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DO URBAN AIR QUALITY MANAGEMENT PLANS WORK?

A CASE STUDY ON A CHILEAN CITY USING THE SYNTHETIC CONTROL METHOD.

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Contents

Abstract	2
1. Introduction	3
2. Background	4
3. Methods	10
4. Results	14
5. Discussion	21
6. Conclusions	23
Resumen	24
7. References	25
8. Appendix	33

Do urban air quality management plans work? A case study on a Chilean city using the synthetic control method.

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Abstract

Ignacio Casielles. Do urban air quality management plans work? A case study on a Chilean city using the synthetic control method. Tesis, *Magíster* en Economía Agraria y Ambiental, Facultad de Agronomía e Ingeniería Forestal, Pontificia Universidad Católica de Chile. Santiago, Chile, 44 pp. This study uses the synthetic control method to evaluate the effect of an urban air quality management plan on monthly air pollution levels and emergency room visits in Temuco, southern Chile. The results indicate that this programme has had no significant effect, neither on environmental nor health outcomes. These findings are robust to several checks. Several policy implications and alternatives are discussed.

Keywords: Air pollution, Urban air quality management plan, Synthetic control method, Ex-post evaluation

1. Introduction

As cities grow, they usually have to face the problem of air pollution, which threatens the health of their inhabitants. One way to tackle this issue is by creating management plans aimed at controlling the sources of pollutants. This approach is widely used in Chile, where many cities have Atmospheric Decontamination Plans. These policy instruments are varied, as they are specific to each city, according to the origin of the contaminants.

In Temuco, one of the world's most polluted cities, such a plan has since 2015 been in place in order to curb $PM_{2.5}$ levels. Seeing that Temuco's problem comes from domestic use of firewood as fuel for cooking and heating, controlling this has been the central component of the management plan.

The purpose of this study is to assess the impact this particular policy has had in Temuco, both on $PM_{2.5}$ levels and emergency room visits. The synthetic control method is used in order to estimate a valid counterfactual, thus enabling a comparison to measure the plan's effect.

The obtained results show that Temuco's Atmospheric Decontamination Plan has had no significant effect, neither on $PM_{2.5}$ levels nor on emergency room visits. Several robustness checks confirm that these results are trustworthy.

These results contribute to the environmental policy discussion, by showing the lack of effectiveness of urban air quality management plans in a particular context. Even though only evidence of one case is presented, several topics to consider arisen from this analysis, which should be taken into account in order to improve pollution curbing policies.

Regarding the methodology here applied, this is the first study to use the synthetic control approach to evaluate this kind of policy. This method offers many possibilities for the evaluation of integrated air pollution management plans, as it is difficult to find appropriate controls to assess their impact.

This paper proceeds as follows. In the next section, evidence about urban air quality management plans is provided, as well as details about the programme implemented in Temuco. The following section gives details about the synthetic control method and the data used. Then, the results are presented, along several robustness checks that ensure their validity. Afterwards, the findings are discussed, considering the context of this policy, so as to give recommendations for improving this programme. Finally, some closing remarks are given.

2. Background

Urban air quality is a concern all over the world, as rising population and motorised transportation availability drive an increase in atmospheric pollution. Outdoor air pollution, particularly, is linked to both mobile – i.e. cars and the road transport sector – and stationary sources – i.e. industrial, commercial and domestic, as well as power generation.

Air pollution in urban areas is a problem for the population, as it is detrimental for both health and socio-economic outcomes. Regarding health concerns, particulate material (PM) has been shown to have a negative impact on human health, especially on respiratory and cardiovascular wellbeing (Strickland et al., 2010; Stafoggia et al., 2013), therefore increasing mortality (Burnett et al., 2018). This effect on health is particularly strong among children and the elderly (Gent & Bell, 2010; Strosnider et al., 2019).

In addition to the aforementioned, air pollution has an effect on socio-economic outcomes, as it can reduce children's school attendance and their educational achievements. Likewise, atmospheric pollutants have been linked to reduced worker productivity and more lost workdays. Furthermore, health impacts of air pollution result on larger healthcare costs (Boyce et al., 2016).

It is important to note that air pollution – and therefore, its impacts – are not evenly distributed, as people of lower socioeconomic status are disproportionally exposed to it (Brulle & Pellow, 2006) and have less influence on the shaping of policies aimed at curbing this problem (Laurent, 2011). This is particularly relevant in cities, where environmental disparities are most likely to be associated to residential segregation (Schaeffer & Tivadar, 2019). This phenomenon, although first studied in the United States, has also been documented in Chile (Fernández & Wu, 2016).

In order to face this problem, many countries have implemented Urban Air Quality Management Plans (UAQMP), which seek to improve air quality in order to comply with a given standard. These plans usually include specific goals, a monitoring system, the development of a sources apportionment study and an emission inventory, a method for modelling air quality, and an assessment of health and air pollution exposure. All of this then results in an UAQM strategy, which should include public participation mechanisms (Gulia et al., 2015). Considering this, the measures included in each UAQMP should be in accordance with the local context and, particularly, with the sources of pollution. In big metropolises, in which mobile sources are the most important, these plans usually include driving restrictions, fuel and technological restrictions and incentives, as well as more specific measures (Slovic & Ribeiro, 2018).

In order to warrant successful implementation of an UAQMP, it is important to consider the government's (both central and local) technical capabilities (i.e. the capacity to monitor and understand air quality), data capabilities (i.e. the ability to validate, use and disseminate air quality data) and exploiting capabilities (i.e. the institutional and regulatory framework, as well as the potential to take action) (Franco et al., 2019). Other valuable features are the cooperation between different stakeholders (both in government and civil society), including local measurement networks that consider both industrial and domestic sources (Naiker et al., 2012), regional cooperation and the empowerment of local leadership (Isley & Taylor, 2018).

Available evidence on the impact of UAQMP shows mixed results, which vary greatly depending on the kind of measures taken. Auffhammer & Kellogg (2011) find that regulating gasoline content in the United States did not improve air quality, due to the flexibility with which refiners could comply. They also report that, in California, where the regulations were implemented in a more targeted and strict way, ozone concentrations dropped significantly. As for stationary sources, Tanaka (2015) finds that Chinese regulations on the power generating sector had a positive effect on child mortality, reducing it as much as 20%.

Regarding mobile sources, Cutter & Neidell (2009) find that information programs in California have had an effect on reducing traffic volume, as well as increasing use of public transportation. Han et al. (2020) report that driving restrictions reduced air concentrations of carbon monoxide and PM_{10} in Jinan (China). For the latter, there were heterogenous effects, with steeper drops in denser roads. In Beijing, different road space rationing schemes have proved to be able to reduce ambient pollution (Viard & Fu, 2015; Zhong et al., 2017). This effect could be strengthened by high driver compliance. In Quito, finally, driving restrictions diminished carbon monoxide concentrations by nearly 10% (Carrillo et al., 2016).

In Mexico, the results are not as encouraging. Gallego et al. (2013) show that their driving restriction programme has worsened air quality, since there are more vehicles in circulation. To exacerbate the problem, these new vehicles are higher-emitting ones (Davis, 2008). The expansion of this programme into Saturdays did not have positive effects either, as drivers did not switch to public transportation (Davis, 2017). Similarly, Bogotá's road space rationing scheme has not been able to reduce air pollution nor car use, and the more drastic measures have even worsened the situation (Bonilla, 2019).

A different approach to curbing mobile source air pollution is to promote the adoption of new transportation technologies, such as electric vehicles. In China, an initiative of this sort proved to be effective in reducing nitrogen dioxide concentration (Tan et al., 2018).

In regard to programmes focused on domestic heating, previous literature shows positive results. Gould et al. (2018) found that New York City's plan to phase out dirtier heating fuels reduced outdoor $PM_{2.5}$, even though there was no significant change on indoor pollution. The KWZ retrofit scheme, in the United Kingdom, was able to simultaneously reduce domestic carbon emissions and diminish energy poverty (Webber et al., 2015). In Valdivia, lastly, a randomised control trial study found that providing people with information on the emissions of their woodstove could reduce up to 17.3% of residential pollution (Ruiz-Tagle & Schueftan, 2019).

In Chile, evidence shows that the UAQMP aimed at reducing PM_{10} have had no significant effect. The plans focused on $PM_{2.5}$, on the other hand, were able to reduce monthly concentrations of PM_{10}, but not of $PM_{2.5}$ (Mardones & Cornejo, 2020b). In Santiago, in particular, an evaluation of the city's UAQMP provides evidence that the measures triggered by an environmental episode – i.e. a day in which the concentration of particulate material exceeds the national standard – reduce air pollution by up to 20%, having an effect that persists for up to five days (Mullins & Bharadwaj, 2014). It should be noticed, however, that the previous results only consider stand-alone episodes. This is important, as there is evidence that the cost of intertemporally substituting activities is increasing over time. This means that the first environmental alert has an impact, while immediately subsequent ones are less likely to work (Graff Zivin & Neidell, 2009).

2.1. Temuco – Padre Las Casas' UAQMP

Atmospheric Decontamination Plans (PDA) are the Chilean UAQMP, and they are designed and implemented when a city is declared to be saturated – i.e. environmental standards for a certain pollutant are consistently exceeded. There are currently 14 PDA for PM_{10}, and 10 for $PM_{2.5}$, most of them in southern Chile – as can be seen in table A1 in the Appendix.

The prevalence of PDA in this area is mostly related to the use of firewood as domestic heating and cooking fuel, especially during the winter months. Households in southern Chile are usually affected by low thermal comfort, their houses have low thermal efficiency, and a large share of their income is spent on energy. All these factors together place many of them in a state of energy poverty (Schueftan et al., 2016). Considering the lax building codes under which many of the houses were built, there is high potential for firewood consumption reduction (Schueftan & González, 2013).

The previous problems are unevenly distributed, as there is heterogeneity based on income. It has been documented that more affluent people use better quality firewood, are able to replace their stoves with more efficient ones, and are more aware of public programmes regarding domestic fuels (Schueftan & González, 2015).

Temuco – Padre Las Casas (henceforth, Temuco) was the first metropolitan area south of Santiago to have a PDA, both for PM_{10} (2010) and $PM_{2.5}$ (2015). This city has long had air quality problems, and it has been dubbed one of the world's most polluted (Millan Lombrana et al., 2020). This is due to the widespread use of firewood appliances, which is related to low temperatures, especially during the winter months; the lower price of this fuel, relative to other, cleaner ones; its local availability; and the cultural embeddedness of this practice. To exacerbate the problem, firewood in Temuco does not comply with quality standards, the appliances in which it is burnt are outdated and high-emitting, and the buildings are not thermally efficient (Ministerio del Medio Ambiente, 2015).

Temuco's PDA is aimed at reducing daily air concentrations of $PM_{2.5}$, so as to comply with national standards by 2025. By reducing $PM_{2.5}$, the PDA also enables a significant reduction of PM_{10}, therefore ensuring the compliance of that standard as well. If this goal is achieved, the programme is expected to improve the health of the population.

In order to achieve its objectives, the PDA establishes a series of measures, some of which come into effect immediately, while others have a few years to be implemented or get progressively more stringent:

Use and improvement of firewood: all firewood sold in the city has to be properly dried. Vendors have to be registered, and they have to provide information about the heating power of the firewood they offer.

Use and improvement of appliances: burning fuels other than firewood – e.g. coal, garbage – in firewood appliances is forbidden. Certain appliances can no longer be used. The local office of the Ministry for the Environment is to run a voluntary appliances' renewal programme.

Improvement of houses' thermal efficiency: the local office of the Ministry for Housing offers subsidies to finance retrofits aimed at improving thermal efficiency in housing buildings. Households that receive this subsidy have to comply with certain building regulations. Social housing projects have to be designed so as to require less heating.

Stationary sources emission control: boilers now have a maximum amount of pollution allowed, depending on their thermal power. Generators have to record how many hours they are used.

Agricultural burning emission control: agricultural burning is forbidden during the colder months of the year. The local office of the Ministry for Agriculture runs a programme to incentivise alternatives to burning agricultural waste.

Mobile sources emission control: the Regional Government is to renew buses used for public transportation. Motorised vehicles have to annually certify their compliance with emissions regulation.

Environmental episodes management: whenever the level of PM in the air is predicted to exceed a certain level, additional measures come into effect. These include limiting the use of firewood appliances and restricting the use of firewood boilers.

Environmental education: the local offices for the Ministry for the Environment and the Ministry for Education run education and awareness initiatives, both for students and the general population.

Emission compensation: any activity that goes through an environmental assessment and has a high level of emissions, has to compensate those emissions.

Considering that most of the emissions come from domestic use of firewood, the first three measures are the most relevant, as well as the ones that occupy most of the programme's budget. Regarding these, it is important to note that in southern Chile there is an affect for firewood use, and pollution curbing policies are generally rejected, factors which could endanger the impact of the programme (Boso et al., 2018). Furthermore, almost half of consumers have been documented to be price sensitive, and they would not be willing to pay for certified firewood (Vásquez Lavin et al., 2020).

In addition to the aforementioned, the general context of energy poverty makes it difficult to enforce heating restrictions, as these would prioritise pollution control over wellbeing (Reyes et al., 2019). Therefore, policies focused on reducing the use of firewood could not be as effective as other approaches, such as energy saving through thermal efficiency (Reyes et al., 2015).

The ex-ante evaluation of the PDA shows that if its goal of 67% reduction in $PM_{2.5}$ concentration – equivalent to 97μg/m^3 – is achieved, there would be a gain of US$1,261 million, while the costs would be US$207 million, with a net benefit of US$1,054 million (Ministerio del Medio Ambiente, 2015).

An evaluation of this PDA, contracted by the Ministry for the Environment, reports a significant, albeit small, reduction in PM_{10} monthly concentration (Mardones, 2017). This impact falls below the goals set by the plan, showing an underperforming policy. A further evaluation of the critical episodes management component of the PDA (Mardones & Cornejo, 2020a) is more optimistic, as its results reveal that declaring one of the more serious environmental episodes (emergency or pre-emergency) has a significant effect on reducing both PM_{10} and $PM_{2.5}$ hourly concentrations.

Considering all the aspects mentioned above, this research project aims to establish if the PDA implemented in Temuco in 2015 has had an effect on either air pollution levels or on the city dwellers' health. In order to achieve this, a valid counterfactual of the city has to be estimated, a process more thoroughly detailed in the next section. Then, it is possible to measure the effect achieved by the PDA, as presented in the results.

3. Methods

3.1. Synthetic control method

In order to estimate the PDA's impact, it is required to know what would have happened in Temuco if the programme had not been implemented. Since this cannot be observed, a valid counterfactual has to be estimated. The econometric method used for this purpose is the synthetic control method (SCM), first proposed by Abadie & Gardeazabal (2003) – and further explored by Abadie et al. (2010; 2015) – as an identification strategy in cases in which there is reduced availability of control units, and direct comparisons would not be a valid estimate of the effect of an intervention.

Assume there is a sample of J + 1 units, of which unit j = 1 has received treatment, and units j = 2 through j = J + 1 are potential controls (henceforth, the donor pool). The sample includes longitudinal data, ranging from period t = 1 to t = T. Then, T can be divided in a pre-intervention period, T_0, and a post-intervention period, T_1, such that $T = T_0 + T_1$. Unit j = 1 has been exposed to the intervention in periods $t = T_0 + 1$ through $t = T_1$.

A synthetic control, then, is a weighted average built using a combination of the units in the donor pool. That is, the aim is to estimate a (J x 1) vector of weights, $W = (w_2, \ldots, w_{J+1})'$, with $0 \leq w_j \leq 1$ for j = 2, …, J, and $w_2 + \ldots + w_{J+1} = 1$. If X_1 is a (k x 1) vector of observed characteristics of unit j = 1 in the pre-intervention period, and X_0 is a (k x J) matrix of the same covariates for the untreated units previous to the intervention, then the values of W* minimize $X_1 - X_0W$. It is important to note that X_0 and X_1 may include the outcome of interest as one of the variables with predictive power.

If Y_{jt} is the outcome variable, for unit j at time t, Y_{1T_1} is a (T_1 x 1) vector containing the outcome values for the treated unit in the post-intervention periods, and Y_{0T_1} is a (T_1 x J) matrix with the values for the outcome variable for the untreated units in the post-intervention periods; then the synthetic control estimator of the average effect of the treatment on the treated can be expressed as $Y_{1T_1} - Y_{0T_1}W^*$. In other words, a weighted average of units from the donor pool can be used to create a valid untreated counterfactual, which can then be compared with the treated unit in each post-intervention period[1].

In order for the SCM to estimate a valid measure of the treatment effect, three assumptions need to hold (Bennett, 2020):

(i) Treatment assignation is random, conditional on the donor pool, the covariates included (X_1 and X_0), and the path of the outcome previous to the intervention. In other words, the real and synthetic treated unit need to have a good fit before the programme came into effect. In order to assess this, the pre-intervention Root Mean Squared Prediction Error (RMSPE) is reported. This measure is an aggregate of the distance between both paths, and is defined as:

$$\sqrt{\frac{\sum_{t=1}^{T_0} (Y_{1t}-Y_{0t}W)^2}{T_0}}$$

(ii) Stable Unit Treatment Value Assumption (SUTVA), meaning that there is no spillover effect of the intervention on the untreated units. In order to address this, no other cities from the Araucanía Region, apart from Temuco, are considered in the donor pool.

(iii) The intervention had no effect before its implementation. Since PDA take a long time to come into effect, this assumption is the most difficult to ensure. From the moment a city is declared as saturated, households could anticipate the PDA and start migrating away from firewood use, or invest in cleaner heating. However, given the general rejection of these kinds of policies, such an effect is unlikely to have occurred. If this assumption was violated, however, the estimates of the impact of the programme would be biased downward, giving a more conservative result.

The SCM has been used in a broad array of subjects, including economic development (Abadie & Gardeazabal, 2003; Abadie et al., 2011; Mideksa, 2013; Severnini, 2014; Abadie et al., 2015; Grier & Maynard, 2016; Reimer et al, 2017; Rieger et al., 2017), democratic institutions (Liou & Musgrave, 2014; Xu, 2017), health (Abadie et al., 2010;

[1] Further specifications of the SCM have been developed, so as to implement it in more specific contexts. Some of these include the ones described by Ben-Michael et al. (2020), Brodersen et al. (2015), Cerulli (2019), and Xu (2017).

Bruhn et al., 2017; Rieger et al., 2017; Barlow, 2018; Bennett, 2020), and energy (Kallbekken et al., 2013; Jimenez & Mercado, 2014; Kirkpatrick & Bennear, 2014).

Regarding environmental studies, this method has been used to estimate the effect of the Kyoto Protocol on CO2 emissions (Almer & Winkler, 2012); to evaluate forestry strategies (Sills et al., 2015; Rana & Sills, 2018; Rana & Miller, 2019); to assess the impact of a waste pricing scheme (Bueno & Valente, 2018); and to measure the economic and environmental effect of car scrappage programs (Klößner & Pfeifer, 2015).

Since this method has not been previously employed in the evaluation of UAQMP, this study presents a novel application of the SCM. This is particularly relevant, since these policies are implemented in large regions that don't have many comparison units, making it difficult to establish valid comparisons.

3.2. Robustness checks

Since the SCM does not provide standard errors, it is not possible to run tests that assess the statistical significance of its results. In order to solve this problem, several robustness checks are run, so as to ensure that the estimated impact is a result of the treatment, and not due to the methodology or randomness in the data.

Firstly, a placebo study – also known as local permutation – is presented. This technique, which was part of the earliest SCM applications (Abadie & Gardeazabal, 2003; Abadie et al., 2010), consists of creating synthetic controls for the units in the donor pool. Since those units are not treated, no effect should be found – i.e. the synthetic and the actual units should have the same values. Therefore, the treated unit would have the greatest prediction error – or actual-synthetic gap – which could be found in a visual examination of the paths, or using a pseudo p-value – i.e. a ratio of the position of the treated unit in the ranking of prediction errors, relative to the amount of total units. Another way to look at this is to examine the post/pre RMSPE ratios, which show the strength of the impact relative to the fit of the method. With this measure, if the treatment is effective, the treated unit should have the largest value.

Another valuable robustness check is to perform temporal permutations – or temporal placebos –, as done by Jimenez & Mercado (2014) and Grieg & Maynard (2016). This method is implemented by moving the date of the intervention to a previous period, and then examining the path of the outcome up to the actual date of the intervention. Since there is no treatment, both the real and synthetic units should follow the same trajectory.

In order to further check the robustness of the method, SCM analysis changing the specification – as done by Liou & Musgrave (2013) and Mideksa (2013) – and the donor pool – as proposed by Almer & Winkler (2012) – are shown. If the results are robust, then there should be no change. In the first case, variables are added to each specification, using covariates from the health model in the air quality model, and vice versa. In the latter, cities north of Santiago – originally excluded due to the different pollution determinants – are included in the model[2].

Finally, a synthetic control analysis using daily data is shown, in order to assess if there are differences in the results depending on data granularity. This was done for both models, but only data for winter months (June, July, August) was considered.

3.3. Data and data sources

For the main analyses, the SCM is used to estimate air quality – measured as monthly concentration of $PM_{2.5}$ – and health impacts – measured as monthly emergency room visits related to respiratory causes[3]. Both models share many covariates: average temperature, average rainfall, population and population density, green area surface, amount of cars registered in the city, percentage of people employed in agriculture, manufacturing and construction – these variables aim to represent how big there industries are, as they are important sources of air pollution – and percentage of households using firewood as fuel for heating or cooking. Furthermore, the air quality model also includes average wind speed; while the health model considers the share of elderly people (65 or over) and infants (4 or younger), the share of urban population, and average household income.

As for data sources, $PM_{2.5}$ concentration was taken from the National Air Quality Information System (SINCA), while emergency room visits were retrieved from the Health Statistics and Information Department (DEIS). Temperature and wind speed data were

[2] This last procedure was only done in the emergency room visits analysis, as there is no data available for $PM_{2.5}$ for cities north of Santiago on the period considered.
[3] Only ER visits in hospitals were considered. Even though primary and secondary health centres receive emergency visits, the data is not trustworthy in all of the cities.

also taken from the SINCA; rainfall data was retrieved from the General Water Directorate (DGA); population and population density data was taken from the census at the National Institute for Statistics (INE), as well as share of elderly people and infants; green area surface was retrieved from the Urban Development Standards and Indicators System (SIEDU) at INE; car registrations were retrieved from INE as well. The remaining covariates – i.e. share of people in agriculture, manufacturing and construction; share of households using firewood as fuel; share of people in urban areas; and household income – were taken from the National Socioeconomic Characterisation (CASEN) survey, run by the Ministry for Social Development.

The donor pool includes major cities without a PDA for which there was available data. Both models consider Greater Rancagua, Curicó, Greater Talca, Los Ángeles, and Coyhaique. The health model, for which data is more widely available, also includes Rengo, San Fernando, Linares, Greater Concepción, Greater Puerto Montt, and Punta Arenas. As for the other cities used as robustness check, these include Arica, Greater Iquique, Antofagasta, Copiapó, Greater La Serena, and Greater Valparaíso[4].

4. Results

4.1. Impact of the programme on air quality

The SCM was used to construct a counterfactual against which to compare Temuco, in order to assess the impact of the PDA on monthly $PM_{2.5}$ concentrations. Table 1 shows a comparison of pre-treatment characteristics of the actual Temuco and the estimated one. These numbers reflect that, even though the SCM accurately reproduces $PM_{2.5}$ values, it fails to emulate most of the other variables, creating an untreated unit that is warmer, dried, smaller and more rural, as well as less dependent on firewood.

[4] For daily data analyses Valdivia is also included in the donor pool, since it did not have a PDA during the predicted period.

Table 1. $PM_{2.5}$ predictor means.

Variables	Actual Temuco	Synthetic Temuco
$PM_{2.5}$ concentration (μg/m^3)	35.68	36.01
Temperature (ºC)	11.12	14.91
Wind speed (m/s)	1.59	2.07
Rainfall (mm)	88.82	47.16
Population	364’372	239’611
Population density	65.14	44.5
Registered cars	84’834	69’203
Green area surface (m2)	2’744’338	1’906’934
Share of workers in agriculture	5.78%	9.45%
Share of workers in manufacturing	8.78%	7.88%
Share of workers in construction	10.65%	8.84%
Share of households using firewood	77.46%	47.15%

Table 2 reports the weights given to the donor pool cities, confirming that the synthetic Temuco is drier and smaller, since most of it comes from Rancagua, a city with these characteristics. The presence of several non-zero weights confirms that using a combination of cities to assess the programme is appropriate, as there is no single city that can, by itself, be similar enough to Temuco.

Table 2. City weights in the synthetic Temuco ($PM_{2.5}$ model).

City	Weight
Rancagua	0.626
Curicó	0
Talca	0
Los Ángeles	0.211
Coyhaique	0.163

Figure 1 shows the path of $PM_{2.5}$ concentration in both Temuco and its synthetic counterfactual. Both lines have a good pre-treatment fit – with the exception of some summer and winter months –, but there are not any noticeable differences once the programme comes into place. When considering the RMSPE, the pre-intervention periods have a value of 7.64, while after the intervention it goes to 7.49, showing an even better fit after the PDA was implemented. These results suggest that the programme had no impact on air quality.

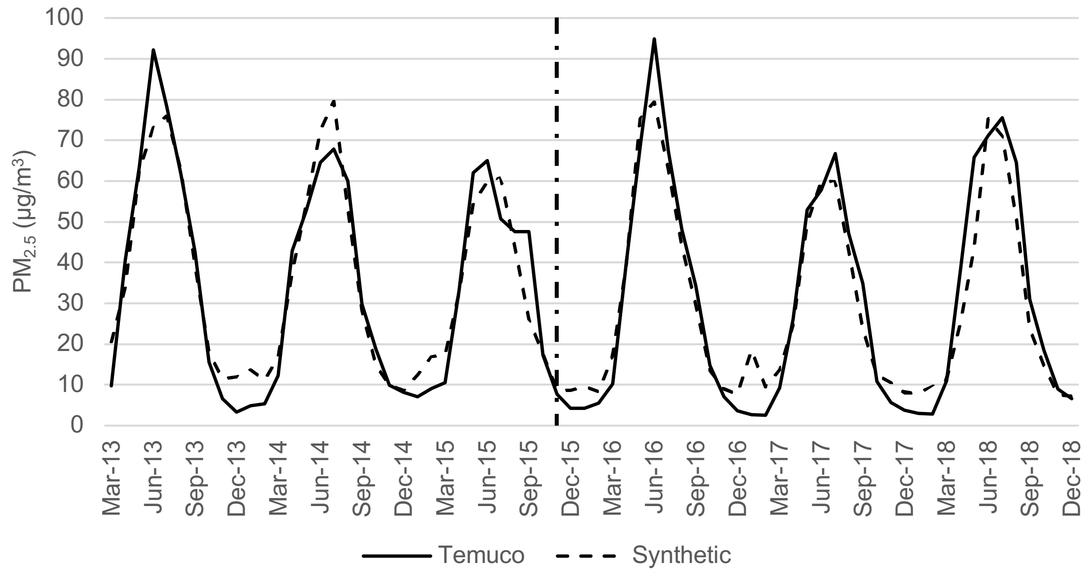

Figure 1. Trends in $PM_{2.5}$ concentration: Temuco vs. synthetic Temuco.

Figure 2 plots the prediction error – i.e. the gap between each actual city and its synthetic control – for the local placebos. As can be seen, Temuco – the bold line – does not show a clear negative gap, confirming that the programme has had no effect on $PM_{2.5}$ concentration. Figure 3 further explores this by showing post/pre RMSPE ratios. Temuco has one of the smallest values, ratifying the PDA's lack of impact.

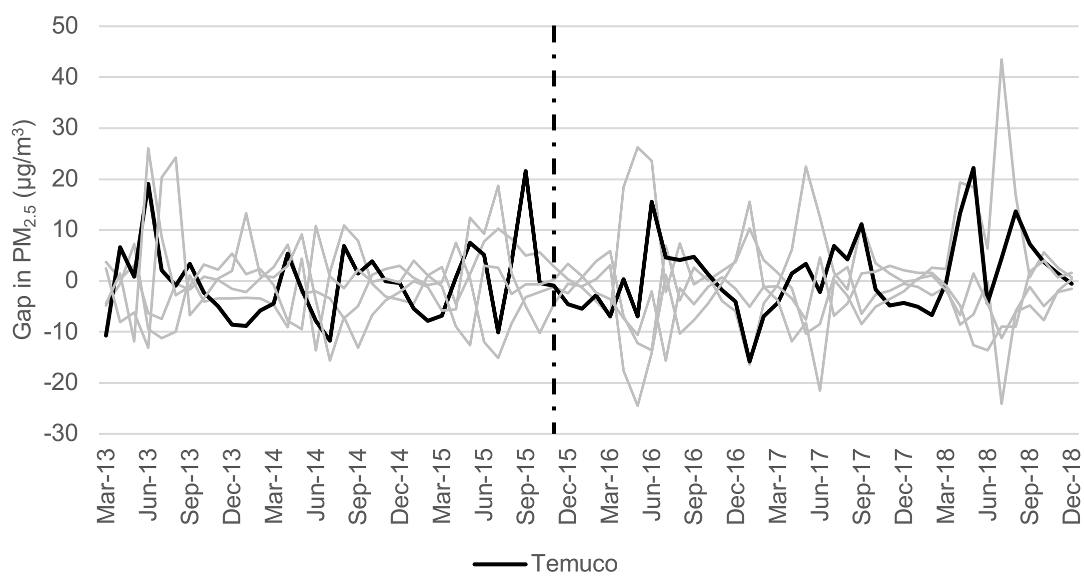

Figure 2. $PM_{2.5}$ gap between Temuco and synthetic Temuco.

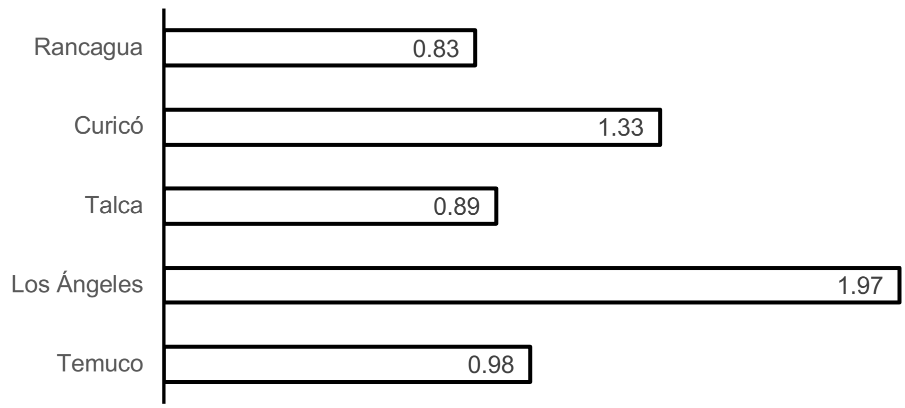

Figure 3. Post/pre intervention RMSPE ratios ($PM_{2.5}$ model).

Temporal permutation analysis for the $PM_{2.5}$ model (tables A2 and A3, figure A1 in the Appendix) does not show any significant variations, providing evidence in favour of the method. Changing the specification of the model results on the exact same synthetic control, thus adding robustness to the previous analysis.

Using the SCM with daily data creates a counterfactual that follows Temuco's trends, but largely ignores extreme values (figure A2 in the Appendix). This could happen if those particular days are outside the support of the cities in the donor pool. An important difference in this case is that Valdivia – a highly polluted city that is ignored on the monthly analyses due to having a PDA implemented in 2017 – is included, and gets a significant weight. Once again, the method gets an accurate pre-treatment balance (tables A4 and A5 in the Appendix).

Still, the daily data does not show positive results linked to the programme, and neither does the analysis of its placebos (figures A3 and A4 in the Appendix).

4.2. Impact of the programme on emergency room visits

The synthetic control for estimating the impact of the PDA on emergency room visits related to respiratory causes replicates this outcome adequately, as is shown in table 3. This table also indicates that both the actual and synthetic Temuco are similar on most variables. The synthetic control, however, is less populated, uses less firewood, has less green area surface, and has a higher share of agricultural workers.

Table 3. Emergency room visits predictor means.

Variables	Actual Temuco	Synthetic Temuco
ER visits (respiratory causes, hospitals)	1970.4	1956.68
Temperature (ºC)	11.27	12.2
Rainfall (mm)	83.31	76.8
Population	357’710	194’667
Population density	63.87	55.26
Registered cars	74’876	44’998
Green area surface (m2)	2’744’338	1’127’027
Share of urban population	85.02%	81.09%
Share of elderly population	9.19%	9.29%
Share of infant population	6.93%	7.29%
Share of workers in agriculture	7.02%	10.75%
Share of workers in manufacturing	9.11%	9.83%
Share of workers in construction	10.3%	10.32%
Mean household income ($)	864’437	842’305
Share of households using firewood	77.46%	64.24%

The weights given to the donor pool cities are detailed in table 4. These values show that the biggest donor in this case is Los Ángeles, a city that is geographically close to Temuco. Most cities on the donor pool have positive weights.

Table 4. City weights in the synthetic Temuco (ER visits model).

City	Weight
Rancagua	0
Rengo	0.251
San Fernando	0.16
Curicó	0
Talca	0.119
Linares	0.056
Los Ángeles	0.353
Concepción	0.018
Puerto Montt	0.148
Coyhaique	0.043
Punta Arenas	0.103

Figure 4 plots the path of ER visits for both actual and synthetic Temuco. Previous to the treatment both show a good fit, with the exception of a few months in late 2012 and in the winter of 2013. During 2015 the values for synthetic Temuco are already higher than the actual one, hinting that the programme might have had some effect previous to its implementation. After the intervention, values for the synthetic control seem to be higher than those for the actual city, especially during the winter months. On average, Temuco has 187 fewer monthly ER visits that its synthetic counterpart, which is a reduction of 12.98%.

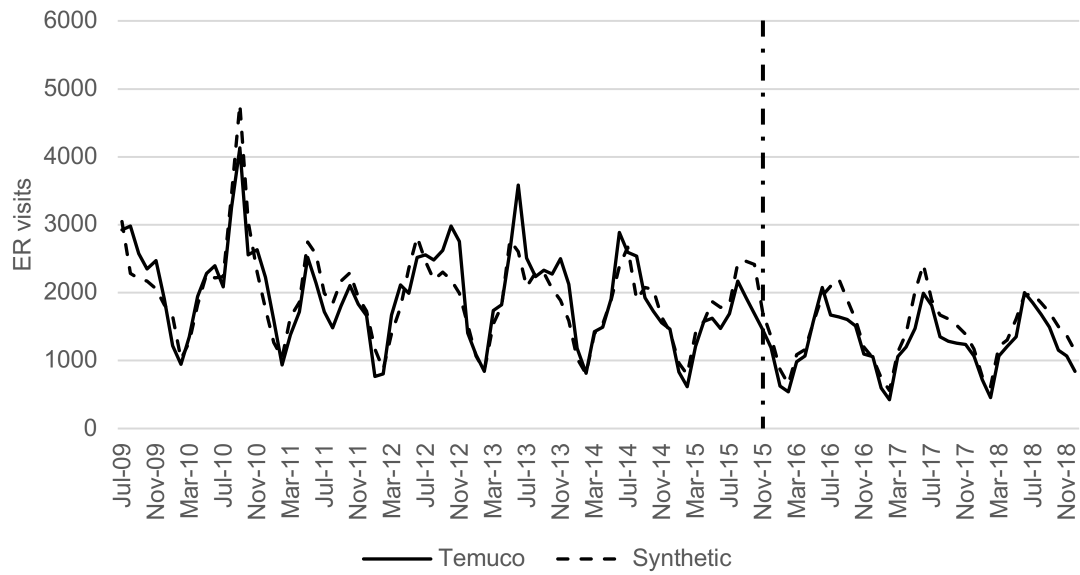

Figure 4. Trends in ER visits: Temuco vs. synthetic Temuco

The prediction error for both Temuco and the placebos can be seen in figure 5. This plot shows that Temuco, after the PDA, does not lead on the RMSPE measure, meaning that the previously described effect of the programme is not significant, as it can be a result of the SCM estimation error. Figure 6 shows the post/pre RMSPE ratios, confirming that Temuco has one of the lowest values, which ratifies that the PDA has not had an effect on health.

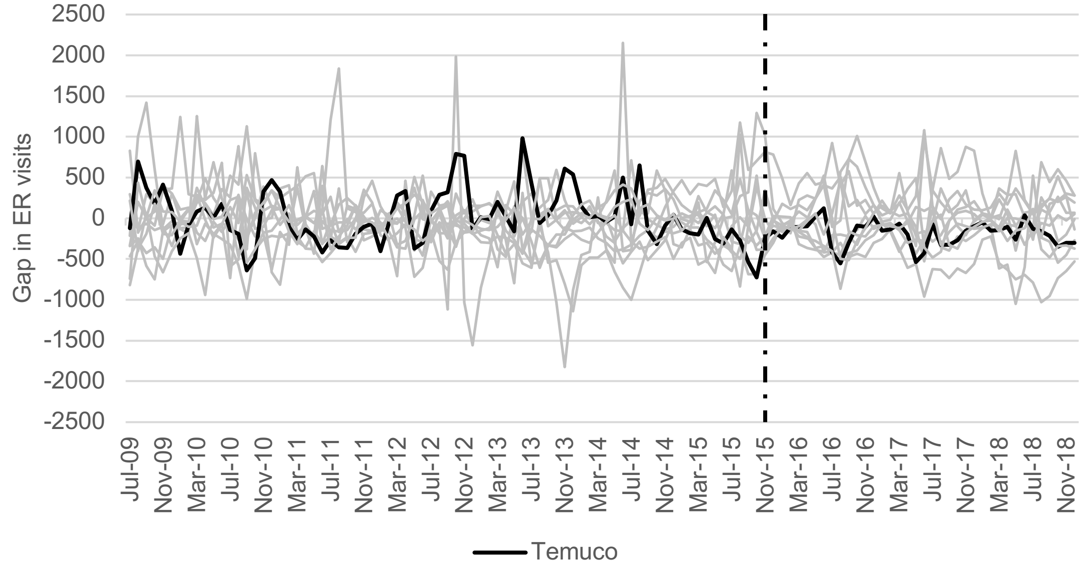

Figure 5. ER visits gap between Temuco and synthetic Temuco.

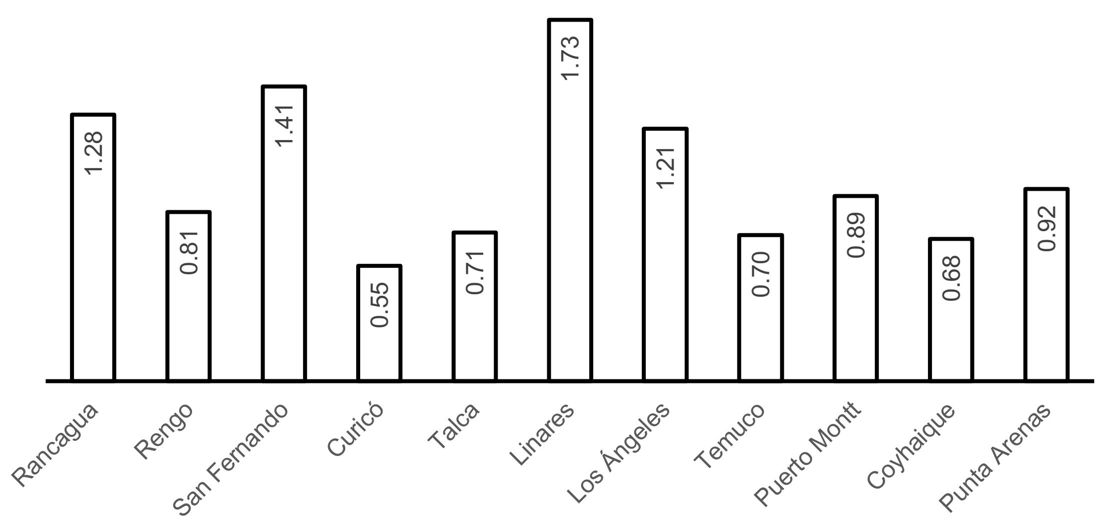

Figure 6. Post/pre intervention RMSPE ratios (ER visits model).

Temporal permutation analysis for the health model (tables A6 and A7, figure A5 in the Appendix) does not create a gap between Temuco and its synthetic control, confirming that the methodology is robust. Adding new covariates introduces some changes in the results, estimating an ATT of 361 fewer ER visits, but these results are not significant (tables A8 and A9, figure A6 in the Appendix).

When the SCM also considers cities in northern Chile the weights given to each unit change (tables A10 and A11 in the Appendix), even though the new cities are barely included in the synthetic unit. The results, in this case, do not offer any new insights, and further confirm the model's robustness (figure A7 in the Appendix).

The daily analysis of ER visits, once again, gives an important weight to Valdivia, a city that is not included in the monthly analysis, and gets a good fit on the covariates (tables A12 and A13 in the Appendix). The results do not show any evidence of a positive impact of the PDA, and neither does the local permutation analysis (figures A8 through A10 in the Appendix).

5. Discussion

The results previously described show that Temuco's PDA has had no effect either on air quality or health, raising several topics of discussion that have to be addressed in order to improve air pollution curbing policies.

First of all, it is important to consider that, since the programme has not achieved its goals, the assumptions included in the ex-ante evaluation are most likely erroneous, as has been mentioned by Mardones & Cornejo (2020b).

The most important design flaw, in this case, is related to low compliance. This is a consequence of the trade-off households face between thermal comfort and air quality (Reyes et al., 2019). In this context of energy poverty, environmental concerns are secondary, as consumers need to heat their homes. Given their financial constraints, only a fraction of them are willing to pay for certified firewood (Vásquez Lavín et al., 2020), creating a black market of uncertified vendors, forcing consumers to pick their own firewood, or even incentivising the use of other materials – such as coal and garbage – as fuel.

Low compliance is also related to cultural factors, since people in southern Chile have a special regard for the use of firewood as domestic heating fuel (Boso et al., 2018). This points to another design flaw, namely, the lack of public participation. Air pollution curbing policies' low support is related to lack of information and the use of measures that are unlikely to hold in the context in which they are implemented. Involving consumers in the response to this problem is a key factor for a more effective UAQMP (Naiker et al. 2012; Gulia et al., 2015).

Regarding the critical episodes component of the PDA, whose positive short-term results have been documented (Mardones & Cornejo, 2020a), there are two points to be noted. First, the more stringent actions triggered by high pollution forecasts could have a stronger impact, in terms of thermal comfort, in poorer households, which have fewer alternatives to firewood. This could lead to other health and wellbeing consequences.

Moreover, using these episodic approach could have a limited long-term effect, as consumers take evasive actions only for a short period of time (Graff Zivin & Neidell, 2009). Therefore, these measures could become less effective after the first consecutive environmental episode.

Considering this, and given the importance of improving air quality levels in Temuco, a better approach in order to achieve this goal could be to rely more heavily on thermal efficiency retrofit programmes. This kind of initiative has demonstrated its efficacy (Webber et al., 2015), and it has been estimated to be able to improve both air quality and energy access levels (Schueftan & González, 2015; Schueftan et al., 2016).

Programmes in this direction should expand subsidies, such as the ones already encompassed in the PDA (Schueftan & González, 2015), but also offer innovative ways to finance insulation improvements, including flexible credits and saving encouragement (Schueftan et al., 2017).

Another policy option to consider is providing consumers with information to make better use of their appliances. This kind of programme has proved to be effective in Chile, and could easily be implemented (Ruiz-Tagle & Schueftan, 2019). Information about the effects of air pollution could also raise awareness and increase approval of the programme, thus promoting compliance (Boso et al., 2018). Even though PDA have an environmental education component, there are not enough resources allocated to this purpose.

Regarding data collection and analysis, it is vital to improve the functioning of measurement stations, in order to have constant and reliable air quality information from different cities. It is common for stations to be down for several months at a time, which makes it difficult to use panel data analysis techniques to evaluate the impact of different initiatives. It is also important to come up with creative identification strategies that provide decision-makers with information that goes beyond naïve analyses.

6. Conclusions

This paper is focused on evaluating the impact on environmental and health outcomes of an urban air quality management plan. The synthetic control method is used in order to estimate a valid counterfactual of a city in southern Chile, and the results show that the programme has had no effect on improving air pollution levels, nor on reducing emergency room visits. These findings are robust to several checks.

Considering the seriousness of the issue, it is necessary to come up with a timely response that takes into account the particularities of the context and is able to effectively reduce the health risks to which the population is exposed, while protecting their wellbeing. Promoting retrofit programmes, for example, is an alternative that could be much more effective. Moving forward, the use of data – and creative methods for its analysis – has to be a key component in the design of environmental policies.

Due to the lack of proper comparison units, pollution curbing policies are usually assessed using weak identification strategies – if any at all. This paper has shown that the SCM is a viable and efficient way of evaluating this kind of policies, thus contributing to the discussion about environmental regulation instruments and their effectiveness.

Resumen

Ignacio Casielles. Do urban air quality management plans work? A case study on a Chilean city using the synthetic control method. Tesis, *Magíster* en Economía Agraria y Ambiental*,* Facultad de Agronomía e Ingeniería Forestal, Pontificia Universidad Católica de Chile. Santiago, Chile, 44 pp. Esta investigación usa el método de control sintético para evaluar el impacto de un plan urbano de gestión de calidad del aire sobre los niveles mensuales de contaminación atmosférica y de atenciones de urgencia en Temuco, sur de Chile. Los resultados muestran que el programa no ha tenido efectos significativos, ni en la variable ambiental ni en la de salud. Estos resultados son validados con varias pruebas de robustez. Se discuten implicancias y alternativas para las políticas ambientales.

Palabras clave: Contaminación atmosférica, Plan urbano de gestión de calidad del aire, método de control sintético, evaluación ex-post.

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8. Appendix

Table A1. Implementation date of PDA (from north to south).

City	PM_{10} PDA	$PM_{2.5}$ PDA
Tocopilla	October 2010	-
Huasco	August 2017	-
Andacollo	December 2014	-
Concón, Quintero and Puchuncaví	April 1993	March 2019
Santiago	June 1998	April 2010
Rancagua, San Fernando and Rengo	August 2013	-
Curicó	-	December 2019
Talca	March 2016	-
Chillán	March 2016	March 2016
Concepción	December 2019	December 2019
Los Ángeles	January 2019	January 2019
Temuco	June 2010	November 2015
Valdivia	June 2017	June 2017
Osorno	March 2016	March 2016
Coyhaique	March 2016	July 2019

Table A2. $PM_{2.5}$ predictor means (temporal permutation).

Variables	Actual Temuco	Synthetic Temuco
$PM_{2.5}$ concentration (μg/m^3)	38.66	38.4
Temperature (ºC)	10.74	13.54
Wind speed (m/s)	1.48	2.42
Rainfall (mm)	85.49	69.67
Population	362’597	213’813
Population density	64.82	53.76
Registered cars	82’889	57’926
Green area surface (m2)	2’744’338	1’380’260
Share of households using firewood	77.46%	63.41%

Table A3. City weights in the synthetic Temuco ($PM_{2.5}$: temporal permutation).

City	Weight
Rancagua	0.344
Curicó	0
Talca	0
Los Ángeles	0.501
Coyhaique	0.155

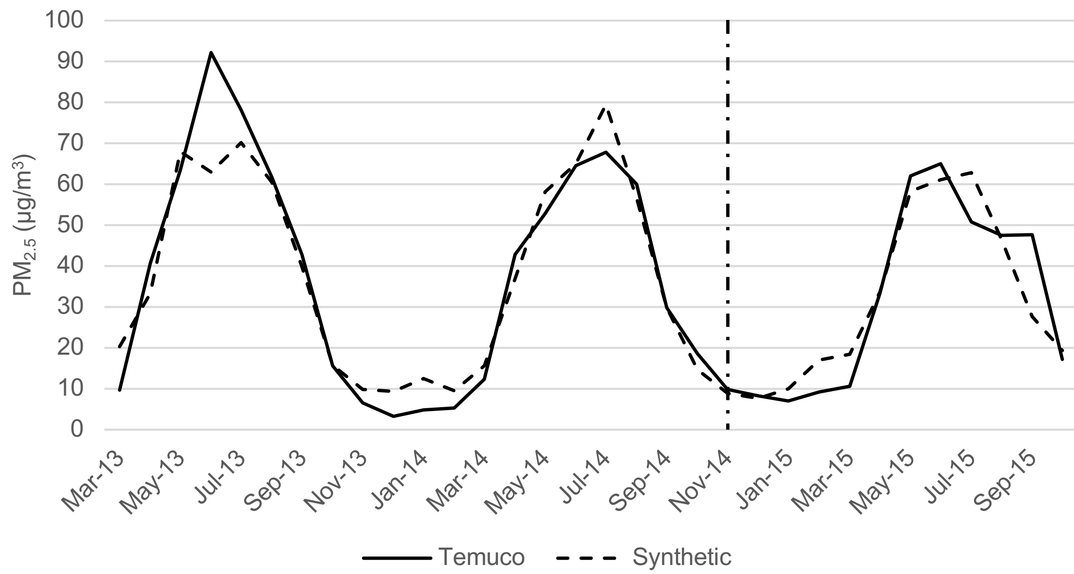

Figure A1. Trends in $PM_{2.5}$ concentration: Temuco vs. synthetic Temuco (temporal permutation)

Table A4. $PM_{2.5}$ predictor means (daily analysis).

Variables	Actual Temuco	Synthetic Temuco
$PM_{2.5}$ concentration (μg/m^3)	58.2	58.27
Temperature (ºC)	9.24	9.06
Wind speed (m/s)	1.65	1.87
Rainfall (mm)	187.4	159.84
Population	367’614	194’830
Population density	65.14	44.19
Registered cars	84’834	54’242
Green area surface (m2)	2’744’338	1’580’146
Share of workers in agriculture	5.78%	9.02%
Share of workers in manufacturing	8.78%	9.03%
Share of workers in construction	10.65%	8.02%
Share of households using firewood	77.46%	69.34%

Table A5. City weights in the synthetic Temuco ($PM_{2.5}$: daily analysis).

City	Weight
Rancagua	0.127
Curicó	0.137
Talca	0.072
Los Ángeles	0.162
Valdivia	0.482
Coyhaique	0.02

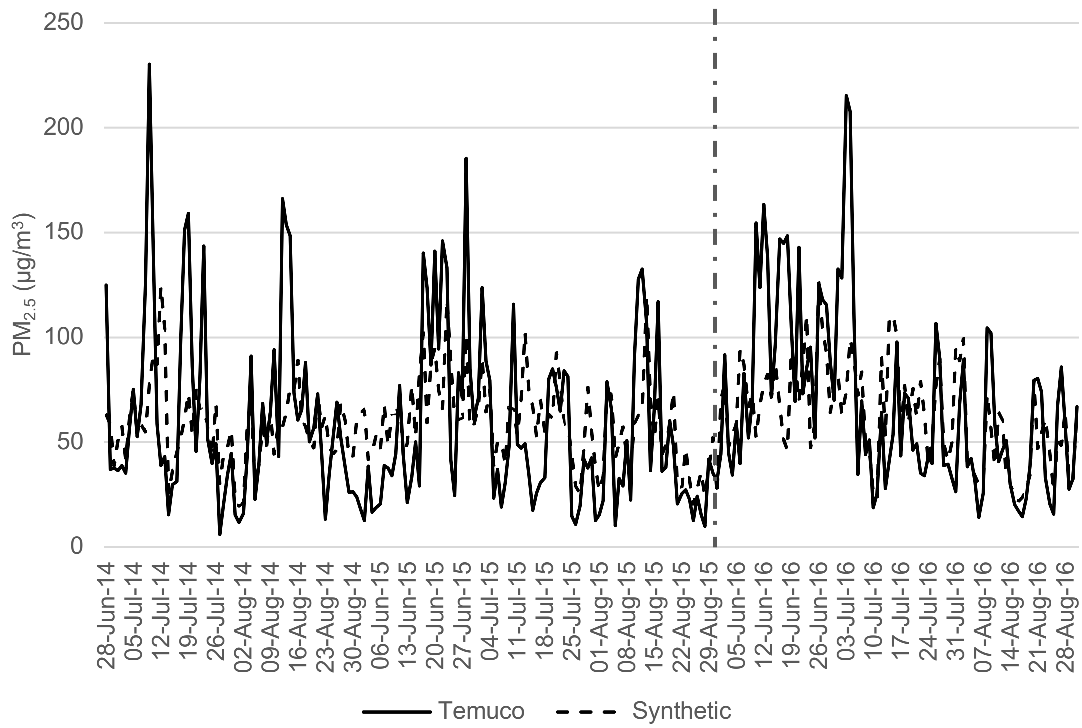

Figure A2. Trends in $PM_{2.5}$ concentration: Temuco vs. synthetic Temuco (daily analysis).

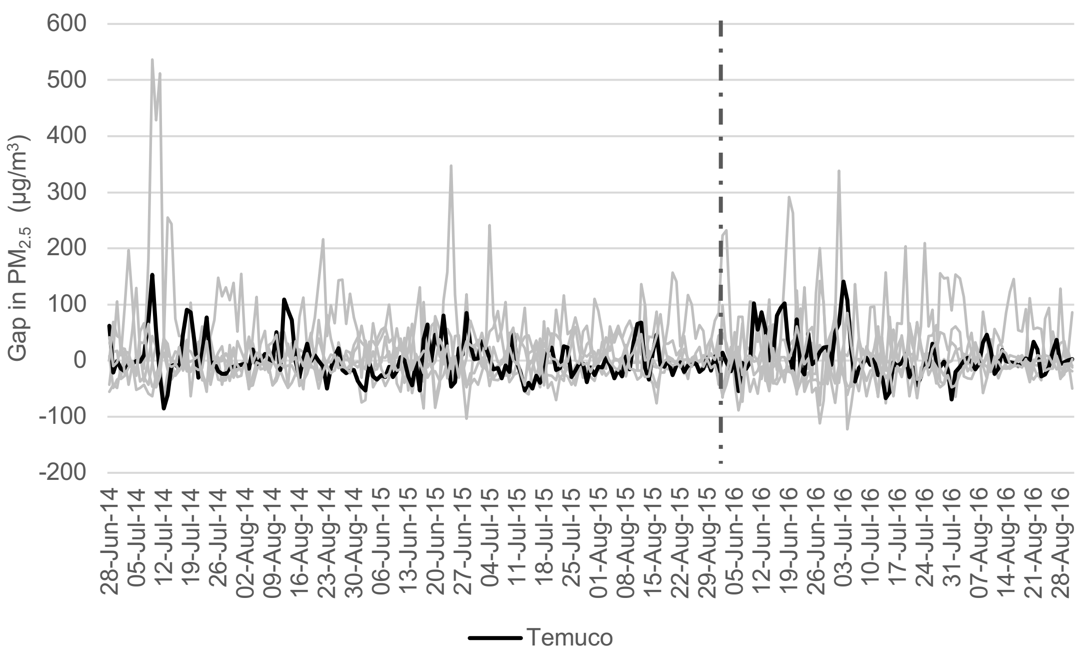

Figure A3. $PM_{2.5}$ gap between Temuco and synthetic Temuco (daily analysis).

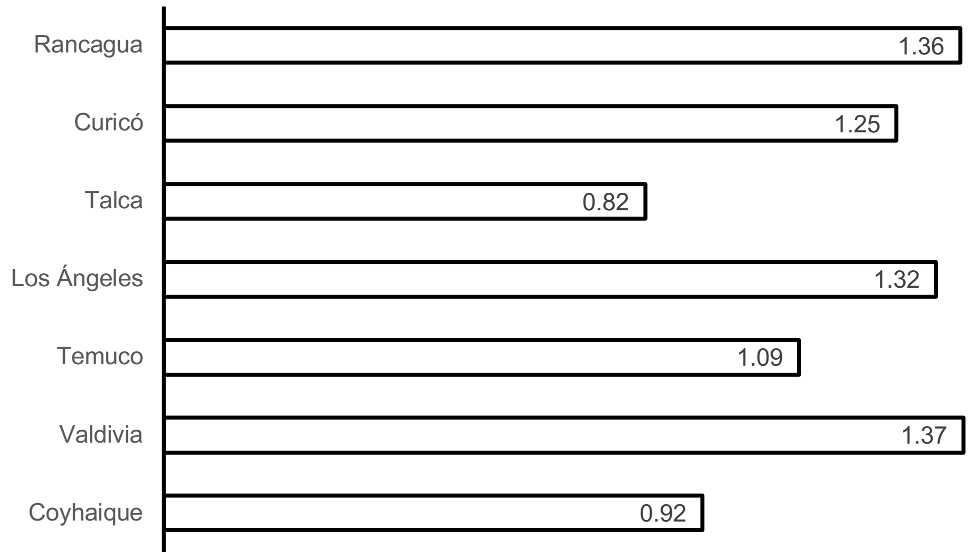

Figure A4. Post/pre intervention RMSPE ratios ($PM_{2.5}$: daily analysis).

Table A6. Emergency room visits predictor means (temporal permutation).

Variables	Actual Temuco	Synthetic Temuco
ER visits (respiratory causes, hospitals)	2092.79	2089.18
Temperature (ºC)	11.44	12.64
Rainfall (mm)	79.3	74.36
Population	354’096	157’693
Population density	63.23	58.6
Registered cars	69’897	33’496
Green area surface (m2)	2’744’338	803’612
Share of urban population	85.33%	77.15%
Share of elderly population	8.97%	8.97%
Share of infant population	6.99%	7.56%
Share of workers in agriculture	7.64%	13.21%
Share of workers in manufacturing	9.28%	9.28%
Share of workers in construction	10.12%	10.29%
Mean household income ($)	844’560	735’306
Share of households using firewood	77.46%	74.15%

Table A7. City weights in the synthetic Temuco (ER visits: temporal permutation).

City	Weight
Rancagua	0
Rengo	0
San Fernando	0.339
Curicó	0
Talca	0
Los Ángeles	0.428
Concepción	0.012
Puerto Montt	0.107
Coyhaique	0.114
Punta Arenas	0

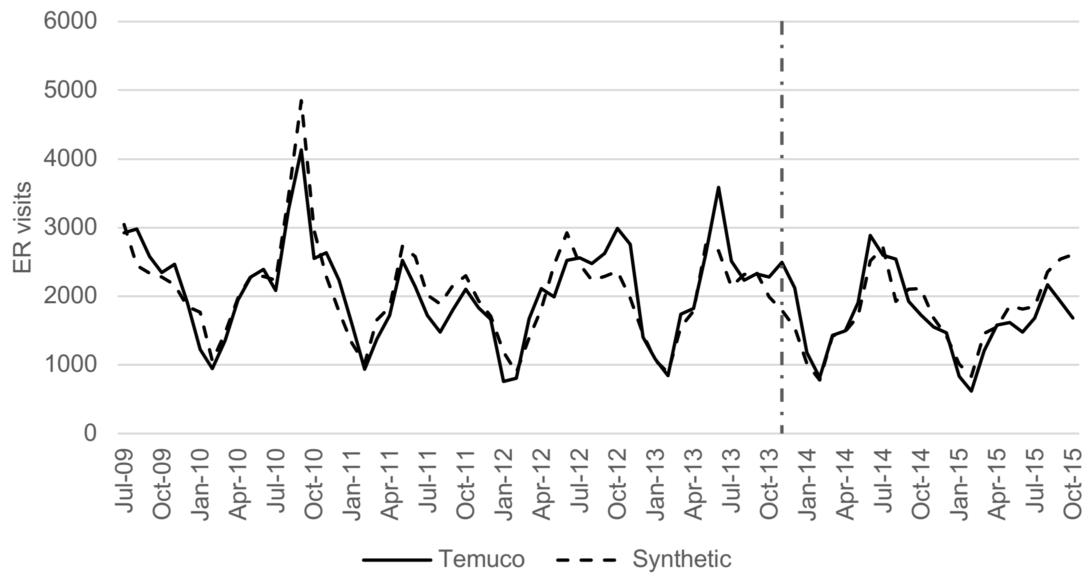

Figure A5. Trends in ER visits: Temuco vs. synthetic Temuco (temporal permutation).

Table A8. Emergency room visits predictor means (different specification).

Variables	Actual Temuco	Synthetic Temuco
ER visits (respiratory causes, hospitals)	1970.4	1958.55
Temperature (ºC)	11.27	12.17
Rainfall (mm)	83.31	83.22
Population	357’710	243’779
Population density	63.87	43.52
Registered cars	74’876	53’453
Green area surface (m2)	2’744’338	1’633’415
Share of urban population	85.02%	84.81%
Share of elderly population	9.19%	8.76%
Share of infant population	6.93%	7.19%
Share of workers in agriculture	7.02%	15.62%
Share of workers in manufacturing	9.11%	9.46%
Share of workers in construction	10.3%	9.27%
Mean household income ($)	864’437	797’635
Share of households using firewood	77.46%	69.66%
Wind speed (m/s)	*1.62*	*2.18*

Table A9. City weights in the synthetic Temuco (ER visits: different specification).

City	Weight
Rancagua	0
Rengo	0
San Fernando	0
Curicó	0.528
Talca	0
Linares	0.046
Los Ángeles	0
Concepción	0.072
Puerto Montt	0.32
Coyhaique	0.033

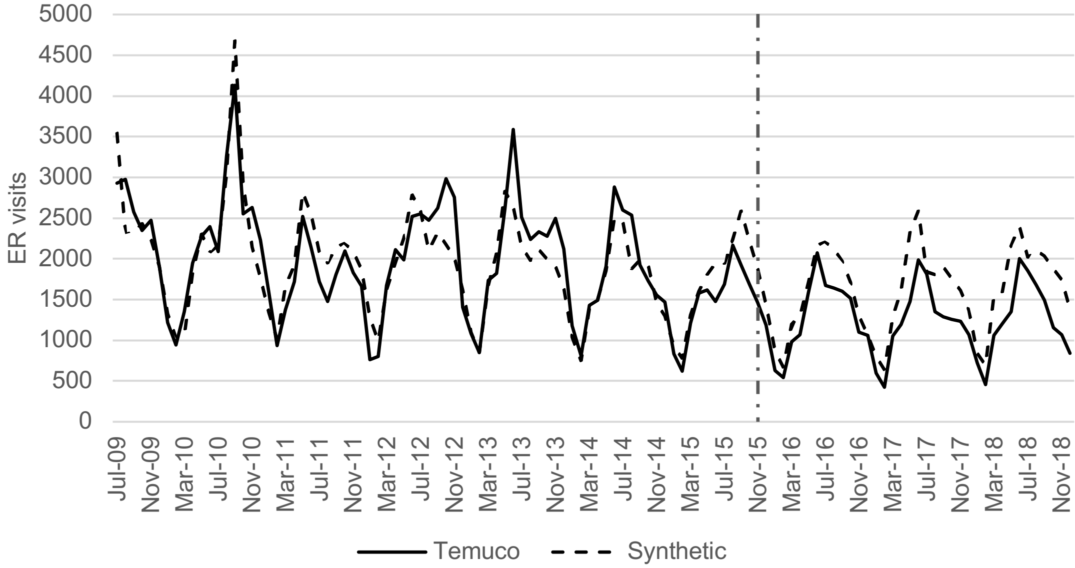

Figure A6. Trends in ER visits: Temuco vs. synthetic Temuco (different specification)

Table A10. Emergency room visits predictor means (northern cities included).

Variables	Actual Temuco	Synthetic Temuco
ER visits (respiratory causes, hospitals)	1970.4	1969.7
Temperature (ºC)	11.27	11.66
Rainfall (mm)	83.31	68.78
Population	357’710	209’763
Population density	63.87	46.28
Registered cars	74’876	49’513
Green area surface (m2)	2’744’338	1’409’004
Share of urban population	85.02%	84.95%
Share of elderly population	9.19%	9.18%
Share of infant population	6.93%	7.12%
Share of workers in agriculture	7.02%	12.81%
Share of workers in manufacturing	9.11%	9.22%
Share of workers in construction	10.3%	10.29%
Mean household income ($)	864’437	863’338
Share of households using firewood	77.46%	56.03

Table A11. City weights in the synthetic Temuco (ER visits: northern cities included).

City	Weight
Arica	*0*
Iquique	*0*
Antofagasta	*0*
Copiapó	*0*
La Serena	*0.03*
Valparaíso	*0*
Rancagua	0
Rengo	0
San Fernando	0
Curicó	0.362
Talca	0
Linares	0.008
Los Ángeles	0.197
Concepción	0.039
Puerto Montt	0.135
Coyhaique	0.034
Punta Arenas	0.194

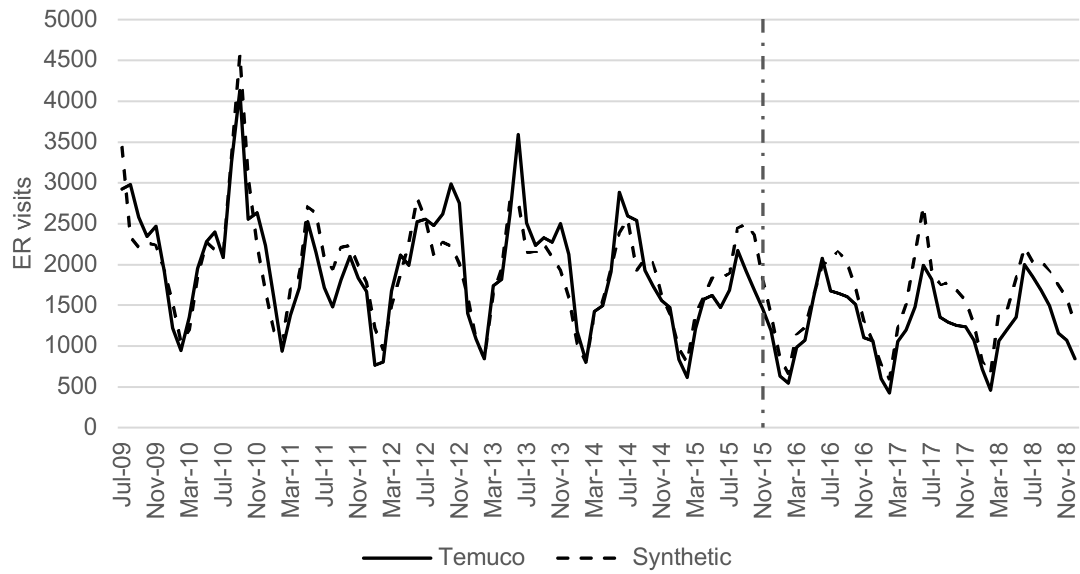

Figure A7. Trends in ER visits: Temuco vs. synthetic Temuco (northern cities included)

Table A12. Emergency room visits predictor means (daily analysis).

Variables	Actual Temuco	Synthetic Temuco
ER visits (respiratory causes, hospitals)	68.8	68.04
Temperature (ºC)	9.24	8.84
Rainfall (mm)	187.4	200.47
Population	367’614	195’485
Population density	65.14	51.32
Registered cars	84’834	50’730
Green area surface (m2)	2’744’338	1’257’199
Share of urban population	84.41%	81.56%
Share of elderly population	9.63%	10%
Share of infant population	6.8%	6.89%
Share of workers in agriculture	5.78%	13.32%
Share of workers in manufacturing	8.78%	9.4%
Share of workers in construction	10.65%	8.56%
Mean household income ($)	904’191	905’140
Share of households using firewood	77.46%	73.12%

Table A13. City weights in the synthetic Temuco (ER visits: daily analysis).

City	Weight
Rancagua	0.014
Rengo	0
San Fernando	0.076
Curicó	0.182
Talca	0
Linares	0.111
Los Ángeles	0.247
Concepción	0.023
Valdivia	0.236
Puerto Montt	0.112
Punta Arenas	0

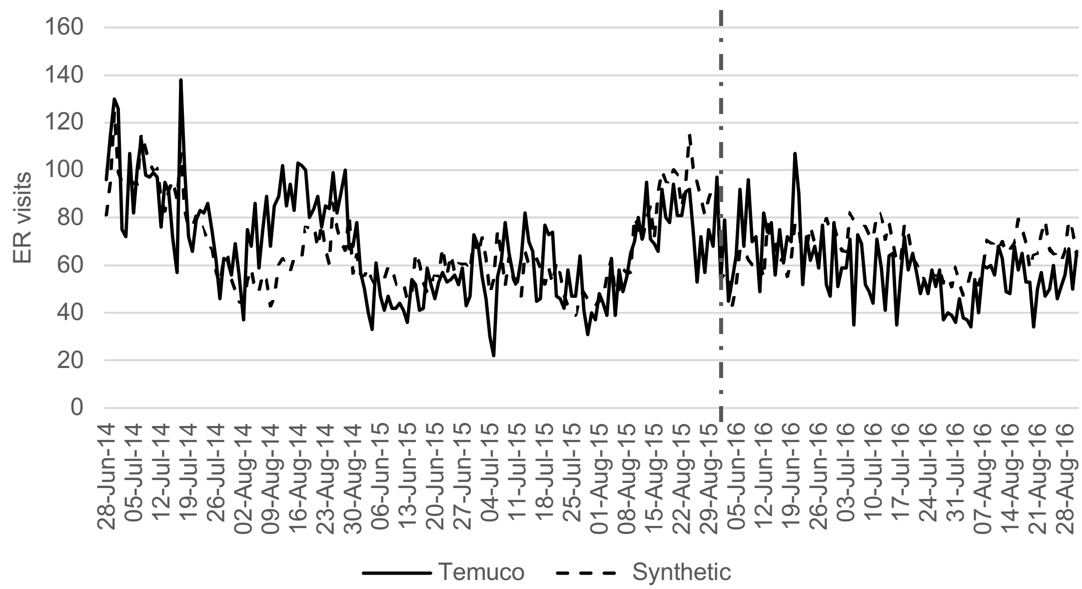

Figure A8. Trends in ER visits: Temuco vs. synthetic Temuco (daily analysis).

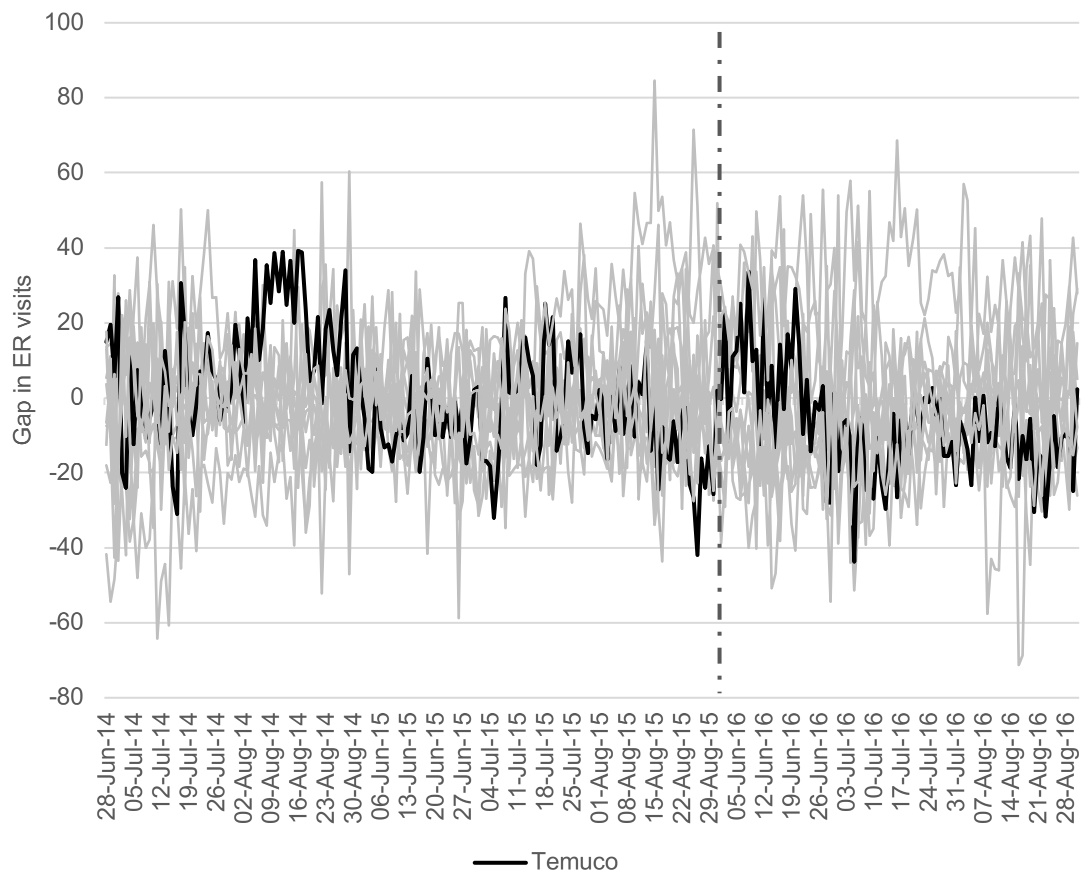

Figure A9. ER visits gap between Temuco and synthetic Temuco (daily analysis).

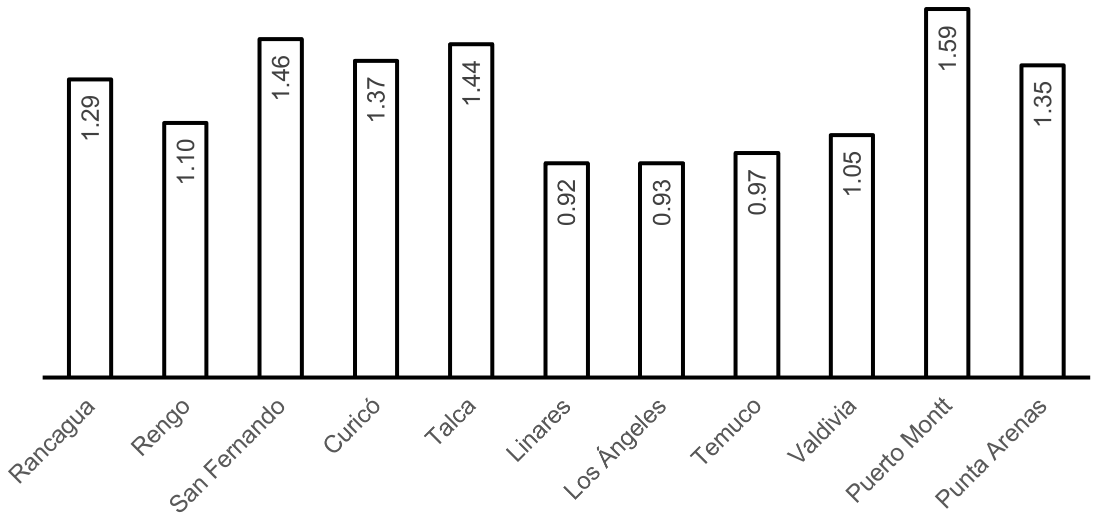

Figure A10. Post/pre intervention RMSPE ratios (ER visits: daily analysis).