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

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

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Abstract

Zoning reform is increasingly advocated to redress unaffordable housing, but there are few real-world examples to demonstrate its efficacy. However, 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 zoning reform reduced housing costs, adopting a synthetic control method to specify rental prices in Auckland under the counterfactual of no zoning change. Rental prices are measured using a hedonic index that quality-adjusts prices based on observable attributes of the rental properties. Six years on from the reform, the synthetic control from our preferred empirical specification implies that rents would be approximately 28% higher under the counterfactual. This difference is statistically significant at a five percent level under the conventional rank permutation method applied to post-treatment root mean squared error. Our findings support the proposition that large-scale zoning reform can enhance housing affordability.

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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 large number of economists and urban planners attribute unaffordable housing, at least in part, to restrictive zoning (Gyourko and Molloy, 2015; Been, 2018; Hamilton, 2021). Zoning reform is consequently advocated to reduce housing costs by relaxing regulatory restrictions on the supply of medium and high density housing, such as plexes, rowhouses and apartments (Glaeser and Gyourko, 2003; Freeman and Schuetz, 2017).[1] However, up until very recently, few cities have pursued large-scale upzonings to enable affordability (Schill, 2005; Freeman and Schuetz, 2017), meaning there is little empirical evidence to support the posited effects of zoning reform. In particular, there is, as yet, no empirical evidence to support claims that large-scale zoning reform can reduce the cost of housing.

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; Greenaway-McGrevy, 2023a), and affording us six years of data to examine the impact of the reform on housing costs. In this paper, we assess the impact of the reform on rental prices, adopting a synthetic control approach to specify the counterfactual scenario to the policy change. The synthetic control is constructed from a donor pool comprising other commuting zones (which we refer to as "urban areas") 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 among renting households. Rental prices are measured using a hedonic price index constructed from individual dwelling data on rents available between 2000 and 2022.[2]

Differences between actual and synthetic rental price indexes measure the impact of the reform. However, the magnitude of the estimated policy impact is somewhat sensitive to model specification. Our baseline specification implies that rents are 26.1% lower by 2022, or, equivalently, rents would be 35.4% percent higher in Auckland under the counterfactual of no reform (since $0.354 = 0.261/(1 - 0.261)$). One particular donor unit receives a weight of over seventy percent in this specification. When this unit is omitted from the donor set, the estimated decrease in rents falls to 21.6%, indicating that the findings from the baseline model are highly dependent on the specific donor. To be conservative in our assessment of policy effects, we select a model specification that omits this donor as our preferred model. Thus, our preferred empirical specification implies that rents in 2022

[1] "Plexes" refers to duplexes, triplexes, sixplexes, etc.

[2] At the time of writing, data were available for the years 2000 through 2022. We anticipate updating the paper once data for 2023 become available.

would be 27.6% percent higher had Auckland not implemented zoning reform in 2016 (since $0.276 = 0.216/(1 - 0.216)$)).

The finding that large-scale zoning reform can reduce housing costs is important. While researchers and policymakers have advocated for large-scale zoning reform as a means to increase supply and enhance affordability, studies that focus on localized (or "spot") upzonings typically show muted or no effects on housing supply and/or affordability (Freemark, 2020; Dong, 2021), casting doubt on the ability of zoning changes to meet intended objectives (Rodríguez-Pose and Storper, 2020). Such studies are also misused by advocates and policymakers opposed to zoning reform as evidence that large-scale reforms will fail (Cheung et al., 2023). Recently, Stacy et al. (2023) examine over fifty upzonings in various cities in the U.S., finding only small effects on housing construction and costs. Results from the present synthetic control approach indicate that the zoning reform undertaken as part of the Auckland Unitary Plan did enhance housing afford ability, when measured by rents, suggesting that large-scale reforms have substantially different impacts to localized upzonings. This should be unsurprising. Compared to large-scale upzoning, conferring redevelopment rights to a limited number of locations reduces the number of development opportunities, and consequently generates less housing supply and smaller effects on housing costs.

Rental price indexes are constructed using the Ministry of Housing and Urban Development (MHUD) dataset on individual rental bonds, which reports the weekly rent on new tenancies in the country. The dataset also includes information on the number of bedrooms, property type (house, apartment or flat), state or private ownership, and location (by meshblock). From these data, we calculate imputed hedonic price indexes using new tenancies within each commuting zone. The price indexes are therefore quality-adjusted using the observable attributes of the tenancies, including the number of bedrooms, housing type, and location.

We use rents, rather than house prices, to measure housing costs 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, 2023b), reflecting the increased capacity of the land to 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. Greenaway-McGrevy et al. (2021) present evidence consistent with this reasoning after the reforms in Auckland. 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.

To assess the statistical significance of estimated rent decreases, we apply the rank permutation test to the post-intervention root mean square errors (RMSEs) when the placebo interventions are applied to donor units. Auckland has the largest post-treatment RMSE among all 49 units in the donor pool, indicating that the counterfactual does a poor job of describing actual outcomes, as would be anticipated if the policy was effective. If one were to assign the intervention at random, the probability of obtaining a ratio as large as Auckland's is at most 0.02 (= 1/50). However, applying the rank permutation test to the ratio of post- to pre- intervention RMSEs (Abadie et al. 2010), Auckland ranks between third and twelfth, depending on model specification.

The synthetic control method has been applied to evaluate policy in a variety of contexts (see Abadie, 2021 for a comprehensive review). 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 2000, when data for individual bond tenancies begin, to 2022, with the intervention occurring in 2016. Second, we examine how robust our findings are to changes in modeling assumptions, including changes in the viable units in the donor set. Although the magnitude of implied rent decreases does vary somewhat between specifications, in all specifications the decreases are substantial. Third, our findings are largely unchanged under conventional robustness check exercises that are commonly adopted in the synthetic control literature, including 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.

Nonetheless, there are inherent limitations to the synthetic control method. Donor units will be affected by the policy intervention if increased housing supply in Auckland affects inter-city migration of tenants. Note, however, that in-migration to Auckland due to lower housing costs generates attenuation bias in estimates of the casual impact, since it reduces housing demand in other cities. 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 June 2020 and June 2022, before increasing by 2.4% between June 2022 and June 2023. Although media attention at the time focused mainly on Auckland, the same population estimates show that other cities experienced population decreases between 2020 and 2022, 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. Rents in Auckland are

17.3% less than those of the synthetic control at this point. Second, we include estimates of population decrease between 2020 and 2022 in the set of matching variables, and drastically reduce the set of matching variables to those that feasibly predict the exodus, so that the population decrease variable plays a prominent role in constructing the synthetic control for Auckland. Rents are 22.9% less than those of the synthetic control in this specification – a larger decrease than that obtained under our preferred specification.

The remainder of the paper is organized as follows. The following section provides the institutional details of the policy and provides a general background on Auckland and New Zealand. Section three describes the data. In section four presents the method and results. We first present our baseline empirical specification, before exploring variations of the baseline model. 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 in 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 as of 2018.

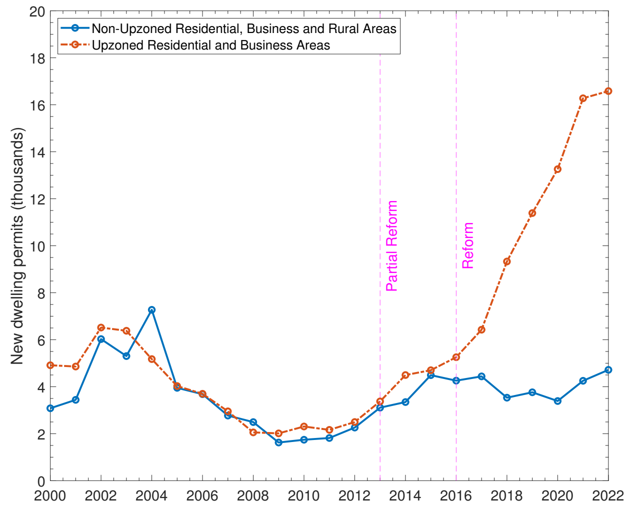
Auckland is the largest city in New Zealand, with a population of 1.57 million as of 2018 (source: New Zealand census). In March 2013, the city announced the first version of the Auckland Unitary Plan (AUP), which introduced and applied a standardized set of planning zones across the jurisdiction, including four new residential zones. Three of these zones encourage various gradations of medium to high density housing. After several rounds of reviews and consultation, the plan was made operative 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). For additional details on the implementation of the plan and the spatial distribution of upzoning, see Greenaway-McGrevy and Jones (2023).

Although the plan was operationalized in 2016, an agreement between the Auckland Council and the central government called the 'Auckland Housing Accord' allowed devel-

[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. Data for Auckland is not available.

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

Figure 1: New dwelling permits in Auckland by 2016 zoning reform, 2000 to 2022



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 was implemented in early October 2013 under the Auckland Housing Accord. Between October 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: Greenaway-McGrevy (2023a).

opers to build to the rules of the 'Proposed' Auckland Unitary Plan (PAUP), announced in September 2013.[5] 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 land use regulations under the PAUP.[6] The program ended once the AUP was implemented.

Housing supply quickly responded once the AUP was operative in 2016. Figure 1 exhibits new dwelling permits issued per year, decomposed into upzoned and non-upzoned areas. Permits increased significantly year-on-year from 2016 onwards, after the AUP is operative, with all of the new construction occurring in upzoned areas. There is some limited evidence of divergence from 2013 onwards, reflecting policy "leakage" as some developers took advantage of the relaxed regulations under the PAUP (see Figure 11 in the Appendix, which separately identifies PAUP-SpHA permits in the data). Nonetheless, we use 2016 as the date of the policy intervention in the synthetic control exercise, since this the date after which the divergence becomes most evident, and accords with the full reform becoming operative.

Our outcome of interest – rents – are likely to have been impacted by several legislative changes over the period of analysis. However, these changes affected rental housing across

[5]See https://www.beehive.govt.nz/sites/default/files/Auckland_Housing_Accord.pdf

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

the whole country, and we have little reason to think these changes would have a disproportionate effect on Auckland. The sixth Labour government (2017–2023) substantially altered regulations governing tenancies and the taxation of housing investors. Beginning in 2018, it introduced a series of bills to: protect and enhance renters' rights, including the prohibition of letting fees and bidding for tenancies; limit tenant liabilities; and restrict rent price increases (to every twelve months) and cause to terminate tenancies.[7] Legislation to enhance minimum health and safety standards was passed in July 2019.[8] Tax treatment of property investment also changed. From April 1, 2019, landlords could no longer offset property investment losses against other sources of income when calculating their income tax liability (known as 'ring-fencing'),[9] and their ability to claim mortgage interest as an expense on the rental property was phased out from October 2021.[10] Our sample period also spans recent demand-side policies intended to curb housing demand to promote house price affordability, including severe restrictions on foreign ownership, disincentives to investor speculation, and macroprudential banking restrictions.[11] These changes affected houses in all urban areas of the country, but nonetheless underscore the need for the informed selection of a counterfactual scenario for policy evaluation.

3 Data

Individual data on new tenancies are collected by the Ministry of Housing and Urban Development (MHUD) on a quarterly basis. The data are not public, but can be accessed via Statistics New Zealand's Integrated Data Infrastructure (IDI). In addition to the rental price, the dataset contains information on the rental property, including the number of bedrooms, housing types ("Flats" and "Houses"), public or private ownership, and meshblock, which are equivalent to census tracts in the U.S. and provide a measure of location. From these data we construct hedonic imputation price indexes, using number of bedrooms, and indicators apartment, flat, and location (specifically, statistical area 2 units, which comprise meshblocks).[12] We use the "double" imputation method, whereby the hedonic regression is used to estimate prices in both the period of transaction and the period prior

[7] See https://www.legislation.govt.nz/act/public/2018/0044/latest/LMS24553.html, https://www.legislation.govt.nz/act/public/2020/0059/latest/LMS294929.html and https://www.legislation.govt.nz/act/public/2019/0037/latest/DLM7247512.html

[8] Known as the "Healthy Homes Standards". See https://www.legislation.govt.nz/regulation/public/2019/0088/latest/whole.html.

[9] See https://www.legislation.govt.nz/act/public/2007/0097/486.0/LMS223653.html

[10] See https://www.legislation.govt.nz/act/public/2007/0097/latest/LMS675468.html

[11] Loan to value ratios on new residential mortgages were introduced in 2013; a capital gains tax based on duration of ownership was introduced in 2015; and legislation preventing foreign ownership (excepting Australia and Singapore) in 2018. See Greenaway-McGrevy and Phillips (2021) for additional details.

[12] We use fixed effects at the larger statistical area 2 (SA2) level, rather than meshblocks, due to data sparsity at higher geographic resolutions. SA2s contain 2,000 to 4,000 persons in urban areas.

to the transaction (Eurostat, 2013). Refer to the appendix for a detailed description of the method.[13]

We use hedonic imputation to measure rental price changes because dwellings are heterogenous and infrequently transacted. Hedonic methods are more appropriate for differentiated products or services (Silver and Heravi, 2007) than common alternatives such as repeated transaction (matched model) methods. For instance, repeated transaction methods are subject to 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. Price differentials between different products are not used in the measurement of inflation, which becomes problematic when new products are introduced and extant products are retired each period. The problem is particularly acute in housing, as each dwelling is different and infrequently transacted. Repeated transaction methods are also subject to the "lemon's bias" when applied to housing, because measured prices become biased towards more frequently transacted properties (Clapp and Giaccotto, 1992).

Among the different hedonic approaches, hedonic imputation offers greater flexibility than the hedonic time dummy approach, as it allows the hedonic coefficients on product or service attributes to change over time. Pakes (2003) advocates for the use of hedonic imputation over time dummy methods "since hedonic coefficients vary across periods it [the time dummy hedonic method] has no theoretical justification." Hedonic imputation methods are generally preferred by statistical agencies such as Eurostat when measuring house prices (Eurostat, 2013, pp. 159).[14]

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.[15] There are 53 FUAs in New Zealand, including Auckland. Henceforth, we use "urban areas" (UAs) as shorthand for FUAs.

Figure 2 exhibits the rental price indexes for Auckland and the other urban areas of New Zealand. Indexes are normalized to one in 2016, the year in which the zoning reform becomes operational. We include a population-weighted average of the other urban areas.

Over the decade prior to the reform, rents in Auckland are growing at a faster rate

[13] A previous version of this paper available here used the geometric mean of rents to measure rental costs. As discussed in that version, a drawback of using averages (as opposed to quality-adjusted price indexes) is that systematic changes in the composition of the rental stock can manifest as price changes.

[14] Statistics New Zealand produces rental price indexes for five regions using a time dummy hedonic model that is fitted to individual rental bond data over an eight-year sample window (see Bentley, 2022). Because the model includes individual dwelling fixed effects, rental price changes are inferred from repeated tenancies within the sample window, and are therefore subject to the new goods problem and lemon's bias.

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

that in the rest of the country (the rental price index is higher than the Auckland index between 2007 and 2014 or so). In the six years since the reform, rental price increases in the other urban areas have far exceed those in Auckland. By 2022, the rental price index in Auckland is 1.181, whereas the population-weighted price index is 1.513. Rental prices in other urban areas (as measured by the population-weighted average) have increased by 33.2 percentage points relative to Auckland between 2016 and 2022. This is a substantial divergence.

Figure 2 also presents the index for Auckland against other the "metropolitan" urban areas of the North Island of New Zealand: Auckland, Hamilton, Tauranga and Wellington.[16] We select these three urban areas as they are large cities that are comparatively close to Auckland. (This comparison is purely for expositional purposes: In the analysis to follow we use the synthetic control method to select appropriate controls.) Prior to the reform, rental prices in Auckland were growing at a faster rate than in Hamilton and Wellington, but at a slower rate than Tauranga. After the reforms, rental prices in Auckland are growing at a slower rate than all three cities. By 2022, the rental price indexes of Tauranga, Hamilton and Wellington range between 1.396 to 1.434. Thus, between 2016 and 2022, rental prices in the other metropolitan cities of the North Island increased by 21.5 to 24.3 percentage points more than Auckland. In other words, the inflation rate in Auckland after the AUP was approximately half of that of proximate metropolitan cities.

3.1 Matching Variables

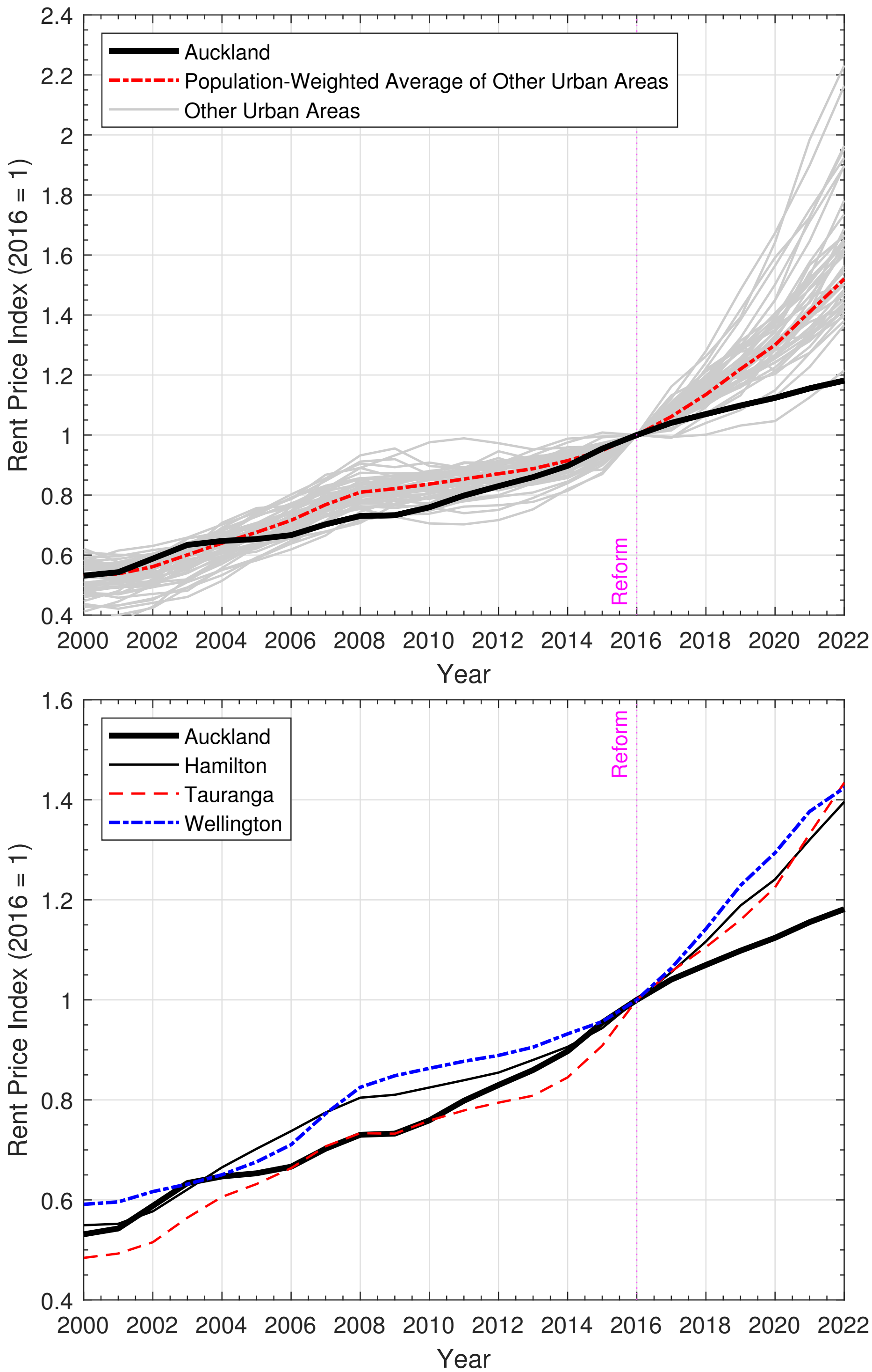
As we demonstrate in more detail in the following section, the synthetic control method selects comparable control units by matching outcomes prior to the policy intervention. These can include the outcome of interest (in our application, rental price indexes) as well as other related variables. Here we describe the additional matching variables, all of which are housing market outcomes, determinants of outcomes, or exogenous constraints on housing supply.

Population growth. This is the log difference of estimated population by FUA. Censuses occur in 2001, 2006, 2013 in the pre-reform era.

Dwellings per capita. This is the number of occupied dwellings in the FUA divided by the usually resident population in the FUA. Both figures are obtained from census data. The measure is obtained for the pre-reform census years of 2001, 2006, and 2013.

[16] Statistics NZ classifies urban areas as either "metropolitan", "large", "medium" or "small".

Figure 2: Rental price indexes in urban areas, 2000–2022



Notes: Rental price indexes for Auckland and other urban areas of New Zealand, 2000 to 2022. Population weights based on 2018 census populations. Indexes normalized to one in 2016, the year of Auckland's reform.

Personal income. We obtain the average personal income (from all sources) for the census years 2001, 2006 and 2013 by FUA from Statistics New Zealand.

Proportion of renting households. Proportion of renting households within the FUA for the two census years prior to the intervention, 2006 and 2013, by FUA from Statistics New Zealand. Data for earlier census years for the required geographic units is unavailable.

Share of housing costs for renting households. We include the average proportion of household income spent of rental costs for renting households, for 2006 and 2013. Census data obtained from Statistics New Zealand. Data for earlier census years for the required geographic units is unavailable.

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 measure is inspired by Saiz (2010), who uses land under a 15% slope as an exogenous instrument for housing supply, as such land can be easily developed.

4 Synthetic Control Method and Results

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

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 are unaffected by the intervention.[17] 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 synthetic control estimator of $y_{1,t}^N$ is $\hat{y}_{1,t}^N = \sum_{i=2}^{N+1} w_i y_{i,t}$. Let $y_{1,t}^N$ be the (unobservable) outcome without intervention for the first unit, while $y_{1,t}^I$ is the outcome under the intervention in period $t > T_0$. The effect of the intervention is then $y_{1,t}^I - \hat{y}_{1,t}^N$.

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.

[17]This section borrows heavily from Greenaway-McGrevy (2023a).

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 $w_h \in [0, 1]$ 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 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 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 is considered a state of the art evolutionary optimizer (Li et al., 2020).[18]

In our application, we include all pre-treatment realizations of the outcome variable, rents, in the set of predictors. 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 2000 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.

The synthetic control 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. We normalize the price indexes to be one in 2016, and then take logs. Auckland's price index satisfies the convex hull condition prior to treatment.

We employ a hierarchical restriction of the donor pool for each urban area based on Statistics New Zealand categories. Urban areas (UAs) in New Zealand are categorized as "metropolitan", "large", "medium" and "small", depending on size. "Metropolitan" consists of six cities; "large" consists of eleven; and "medium" a further fourteen. The remain-

[18]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`).

der are "small". Metropolitan UAs have their donor pool restricted to other metropolitan UAs and large UAs in order to encourage similarity between Auckland its potential donors. Abadie (2021, p. 409) notes that restricting the donor pool to units with similar characteristics to the treated unit helps minimize interpolation biases. For placebo tests, large UAs have their donor pool restricted to metropolitan, large and medium UAs. Medium and small UAs do not have their donor sets restricted.

We omit Christchurch from the donor pool due to the impact of the 2011 earthquake on its housing stock and other housing outcomes. As noted by Abadie (2021) (p. 409), potential donor units that are subject to large idiosyncratic shocks to the outcome variable should be withheld from the donor set. We also omit Queenstown, where rents fell by 20.3% in a single year, between 2019 and 2020. This sudden decrease is almost certainly due to the policy response to COVID-19, as the region is highly dependent on tourism and foreign workers, many of whom are on temporary work visas. (In the 2018 census, 47.7% of the population was foreign-born, compared to 27.4% for the nation as a whole.) We also omit Warkworth, as the commuting zone is part of the Auckland region and thus was also affected by the same zoning reform. This leaves a total of 50 UAs in the dataset. However, of Christchurch, Queenstown and Warkworth, only Christchurch is a metropolitan or large urban area. Thus, the omission of Queenstown and Warkworth has no impact on the estimated synthetic control for Auckland in our baseline model. Taking into account these restrictions, Auckland's donor pool incorporates the other metropolitan UAs except Christchurch (Hamilton, Tauranga, Wellington, Dunedin), as well as eleven other large UAs, including the nearby cities such as Whangārei and Rotorua.

We also consider non-hierarchical selection of the donor units, whereby the full set of 49 urban areas may be selected. These variations are presented in section 4.4.

4.2 Results

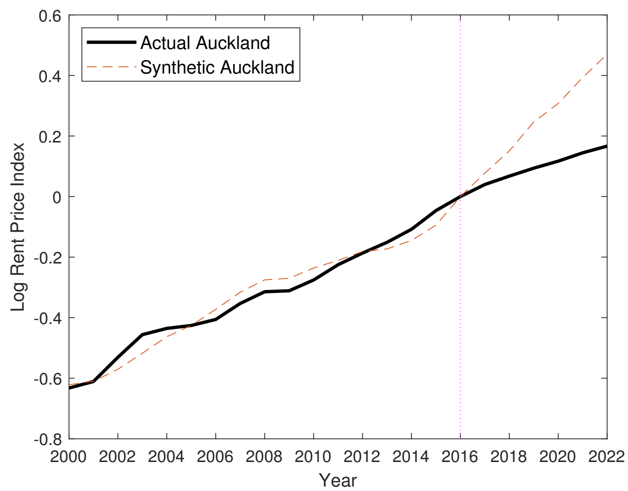
Table 1 exhibits the selected weights for the baseline specification. Rotorua, a large urban area 194 km from Auckland (as the crow flies) with a population of 74,000 receives a significant weight of almost three-quarters. Tauranga receives a weight of 0.188. It is a metropolitan area 150km south east of Auckland with an estimated population of 156,666. Finally, Invercargill is another large urban area over 1000 km from Auckland with a population of 55,386. It receives a weight of 0.069.

Table 2 exhibits Auckland's matching variables and those of synthetic Auckland. We include the average of the donor pool for comparison. Personal income, the proportion of rent households, and the proportion of income allocated to rent among renting households are matched reasonably well. Dwellings per capita are lower in Auckland than its synthetic counterpart. This may reflect regional differences in preferences over family sizes. Popu-

Table 1: Weights

Urban Area	Weight	Urban Area	Weight
Hamilton	0	Napier	0
Tauranga	0.188	Hastings	0
Wellington	0	Whanganui	0
Dunedin	0	Palmerston North	0
Whangārei	0	Kāpiti Coast	0
Rotorua	0.743	Nelson	0
Gisborne	0	Invercargill	0.069
New Plymouth	0		

Figure 3: Synthetic and actual rental price indexes



lation growth is also very poorly matched. Finally, the proportion of developable land is much larger in synthetic Auckland. Because the inner loop of the synthetic control method minimizes RMSE prior to the intervention, these results imply dwellings per capita, population growth, and the proportion of developable land are not useful in explaining variation in rental price changes prior to the reform.

Figure 3 depicts actual and synthetic rental price indexes for Auckland. There is a notable divergence from 2016 onwards, with prices growing much more slowly than synthetic prices. By 2022, log rents in Auckland are 0.303 less than the synthetic control, corresponding to a 26.1 percent ($= 1 - e^{-0.303}$) decrease in rents relative to the counterfactual of no zoning reform. Equivalently, rents in 2022 would be between 35.4% percent higher had Auckland not implemented the reform.

However, we show in section 4.4.1 that the estimated reduction in rents due to the reform falls to 21.6% when Rotorua is omitted from the donor set. The results are therefore somewhat sensitive to inclusion of Rotorua.

Table 2: Matched variables

Variable	Auckland	Synthetic Auckland	Average of Donors
Dwellings per capita, 2013	0.332	0.387	0.389
Dwellings per capita, 2006	0.338	0.378	0.385
Dwellings per capita, 2001	0.343	0.374	0.384
Population growth, 2006 to 2013	0.125	0.039	0.067
Population growth, 2001 to 2006	0.091	0.029	0.031
Proportion of developable land	0.453	0.554	0.372
Personal income ($), 2013	30,200	27,080.26	27,744.24
Personal income ($), 2006	27,200	23,621.96	23,417.84
Personal income ($), 2001	21,500	17,993.57	17,595.20
Proportion of households renting, 2013	0.388	0.365	0.336
Proportion household renting, 2006	0.363	0.336	0.317
Proportion of income spent on rent, 2013	0.262	0.245	0.250
Proportion of income spent on rent, 2006	0.244	0.224	0.229

Notes: Matching variables also include rent indexes, 2000 to 2016, but these are not tabulated for the sake of brevity. Population growth is log difference of estimated population. Proportion of income spent on rent is based on pre-tax income for renting households.

4.3 Inference

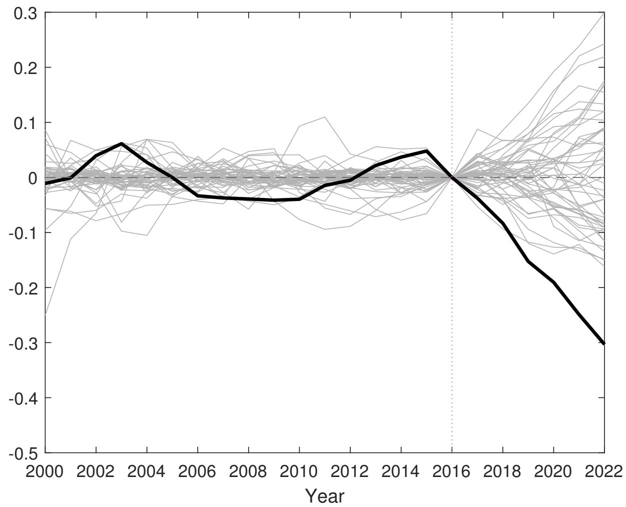
We run placebo interventions on the other donor units to assess whether the decrease relative to the counterfactual is large. Figure 4 plots the difference between the actual outcomes of each donor and its synthetic control. Evidently the decrease in Auckland's prediction error is the largest (in magnitude) among all units over the post-intervention period, indicating that the zoning reform had a substantive negative impact.

To conduct statistical inference we apply the rank permutation approach to the root mean square prediction errors (RMSEs) between the actual and synthetic units in the post-intervention period. Define the RMSE for unit i over $t = t_1$ to $t = t_2$ as

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

$R_i\left(T_0 + 1, T\right)$ is therefore the post-treatment RMSE for unit i. The post-treatment RMSE is constructed for Auckland and all placebo runs. (These is sometimes referred to as "in space placebos".) The rank permutation test is then based on where the RMSE for the treated unit ranks among all placebo runs. For example, if the ratio was ranked second among all 50 runs, then if one were to assign the intervention at random, the probability of obtaining a ratio that is second largest is 0.04 (= 2/50).

Figure 4: Prediction errors



Notes: Prediction errors are the difference between actual and synthetic outcomes for Auckland (black) and placebo runs (gray).

Figure 5 depicts the histogram of the ratios. Auckland has the largest RMSE, meaning that the probability of obtaining a ratio that is largest is 0.02 ($= 1/50$).

Abadie et al. (2010) also suggests using the ratio of pre- to post- intervention RMSE as a basis for inference, namely

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

The ratio is constructed for the treated unit and all placebo runs, and the rank permutation test is then based on where the ratio for the treated unit ranks among all placebo runs.

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 reform 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 one-tailed test, we compute

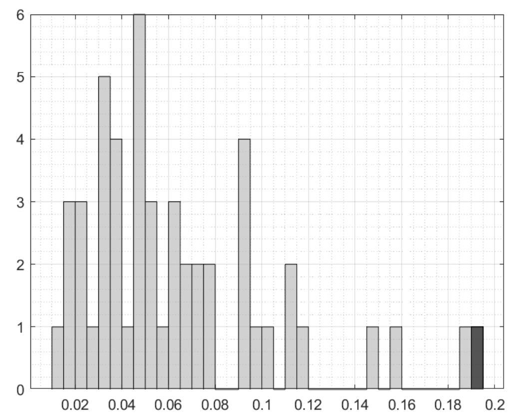
$$r_i^- = \frac{R_i^-\left(T_0+1, T\right)}{R_i\left(1, T_0\right)}$$

where

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

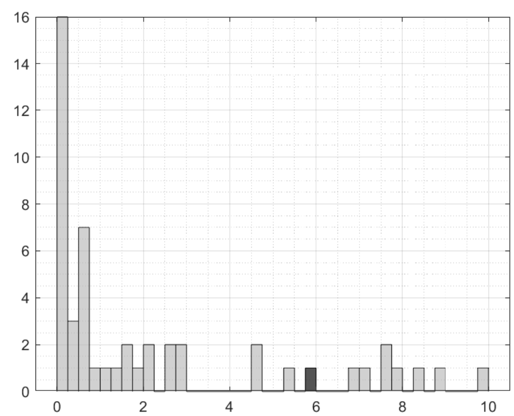
where $\lfloor x \rfloor = 0$ iff $x > 0$ and $\lfloor x \rfloor = x$ otherwise. We refer to this as the "Negative Error

Figure 5: Post-treatment root mean square errors



Notes: Auckland appears in black.

Figure 6: Negative-error RMSE ratios



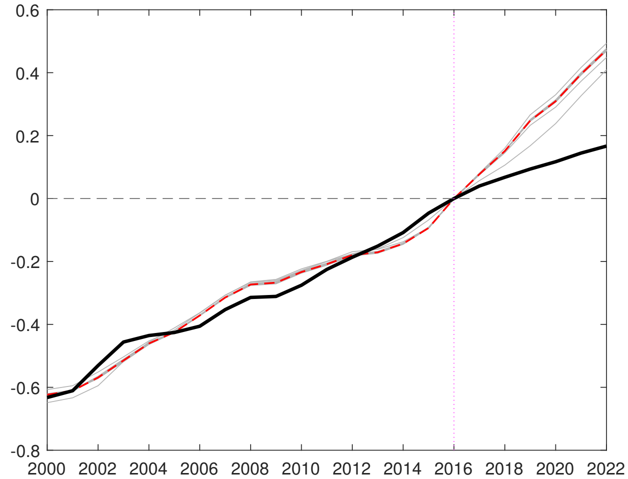
Notes: Auckland appears in black.

RMSE Ratio", or NE-RMSE-R.[19]

Figure 6 depicts the histogram of the ratios. Auckland is ranked ninth out of fifty, outside conventional levels of statistical significance. While its post-intervention RMSE is second largest, Auckland's pre-intervention RMSE is also somewhat large, causing the NE-RMSE-R to be ranked somewhat lower that the post intervention RMSE.

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

Figure 7: Leave-one-out robustness check



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

4.4 Robustness Checks

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.

Figure 7 exhibits the full-sample synthetic control (FS-SC, given by the red dashed line) alongside leave-one-out synthetic controls (LOO-SCs, given by the gray lines). In general, each of the LOO-SCs follow a common trend over both the pre- and post- sample period. This indicates that the results are not particularly sensitive to any one urban area being included in the donor set.

There is, however, one clear case in Figure 7 where synthetic rents are slightly lower over the post-treatment period. This corresponds to when Rotorua, which receives a weight of almost three quarters, is omitted from the donor set.

Given that results are somewhat sensitive to the inclusion of Rotorua in the donor set, we single out the case where Rotorua is left out. Under this specification, Tauranga receives a weight of 0.575, while Palmerston North receives 0.424. The latter is a large urban area of approximately 100,000 residents, 400km south of Auckland. Table 4 in the Appendix exhibits the matching variables, showing that population growth is now much better matched by the synthetic unit, while the match to the proportion of renting households is slightly worse.

The top left panel of Figure 8 depicts actual and synthetic rental price indexes. The synthetic control implies a 0.243 reduction in log rents, corresponding to 21.6% decrease.

Equivalently, rents would be 27.6% higher under the counterfactual of no reform (since $0.276 = 0.216/(1 - 0.216)$). Auckland's post intervention RMSE still ranks first among placebos, indicating that the smaller reduction is nonetheless statistically significant when evaluated by this measure. It's NE-RMSE-R ranks twelfth.

As discussed in the introduction, we select this as our preferred specification. The inclusion of a single unit – Rotorua – in the donor set has a substantial effect on estimated policy impacts. Once it is removed from the donor set, the policy impact is somewhat smaller in magnitude. To be conservative in our assessment, we headline these results as our preferred empirical specification.

4.4.2 Unrestricted Selection of Donor Units

In our baseline set of models, donor units for Auckland and "metropolitan" 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 other 49 urban areas in the sample.

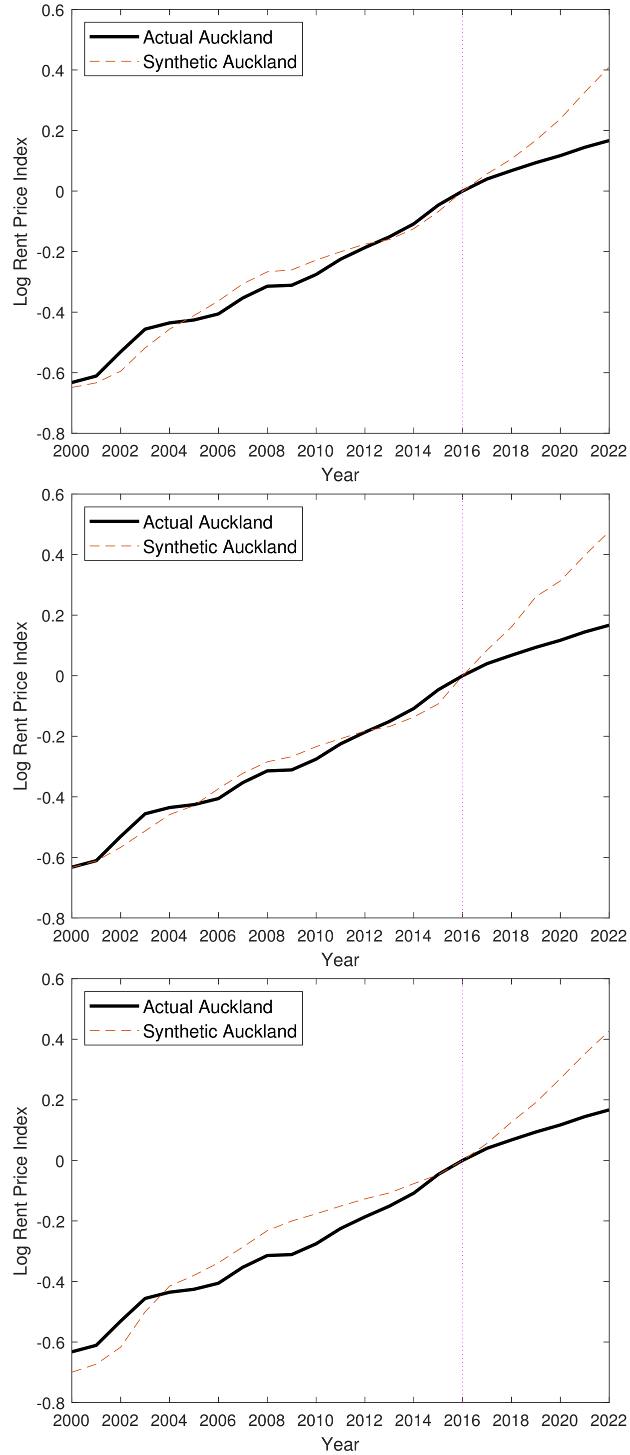
Rotorua, Gore and Wānaka receive weights of 0.678, 0.204, and 0.118. Thus, the large weight on Rotorua is similar to the baseline specification presented in section 4.2, while Gore and Wānaka replace Invercargill and Tauranga. Wānaka is a small urban area 990 km south from Auckland (as the crow flies) with a population of 15,000, while Gore in a small urban area 1150 km south of Auckland with an estimated population of 12,500. The top right panel of Figure 8 exhibits synthetic and actual rental indexes. By 2022, log rents in Auckland are 0.310 less than the synthetic control, corresponding to a 26.7 percent ($= 1 - e^{-0.310}$) decrease in rents relative to the counterfactual of no zoning reform. Thus, under non-hierarchical selection, the decrease in rents due to the reform is estimated to be even larger. Auckland has the second largest post-treatment RMSE. The probability of obtaining the largest RMSE is 0.041 ($= 2/49$). Meanwhile, Auckland's NE-RMSE-R ranks tenth

4.4.3 Population Decreases after COVID-19

According to Statistics New Zealand estimates, Auckland's population decreased by 1.07% between 2020 and 2022.[20] 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

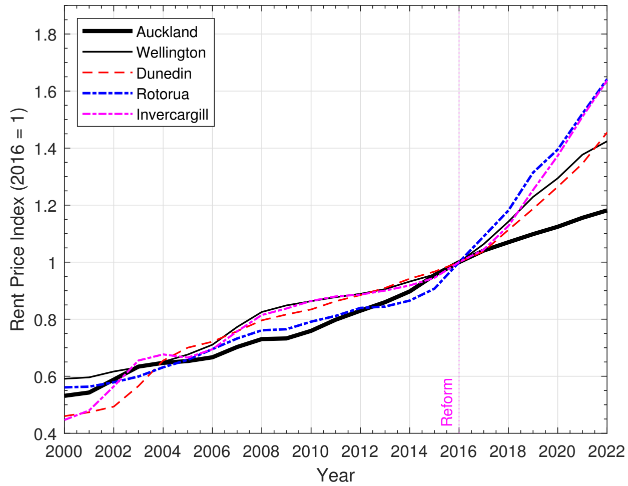
[20] Population estimates are as at June. For information on methodology, see https://datainfoplus.stats.govt.nz/item/nz.govt.stats/951e3175-d94d-4d67-9af7-47c0a75f90d9/7. As of May 2023, the subnational population estimates at 30 June 2021 and 2022 are both provisional. Estimates for the year to June 2023 were released on 25 October, showing that there was a 2.8% increase in the Auckland Region's population over this period. This gain is more than sufficient to reverse the loss in population over the previous two years.

Figure 8: Synthetic and actual rental price indexes, robustness checks



Notes: Top: Donor with the largest weight (Rotorua) omitted from the donor set. Middle: Unrestricted selection of donors, including medium and small urban areas. Bottom: Matching to urban areas with population decreases between 2020 and 2022.

Figure 9: Rental prices for urban areas with population decreases between 2020 and 2022



Notes: Rental price indexes for urban areas that experienced a decrease in estimated population between 2020 and 2022.

select control units that experienced similar decreases. In this regard, Auckland was not unique among urban areas in experiencing a decline. Among the metropolitan and large urban centers, Wellington (-0.16%), Dunedin (-1.83%), Rotorua (-0.55%), Invercargill (-0.53%) also experienced decreases in (estimated) population. Notably, some of these urban areas 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 9 depicts rents of urban areas 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 urban area that experienced a larger population exodus than Auckland. Thus, despite having a larger population exodus than Auckland, Dunedin experienced a substantially larger increase in rents.

Although Auckland was not the only urban area 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 urban areas that experienced a decrease in population from 2020 onwards.

Ending the sample in 2020. By 2020, log rents in Auckland are 0.192 less than the synthetic control, corresponding to a 17.3 percent ($= 1 - e^{-0.190}$) decrease in rents relative to the counterfactual of no zoning reform. Auckland has the largest post-intervention RMSE, meaning that the probability of obtaining a RMSE that is largest is 0.02 ($= 1/50$). Auckland's NE-RMSE-R ranks eighth.

Matching post 2020 population decreases. We set the matching variables to include the log population change between 2020 and 2022. We also include the proportion 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. We also restrict the donor pool to urban areas that experienced a population decrease between 2020 and 2022.

Motueka, Dunedin, Rotorua, Gore, Invercargill, Dannevirke and Wellington receive weights of 0.319, 0.267, 0.0947, 0.0946, 0.0913, 0.071 and 0.062. The model is able to match population decrease exactly due to the few number of matching variables. The bottom right panel of Figure 8 exhibits synthetic and actual rents. Pre-intervention fit of the synthetic unit is noticeably impaired when compared to the baseline model. By 2022, log rents in Auckland are 0.261 less than the synthetic control. This is a smaller decrease than under the baseline model, but nonetheless implies a 22.9% ($= 1 - e^{-0.261}$) reduction in rents. Auckland has the eighth largest post-intervention RMSE, and the third largest NE-RMSE-R. The probability of obtaining a ratio that is third largest is 0.06 ($= 3/50$).

5 Concluding Remarks

In 2016, Auckland implemented a large-scale zoning reform that precipitated a boom in housing construction. In this paper we adopt a synthetic control approach to evaluate the impact of the reform on rents. Across different specifications, the synthetic control method indicates that, six years on, rents in Auckland would be at least 27% higher had Auckland not pursued this reform.

The effects of large-scale upzoning posited by advocates of reform should no longer be considered to be purely theoretical. Auckland's experience suggests that zoning reform can stimulate housing supply and reduce housing costs. Policymakers seeking to redress persistent housing shortages and unaffordability should consequently consider reforming residential zoning codes to allow cities to build medium and high density housing.

Our findings for Auckland are, however, a medium-run evaluation of the reform, given the six-year horizon of the study. Long-run effects may depend on inter-regional migration in response to lower housing costs, with in-migrants potentially eroding away reductions in rents, and underscoring the need for coordinated or concurrent action across different cities. New Zealand's recently-elected center-right government has pledged to repeal similar reforms that it recently helped pass to enable medium density housing in New Zealand's largest cities.[21] Repealing this legislation will potentially increase in-migration pressures into Auckland in response to its earlier, unilateral, reform, potentially reducing the effect of the reform on housing affordability over the long term if other large cities do not (or are not incentivised to) follow Auckland's lead and reform their zoning codes to allow more housing development.

We conclude by noting that housing costs in Auckland remain among the most expensive in the world, as measured by either the proportion of disposable income spent on housing or house prices relative to incomes. This observation is not, however, evidence against the efficacy of Auckland's reform, since it leaves the counterfactual unspecified. The evidence presented herein indicates that housing costs would have been even more expensive had Auckland not reformed its zoning code. Nonetheless, our findings do suggest that Auckland's reform is not a panacea, and that additional policy tools and further reforms may be necessary to bring housing costs down to affordable levels.

[21] In December 2021, the center-left Labour and center-right National parties voted to pass the Medium Density Residential Standard (MDRS), which requires the five largest cities in New Zealand to employ a medium density default of three storeys and three dwellings per parcel in residential areas. To date, only two councils (Hutt City and Upper Hutt) have operationalized the MDRS.

6 Appendix

6.1 Hedonic Imputation Index

Our sample of rental bonds consists of apartments, houses and flats. Bonds with no record of the dwelling type are omitted. We restrict the sample to private dwellings, as many public rentals are subsidized, and this is the convention followed by Statistics New Zealand when constructing rental price indexes. Let $p_{i(t),t}$ denote the logged weekly rent of house $i\,(t)$ sold in period t, and let $X_{i(t),t}$ be a vector of characteristics. The hedonic regression is

$$p_{i(t),t} = X'_{i(t),t}\beta_t + \varepsilon_{i(t),t}, \tag{2}$$

where $t = 1, ..., T$ indexes time periods (years), and $i(t) = 1(t), ..., n(t)$ indexes the cross sections observed in period t. We include the following observable characteristics in $X_{i(t),t}$: number of bedrooms, a dummy for apartment, a dummy for flat, and locational dummies (specifically, SA2 dummies). The vector of characteristics $X_{i(t),t}$ also includes a constant. For each FUA, we fit (2) to the cross section of rents for $t = 1, ..., T$, obtaining $\left\{\hat{\beta}_t\right\}_{t=1}^{T}$. For each observation $i(t)$ in period t, we use the estimated hedonic function to impute rents in period t as $\hat{p}_{i(t),t} = X_{i(t),t}{}'\hat{\beta}_t$, and $t-1$ as $\hat{p}_{i(t),t-1} = X_{i(t),t}{}'\hat{\beta}_{t-1}$. We then run the following regression

$$\hat{p}_{i(t),t} - \hat{p}_{i(t),t-1} = \delta_t + u_{i(t),t}, t = 2, ..., T$$

The sequence $\left\{e^{\hat{\delta}_t}\right\}_{t=1}^{T}$ yields the hedonic imputation price index, where $\hat{\delta}_1 = 0$.

6.2 Additional Tables and Figures

Figure 10: Metropolitan and large urban areas of New Zealand

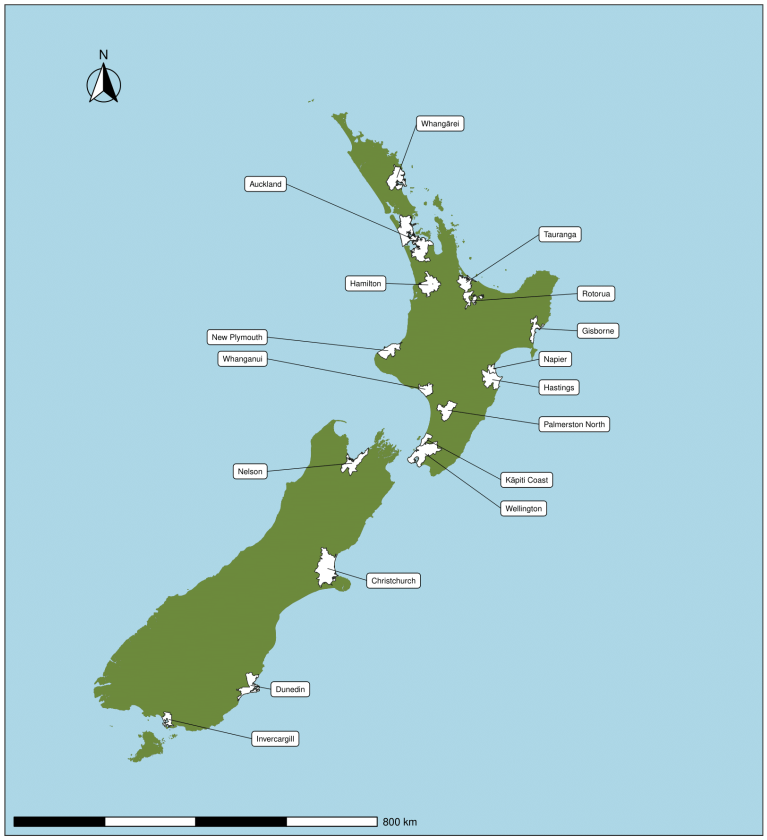
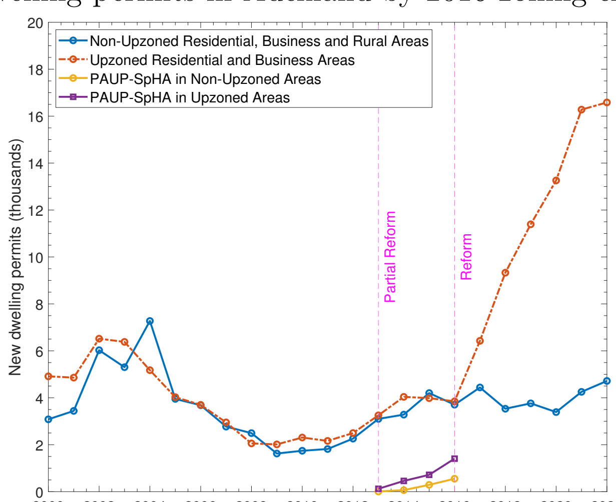


Figure 11: New dwelling permits in Auckland by 2016 zoning change, 2000 to 2022



Notes: New dwelling permits in areas that were and were not upzoned in 2016 under the AUP, with permits issued under to Special Housing Areas (SpHA) separately identified. See notes to Figure 1 for additional details.

Table 3: Functional urban area statistics

Urban Area	Population	Dwellings	Pers. Inc. ($)	Area (km^2)	Prop. dev. 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: Authors' calculations based on 2018 census. Notes: Only metropolitan and large urban areas are tabulated. Dwellings are occupied dwellings. Note that Christchurch is omitted from Auckland's donor pool due to the effect of the 2011 earthquakes on the housing stock and subsequent rebuild.

Table 4: Matched variables, Rotorua omitted from donors

Variable	Auckland	Synthetic Auckland	Average of Donors
Dwellings per capita, 2013	0.332	0.389	0.389
Dwellings per capita, 2006	0.338	0.387	0.386
Dwellings per capita, 2001	0.343	0.386	0.385
Population growth, 2006 to 2013	0.125	0.115	0.071
Population growth, 2001 to 2006	0.091	0.084	0.033
Proportion of developable land	0.453	0.527	0.361
Personal income ($), 2013	30,200	27,926.99	27,808.35
Personal income ($), 2006	27,200	23,742.41	23,399.14
Personal income ($), 2001	21,500	17,552.28	17,549.18
Proportion of households renting, 2013	0.388	0.347	0.333
Proportion of household renting, 2006	0.363	0.332	0.314
Proportion of income spent on rent, 2013	0.262	0.252	0.251
Proportion of income spent on rent, 2006	0.244	0.227	0.229

Notes: Matching variables also include rent indexes, 2000 to 2016. These are not tabulated for the sake of brevity. Population growth is log difference of estimated population. Proportion of income spent on rent is based on pre-tax income for renting households.

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