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Shaky Growth: Chile's earthquake and its effect on GDP

Did the 2010 earthquake change Chile's growth path? Evidence of a synthetic control study

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Abstract: This quasi-experimental study analyses the effects of the 2010 Chile earthquake and finds an effect GDP per capita in the years following the event, by using the synthetic control method. After the shock, the country experienced an increase of 7% on GDP per capita on average, an effect which is significant yet only transitory as Chile and its counterfactual catch up again 5 years after the event. These findings are consistent with some economic models yet differ from previous literature on the short run given that the previous macroeconomic and institutional conditions of the country were relatively strong. Furthermore, this opens a new line of study to understand natural disasters and their consequences as I argue that the number of fatalities and magnitude of economic damage are not the only variables affecting the performance of an economy after a disaster occurs.

Keywords: synthetic control method, quasi-experimental study, earthquake, Chile, natural disasters

JEL: C21, H60, O11, O23, O47, R11

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A mi papá y a mi mamá.

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1 Introduction

Natural disasters are defined as a situation or event, which overwhelms local capacity, necessitating a request to national or international level for external assistance. They are unforeseen and often sudden events, causing great damage, destruction and human suffering. Though often caused by nature, disasters can have human origins.[1]

Examples of these are floods, hurricanes, earthquakes, volcanoes, tsunamis and so on. These events are characterized by their unpredictability, violence and constant occurrence through time, as well as creating havoc and loss of lives. In the past decades, natural disasters have enjoyed higher media exposure, thereby increasing public awareness on their consequences and raising questions on how to mitigate their impact. Historically, several efforts have been done to diminish their damage in terms of life and economic harm. From the creation of emergency communication and alert systems seeking to prevent fatalities by quickly informing local populations in due time, to advanced prediction systems. A late example on the efforts to predict earthquakes for instance was performed by Venegas-Aravena et al. (2020) in which the authors found a strong relationship between lithosphere stress changes with magnetic anomalies. Although a theoretical approach, it shows a significant effort on the field of disaster studying in order to improve in-time responses to them.

Moreover, natural disasters are diverse in their dimension, effect, number of the people affected, location, and so on. They can be local, like small shield volcanoes which harm mainly livestock, to massive floods affecting up to 85% of the population of the country, as it has been the case in Malaysia, with a population of 31 million inhabitants. The economic cost can differ as well; for instance, hurricanes cost 0,3 percent of the GDP every year in the United States in damages alone, without taking into consideration the expenditure and regulation required to make these numbers small. On the other hand, the Haiti earthquake of 2010 cost the country around 75% of that year's GDP. Furthermore, natural disasters provide a unique opportunity to study effects on a country's trajectory, as they are by definition an exogenous shock and can be used as a natural experiment. In 2010, Chile experienced one of the largest earthquakes registered in history; this paper studies whether it affected the country's growth in the then upcoming decade (2010-2019) by using the synthetic control method.

[1] Definition considered in EM-DAT.

The remainder of the paper is organized as follows. Section 2 provides a review on previous literature as well as a theoretical approach on natural disasters and growth. Section 3 presents the empirical methodology used to estimate the effects of the earthquake on GDP and data used. Section 4 presents the results as well as several robustness checks and possible transmission channels. Section 5 discusses the results and their relevance for public policy. Finally, section 6 concludes.

2 Theory

2.1 Research Question

What is the effect of natural disasters on economic growth?

It is relevant to understand such question because it allows to understand the short and long-term consequences of these shocks, and therefore determine whether aid is required and which type of policies are more effective in mitigating the negative effects disasters have on regions, nations and countries.

Proper knowledge on this matter can help policymakers improve the targeting of their strategies. Should a country be given loans for infrastructure? Or perhaps focus on building social infrastructure[1] as to diminish the fatalities natural disasters convey? Maybe a country prone to natural disasters should focus on having solid macroeconomics via long-term policies aiming to strengthen the fiscal position, or a combination of all the former?

The classic problem of economics is having infinite needs and limited resources that prevent us from tackling every economic problem existing. Understanding which (and if) disasters are relevant is a step forward this question and will permit a more effective resource allocation and design better public policies which will have the greatest impact on individuals.

2.2 Background

The 2010 Chile earthquake and tsunami (also known as *Terremoto del 27F*) occurred the 27^{th} of February at 3:34 am, lasted around 3 minutes and had a magnitude of 8,8 Mw on the Richter scale[2] according to the United States Geological Survey, and 8,3 Mw according to the Seismological Service of Chile. It is the 2nd largest earthquake in the country's history and the worldwide it is the 17th largest registered to date, according to the USGS. Its epicenter was located 3 kilometers west of Pelluhue, and it was felt on other countries such as Perú, Argentina, and southern Brazil.

[1] Examples of such are natural disaster education programmes in schools (Kahn, 2005), as well as promotion of efficient institutions.

[2] The Richter scale is logarithmic; hence, the difference between a 9 magnitude earthquake and and 8, is 32 fold. As a reference, the Valdivia (Chile) earthquake of 1960 measured 9,5 on the scale, the largest recorded to date. It was x5,011 times larger than the 2010 earthquake.

Following the tremor, a tsunami hit the shores of Chile, along with other countries and islands in the Pacific such as Japan, Russia, Hawaii, New Zealand, French Polynesia, among others. Tsunami warnings were issued in 53 countries. In Chile, the tsunami came in successive waves starting 30 minutes after the initial shock, which reached a height of 3 meters approximately. The tsunami destroyed towns such as San Juan Bautista located in the Juan Fernández archipelago, Dichato in the Bío Bío Region – where 90% of the town disappeared –, and caused severe damage in other cities such as Talcahuano and Temuco.

The most severely affected regions were those of O'Higgins, Maule and Bío Bío. Valparaíso, the Metropolitan area of Santiago, and Araucanía. 80% of the Chilean population live in this area.

The total death toll accounts for 547 dead;[3] 125 as a result of the tsunami, and 422 due to the earthquake. Furthermore, the economic damage was estimated to be 30 billion dollars.[4]

Chile has a long history of earthquakes. The country is located above the subduction of the Nazca plate beneath the South American tectonic plates,[5] and is therefore one of the most seismic countries in the world (Leyton et al., 2009). The plates coexist in constant tension, and it is the rupture of such tension – on what is called *fault zone* – that cause earthquakes. The Nazca plate moves slowly underneath the South American Plate at a range of 79 millimeters a year; however, the 2010 earthquake displaced the Nazca plate was an estimated of 10 meters, releasing a total amount of energy released equivalent to 800.000 Hiroshima bombs. In terms of economic damage, the catastrophe produced destruction of homes, roads, ports and infrastructure of 30 billion dollars or 18% of the national GDP of that year (Contreras and Winckler, 2013). Asides the loss of life and infrastructure, the immediate effects were a state of general disinformation and loss of basic services, such as water and electric power.

Given that the country is geographically located on the Pacific Ring of Fire[6] and its implications, there is a wide regulation and constructions codes on anti seismic construction. Moroni et al. (2004) argue that the most common regulations are shear walls[7]and high wall density ratios,[8] in order to preserve structures under the event of disasters. Confined masonry is common as well. Regulations have been continuously updated over the years, specially after the earthquakes of Chillán (1930), Valdivia (1960), Algarrobo (1985) and Constitución (2010) as the norms have been but to test. This has incidence on the destructive effects of each disaster, as well as the total number of fatalities.

[3]There is still uncertainty on this issue, as data from different institutions differ. Here I am using the report done by the Medical Legal Service (SML) from 2013, 3 years after the event. For more details, read Nahuelpan López and Insunza (2013).

[4]EM-DAT database.

[5]See Appendix A.

[6]See Appendix B.

[7]Walls designed to withstand lateral forces, such as strong winds and seismic forces.

[8]Mass per unit of volume requirements.

Economic consequences of disasters are closely related to the country's previous conditions as well the status of the economy in which the disasters take place, as Barone and Mocetti (2014) argue. These previous conditions include effective institutions, social capital, history, etc. Institutions for instance play relevant role in the aftermath of an earthquake, as countries tend to receive quantities of aid from other nations in order to attenuate short-term effects of the disaster by supplying food, health kits, tents and so on, along with credits to fund critical programmes. If because of corruption, aid is diverted or goes to rent-seeking activities, its effects will be negligible and public transfers will not have an impact on the economy on the short-run.

A better institutional quality can also have effects on the number of fatalities of a natural disaster.[9] Response time can vary greatly and social capital and literacy rates of the population also play a role (Kahn, 2005), as they improve the response of citizens to these events.

However, the long-term were less known until Cavallo et al. (2013) made a significant contribution to this literature by building controls to a set of affected countries, sorting disasters by magnitude – in terms of deaths – and studying their short and long-run effects.

2.3 Why understanding growth matters?

Economic growth has direct repercussions in living standards of a country. In Chile, higher income has been achieved with a combination of Central Bank autonomy, prudent fiscal policy and a well-established rule of law, along with reasonable tax reforms which did not slow economic growth (Schmidt-Hebbel, 2006). Higher income has been identified as a major explaining factor with the persistent reduction of poverty and malnutrition over the past decades, as well as an increase in public expenditure in order to improve education and the health care system, along with large investments in infrastructure and connectivity (Neilson et al., 2008).

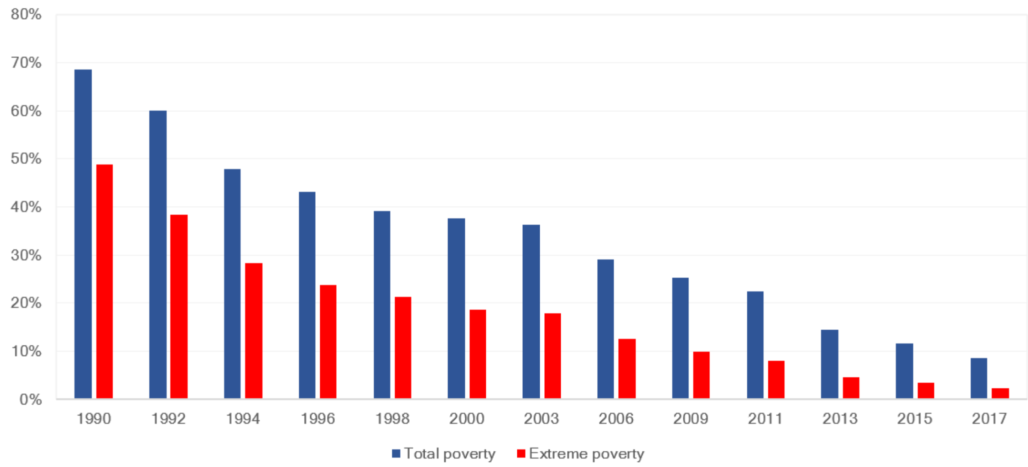
Moreover, Chile has seen a substantial reduction in poverty and extreme poverty in the past 30 years, two-thirds (67%) of which has been estimated to be consequence of rapid economic growth, while the remaining third (33%) occurred due to different government transfer programmes and policies. These have been highly focused on the poorer segments of society, allowing to a substantial improvement in life conditions of those in need (Henoch and Larraín, 2015).

Growth allowed poverty to be reduced more rapidly in Chile than any other country in the region (Ros, 2009), lowering poverty and extreme poverty from 68,5% in 1990 to 8,6% before the COVID-19 pandemic.[10] Other indicators such as life expectancy have improved dramatically as well for the same reason: in

[9] In Chile, it was established that the Hydrographic and Oceanographic Service of the Chilean Navy (SHOA) had direct responsibility due to its negligence in at least 20 fatalities.

[10] A person is considered poor if his/her per capita income is lower than the value of a market basket which satisfies the essential needs of an individual. Extreme poverty is defined as those whose income is lower than two-thirds of that line.

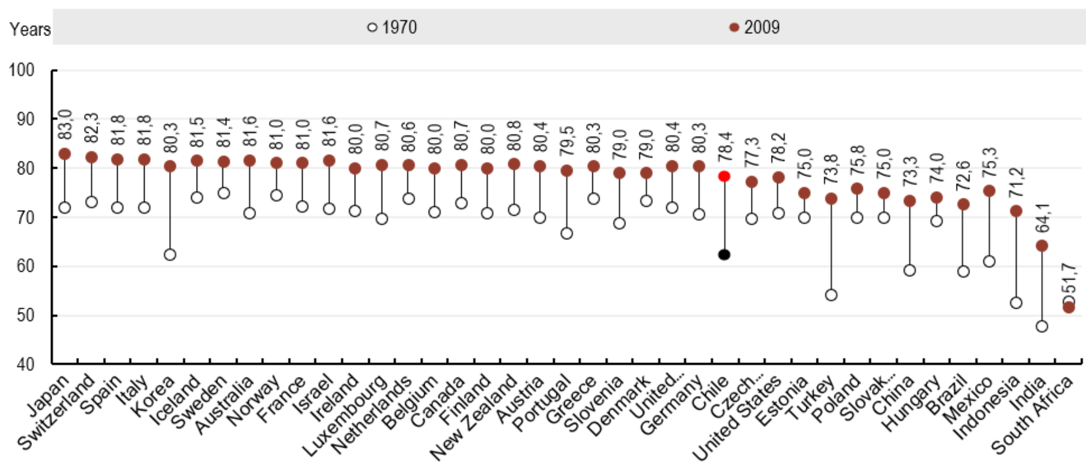
Figure 2.1: Evolution of poverty in Chile



Source: Own elaboration based on Casen survey data

2019, Chile had a life expectancy of 80,6 years compared to 62,3 years in 1970; similar to that of Germany and slightly above the United States, both of which have more than twice the per capita income than Chile.

Figure 2.2: Life expectancy at birth, 1970 and 2009 (or nearest year)



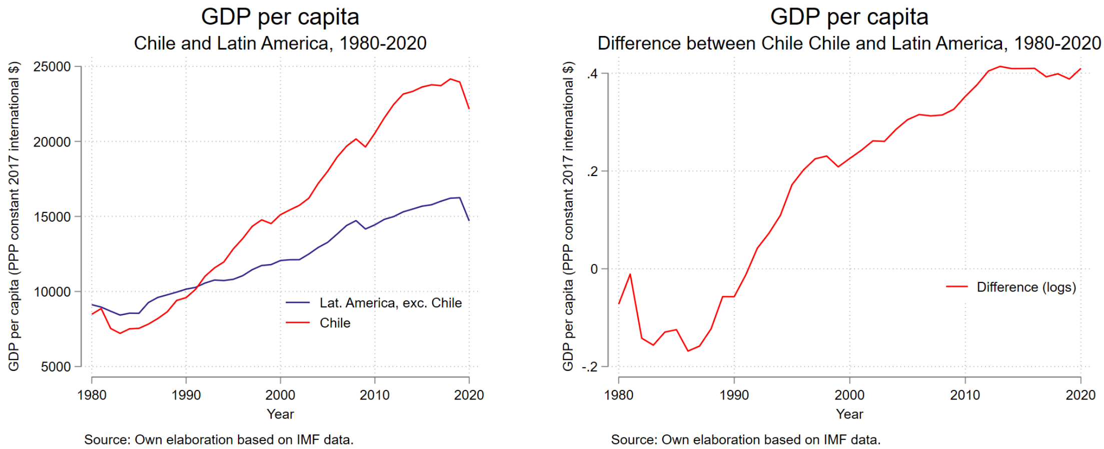
Source: OECD Health Statistics 2011

Table 2.4a shows growth during the 1980-2019 period in Chile versus Latin America (excluding Chile). The downturn in the beginning of the 80s decade is a consequence of the Latin American debt crisis: according to CIEPLAN, [11] output contracted by 14,4% while unemployment arose to over 30%. The crisis originated because Latin American countries had taken heavy loans in dollars, and when the United States hiked interest rates at the beginning of the decade the dollar largely appreciated against local currencies, making the value of the debt much larger and in the end, unbearable, as foreign debt exceeded their

[11] http://www.cieplan.org/wp-content/uploads/2019/12/Capitulo_03_PMeller_Siglo-economia-38-73.pdf

earning power. This, along with poor monetary policy from Chile, gave way to a deep crisis in the country. After several reforms which included autonomy of the Central Bank – to control inflation – along with a conservative fiscal policy and favourable conditions to encourage direct investment, the economy recovered until surpassing the rest of the region. In all, GDP per capita arose from USD 8.500 in 1980 until USD 22.000 in 2019.

Nonetheless, Chile's growth is somewhat atypical. The country is inserted in a region with generally high levels of poverty and unemployment, as well as low growth rates. Chile has has outperformed these countries and the region overall during the past 40 years and has been an outlier on progress and improvement of living standards. Figures 2.3a and 2.3b show the GDP per capita levels and growth rates of Chile and the region, as well as their log differences to understand the latter. This is a consequence of Chile having consistently larger growth rates comparing with the region, as shown on figures 2.4a and 2.4b.



(a) GDP per capita levels

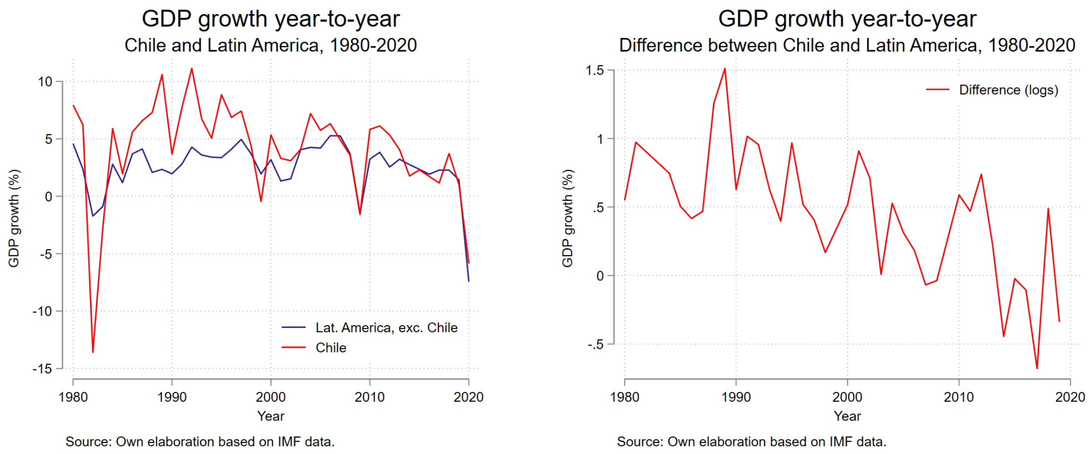
(b) GDP per capita differences, in logs

Figure 2.3: GDP: Chile and Latin America

2.4 Previous Research

Natural disasters have become more common in the past decades, as the number of natural disasters reported in the world in the past decade is five times larger that reported in the 1960s due to improved reporting and more extreme weather.[12] Their effects on economies have been largely studied; Rasmussen (2004) shows that natural disasters on average cause a median drop of 2,2 percent in same-year real GDP growth, as well as an increase in the current account deficit and public debt, using a cross-country sample from 1970 to 2002. Noy (2009) finds that smaller and less developed countries face larger output drops than larger or more developed countries, comparing for events of similar magnitude. His findings also reveal that better institutions and higher levels of government spending play a relevant role at limiting the contagious

[12] EM-DAT database.



(a) Growth rates

(b) Growth rate difference, in logs

Figure 2.4: Growth: Chile and Latin America

effect of disasters into domestic production. Moreover, financial conditions also matter; countries with more open capital accounts and larger foreign exchange reserves as well as with higher access to domestic credit seem to be more able to withstand natural disasters economically.

Other researchers have found mixed results. Skidmore and Toya (2002) investigate the long-run relationships among disasters, capital accumulation, total factor productivity, and economic growth, by using a cross-country data set. They find that while disaster risk lowers the projected rate of return on physical capital, it also raises the relative rate of return on human capital. As a result, physical capital investment may decline, but there is a shift toward human capital investment. They discover that climatic disasters are linked to stronger long-term economic growth, whereas geologic disasters are associated with slower economic growth.

Lastly, Cavallo et al. (2013) combine data from comparative case studies to look at the short and long run average causal influence of catastrophic natural catastrophes on economic growth. They evaluate the counterfactual of the events analyzed by establishing synthetic control groups that take use of the fact that natural disasters are random, finding that only extremely large disasters – defined as those that kill more than 233 people per million inhabitants – have a negative effect on output on the short and long run, and this is driven by the political instability that arises from the disaster rather than the disaster itself: only disasters followed by radical political revolution caused a significant drop on output.

In all and not surprisingly, evidence suggest mostly that natural disasters have negative effects on economies, although the magnitude of these is discussed.

2.5 Theoretical Approach

Different forms of disasters have dissimilar (even opposing) consequences for growth, according to theory. Disasters which disrupt the supply of essential intermediate inputs in production, such as droughts in agriculture, should have a negative impact on growth, whereas disasters that disrupt the capital-labor ratio, such as earthquakes, can, in theory, have a positive impact on growth by increasing returns and requiring large reconstruction investments.

Earthquakes may have a positive impact on growth, as the destruction of infrastructure will diminish capital-labor rations and thereby increase marginal returns of capital. Thereafter the economy will enter a reconstruction cycle. Schumpeter's theory of destructive creation[13] would predict that if the destroyed capital is replaced by more modern one, this would increase its productivity – hence growth – even further.

A flood, however, might be different. If a flood is generalized, it would most likely destroy harvest and fields, crop output, and disable infrastructure rather than destroying it. This would lower overall productivity and hence, output. Nonetheless if it were localized, the effect could assimilate that of a small earthquake; replacement of small machinery might boost local economies as the returns to capital are increased.

The Solow-Swan growth model predicts growth to be defined by technology on the long-run. Assuming steady state, an economy that suffers capital destruction as a consequence of an earthquake would experience accelerated growth afterwards, and resume normal growth path (Loayza et al., 2012). There is an alternative to this theory: a convergence curve with a non-unique steady state might experience transition after a disaster as a consequence of a *big push* in form of investments or expenditure, which could switch the long-term growth as the new steady state implies higher income.[14]

In addition, vintage capital models differentiate from the neoclassical ones by explaining technological change rather than assuming it. These models suggest that any rapid depreciation of capital due to an exogenous shock will result in better productivity growth because technology will be updated, hence any accelerated depreciation of capital will result in higher productivity growth. In the literature, this is referred to as the "build-back-better" theory (Klomp and Valckx, 2014). Lastly, in AK models, the level of accumulated capital in use is connected to output and output per worker, meaning that negative capital shocks have a long-term negative impact on production per worker.

Overall, the theoretical approach does not allow to draw a clear conclusion of the effects of a natural disaster on earthquakes. Research has shown consistent negative effects, but these do not agree with theory as a whole. It is likely that other factors have an influence on the outcome, for instance institutional or cultural factors, which might be hard to reconcile or include in a model.

[13]For more info on this topic, read "Creative destruction in economics: Nietzsche, Sombart, Schumpeter".

[14]Landerretche (2008) elaborates on this theory.

3 Empirical Methodology

3.1 The Synthetic Control Method

The synthetic control method (SCM) aims to estimate the causal effect of a treatment, shock or intervention affecting a unit in a panel data setting. Abadie and Gardeazabal (2003) introduced this method for the first time to evaluate the impact of violence on the output per capita of the Basque country, in Spain, decades after the conflict began on 1968. Other methods such as a pure time-series analysis would have the problem of results being contaminated by the mere economic downturn on the output without considering that this may have happened because of the violence per se; policies are hard to evaluate with time-series due to the presence of shocks to the outcome of interest. On the other hand, a comparative case study approach would pick a similar country or region and examine the difference between both outcomes; the problem with this approach is that *similar* is subjective and the degree of comparison between both units is based on a qualitative approach rather than a quantitative one. Lastly, a difference-in-difference perspective assumes there are no time-invariant unobservables affecting the units; this is called he *parallel trends* assumption. However the problem of such assumption is its impossibility to verify it, which brings uncertainty to the results.

Hence, Abadie elaborated the synthetic control method, which consists on constructing a counterfactual or synthetic control which resembles the unit being studied by weighting a combination of control units. This provides several advantages over the time series, comparative case studies and difference-in-difference approaches: firstly, it does not rely on abstract criteria to define a control unit, as it is data-driven. The algorithm uses the convex hull of a control group of units and creates the counterfactual based on them. The processing of the data is a second advantage. In contrast to regression, the generation of the counterfactual does not necessitate access to the post-treatment results during the design phase of the investigation. The benefit is that it allows the researcher to avoid "peeking" at the results while constructing the model. It's just as easy to look at the outcomes during the design phase as it is to not, but the idea is that using this strategy, it's theoretically possible to focus just on design, rather than estimation (Rubin, 2008). Lastly, the synthetic control method provides a visualization of the effects which make it more intuitive than other methods.

The SCM is applicable to a region, or even a country, and gives the possibility to study a broad range of outcomes affected by variables which conventionally have been difficult to calculate, for instance the effects of economic nationalism (Born et al., 2019), effects of civil wars or country reunifications[1] on GDP per capita (Li, 2012), (Abadie et al., 2015), results of the legalization of prostitution on sexual violence and public health (Cunningham and Shah, 2018), ramifications of hiring-law modifications on immigration (Bohn et al., 2014), consequences of mafias on income (Becker and Klößner, 2017), etc.

In formal terms and following Abadie (2021), assuming we are working with a balanced panel, that is, a longitudinal data set in which all units are observed at the same time periods, let us say we have data for $J+1$ units where $j = 1, 2, \ldots, J+1$ for time periods $t = 1, 2, \ldots, T$. Let $j = 1$ be the treated unit while units $j = 2, \ldots, J+1$ constitute the donor pool that will contribute to the synthetic control. An event or exogenous shock occurs at time $T_0 + 1$ so that $1, 2, \ldots, T_0$ are the pre-treatment periods and $T_0 + 1, T_0 + 2, \ldots, T$ are the post treatment periods. For every unit j, and time t, we observe an outcome Y_{jt}. Every unit j has a set of k observable predictors of the outcome, $X_{1j}, \ldots, X_{kj}$ which may include pre-intervention values for Y_{jt} and which are themselves unaffected by the intervention. Let X_1 be a vector of $(K \times 1)$ dimensions, containing the pre-intervention characteristics of the treated unit. We aim to match these characteristics as close as possible, and let X_0 be a matrix of $(K \times J)$ dimensions which collects the values of the same variables for the units at the donor pool.

To build the synthetic control, we define a $(J \times 1)$ vector of weights $W = (w_2, \ldots, w_{J+1})^{'}$. Given a set of weights $\mathbf{W}$ such that $W_j \geq 0$ for $j = 2, \ldots, J+1$ and $\sum_{j=2}^{J+1} W_j = 1$. The sum to one non-negativity condition has as objective that the weight of each control represents its true contribution to the synthetic control created, whereas the sum to one condition must hold in order to avoid extrapolation. Both conditions together will result in a synthetic control that are weighted averages of the outcomes of units in the donor pool, with typically dispersed weights. Each W represents one particular weight of control units and therefore one potential synthetic control unit.

To choose $(w_2, \ldots, w_{J+1})$, the criteria is to create a synthetic control that best resembles the pre-intervention data of the predictors of the outcome variable for the treated unit. Let $V = (v_1, \ldots, v_k)$ be a a set of non-negative constants reflecting the predictive power and weight of variable X on the outcome variable. Then the choice of $V = (v_1, \ldots, v_k)$ will produce a synthetic control $W(V) = (w_2(V), \ldots, w_{J+1}(V))^{'}$ which is determined by minimizing:

$$\|\mathbf{X_1} - \mathbf{X_0 W}\| = \left(\sum_{h=1}^{k} v_h (X_{h1} - w_2 X_{h2} - \ldots - w_j X_{hJ+1})^2 \right)^{1/2} \tag{3.1}$$

subject to the restrictions of the weights adding up to one and non-negativity. The norm used in 3.1 is the euclidean norm.[2] Defining two potential outcomes,

[1] German reunification of 1990.

[2] Abadie (2021) argues that other norms can also be used as well.

Y_{it}^N for the outcome that would be observed for unit i at time t if unit i was not exposed to an intervention, while outcome Y_{it}^I refers to the outcome that would be observed for unit i at time t if unit i was in fact affected by the intervention. The effect of interest is:

$$a_{it} = Y_{it}^I - Y_{it}^N, \forall t > t_0 \tag{3.2}$$

which is the policy (or treatment) effect. If the conditions mentioned above hold, then the effect of the treatment for the treated unit at time $t = T_0 + 1, \dots, T$ can be redefined as:

$$\hat{\tau}_{1t} = Y_{1t} - \sum_{j=2}^{J+1} w_j * Y_{jt} \tag{3.3}$$

which will yield an estimator for a_{1t} in periods $T_0 + 1, T_0 + 2, \dots, T$. The non-negative constants $V = v_1, \dots, v_k$ in 3.1 reproduce the values of each one of the k predictors for the treated unit $X_{11}, \dots, X_{k1}$. Obtaining the set of weights $V = v_1, \dots, v_k$ can be done by selecting v_h inversely to the variance of $X_{h1}, \dots, X_{hJ+1}$ Abadie and Gardeazabal (2003) suggest doing so by selecting a $V = v_1, \dots, v_k$ such that the synthetic control *W(V)* minimizes the mean square prediction error (MSPE)[3] with respect to Y_{1t}^N:

$$\sum_{t=1}^{T_0} (Y_{1t} - \sum_{j=2}^{J+1} w_j^*(V) Y_{jt})^2 \tag{3.4}$$

What the synthetic control tries to do is to replicate the behaviour of the unit *before* the event to be evaluated takes place, so that it resembles what would have happened *after* the event. It is important that the replication of the periods $t = 1, 2, \dots, T_0$ is as precise as possible, given that the periods $t = T_0 + 1, \dots, T$ cannot be observed for Y_{1t}^N and we rely solely on the control. The weights selected to minimize the MSPE will be used to predict the behaviour of the unit *had the event not occurred*.

3.1.1 Sources of Potential Bias

Considering Y_{1t}^N is generated by a linear model,[4] review the following linear model for Y_{jt}^N:

$$Y_{jt}^N = \delta_t + \theta_t Z_j + \lambda_t \mu_j + \epsilon_{jt} \tag{3.5}$$

where δ_t is a time-fixed effect, Z_j is a $(r \times 1)$ vector of time-invariant measured effects (not affected by the intervention) with time-varying effects θ_t

[3] Although a simple way of obtaining the set of weights $V = v_1, \dots, v_k$ would be by selecting v_h inversely to the variance of $X_{h1}, \dots, X_{hJ+1}$.

[4] Abadie et al. (2010) discusses properties of a Y_{1t}^N generated by a vector autoregressive model.

$(1 \times r)$. Additionally, μ_j is a vector of unobserved time-invariant predictors, with time-varying effects λ_t of $(r \times 1)$ dimensions. The term ϵ_{jt} is an error term corresponding to unobserved transitory shocks with zero mean.

Noise Induced Bias

Let X_1 be a vector including the Z_1, that is, the pre-intervention measured effects for the treated unit. Let X_0 be a $(k \times J)$ matrix of the k variables of the J controls. If the replication is done well, then $X_1 = X_0 W^*$, as we are trying to minimize $\|\mathbf{X_1} - \mathbf{X_0 W}\|$. Hence, W^* is chosen to minimize the norm distance by reproducing the characteristics of the treated unit. A synthetic control that correctly replicates the values Z_1 and μ_1 will be unbiased. However, μ_1 cannot be observed so it is not possible to know whether the control replicates the data correctly or not. This raises the risk of *over-fitting bias*, in which significant transitory shocks compensate for the otherwise incompatible relationship between the synthetic control and the treated unit. Therefore the matching of the pre-intervention data will be partially based on the noise, and will lead to a systematic deviation between $\mu_i = treated$ and $\sum_{i=1}^{T_0} wi^* * \mu_i$. This problem may also be enhanced when the number of control units available is small and the number of X variables used to predict outcomes is relatively large.[5] However, the over-fitting bias is unlikely to occur if the transitory shocks ϵ_{it} are small, the number of pre-treatment periods T_0 is rather large or if the donor group is sizable. Aggregation of data attenuates the magnitude of the noise.[6]

Interpolation Bias

Interpolation bias may arise when the units at the donor pool have characteristics too dissimilar to those of the unit being replicated. A solution can be found and the condition $X_1 = X_0 W^*$ will be met, however with unit values far-off the control ones. To prevent this issue, the donor pool should be restricted to similar controls, or a penalty term can be added on the objective function $\|\mathbf{X_1} - \mathbf{X_0 W}\|$.[7] Additionally, if the attributes of the units are non-linear, this could result in large interpolation biases as well.

Extrapolation Bias

The idea of extrapolation bias is based on the concept of convex hull. The objective of restricting weights to belong within the [0,1] range and to sum up to one, prevent this bias from occurring. If these conditions are not satisfied and the unit being recreated has variable values beyond the range of those of the control, then the weights of some of the controls need to be larger than one, which implies assuming that the characteristics of the control would hold if scaled up.

[5] This problem may also be enhanced when the number of control units available is small and the number of X variables used to predict outcomes is relatively large.

[6] Cummins et al. (2019) elaborates on this issue and provides Monte Carlo simulations to test it.

[7] Abadie and L'Hour (2021) propose such method.

3.1.2 Inference

Abadie and Gardeazabal (2003) propose a series of inference techniques such as and in-time placebo, leave-one-out and full sample test. An in-time placebo test changes the treatment period from T_0 to $T_0 - k$ where k is a positive integer. This allows studying whether the effect of the treatment – if any – exists in a different period of time. If so, this means that the alleged effect is consequence of bad predictors rather than causal effect.

Moreover, leave-one-out (LOO) is useful to examine the sensitivity of the results to the units selected as donors. This method iteratively restricts the selected units of the synthetic control from the donor pool, and runs the algorithm again. A full sample test consists on using larger samples to verify if the results of the conclusion change depending on the donor pool used. All the methods described above are useful as a whole to check the robustness of the results obtained.

3.2 Data

To empirically study the effect of the 2010 Chilean earthquake on per capita income, I constructed a panel with GDP per capita information between 1990 and 2019 with 53 different countries including Chile. The outcome variable is GDP, and it was obtained from International Monetary Fund (IMF), as was investment and government expenditure as share of the GDP. Population and land square area in square kilometers was obtained from World Bank's World Development Indicators (WDI). Trade openness, which is the orientation of a country in the context of international trade, was obtained from the same source; it is defined as the sum of the absolute values of exports and imports, divided by the total output of each country, per year. Data regarding latitude[8] was obtained from the The World Factbook, and it is used on absolute value, to account the effect of size and equatorial distances on growth. Additionally, the value of Capital Stock was obtained from Penn World Tables (PWT) version 10.0. The advantage of this version compared to the previous ones, is that it already applies the perpetual inventory method and it is not necessary to calculate it manually anymore. This method is used to calculate the value of the capital stock of a country by accumulating investments into capital stock using asset-specific geometric depreciation rates. I include the variable to account for productive differences between countries. For more details on this, check Feenstra et al. (2015).

Should be noted, the Penn World Tables include GDP data directly, but the reason why I chose not to use it is because World Bank data is more accurate according to Pinkovskiy and Sala-i Martin (2016) and provides better information of the total output of countries.

To account for land area and population differences between countries, I created and included a *density* as predictor, which is the total population of a

[8] Gallup et al. (1999) elaborates on the effect of latitude on economic growth.

country divided by its land area in square kilometers, resulting in population per square kilometer.

Lastly, I included a lagged variable for GDP per capita on 2007, in 2017 (PPP) international dollars. Following Abadie (2021), in the linear factor model of equation 3.5 pre-intervention values of the outcome variable, which are readily available in panel data settings, play a critical role in recreating the unobserved component loadings in j.

Additionally, for robustness checks I included Polity IV data which was used to assess the institutional grade of each country, and it was obtained directly from the Polity project database. The Polity project consists on a database from all independent countries ranging from 1800 until 2019, and constantly monitors regime changes among them. Its objective is to assess and quantify the quality of the authority regime existing, by assigning an score covering 21 integer numbers, from -10 to 10, where the minimum score is assigned to hereditary monarchies, while a maximum score is assigned to consolidated democracies. Values -10 to -6 are given to autocracies, -5 to 5 to anocracies - regimes which are part dictatorship, part democracy, that is, they have mixed features of both Fearon and Laitin (2003). Values ranging from 6 to 10 are assigned to democracies. Special values of -66, -77 and -88 are assigned to particular cases of anocracies; foreign interruption, cases of interregnum or anarchy, and cases of transition, respectively. In the database, these data-points were treated as missing values, replaced with zero, and prorated across the period of transition, respectively. [9] Including the variable is relevant as the donor pool is fairly large and it allows testing for institutional differences existing within it.

3.2.1 Some donor pool and pre-treatment period considerations

As stated before (section 2.3, and figures 2.3 and 2.4), economically speaking, Chile is an outlier on the region – along with Panamá for the matter. This poses a challenge from the synthetic control method perspective: cultural and political similitude exist with neighbouring countries, such as religion, language, economy, dependency on raw material exports – hence on terms of trade and their inherent volatility – and so further. Nevertheless, these countries do not perform in a similar fashion. Moreover, the problem is the difficulty in finding a proper donor pool to build the synthetic control. If countries are taken from the region alone, Chile will be outside the convex hull and it will not be possible to construct an appropriate synthetic Chile. Another grouping criteria could be or instance building a synthetic control subject to membership to the OECD (Organisation for Economic Co-operation and Development), institution of which Chile is a member of since 2011. However Chile was the first South American country to be included in it, and out of its 37 members as of 2022, Chile has the 4^{th} lowest GDP per capita in international dollars, followed by Colombia, Costa Rica and Mexico.[10]

[9] For more details read https://www.systemicpeace.org/inscr/p4manualv2016.pdf, page 21.

[10] Chile surpassed Mexico's GDP per capita in 2004.

In simple, the OECD admits as a member countries which have " *(i) democratic societies committed to rule of law and protection of human rights; and (ii) open, transparent and free-market economies*" and would constitute a good criteria to define countries as *similar to certain extent*, but in this case it is inapplicable given the large differences between members of the institution, and between countries of the region, regardless of it being South and Latin America.[11]

For these aforementioned reasons, I have given my synthetic control pool large liberty and have not selected the sample based on any regional nor organizational membership criteria. I have, however, discarded countries which have been involved or have been close to countries involved in direct military conflict, as well as countries which are not considered a proper country by a large portion of other states (Republic of Kosovo for instance) or which have disputed sovereignty. Additionally, countries with insufficient data have been automatically dropped out rather than completing or averaging missing data by the one available on the closest years.

Regarding the pre-treatment period, there should be enough periods to estimate the treatment effect (Abadie et al., 2010). A long period is preferable given that it will provide more data therefore a better choice of predictors and weights. However, the case for Chile is rather particular. Chile suffered the effects of the 1982 debt crisis more intensely than most countries of the region and went through severe reforms as a consequence. Its GDP per capita levels only recovered to pre-crisis levels in 1990, in a similar fashion to countries as Perú or Bolivia.[12] Hence the name for the 80s as "the lost decade of Latin America". This is relevant when it comes to the selection of the pre-treatment period: Chile is located in a region affected severely by a crisis that the rest of the world did not face, however with a history of growth that does not go in line with the region itself. Therefore I took 1990 as first pre-treatment starting point; including the entire 80s makes the root-mean-square-error considerably larger and biases the entire fit of the pre-treatment data. Nonetheless, the results of this study do not change.

Moreover, to avoid interpolation bias (see section 3.1.1) and to have a donor pool that will be relatively close to Chile in terms of income, I have left out of the database all countries with an average GDP per capita of less than 6.000 and above 45.000 dollars during the pre-treatment period. This left my database with a group of 53 different countries that could be used as a donor pool to create the synthetic Chile. As a reference, Chile has a mean of 11.020 dollars of income per capita during the pre-treatment period.

[11]See Appendix D for restricted samples of the Synthetic Control Method.

[12]Others such as Argentina, took 18 years to achieve similar per capita income levels as previous to the crisis.

4 Results

4.1 Synthetic Chile

In this subsection I present the data-driven synthetic control, and my estimates for the average causal impact of the 2010 Chilean earthquake on GDP per capita. It is important to keep in mind that the estimator does not disentangle between direct and indirect effects nor gives an explanation on the transmission channel of these on the outcome variable; it simply estimates the causal effect of a specific natural disaster on GDP per capita.

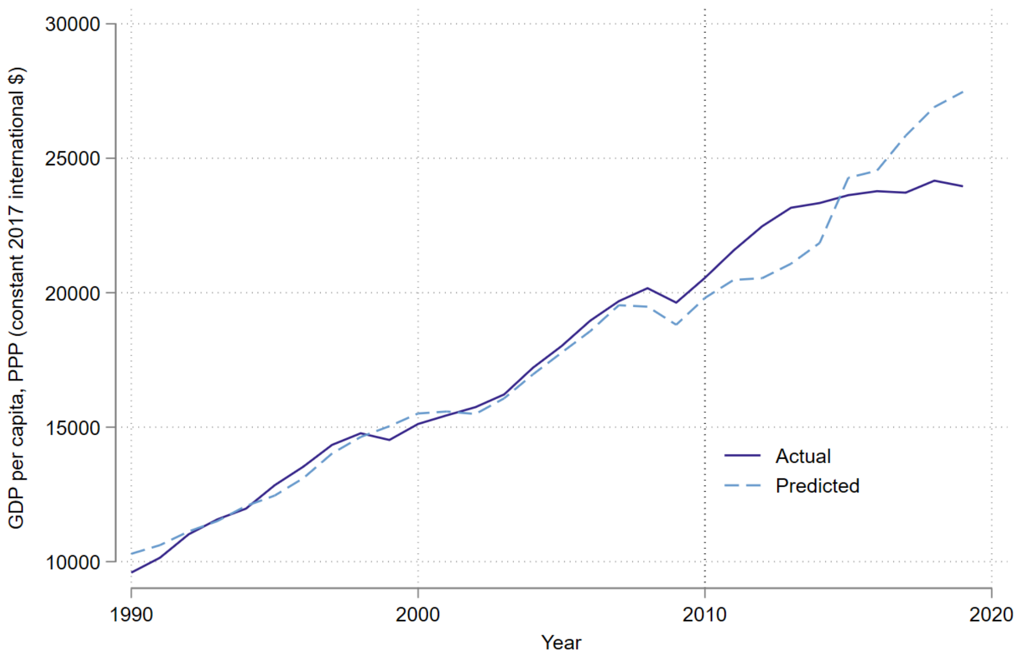


Figure 4.1: Plot of GDP per capita between 1990 and 2019: Chile versus Synthetic Chile

Results on figure 4.1 show a significant yet temporary effect of the treatment. The effect is the difference between the actual and predicted lines of the figure, corresponding to Chile and synthetic Chile respectively. The figure shows that since 2010 onward Chile outperforms its synthetic counterfactual, yet however significant this effect might be, it is only temporary. The figure shows a rapid expansion on per capita income as a result of the earthquake, followed by an attenuation and convergence on a longer term.

If synthetic Chile is able to track accurately the real one, results exhibit a 5-year lasting effect before it synthetic Chile and Chile converge again. During the period from 2011 until 2014 or *first divergence period*, Chile had an income higher by 7,26% ($1.648) than its synthetic control, while during the period ranging from 2015 to 2019 or *second divergence period* this difference the opposite; an average of-8,17% ($1.954). These results are interesting for two reasons. Firstly, they do not align on the short term with the findings of Cavallo et al. (2013). The authors of the study find a slightly negative effect on real GDP per capita on the short run, effect which is normalized after 4 years, on average, for disasters not considered *catastrophic*. After such period, the trend of the country follows the same path as its synthetic control. This applies for countries under the 99^{th} percentile of disasters ordered by number of deaths, or those which kill less than over 233 people per million. Chile's earthquake is outside that group by a wide margin, as 17 for every million inhabitants died, therefore it would be included in it.

However, the long run effects are less certain. By the end of 2014, a tax reform which aimed to collect around 3% of the GDP was approved by the Chilean congress. The reform took place in several stages, the last of which would take place in 2018. In spite of the existent discussion on how much was growth affected by it, there is economic consensus on tax policies having an effect on the economy, as taxes can be understood as negative fiscal policy, hence affecting output as a whole.[1] For this reason, I deem the first 4 years post earthquake as effect of the the treatment per se, but do not trust the period from 2015 onward as pure effect from the disaster. The reform itself was likely not a consequence of increased spending the years following the earthquake, but due to a political promise done for the election of 2014 which implied changing the funding scheme of education from a private to a public model. Naturally in economics, expectations play a major role and a policy can exercise an effect eve before they take place. Nonetheless, the convergence to synthetic Chile was likely to happen sooner or later as the trends started doing so before the reform took place, and the tax reform might only have accelerated this convergence process.

In summary, figure 4.1 indicates that the earthquake in Chile had a positive and significant effect on GDP per capita on the short run, yet this effect is transitory only, and not permanent. After 5 years, the outcomes of Chile and its synthetic control are similar, meaning that effect fades out over time. This correction of the trends begin as early as 2013, and it ends by 2015. The nature of the difference after that year are uncertain and possibly related to other shocks.

[1] Specially in this case, as the reform was so complicated that a "reform to the reform" was required in order to simplify it. Regardless, the country ended up having two different tax systems.

4.2 Chile versus Synthetic Chile

The composition of synthetic Chile is done by four countries with the following weights:

Table 4.1: Country weights

Unit	Unit weight
China	0,3630
Argentina	0,2330
Paraguay	0,1770
Ireland	0,1770
Guatemala	0,0610
United States	0,0220

Note: weights add up to 1, to avoid extrapolation. Additionally, weights cannot be negative.

While the results of the data-driven process yields the following averages for the predictor variables:

Table 4.2: Predictor means before the earthquake

Variable	Chile	Synthetic Chile	Sample Mean
GDP per capita (2007)	19.684,9	19.535,1	26.097,9
Trade openness	62,6,2	62,7	79,7
Gov. expenditure (% of GDP)	21.6	21,7	33,7
Total investment (% of GDP)	24,2	26,4	24,4
Capital stock (billions of USD)	0,6	8,4	3,4
Density	20,5	69,5 0	133,4
Latitude	35.6	35.5	29,1

Notes: GDP per capita is in 2017 dollars (PPP). Trade openness corresponds to exports plus imports as share of GDP. Capital stock is computed through inventory method. Density is defined as population per square kilometer. Latitude is in absolute value. The last column provides the average predictor data for the controls available in the data set

Table 4.1 shows the combination of synthetic Chile in decreasing order of the *W* weights assigned by the algorithm. Countries with a weight of zero are not reported, but can be seen in the Appendix C. The largest weight is given to China, with (0,3630). This can be explained by considering both countries have experienced similar growth in absolute and relative terms during the two decades of the pre-treatment period, as well as high dependency and focus on exports. Argentina is the second country with the largest weights, with which Chile economic and cultural characteristics. For instance, Chile has had a Polity IV[2] score of 9, while Argentina scored 6,65 for the average 1990-2019 period. Nevertheless, I did not add the variable as it only worsens the

[2]Polity IV assigns a a score from - 10 to 10, where -10 is equivalent to dictatorship, while 10 corresponds to a full-democracy.

estimations, probably as it is an incomplete measure of institutional quality.[3] Nonetheless, the countries share cultural and political similarities.

Paraguay has similar latitude to Chile, and both share the dependency on exports, and are considered developing countries by the World Bank. Additionally, investment rates are close as well, with 27% and 25% respectively. In the case of Ireland, it shares a similar growth rate as Chile does. The other two countries, Guatemala and United States, are harder to assess; asides from latitude, the rest of the variables are not particularly close. Therefore I think the countries take a balancing role only; this is not worrisome as their weight is only 8,3% of the total. In all, the algorithm assigned as donor countries a group with has similar characteristics to Chile as well as a reasonable total weight (47,1%) assigned to countries which are geographically close.

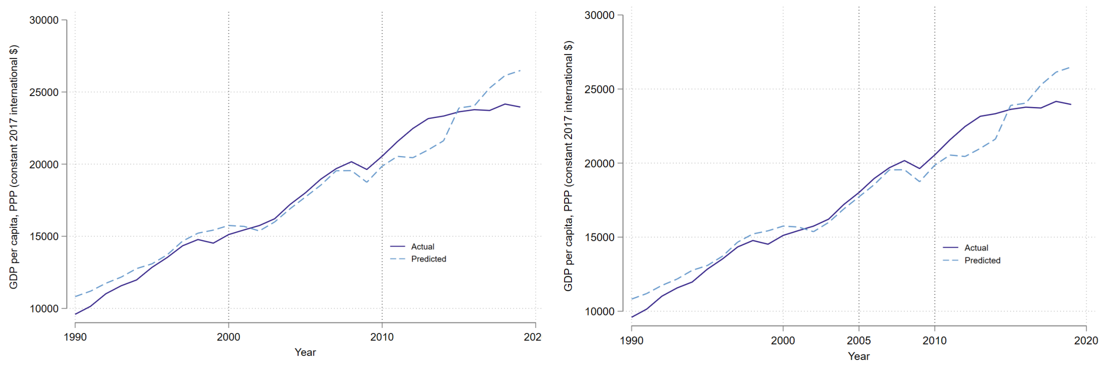
Table 4.2 compares Chile's pre-treatment features to those of a synthetic Chile and a population-weighted average of the donor pool's 53 countries. Overall, the results in table 4.2 indicate that the synthetic Chile is a far better comparison for Chile than the average of our sample. In terms of pre-2010 GDP per capita (2007), trade openness, trade openness, government expenditure, total investment, capital stock, density, and latitude, the synthetic Chile is extremely similar to the real Chile.

The *V matrix* yields the following weights: latitude has the largest share, with (0,3161), followed by GDP per capita (2007) with (0,2954), government expenditure (0,2800), trade openness (0.1058), density (0,0024), while total investment and capital stock weight <(0,001) so they are irrelevant. Predictor variables tend to be well replicated, with a exception on density and capital stock. Regarding the former, Chile is a rather large (756.950 square kilometers, roughly the same size as Turkey) but with a population of only 19 million. However, the weight given to that predictor is quite low, with only (0,0024) in the *V* matrix. Regarding capital stock, it is measured in value (billions of USD) and given the difference in the size of the economies of the donor pool, its weight is deemed irrelevant being approximately zero. I also tried standardizing it to capital stock per capita to make it more comparable, but his did not improve the pre-treatment estimations. Hence, the difference on both variables for Chile and Synthetic Chile should not be a concern given their weights.

4.3 Inference

In order to verify the results obtained, in this section I show a series of robustness checks: in-time placebo and leave-one-out. An in-time placebo changes the time of the treatment for a fictitious one. If there is an effect after such year even though no structural changes occurred at that time, then the real treatment would lose validity as the treatment shows an effect when there actually are none. For the in-time placebo tests, and following Abadie et al. (2010), I removed the lagged GDP per capita variable from 2007. I shifted the year of treatment from 2010 to 2000 as seen in 4.2a, that is, simulating that

[3]See Appendix E for the SCM with Polity IV included as a covariate.



(a) Placebo In-Time Test: 2000

(b) Placebo In-Time Test: 2005

Figure 4.2: Placebo In-Time Tests

the earthquake took place 10 years earlier than it actually did. Additionally, I performed a placebo test on 2000 (4.2b). If the variables are accurate predictors of GDP per capita, we should be able to see a similar predicted trend as compared to the real data. If the trends do not match, this would shed doubt on the actual effect of the earthquake on GDP per capita.

Nevertheless, figure 4.2 shows two different placebo tests taking place on 2000 and 2005, which show similar trends as figure 4.1. There is a slight increase on the MSPE between the years 2007 and 2008, although barely noticeable.

Additionally, I perform the leave-one-out (LOO) test, which consists on leaving each of the countries with positive weights outside the donor pool and then run the synthetic control method iteratively. This should clarify whether the results depend on a single control; the test is particularly useful considering the rather large participation of two controls (China and Argentina) on the creation of synthetic Chile, with W weights of 0,3630 and 0,2330.

Figure 4.3 shows the six new estimations (gray), one for the removal of each of the original six countries of the donor pool selected by the synthetic control method. For the original estimation, the average treatment effect – in parenthesis, I include the number without 2019 by the end of the year, COVID-19 started – is -$353 per year ($333) if one considers the whole post-treatment variation as a consequence of the earthquake. Considering only the pre-convergence period (2011 to 2014), the average effect is $2.150 per year and -$734 for the period ranging between 2015 to 2019 (-$377). When running robustness checks, the average treatment effects change – considering the same periods defined above – from a minimum of -$647 (-$236) to a maximum of $548 ($887) for the entire period, and a minimum of $1.452 and a maximum of $2.150 in what I defined as pre-convergence period.

Leave-one-out tests change the magnitude yet not the conclusions of this study. The average treatment effect lowers to -$353 considering the whole period from 2011-2019 ($42). The pre-convergence period changes remains being $1.648 per year on average, and -$1.954 (-$1.565) for the post convergence period (2015-2019). It should be taken into account that the donor pool I use is rather large, serving itself as a full-sample test as well.

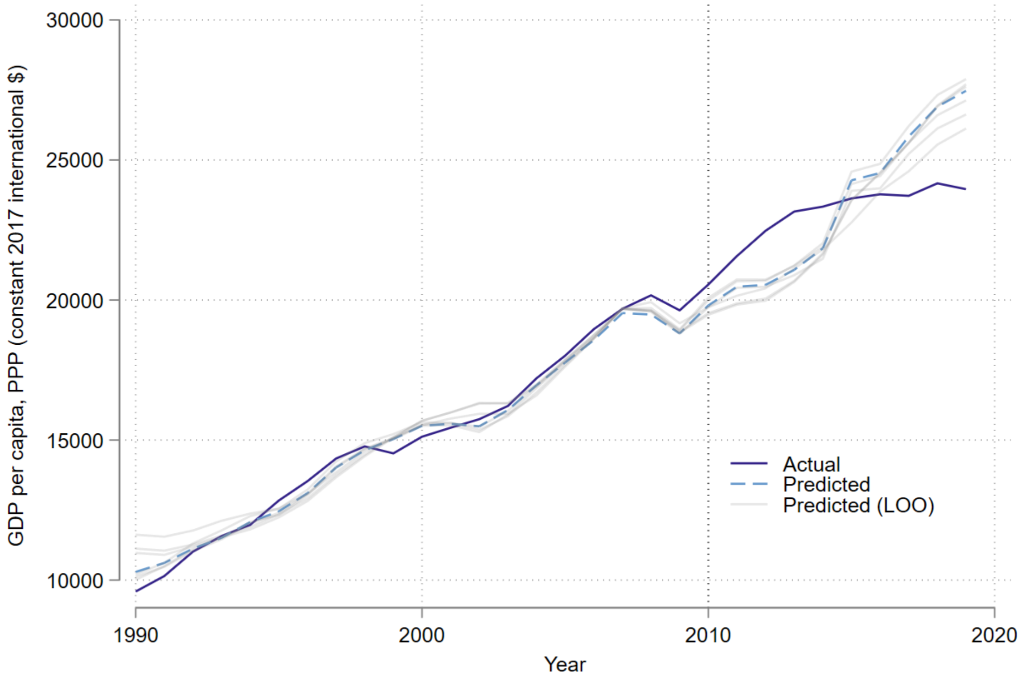


Figure 4.3: Leave-One-Out: Distribution of the Synthetic Control for Chile

4.4 Transmission channels

A question that remains to be answered is how did the earthquake result in higher income per capita for the years after the disaster compared to the scenario in which the earthquake did not happen. Strong fiscal policy is the most likely reason for this, combined with stimulative monetary policy. The Central Bank of Chile (BCCh) maintained the monetary policy rates at near minimums of 0,5% during large parts of 2010 even though the economy showed strong sings of recovery early on.[4]

Chile achieved a strong macroeconomic position by focusing on solving the dynamic inconsistency problem with two different policies. First, Chile's adopted a structural, budget-balance fiscal rule in 2001, which created targets for the government's budget balance, thereby seeking macroeconomic stability and preventing corruption. Secondly, early inflation targeting played a role for promoting a balanced monetary policy which gave the country an additional tool to use when required. Moreover, through the following years two sovereign wealth funds (SWF) were created, to which budget surpluses were transferred and from which resources are withdrawn to finance budget deficits.[5] These funds allowed pouring additional 9,3 billion dollars (almost a third of the damage caused by the disaster) into reconstruction of infrastructure, which implied an increase of 15,2% on public spending, along with an increase on private investment on 9,4% relative to the year 2009 (DIPRES, 2013). Besides,

[4] https://www.reuters.com/article/negocios%2Deconomia%2Dchile%2Dencuesta%2DidLTASIE63B0GI20100412

[5] Pension Reserve Fund (PRF) in 2006, Economic and Social Stabilization Fund (ESSF) in 2007.

and as a consequence of strong previous macroeconomic management, Chile had a high credit rating (A+), the best one in the region, which allowed the country to access the credit market via bond emissions fast: Chile issued bonds to acquire additional funding by 1,5 billion dollars.

In summary, Chile had strong and favourable macroeconomic indicators which allowed the country to execute countercyclical policies that reversed the otherwise negative effects of disasters in an economy. This was a combined effort of public and private sector, as well as effective institutions, which permitted a rapid response to the earthquake.

4.5 Concerns

Must be noted, there is a small divergence between Chile and Synthetic Chile on 2009, the year right before the treatment. This is due to the global financial crisis that began on September 2008 which had a worldwide – and uneven – impact on growth. I tested adding lagged GDP per capita variables so to fix this issue, however they absorbed almost all the weight (99%), deeming the other GDP predictors as irrelevant. I discarded this approach because then the synthetic control method changes rather gets closer to following a the same country's trend rather than GDP per capita prediction based on variables that empirically do influence growth. The conclusions of this study does not change, however its magnitudes should might be an upper bound of the real effect. I added in Appendix F another SCM in which I forced a matching right before the treatment, which yields an even higher treatment effect. The sign and magnitude of the effect help ease these concerns, and provides evidence that the effect seen on figure 4.1 is not a product of a mismatch right before the treatment.[6]

As mentioned before, I am not certain of the earthquake having a positive and then negative effect on the long run because there was another treatment in the middle of the post-treatment period. In the immediate 4 years after the earthquake there is a substantive positive effect on GDP per capita as a consequence of the disaster, which are followed by a downturn in which Synthetic Chile catches up and then surpasses Chile's GDP per capita. Nonetheless, this might be somewhat influenced by the tax reform. Hence, the total magnitude of the event is debatable.

I define this two periods because according to Cavallo et al. (2013), there is no large effects for disasters which are not considered *extreme* on the long run, and given that there is another shock – the tax reform mentioned before – that takes place. Therefore I do not believe the earthquake to have a long-run effect of 9 years in this particular case, but a 4-year lasting effect. This effect would have been likely to be transitory in spite of the tax reform given that the differences between Chile and Synthetic Chile became consistently smaller after 2013.

[6]However, I did not use this model given that it yields a considerably higher MSPE.

5 Discussion

My results are consistent with economic theory as well as with literature regarding natural disasters. Destroyed capital could have been replaced by new, more productive one, consistent with Shumpeter's theory of destructive creation in addition to the Solow-Swan model: technology is the driver of growth on the long run. Hence the higher growth on the short term is merely a return to the former path of the economy towards the steady state existing in this model. From an empirical point of view, my results are corresponding to those of Cavallo et al. (2013), as they find no effect of non-catastrophic natural disasters on the long run. Chile shares the same long-term outcome, with some nuances. Firstly, instead of the drop in GDP shown in their study and others (Rasmussen, 2004), Chile's GDP increased significantly over its synthetic counterfactual in the years following the disaster. This is likely a consequence of good macroeconomic policies as well as strong economic and institutional position. Nonetheless, there is a significant convergence towards the synthetic control which begins before the tax reform, hinting that the growth effect seen on this study is transitory only. Given the occurrence of another significant treatment staring on the year 2014/5 but being foreseen we well, it is harder to asses the speed of such convergence afterwards.

Nonetheless, I believe that Chile and synthetic Chile would have met on the longer run regardless, which is consistent with the study mentioned before. In spite of an existent on 2009 as a consequence of the subprime crisis, immediately before the earthquake took place in 2010, the effect of the treatment is large enough to conclude a positive and significant effect of the earthquake on output. The magnitude found in this study is likely an upper bound, but its sign is robust to different tests performed in this paper.

These results are relevant for two reasons. Firstly, in spite of natural disasters being largely unpredictable, countries are able to prepare policies and which help greatly in mitigating their negative effects on the short run. Secondly, it reaffirms – although with less robustness given the additional treatment taking place in 2014 – that some non-catastrophic disasters may actually not be pernicious in the short run for every country but rather the contrary.

6 Conclusion

Natural disasters are a growing phenomena which affect lives and well-being in almost if not all countries of the world. Understanding them and their effects is crucial to design efficient and effective economic policies that help mitigate their effects.

This study empirically finds a significant yet transitory effect of Chile's 2010 earthquake on GDP per capita by using the synthetic control method. The natural disaster increased output per capita by an average of $1.648 per year, followed by a reduction of $1.954 per year. These numbers are debatable in their magnitude and I mentioned a few concerns on the time-frame involved, yet the sign of them are consistent even after performing several independent robustness checks.

Initially, I hypothesized that given Chile's solid financial position, the country would be able to engage in strong fiscal policy which would promote output growth, even after having suffered significant productive capital destruction and loss of lives. Contrary to other studies that find in great majority find negative effects of natural disasters on GDP per capita, this paper finds exactly the opposite. This opens a new line of study in which macroeconomic position should be taken into account, as well as the institutional grade of the country in question.

Furthermore, studying disasters by their amount of destruction as a share of GDP, as well as considering institutional quality, literacy rates and social capital factors could shed some new light on how to prepare and face these events in a better way on the future. Understanding why similar countries face different outcomes when facing similar events can improve government and policymakers efforts to prepare for them better, and they may play a major role on affecting these outcomes.

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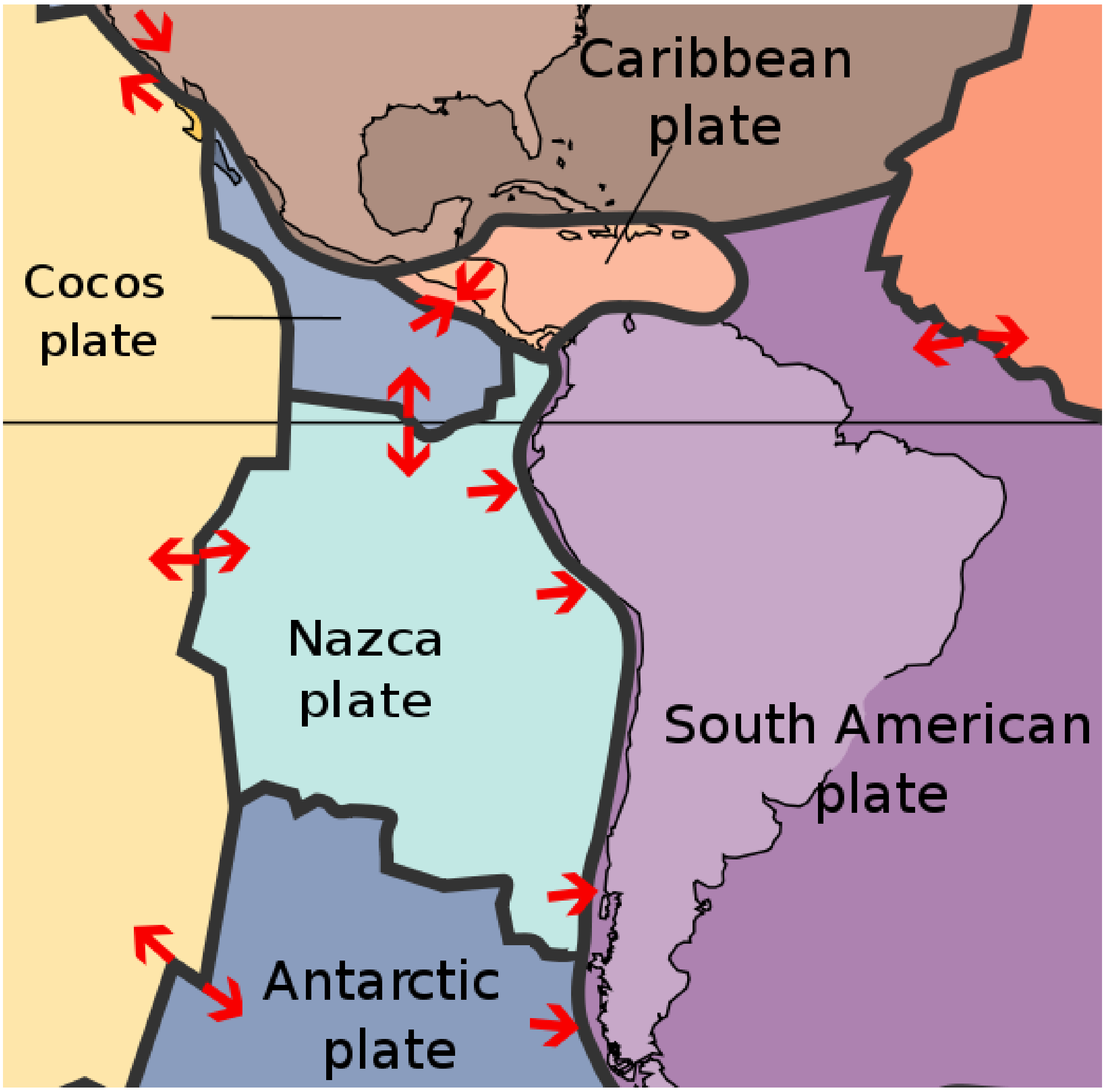
A Nazca and South American plates

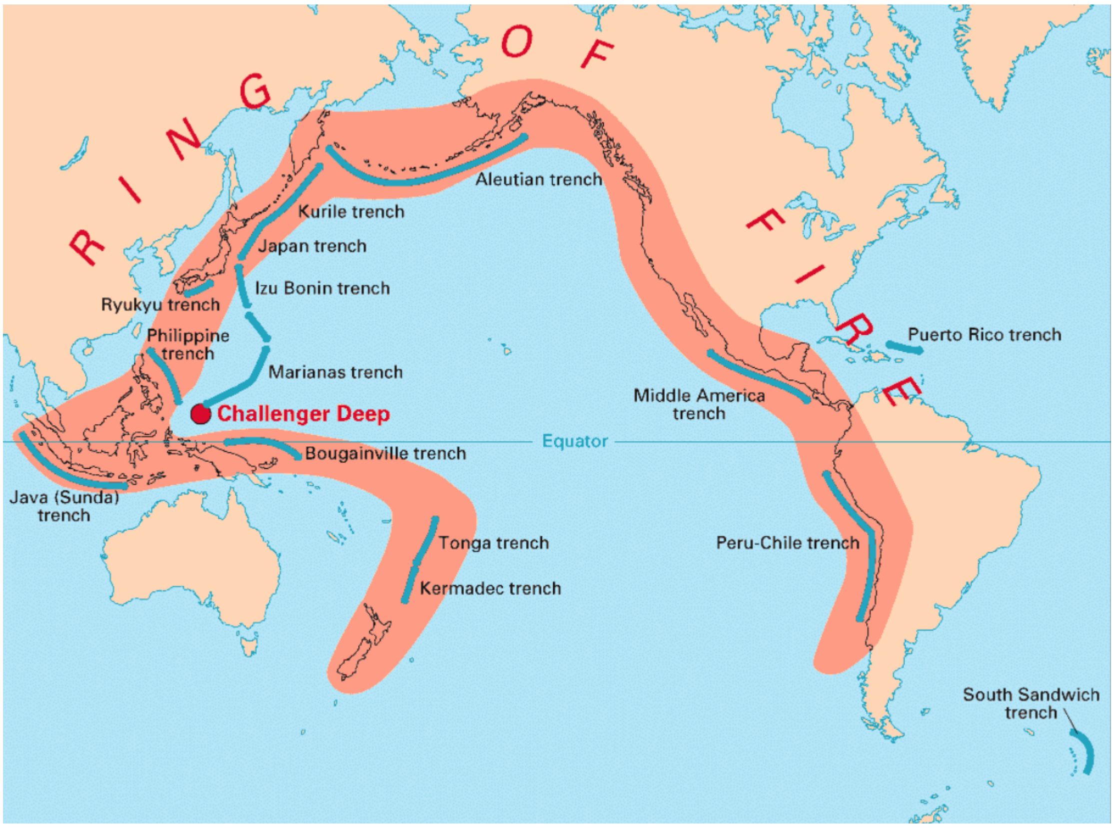
Figure A.1: Nazca and South American plate.



Source: Physical Geology, 2^{nd} edition.

B Pacific Ring of Fire

Figure B.1: Pacific Ring of Fire.



Source: USGS.

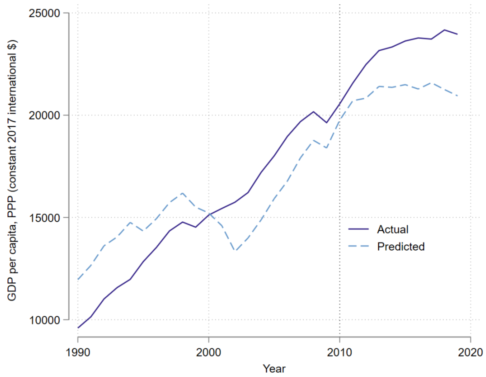
C Donor pool

Table C.1: Pool weights

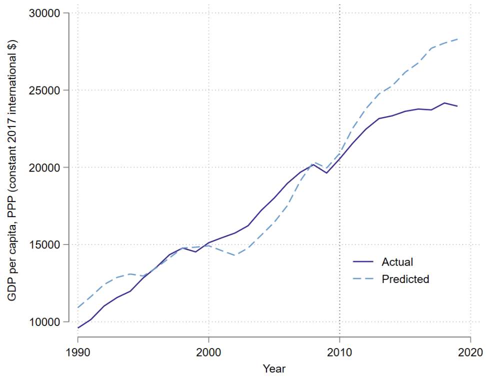
Unit	Unit weight	Unit	Unit weight
Algeria	0	Iceland	0
Argentina	0,2330	Indonesia	0
Australia	0	Ireland	0,1770
Austria	0	Italy	0
Bahrain	0	Japan	0
Barbados	0	Jordan	0
Belgium	0	Malaysia	0
Belize	0	Mauritius	0
Bhutan	0	Mexico	0
Botswana	0	Morocco	0
Brazil	0	Netherlands	0
Cabo Verde	0	New Zealand	0
Canada	0	Panama	0
China	0,3630	Paraguay	0,1770
Costa Rica	0	Peru	0
Denmark	0	Portugal	0
Dominican Republic	0	Saudi Arabia	0
Ecuador	0	Seychelles	0
El Salvador	0	Spain	0
Eswatini	0	Sri Lanka	0
Fiji	0	Sweden	0
Finland	0	Thailand	0
France	0	United Kingdom	0
Gabon	0	United States	0,0220
Germany	0	Uruguay	0
Guatemala	0,0610		

Note: weights add up to 1, to avoid extrapolation. Additionally, weights cannot be negative.

D Restricted donor pool



(a) Pool: South American countries



(b) Pool: Latin American countries

Figure D.1: Synthetic Control Method with restricted samples

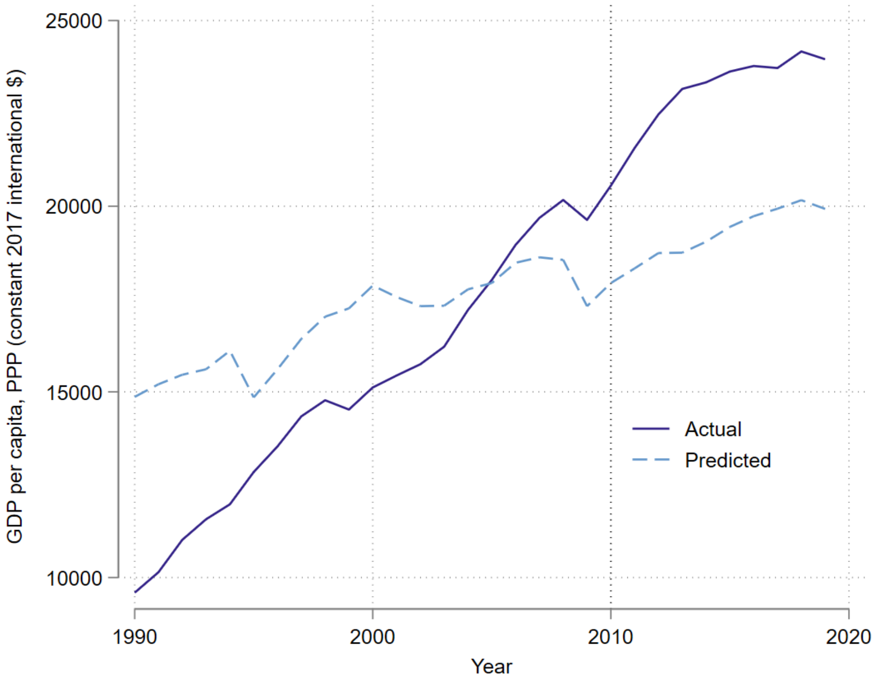


Figure D.2: SCM: OECD countries as donor pool

E Polity IV

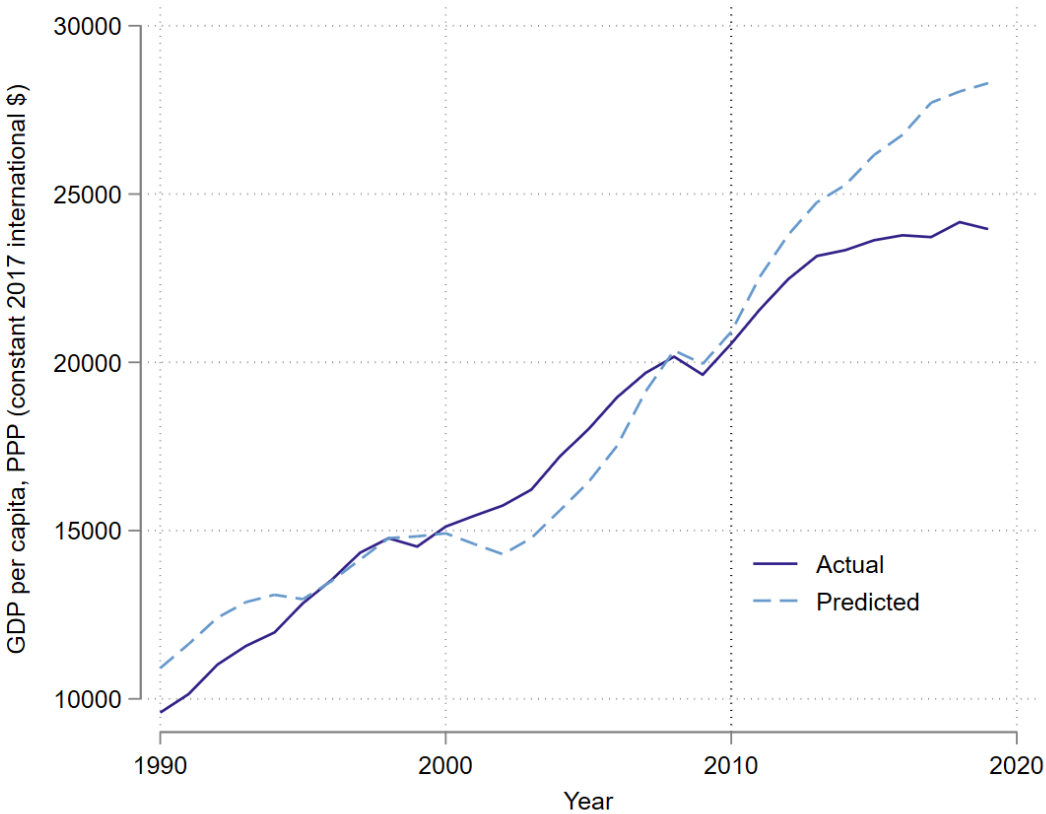


Figure E.1: SCM: Polity IV as covariate

F Alternative SCM

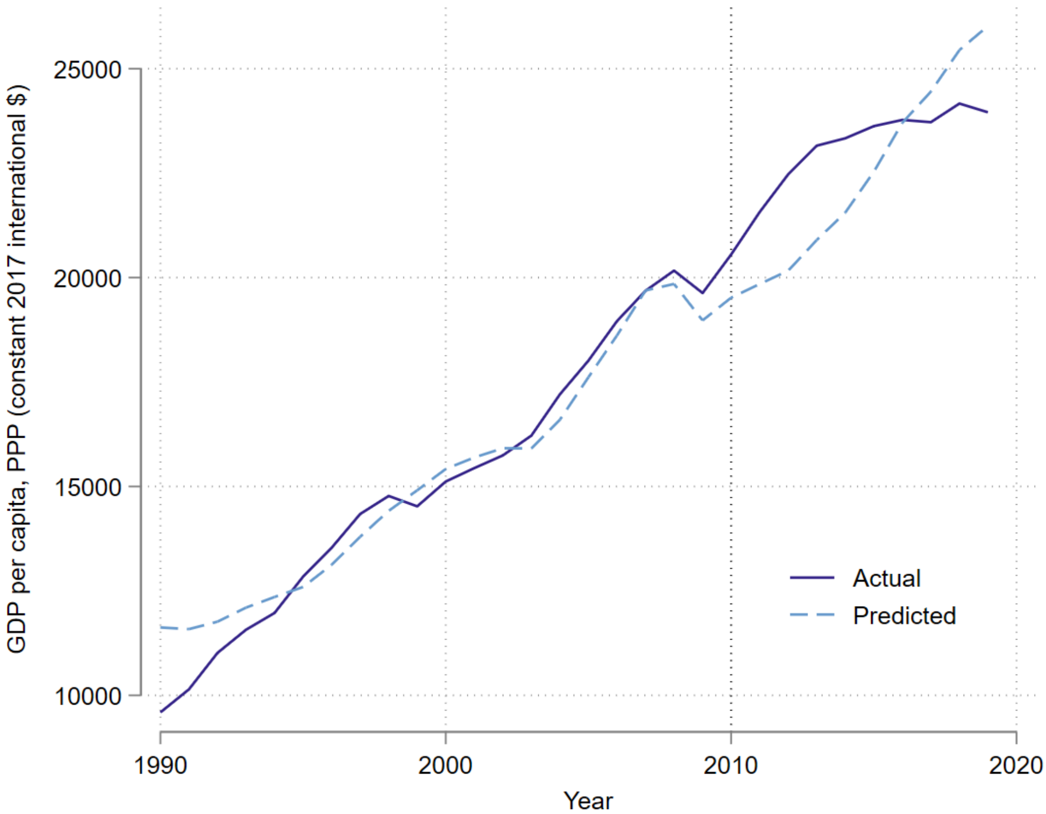


Figure F.1: SCM: Matching during the subprime crisis.