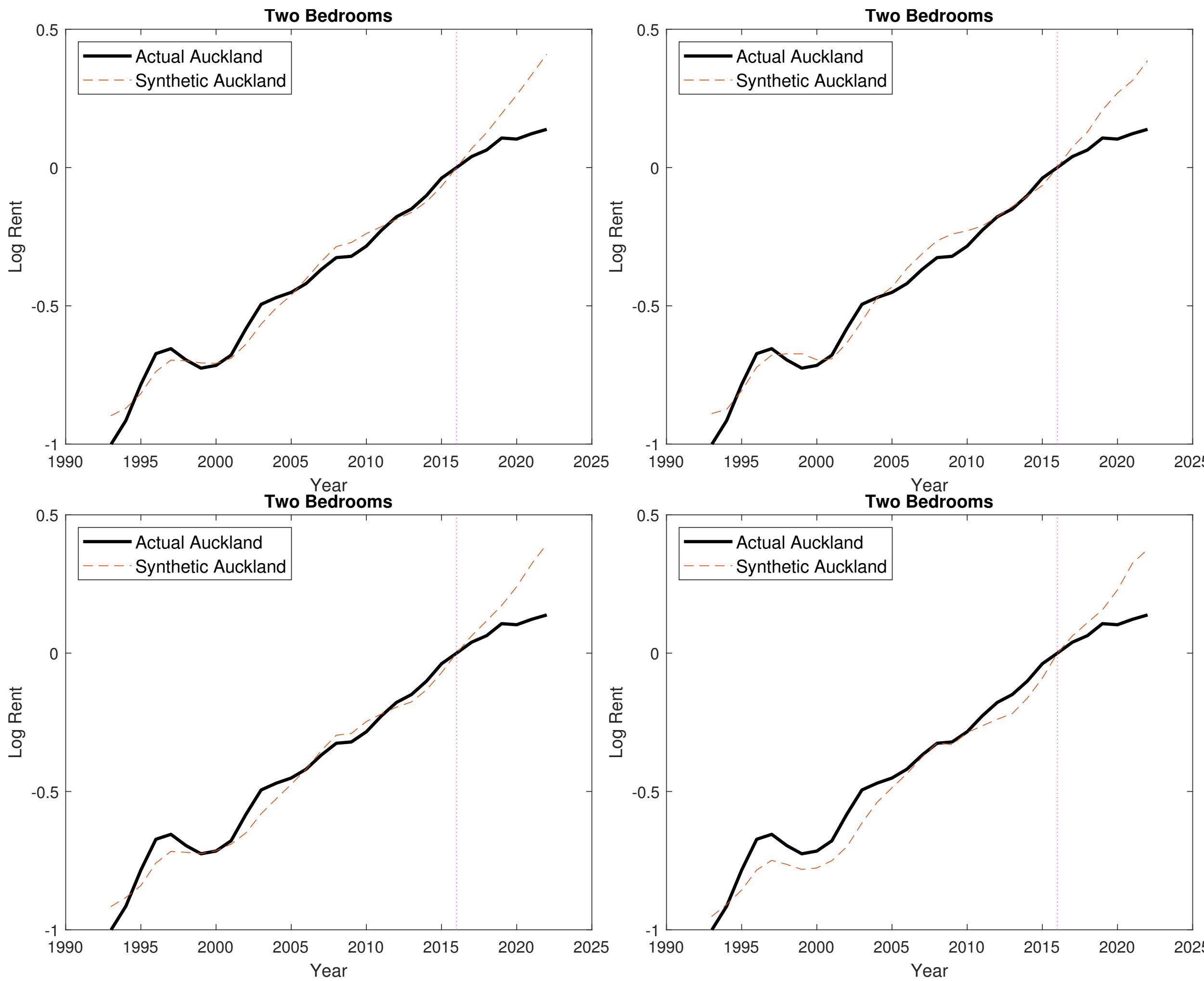
However, one drawback of the ratio is that it does not distinguish between positive and negative deviations from the synthetic unit, whereas many hypotheses posit a directional change from an intervention. For example, the relevant alternative hypothesis in our case is that zoning reforms reduced housing costs. Substantial increases in power can be obtained by testing for reductions relative to the synthetic control, rather than absolute differences (Abadie, 2021). To conduct a

Figure 3: Synthetic and actual rents, 3 bedroom dwellings



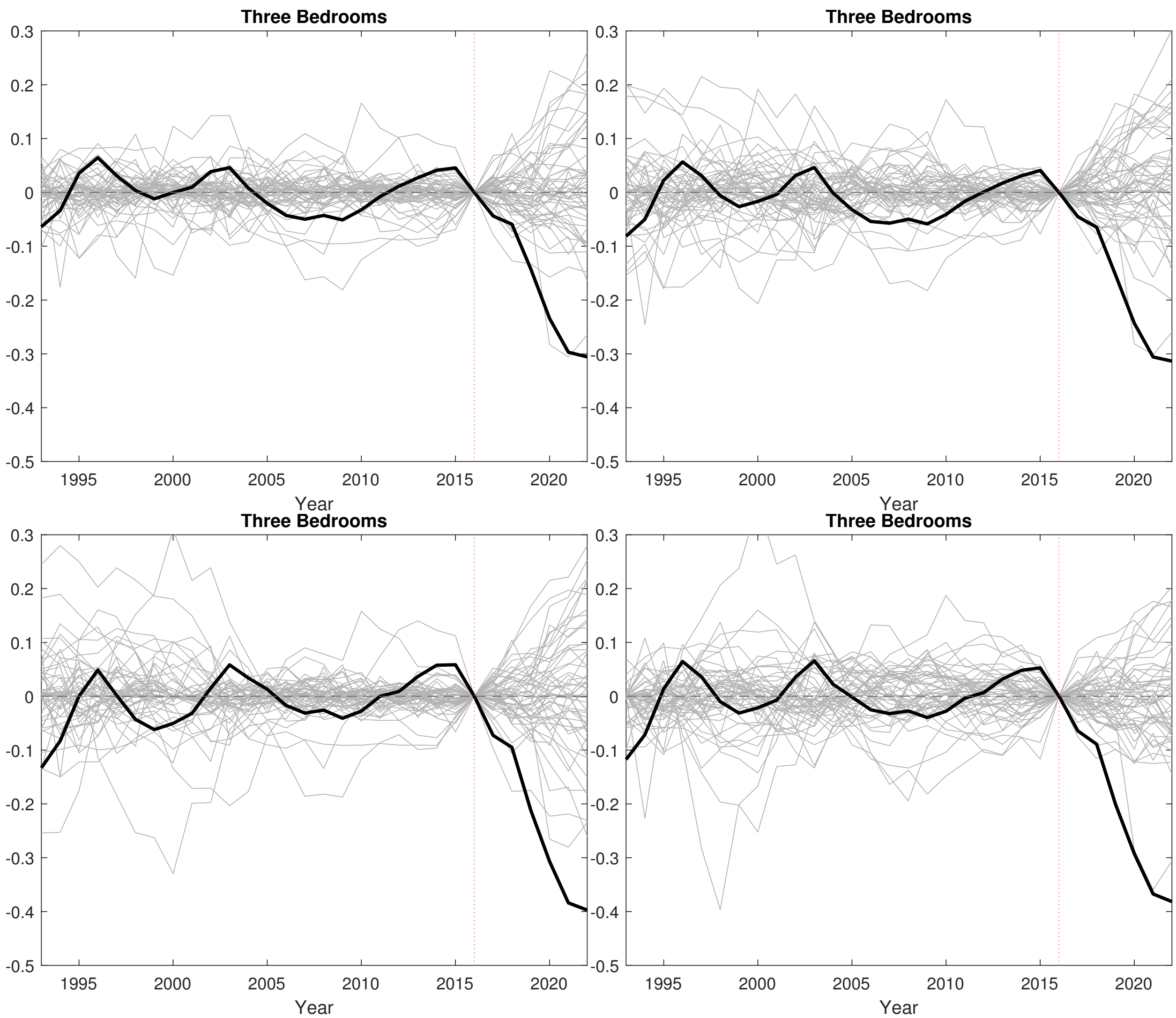
Notes: y-axis is the log normalized rent. Top left depicts model (A); top right, model (B); bottom left, model (C); bottom right, model (D). See notes to Table 1 for a description of the models.

Figure 4: Synthetic and actual rents, two bedroom dwellings



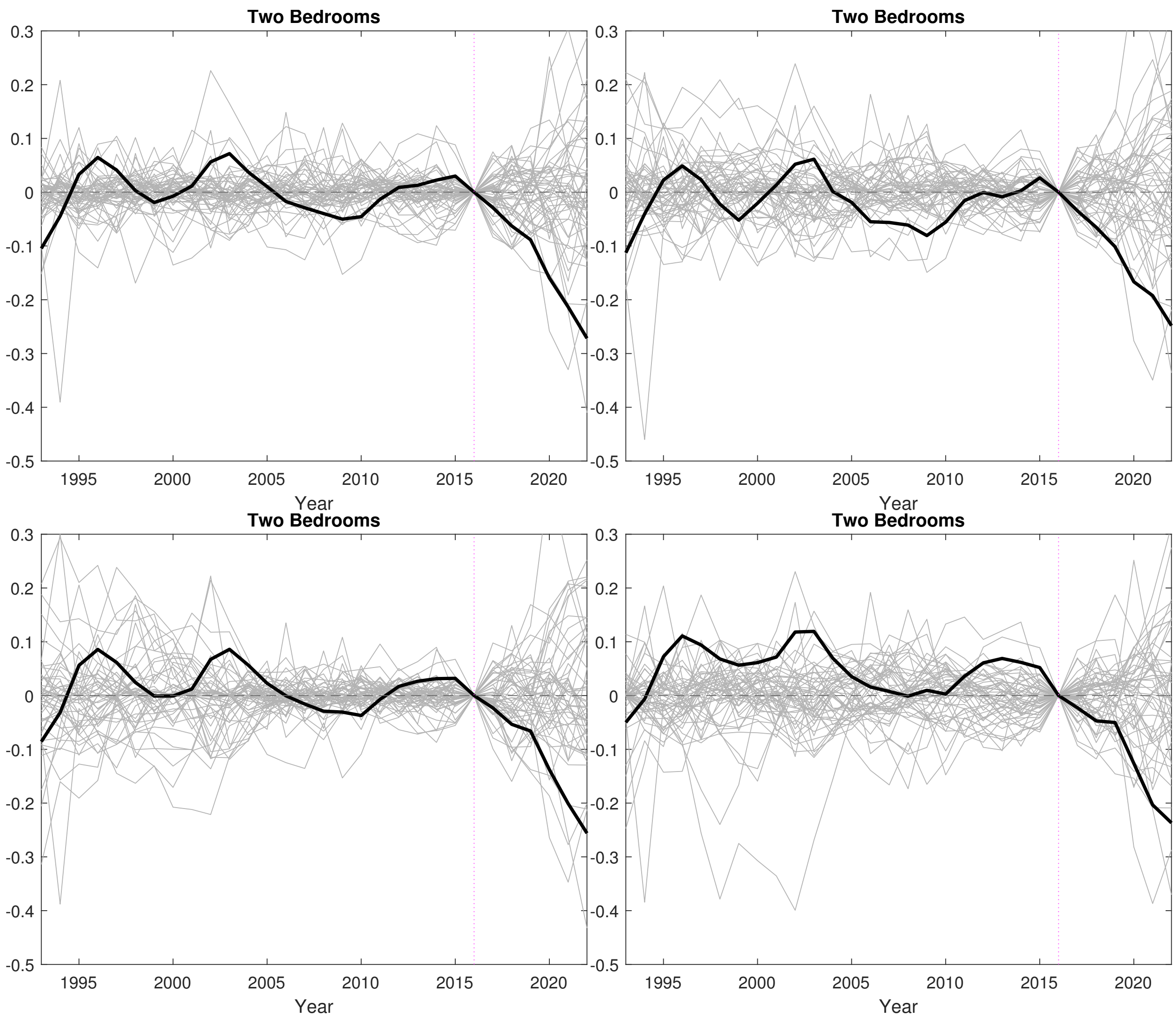
Notes: y-axis is the log normalized rent. Top left depicts model (A); top right, model (B); bottom left, model (C); bottom right, model (D). See notes to Table 1 for a description of the models.

Figure 5: Prediction errors, three bedroom dwellings



Notes: Difference between actual and synthetic outcomes. Auckland in black. Placebos in grey. Top left depicts model (A); top right, model (B); bottom left, model (C); bottom right, model (D). See notes to Table 1 for a description of the models.

Figure 6: Prediction errors, two bedroom dwellings



Notes: Difference between actual and synthetic outcomes. Auckland in black. Placebos in grey. Top left depicts model (A); top right, model (B); bottom left, model (C); bottom right, model (D). See notes to Table 1 for a description of the models.

Table 1: Weights

	3 Bedroom Dwellings				2 Bedroom Dwellings			
Urban Area	(A)	(B)	(C)	(D)	(A)	(B)	(C)	(D)
Hamilton	0.495	0.512	0.030	0.073	0.303	0.972	-	-
Tauranga	0.138	-	-	-	0.339	-	0.587	1
Dunedin	-	0.099	-	0.154	-	-	-	-
Rotorua	0.328	0.389	0.897	0.773	0.041	0.028	-	-
Kapiti Coast	-	-	0.073	-	0.252	-	0.322	-
Nelson	-	-	-	-	-	-	0.090	-
Invercargill	0.038	-	-	-	0.065	-	-	-
Total	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Notes: Model (A) includes rent time series and matching variables in the predictor set; (B) includes matching variables and rents in 2006 and 2013 in the predictor set; (C) uses out-of-sample validation (OOSV) for selection of $\boldsymbol{v}$ in (1) and only includes rent time series in the predictor set; (D) uses (OOSV) for selection of $\boldsymbol{v}$ in (1) and includes other housing market matching variables for 2006 in the predictor set.

one-tailed test, we compute

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

where

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

where $\lfloor x \rfloor = 0$ iff $x > 0$ and $\lfloor x \rfloor = x$ otherwise. We refer to this as the "Negative Error MSE ratio", or NE-MSE-R.[15]

Figures 7 and 8 depicts the histogram of the ratios. For three bedroom dwellings, Auckland has the largest NE-MSE-R in all models. 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). There is therefore strong statistical evidence that the zoning reforms reduced rents on three bedroom dwellings at the conventional five percent statistical level. It is notable that the decreases are statistically significant despite the donor units being different for in-sample and out-of-sample methods for selecting the weight vector $\boldsymbol{v}$. This offers some reassurance that the results are not driven by a specific donor unit.

For 2 bedroom dwellings, Auckland's NE-MSE-R is ranked second under model B, corresponding to a p-value of 0.038 (= 2/52). It is ranked third under model C (corresponding to a p-value of 0.058) and fifth under model A (corresponding to a p-value of 0.096), which indicates statistical significance at a ten percent level. It is ranked sixth under model D, outside the conventional

[15] Because the final pre-intervention observations are normalized to zero, the pre-intervention MSE omits the intervention year.

ten percent significance level. There is therefore some limited statistical evidence that the zoning reforms reduced rents on two bedroom dwellings.

4.4 Robustness Checks

This section contains the results of various robustness checks on our findings.

4.4.1 Leave-One-Out

We perform 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. This procedure examines the extent to which the synthetic control may be dependent on any single given donor unit. We present results for model A, since this model resulted in the smallest (in magnitude) prediction error for three bedroom dwellings.

Figure 9 exhibits the full-sample synthetic control (FS-SC red dashed line) alongside the 51 other leave-one-out synthetic controls (LOO-SCs, given by the grey lines). In general, each of the 52 synthetic controls follow a common trend over both the pre- and post- sample period. Moreover, for three bedroom dwellings, Auckland's NE-MSE-ranks first in all but three of the 51 LOO replications. It ranks second in the remaining three replications. This demonstrates that the removal any one donor unit does not have a substantial impact on the synthetic control, and lending strong credibility to our findings based on the full sample. For two bedroom dwellings, Auckland's NE-MSE-ranks is either fourth or fifth in 48 of the LOO replications. It ranks 6th twice, and ninth once.

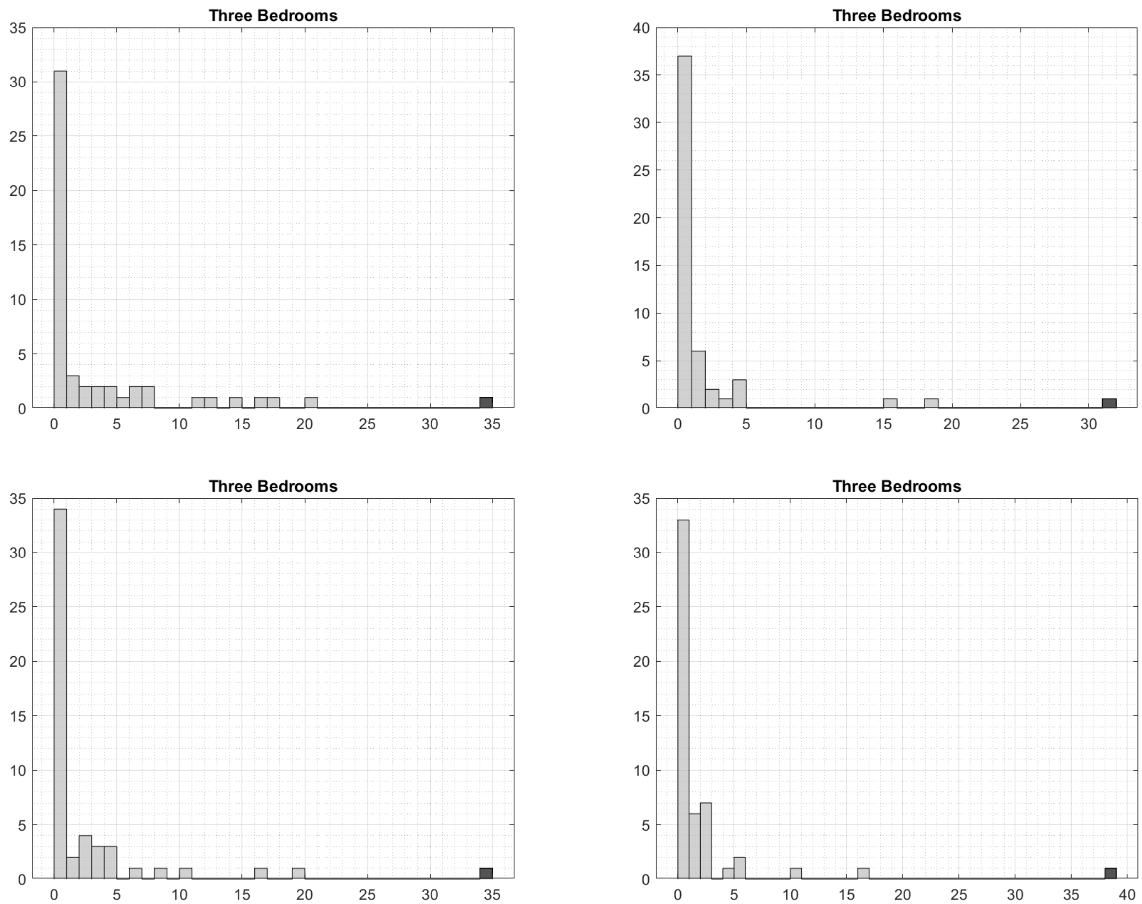
4.4.2 Unrestricted Selection of Donor Units

In our baseline set of models, permissible donor units for "major"and "large" urban areas are restricted. In this subsection we present results when these restrictions are not imposed, such that donor units for Auckland comprise the 52 other UAs in the country.[16]

For brevity, we simply report the results from the rank permutation tests when the donor pool is unrestricted. For three bedroom dwellings, the Auckland NE-MSE-R ranks second in two specifications (models A and D), corresponding to a p-value of 0.039 ($= 2/51$), and first under under the two other specifications (models B and C), corresponding to a p-value of 0.019 ($= 1/51$). We conclude that there remains statistical evidence the zoning reform reduced rents on larger, three bedroom dwellings at the five percent significance level. For 2 bedroom dwellings, Auckland ranks forth under model A, first in model B, third under models C and D. Thus, in all four specifications, the reduction in two bedroom rents is statistically significant at a ten percent level, and at a five percent level in one of the specifications.

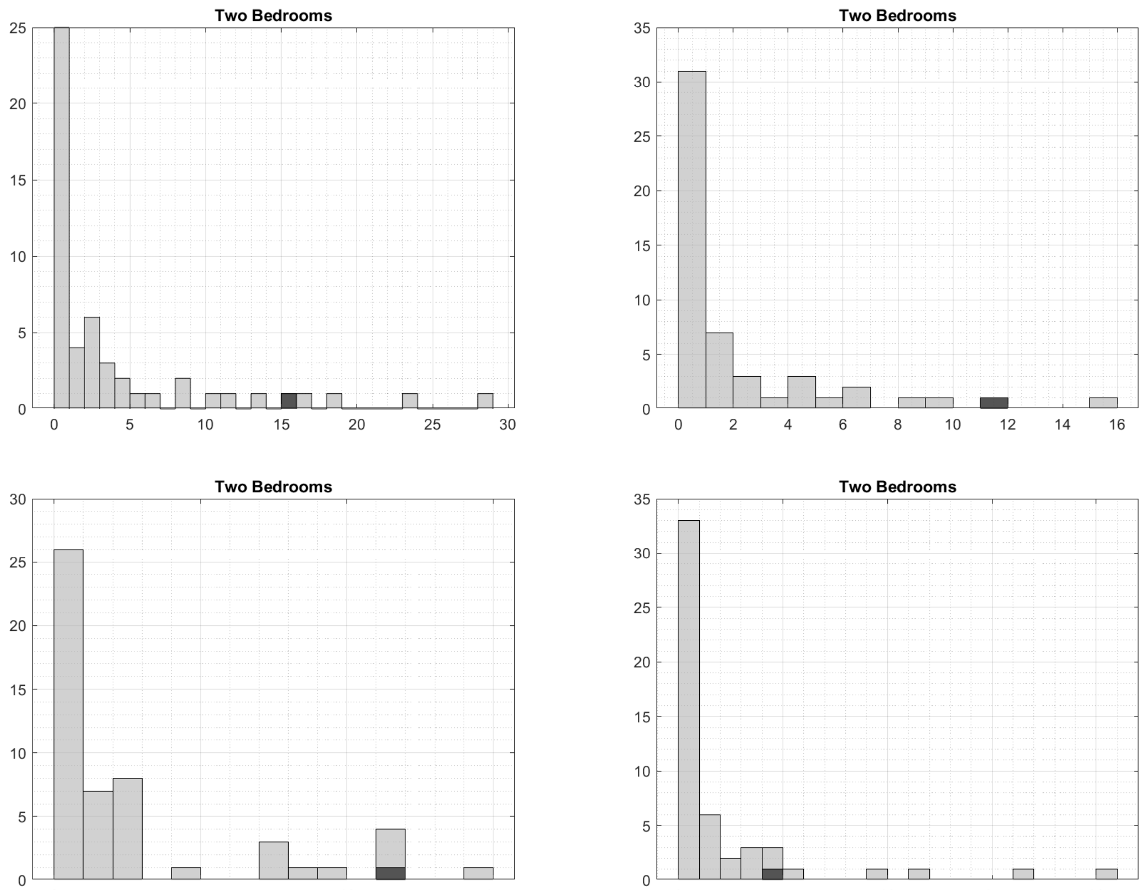
[16] We omit the medium urban area of Warkworth from the donor pool since it was subject to the same reforms as Auckland, and medium urban areas included in Auckland's donor pool in this exercise.

Figure 7: Negative-error MSE ratios, three bedroom dwellings



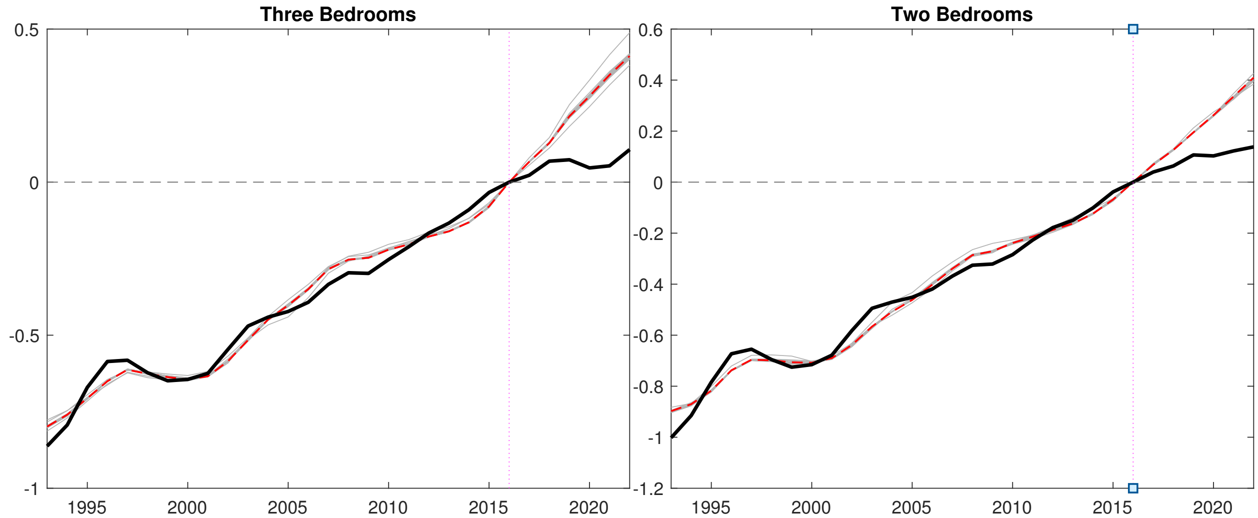
Notes: Auckland appears in black. Top left depicts model (A); top right, model (B); bottom left, model (C); bottom right, model (D). See notes to Table 1 for a description of the models.

Figure 8: Negative-error MSE ratios, two bedroom dwellings



Notes: Auckland appears in black. Top left depicts model (A); top right, model (B); bottom left, model (C); bottom right, model (D). See notes to Table 1 for a description of the models.

Figure 9: Leave-one-out robustness check



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

Table 2: Weights

	3 Bedroom Dwellings				2 Bedroom Dwellings			
Urban Area	(A)	(B)	(C)	(D)	(A)	(B)	(C)	(D)
Hamilton	0.350	-	0.185	-	-	0.885	0.009	0.878
Tauranga	0.263	0.297	0.205	-	0.428	0.095	0.377	0.122
Wellington	-	-	-	-	0.446	0.017	0.010	
Dunedin	-	0.030	-	0.250	-	-	0.007	-
Rotorua	0.359	0.673	0.422-	0.750	0.039	0.003	0.005	-
Napier							0.014	
Palmerston North			0.065				0.006	
Kapiti Coast	-	-	–	-	0.087	-	0.523	-
Nelson					-		0.023	
Invercargill	0.029	-	0.123	-	-	-	0.001	-
Total	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Notes: Model (A) includes rent time series and matching variables in the predictor set; (B) includes matching variables and rents in 2006 and 2013 in the predictor set; (C) uses out-of-sample validation (OOSV) for selection of $\boldsymbol{v}$ in (1) and only includes rent time series in the predictor set; (D) uses (OOSV) for selection of $\boldsymbol{v}$ in (1) and includes matching variables in the predictor set.

4.4.3 Population Decrease after COVID-19

According to Statistics New Zealand estimates, Auckland's population decreased by 1.06% between 2020 and 2022.[17] The ability of the synthetic control to account for the effect of a population decrease on rents in Auckland depends on whether the matching variables select control units that experienced similar decreases. In this regard, Auckland was not unique among urban areas in experiencing a decline. Wellington (-0.14%), Dunedin (-1.79%), Rotorua (-0.40%), Invercargill (-0.66%) and Motueka (-0.65%) also experienced decreases in (estimated) population. Notably, for some model specifications, many of these UAs already feature in the selected donor pool for Auckland, suggesting that the set of predictors may span the set of variables that explain the population decline. Figure 10 depicts weekly rents the UAs that experienced population decreases between 2020 and 2022. All except Auckland exhibit substantial appreciation from 2016 onwards, including Dunedin, which is notable for being the UA that experienced a larger population exodus than Auckland. Dunedin's rents on 3 bedroom dwellings increased by 53.4% between 2016 and 2022, while 2 bedroom rents increased by 51.9% (see Table 3). Thus, despite having a larger population exodus than Auckland, Dunedin experienced a substantially larger increase in rents – in fact, the increase was approximately four times as large.

Although Auckland was not the only UA to experience a population decrease, the incidence and responses to COVID-19 may present a unique shock that disproportionately affected Auckland and that proves difficult for the synthetic control to adequately model from 2020 onwards. We modify our empirical strategy in two different ways to address this potential problem. First, we end the sample in 2020, when estimated population in Auckland peaks. Second, we re-specify the set of matching variables to comprise the decrease in population from 2020 to 2022, and a limited number of rental market characteristics. This tilts the synthetic control procedure towards selecting UAs that experienced a decrease in population from 2020 onwards.

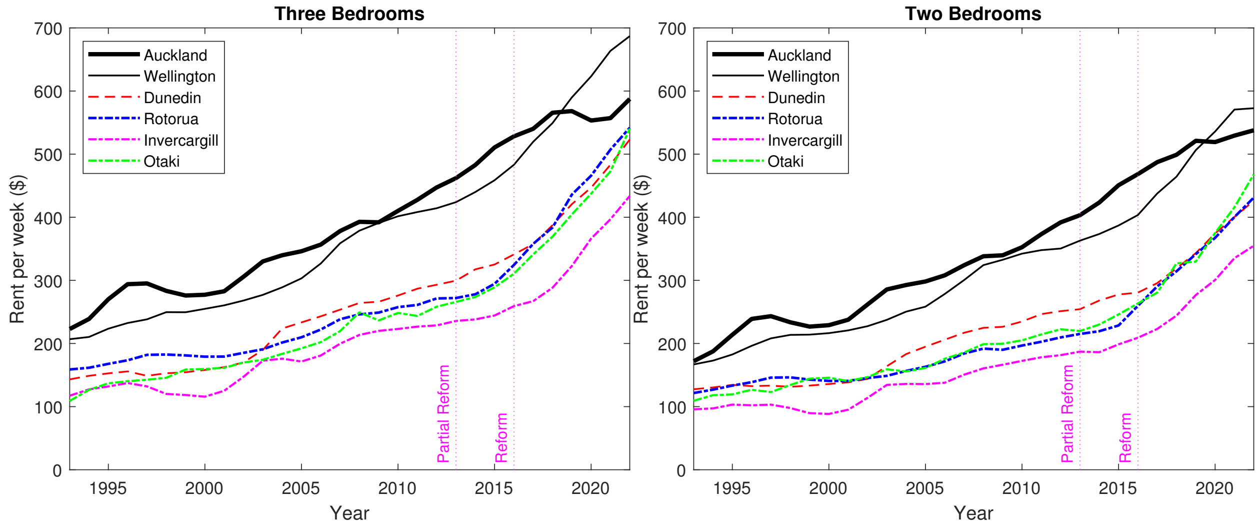
Ending the sample in 2020. For brevity, we simply report the results from the rank permutation tests. For three bedroom dwellings, the Auckland NE-MSE-R ranks either first or second in three of the four model specifications, indicating a statistically significant reduction in rents at the five percent significance level. It ranks third under model B, though we note that the second largest NE-MSE-R is Warkworth, which also underwent zoning reforms as part of the AUP.[18] For 2 bedroom dwellings, Auckland ranks second in model B, and outside the top five in the remaining specifications. We conclude that there remains statistical evidence the zoning reform reduced rents on larger, three bedroom dwellings.

Including post 2020 population change as a matching variable. We set the matching variables to include the log population change between 2020 and 2022. We also include the propor-

[17]For information on methodology, see https://datainfoplus.stats.govt.nz/item/nz.govt.stats/951e3175-d94d-4d67-9af7-47c0a75f90d9/7. As of May 2023, the subnational population estimates at 30 June 2021 and 2022 are both provisional.

[18]Warkworth is a commuting zone approximately 50 kilometers north of the the Auckland CBD. It is part of Auckland Council.

Figure 10: Weekly Rents in selected Metropolitan Areas, 1993–2022



Notes: Geometric mean rents for urban areas that experienced a decrease in estimated population between 2020 and 2022.

tion of people aged 18 to 22 inclusive, to account for the potential effect of the border closure and international students returning home, in 2013. Both Auckland and Dunedin, which experienced the largest population decreases, have a large tertiary sector that serves international as well as domestic students. Finally, we also include rents in 2013. We set the weights $\boldsymbol{v}$ to be a vector of ones in order to tilt the weights towards matching these three variables, rather than the past time series of rents.

For the three bedroom dwellings, the donors and weights are: Invercargill, 0.372; Rotorua, 0.356; and Dunedin, 0.273, implying a 0.88% decrease in population of the synthetic Auckland. Actual rents are 31.9% less than the synthetic unit. For two bedroom dwellings, the donors and weights are: Rotorua, 0.536; Dunedin, 0.281; and Invercargill, 0.184, implying a 0.84% decrease in the population of the synthetic Auckland. Actual rents are 29.4% less than the synthetic unit. In both cases, the NE-MSE-R for Auckland ranks largest, indicating that these reductions rents are statistically significant at a 5% level. Thus, while the synthetic unit has a population decrease that is about 0.2 percentage points less than that realized, when tilted towards selecting donor units to match the population decrease, the synthetic unit implies larger decreases in rents due to the zoning reforms.[19]

4.4.4 Sample of Houses

The rental bond data can be stratified by dwelling type: “houses”, “flats” and “apartments”. In this section, we repeat the analyses described above for the sample of houses, omitting “flats” and

[19]Similar results are obtained when the matching variable only consists of population change, which results in the synthetic Auckland having a population decrease that exactly matches that of Auckland.

"apartments" from the sample.

We begin with our baseline set of four models (models A through D). For three bedroom houses, rents are between 26.7 and 31.9% lower than the synthetic control. These decreases are comparable to those obtained from the sample that did not stratify based on dwelling type. In the rank permutation test, Auckland ranks either first or second across all four specifications, indicating that these decrease are statistically significant at a five percent level. For two bedroom houses, rents are between 14.9% and 20.9% lower than the synthetic control. Notably, these decreases are slightly smaller in magnitude to those obtained from the sample that did not stratify based on dwelling type. In the rank permutation test, Auckland ranks between sixth and ninth, indicating that these decreases are not statistically significant at a ten percent level.

Next we consider the robustness check where the donor sets are unrestricted. For three bedroom houses, Auckland ranks either first or second across all four model specifications in the rank permutation test, indicating statistically significant decreases in rents at a five percent level. For two bedroom houses, Auckland ranks between second and fifth in three of the specifications, indicating statistically significant decreases in rents at at least the ten percent level.

Next we consider ending the sample in 2020. For three bedroom houses, Auckland ranks either first or second across all four model specifications in the rank permutation test, indicating statistically significant decreases at a five percent level. For two bedroom houses, Auckland ranks between fifth and eleventh, indicating decreases in rents are generally not statistically significant at a ten percent level.

Finally, we replicate the exercise where we match population decreases. For three bedroom houses, the selected weights imply a 0.81% decrease in population of the synthetic Auckland, and actual rents are 31.7% less than those of the synthetic unit. Auckland has the largest NE-MSE-R, indicating that these reductions rents are statistically significant at a 5% level. For two bedroom dwellings, the selected donors do not do a good job of matching the population decrease, implying a 0.9% population increase in the synthetic unit. If we instead restrict the set of matching variables to only the population decrease between 2020 and 2022, the synthetic unit matches the population decrease exactly, and implies a 23.8% reduction in rents. Auckland has the forth largest NE-MSE-R, indicating statistical significance at the 10% level.

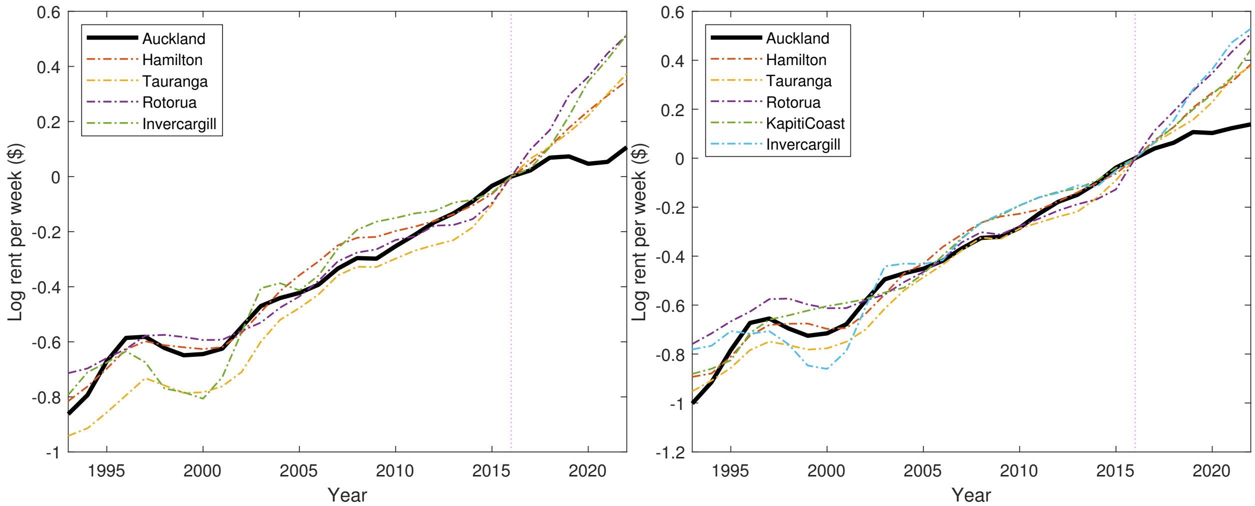
5 Conclusion

We use a synthetic control approach to examine the effects of the 2016 zoning reforms in Auckland on average rents. The synthetic control indicates a 26 to 33% reduction in rents of 3 bedroom dwellings six years on from the policy, relative to the counterfactual of no zoning reform – meaning that average rents in Auckland would be even more expensive if the reforms had not been implemented. These reductions are statistically significant (5%, one tailed) using the rank permutation approach. For 2 bedroom dwellings, the synthetic control indicates a 21 to 24% reduction in rents due to the reform, but these decreases are only statistically significant under some model specifications.

6 Appendix

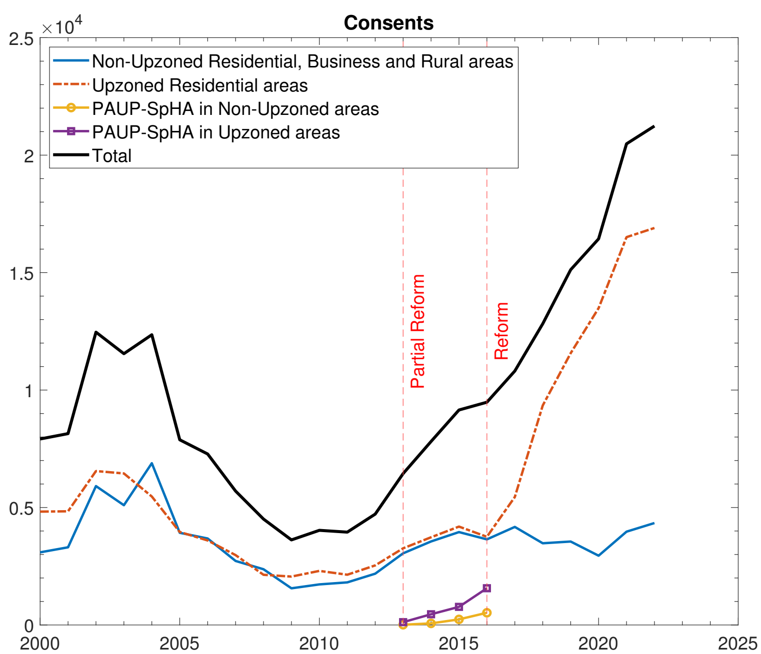
6.1 Additional Tables and Figures

Figure 11: Rents in Auckland and Donor Units



Notes: 3 Bedroom (left) and 2 Bedroom (right). Donor units for model A depicted.

Figure 12: Dwelling Consents in Auckland, 2000 to 2022



Notes: Consents issued per year in different areas of Auckland. The first, "draft", version of the AUP was announced in March 2013, while the "Proposed" AUP (PAUP) was notified in September 2013. 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. "PAUP-SpHA" denotes permits issued under this program. The final version of the AUP became operative in part in November 2016. Thus the first "partial" reform occurred in 2013, with the full reform following in 2016. Source: Greenaway-McGrevy (2023b).

Table 3: Percent increase in urban area rents, 2016–2022

	3 Bedroom	2 Bedroom		3 Bedroom	2 Bedroom
Auckland	11.23	14.82	Greymouth	42.95	8.79
Hamilton	41.55	46.65	Ashburton	23.21	16.02
Tauranga	45.30	45.50	Timaru	34.14	43.54
Wellington	42.20	41.93	Oamaru	40.47	40.39
Christchurch	24.83	26.94	Queenstown	13.64	14.33
Dunedin	53.37	51.87	Kaitaia	76.05	73.63
Whangarei	56.76	58.26	Kerikeri	48.29	58.35
Rotorua	67.07	66.03	Warkworth	34.48	24.64
Gisborne	93.97	91.70	Whitianga	60.55	58.26
Hastings	73.31	75.63	Thames	46.53	50.82
Napier	68.43	70.77	Waihi	52.09	63.37
New Plymouth	50.70	52.52	Huntly	63.34	72.47
Whanganui	97.75	97.24	Morrinsville	47.99	56.46
Palmerston North	65.90	62.84	Matamata	47.53	48.67
Kapiti Coast	56.89	55.77	Katikati	54.00	56.82
Nelson	44.18	41.11	Te Puke	48.54	58.07
Invercargill	67.34	69.69	Kawerau	103.06	94.84
Cambridge	47.27	49.14	Stratford	86.05	85.72
Te Awamutu	61.19	51.36	Hawera	76.08	81.00
Tokoroa	110.37	142.27	Marton	118.02	98.94
Taupo	56.87	62.79	Dannevirke	97.94	87.83
Whakatane	58.43	47.66	Otaki	74.04	77.62
Feilding	80.58	65.68	Motueka	47.40	43.34
Levin	92.16	96.04	Cromwell	44.62	40.24
Masterton	77.20	77.45	Alexandra	49.99	43.28
Blenheim	47.55	57.40	Wanaka	37.55	42.25
			Gore	62.49	48.37

Notes: Percent increase in rents between 2016 and 2022 for functional urban areas of New Zealand.

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