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The 1960 Tsunami in Hawaii: Long Term Consequences of Costal Disaster

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Abstract

Research on the economic and human toll of natural disasters focuses on the short-term, often ignoring the important long-term impacts of these catastrophic events. The main reason for the lack of empirical research on the long-term is the inherent and unavoidable difficulty in identifying any long-term impacts and attributing them to the disaster. On the 23rd of May 1960, a devastating tsunami struck the city of Hilo on the island of Hawaii. Remarkably, there was no significant injury or damage elsewhere in the Hawaiian Islands. This tsunami provides a unique natural experiment as the tsunami was unexpected, and the other Hawaiian Islands, which were not hit by the tsunami, provide an ideal control group that enables us to precisely identify the counter-factual. We use a newly developed synthetic control methodology formalized in Abadie et al. (2010) to measure the long-term impacts of the tsunami. We find that while wages did not decline noticeably, population and employment trends shifted. Fifteen years after the event, unemployment was still 32% higher and population was still 9% lower than it would have been had the tsunami not occurred. We also find a corresponding decrease in the number of employers and sugar production in the county.

JEL: Q54, R11

Keywords: coastal disasters, disaster impact, Hilo, tsunami, Hawaii, synthetic control

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1. Introduction

Research on the economic and human toll of natural disasters tends to focus on the short-term – i.e., the impact of the disaster in the first couple of years.[1] From a policy perspective, however, the long-term impacts of these catastrophic events are equally important. From a theoretical perspective, the long-term impact of disasters is also of intense interest, since much of the growth literature, especially neo-classical growth theory (Solow, 1956), predicts that in the long-term the region of interest will revert back to its fundamentals-dependent steady-state. The main reason for the lack of empirical research on this topic is the inherent and unavoidable difficulty in identifying any long-term impacts and distinguishing these from other post-disaster occurrences. Even only a decade after an event, how many of the observed changes in an economy can confidently be attributed to the event itself?

Tsunami is a Japanese term for large, sometimes destructive waves caused by sudden changes in the topography of the sea floor such as those generated by earthquakes. On the 23rd of May 1960, a devastating tsunami struck the city of Hilo on the island of Hawaii, killing 61 people, injuring 282 and inundating 600 acres. Remarkably, there was no significant injury or damage anywhere else in the Hawaiian islands. This tsunami event provides a unique natural experiment for several reasons: (1) there is now many years of detailed post-disaster economic data as well as a substantial amount of pre-disaster data; (2) the tsunami was unusual and unexpected (beyond a few hours advance notice) and thus clearly an exogenous event; (3) the other Hawaiian Islands, which were not hit by the tsunami, provide an ideal control group that enable us to precisely identify a counter-factual; and (4) Hawaii's experience with disasters is

[1] See Noy (2009), Strobl (2012), and Loayza et al. (2012) for cross-country comparative research.

not unique, so it is likely that the patterns we describe may repeat elsewhere.

To test for the long-term consequences of this disaster, we use a new methodology recently formalized in Abadie et al. (2010 and 2012) and previously employed in Abadie and Gardeazabal (2003). The methodology is based on simulating conditions after an exogenous event based on the relationship to a control group. The island of Hawaii's similarity to the other Hawaiian Islands[2], which were subject to almost identical initial conditions and subsequent shocks, with the exception of the tsunami, enables us to implement this methodology and obtain more precise estimates of the long-term impact of the disaster. We have a fairly long time-series of data from before the exogenous event, and our control group consists of the three other Hawaiian counties. The model presented by Abadie et al. (2010 and 2012) presents an estimation technique uniquely suitable to such a set-up, as weighted projections from the control group can be made with a relatively small sample of pre-treatment observations and a limited number of controls.

Any investigation into the long-term effects of natural disasters is non-trivial since both growth theories and current attempts to empirically examine them obtain contradicting results. Growth theories, for example, can suggest either a growth spurt after a massive destruction of capital, a permanent or temporary growth slowdown, or no observable effect beyond the very short term. There is little empirical research on the long-term impact of exogenous shocks on growth dynamics within the context of this literature.[3]

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[2] 'Hawaii' is normally used both as the name for the whole island archipelago and for its largest (but not most populated) island. To avoid confusion we refer to the State of Hawaii and to Hawaii Island, respectively.
[3] There is a body of research on the long-term impact of war-related destruction, following Davis and Weinstein (2002); see a summary of this research in Cavallo and Noy (2011).

In the policy arena, when longer term effects have been contemplated, there has been substantial discussion about the choice people make to stay and rebuild what was destroyed, or to leave and rebuild their lives elsewhere.[4] Thus, we start our investigation without strong priors. In the next section, we discuss relevant empirical work regarding the ex-post impacts of large disaster events. In section 3, we describe the economy of Hilo, the island of Hawaii and the state of Hawaii, as well as the tsunami's initial impact. We also describe the unique archival data we collected. Section 4 details the synthetic control methodology and our modifications to it, and section 5 describes our results on the long-term impact of the tsunami on Hilo's local economy and population. We conclude with a discussion of these results and implications, particularly in the context of future climate change.

2. The economics of natural disasters

Our project is an investigation of one event. A substantial number of studies of specific natural disaster events have been conducted over the past two decades, but almost all these case studies have been completed only a few years after the disaster has occurred and therefore focus on describing its short term effects (e.g., Horwich, 2000, on the 1995 Kobe earthquake; Vigdor, 2008, on hurricane Katrina of 2005; or Huigen and Jens, 2006, on a super-typhoon in the Philippines). Vigdor (2008), for example, documents significant population declines in a carefully constructed investigation of Katrina's impact on New Orleans. However, as he acknowledges, it is difficult to separate these declines from a general declining trend in the area's population that long predates Katrina or to evaluate whether this demographic

[4] Aldrich (2011) terms this the voice vs. exit choice.

impact will persist in the decades to come.[5] We are aware of three papers that describe the long term enduring macroeconomic or aggregate demographic impacts of specific natural disasters: Coffman and Noy (2012) on Hurricane Iniki in 1992, duPont and Noy (2012) on the 1995 Kobe earthquake, and Hornbeck (2012) on the American Dust Bowl during the 1930s Great Depression era. We will discuss these papers findings within the discussion of our own results in section 5.[6]

Before we proceed to discuss our research, we would like to briefly emphasize that the cross-country literature examining the costs of natural disasters is as constrained in examining short-run effects as the case-study literature discussed above. Skidmore and Toya (2002) initiated the recent research on longer term impacts, and found a positive correlation between the frequency of disasters and long-term GDP growth. On the other hand, Cavallo et al. (2010) fail to find any impact on per-capita GDP in the long-run of even very catastrophic events at the national level, and Deryugina (2011) fails to find much impact of US hurricanes at the county level.[7]

3. Hilo, the Island of Hawaii, the State of Hawaii and the tsunami of 1960

[5] Another set of papers looks at short- and medium-term adjustment at the individual/household level to large natural exogenous shocks (e.g., Carter et al., 2007, on the 1998-2000 Ethiopian draught and Hurricane Mitch in Honduras in 1998 and Sawada and Shimizutani, 2008, on the aftermath of the 1995 Kobe earthquake).

[6] A limited number of research projects has examined the long-term impact of specific catastrophic events on individuals/households (e.g., Maccini and Yang, 2009 on declines in rainfall in Indonesia; and Gørgens et al., 2012, on the Great Chinese Famine of 1959-1961).

[7] Cavallo et al. (2010) find that disasters that were followed by very significant institutional/political changes do have long-term impacts. The prototypical case they discuss is the Iran earthquake of 1978 that was followed less than a year later by the Islamic revolution. Deryugina (2011) finds no macroeconomic impact at the county level, but only after very substantial fiscal transfers from the Federal government.

After the overthrow of the Hawaiian monarchy in 1893, Hawaii was annexed to the United States as a territory in 1898. After a number of failed attempts to achieve statehood, the United States Congress passed the Hawaii Admission Act in 1959, which was followed by a referendum offering residents of Hawaii two choices: to remain as a territory or become a state. 94% chose statehood and Hawaii officially became a state on August 21st, 1959.

The State of Hawaii is comprised of four counties: the City and County of Honolulu, Hawaii County, Maui County, and Kauai County. Honolulu and Hawaii counties are composed of the islands of Oahu and Hawaii, respectively. Hilo is the largest town and political center of Hawaii County/Island. Kauai County includes the island of Kauai and the tiny island of Niihau; Maui County includes the islands of Maui, Lanai, and Molokai. In 1960 (the year of the tsunami), the population of the Hawaiian Islands that comprise the State of Hawaii was about 632,000 while today it is home to nearly 1.3 million people.[8] In 1960, 79% of the population lived in the City and County of Honolulu, while the rest was divided about 10% in Hawaii County, 7% in Maui and 4% on Kauai.[9]

Similar to many other islands in the Pacific, tourism is the largest private sector industry in Hawaii today; but in 1960, agriculture and U.S. federal government spending (much of it military-related) still dominated the economy. In 1960, the city of Hilo was the center of economic and governmental activities on the island of Hawaii. At that time, 42% of the island's population lived in Hilo. The city and its vicinity accounted for 70% of gross retail sales and 83%

[8] Source: State of Hawaii, Department of Business, Economic Development & Tourism, http://hawaii.gov/dbedt (accessed 31/05/2012).

[9] Data are obtained from the University of Hawaii Economic Research dataset, www.uhero.hawaii.edu (accessed 31/05/2012). The population distribution is roughly the same today with 80% in Honolulu County, 8% in Hawaii and Maui counties and 4% in Kauai County.

of gross wholesale receipts on the island. Almost all non-agricultural manufacturing activities were located in the city. The major sources of income on the island were agriculture (dominated by sugar but including other crops and animals) and tourism.

Although the counties (islands) differed in terms of population in 1960, they were nonetheless quite similar in terms of socio-economic conditions. They were largely exporting comparable products (sugar and other agricultural products) and services (mostly tourism) and they were subject to similar external political and economic shocks. Not only do the counties still share similar economic structures but, as they belong to the same political entity, they are subject to the same institutional and legal frameworks. Most taxes are handled at the state level and most expenditures are also decided at the state level; for example, uniquely in the United States, the public education system includes a single state-wide school district.

As the only island state in the US, located in the heart of the Pacific Ocean, and surrounded by the 'Ring of Fire', Hawaii is particularly susceptible to tsunamis. Since 1812, there have been 171 recorded tsunamis in the Hawaiian Islands. Extremely destructive tsunamis have struck the islands at least a dozen times since written records began in the early 19th century. Since 1837, there have been seven tsunamis that directly resulted in the loss of life. Almost 300 people have been killed by tsunamis in Hawaii with the two most deadly tsunamis occurring in 1946 (159 deaths) and 1960 (61 deaths). The 1960 tsunami, the most recent tsunami to cause severe damage and destruction, is the focus of this paper.

The 1946 tsunami was caused by an earthquake in the Aleutian islands of Alaska and travelled 2,300 miles before hitting the Hawaiian Islands in the early morning of April 1st. The tsunami caused damage and death in all four counties with the most severe damage and loss of life occurring in Hawaii County. Almost 500 homes and businesses were destroyed and another 1,000 were severely damaged. The cost of the destruction reached $300 million (measured in 2011 dollars).

Largely in response to the unprecedented destruction and loss of life in the 1946 tsunami, the Pacific Tsunami Warning Center (PTWC) was established in 1949 at Ewa Beach on the island of Oahu. The PTWC today is part of an international network of tsunami warning systems. The center receives information from seismograph stations and whenever an earthquake above 6.5 on the Richter scale occurs, scientists at the center are alerted by special alarms and begin calculating whether a tsunami has been generated and where it is likely to strike. If the earthquake is strong enough to cause a tsunami and the epicenter is located close enough to the ocean, the center will issue a “Tsunami Watch”. If tide gauges at different locations in the Pacific Ocean subsequently confirm that a tsunami has been generated, then a “Tsunami Warning” is issued. When a Tsunami Warning occurs, sirens sound, emergency radio broadcasts are initiated, and Hawaii state agencies begin evacuating citizens from low-lying areas.

On the 22nd of May 1960, a tsunami was generated off the coast of Concepción, Chile, as a result of three major earthquakes there. In Chile itself, 2,000 people were killed and large areas of the southern coast were destroyed. The tsunami continued to wreak havoc as it spread across the Pacific. Pitcairn Island, New Guinea, New Zealand, the Philippines and Okinawa were all hit by the tsunami and close to 300 lives were lost. Damage was recorded in Oregon, California, the Kamchatka Peninsula and Samoa. On Easter Island, the tsunami picked up and moved some of the famous *moai* statues a distance of five hundred feet.

The tsunami struck the Hawaiian Islands just after midnight in the morning of the 23rd of May. In general, the wave action along Hawaiian shores was noticeable but not very significant or destructive (akin to a sped-up tidal change). However, in Hilo Bay on the island of Hawaii, the third wave of the tsunami converted into a bore and caused severe damage. For comparison, on the island of Oahu, the average run-up recorded was 7 feet. In Hilo, run-ups as high as 35 feet were recorded near the waterfront area directly south of the breakwater. Thus, nearly all of the tsunami's effects were centered on Hilo.

The 1960 tsunami killed 61 people and injured 282, all of them in Hilo. This is despite a Tsunami Warning being issued at 6:47pm by the PTWC, at least 5 hours before the tsunami's arrival. Warnings were issued by radio, television, public address and in person. Only a third of the residents in the inundated areas chose to evacuate, as many did not feel there was much of a risk and the warnings were quite ambiguous (Lachman et al., 1960). In particular, radio stations carried reports from Tahiti that the waves were only three feet high. This led to a false sense of complacency; Tahiti is well-protected from tsunami waves because of large offshore reefs, which dissipate the force of the waves. A change in the siren system also caused confusion. Some Hilo residents even went down to the shore to see if they could observe what they thought would be a small tsunami. At 1:04am, a 20-foot high vertical wall of water washed through Hilo town. A minute later, most of the island was plunged into darkness and panic spread.

Nearly 600 acres were inundated and in about half of this area, all buildings were destroyed completely (Eaton at al., 1961). In terms of the size of the destroyed area, this would be roughly equivalent to 60 blocks in downtown Manhattan. The destruction was most severe along

Kamehameha Avenue, the main thoroughfare of the city. There was hardly any damage to the other islands in Hawaii. Only a total of eight houses were destroyed on Maui, one on Lanai and none on Oahu, Molokai or Kauai. There was some flooding and damage caused to buildings' walls and their contents but nothing compared to the destruction in Hilo. The estimated damage to residential, business and public properties was almost $169 million and 158 firms were directly affected by the tsunami (Hung, 1961).

3.1 Historical data for the state of Hawaii

We obtained and searched through archival records to gather information on variables of economic interest: population, employment, wages and production. [10] The variables we observe and analyze are based on data availability both pre- and post-tsunami. We are not testing a specific theory of post-disaster developments; largely because no such comprehensive theory exists and speculations regarding typical post-disaster developments are varied and numerous. We use annual county-level panel data for the City and County of Honolulu, Hawaii County, Kauai County, and Maui County. The period available for each series varies based on the data collection history of the given source. We truncate data collection at 1975 due to structural changes in the state of Hawaii, especially the shift from agriculture to tourism. We suspect the relationships between the islands would not be stable past 1975 and, as a result, the assumptions of the synthetic control method would not hold beyond this period.

[10] In addition to the variables mentioned, motor vehicle registrations were collected for the period 1932-1975, but there was no discernible impact from the tsunami. We also collected but did not analyze data on Job Counts due to concerns about how this data has been collected over time (see Appendix). We have similar concerns regarding the data on Total Wages but present these results in section 5 for the sake of comparison.

Civilian Resident Population was collected from intercensal population estimates from the Department of Planning and Economic Development[11] of the State of Hawaii covering the period 1940-1975. Total Wages and Number of Employers were collected from annual "Employment and Payrolls" reports from the Department of Labor and Industrial Relations of the State of Hawaii from 1951 to 1975. Unemployment data covering 1958 through 1975 was collected from the Hawaii County and the State of Hawaii Data Books. Sugar Production was collected from annual reports of the Chamber of Commerce of Hawaii for the period 1948 to 1975. Table 1 displays summary statistics for each variable and county over the entire period.

4. Methodology – synthetic control for comparative case studies

The synthetic control methodology, proposed by Abadie and Gardeazabal (2003) and developed further by Abadie *et al.* (2010, 2012), creates a counterfactual based on appropriate comparison units. The goal is to replicate the characteristics of the region receiving the intervention (in our case the 1960 Hilo tsunami) using a linear combination of the same characteristics for regions not receiving the intervention.[12] Characteristics are measured as pre-intervention, possibly weighted, averages of relevant variables of interest. The weights of the resulting linear combination are then used to compute a synthetic time series representing the outcome for the region receiving the intervention in the (counterfactual) case that it did not receive the intervention.

[11] This department was subsequently renamed the Department of Business, Economic Development & Tourism.
[12] Abadie and Gardeazabal (2003) and Abadie *et al.* (2010, 2012) restrict themselves to convex combinations.

4.1 Model[13]

More formally, let Y_{it} be defined as the observed value of the variable under investigation for region i in time period t. Further, define Y_{it}^{I} and Y_{it}^{N} to be observations with the intervention and without, respectively. We are specifically interested in α_{it}, defined to be the effect of the intervention for region i at time t. Thus, $\alpha_{it} = Y_{it}^{I} - Y_{it}^{N}$, and $Y_{it} = Y_{it}^{N} + \alpha_{it}D_{it}$, where $D_{it} = 1$ if region i receives the intervention in time period t and equals zero otherwise. For our region of interest, call it region 1, $Y_{1t}^{I} = Y_{1t}$, so that $\alpha_{1t} = Y_{1t} - Y_{1t}^{N}$ for all $t > T_0$, when T_0 is defined as the time of the intervention (disaster event) and the number of pre-intervention time periods.

Abadie *et al.* (2010) suppose that non-intervention observations, Y_{it}^{N}, can be expressed in terms of the following factor model:

$$Y_{it}^{N} = \delta_t + \boldsymbol{\theta}_t \boldsymbol{Z}_i + \boldsymbol{\lambda}_t \boldsymbol{\mu}_i + \varepsilon_{it}.$$

Here δ_t is an unknown common factor, $\boldsymbol{Z}_i$ is a vector of observed covariates not affected by the intervention, $\boldsymbol{\lambda}_t$ is a vector of unobserved common factors, and $\boldsymbol{\theta}_t$ and $\boldsymbol{\mu}_t$ are unknown parameter vectors. This model differs from a standard differences-in-differences model in that $\boldsymbol{\lambda}_t$ is not restricted to be constant over time.

Assuming there are J regions not affected by the intervention and $i = 1$ for the affected region, a synthetic control is defined by a $(J \times 1)$ weighting vector $\boldsymbol{W} = (w_2, \dots, w_{J+1})$. An optimal vector satisfies the following equations:

$$\sum_{j=2}^{J+1} w_j^{*} Y_{jt} = Y_{1t}, \forall\, t \in \{1,2, \dots, T_0\},$$

[13] Section 4.1 follows the exposition in Abadie *et al.* (2010).

and

$$\sum_{j=2}^{J+1} w_j^* \boldsymbol{Z}_j = \boldsymbol{Z}_1.$$

In other words, the weights are constructed such that a weighted sum of control outcomes equals the intervention outcome in all pre-intervention periods and the weighted sum of control covariates equal the intervention covariates. Abadie *et al.* (2010) show that this optimal vector will satisfy the following equation under standard assumptions, provided the number of pre-intervention periods is large relative to the intervention:

$$E[Y_{1t}^N] = \sum_{j=2}^{J+1} w_j^* Y_{jt}.$$

Thus, for $t > T_0$, we can estimate α_{1t} as follows:

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

4.2 Implementation

The first step in computing weights for the synthetic control method is to construct pre-treatment averages for each determinant of the variable of interest. A simple approach would be to take an unweighted average. We go a step further and choose the weights to minimize the root mean squared prediction error (RMSPE) over the pre-intervention period. Let X_1 be a $(K \times 1)$ vector of pre-intervention averages for the region of interest, where K is defined as the number of chosen determinants of the variable of interest. Let X_0 be a $(K \times J)$ matrix of pre-intervention averages for all other regions, where J is as defined above. Choose a $(J \times 1)$ weighting vector W that satisfies the following minimization problem for a given V:

$$\min_{W \in \mathcal{W}} (X_1 - X_0 W)' V (X_1 - X_0 W).$$

Abadie and Gardeazabal (2003) and Abadie et al. (2010) choose V to be a positive semi-definite diagonal matrix that results in smaller RMSPE for the pre-intervention periods. In the 2003 paper (p. 128), they show that the Euclidean norm of V can be normalized to 1. Recognizing W is a function of V, it is clear the choice of V will play an important role in determining the relative importance of different predictors of the variable of interest when $K > 1$. In this paper, we construct a counterfactual for each variable using only observations of that same variable (i.e. setting $K = 1$). X_1 reduces to a scalar (e.g. the pre-intervention population average for the region of interest) and X_0 reduces to a $(1 \times J)$ vector (e.g. the vector of pre-intervention population averages for the J other regions, $X_0 = (\overline{x}_{0,2}, \dots, \overline{x}_{0,J+1})$). Since the Euclidean norm of V can be normalized to 1, we can set the scalar V equal to unity. Thus, the optimal W can be redefined as follows: $W^* = \text{argmin}_{W \in \mathcal{W}} (X_1 - X_0 W)^2$

While Abadie et al. (2010) restrict weights to be nonnegative and sum to one, given that $J = 3$ in the present study, we relax the restrictions on W to accommodate differences in scale and to reflect the similar nature of the Hawaiian Islands. Removing the restrictions on the optimal weights, so that $W \in \mathbb{R}^J$, implies the optimal weights satisfy the following equation:

$$X_1 = \overline{x}_{0,2} w_2^* + \cdots + \overline{x}_{0,J+1} w_{J+1}^*.$$

This is an equation of a solution plane in J space (we assume all elements of X_0 are nonzero, or equivalently we remove from our “donor pool” any region with a zero average). Thus we have identified a continuum of solutions to the minimization problem without constraints.

In the same vein as Abadie and Gardeazabal (2003) when presented with free parameters, we select the vector that minimizes the RMSPE of the pre-intervention period. Define Z_0 as the $(T_0 \times J)$ matrix of pre-intervention observations from the “donor pool” and Z_1

as the ($T_0 \times 1$) vector of pre-intervention observations for Hawaii County. Regressing Z_1 on Z_0, without a constant and subject to the constraint that the coefficients satisfy the following equation, minimizes the RMSPE for the pre-intervention period subject to the set of optimal weights[14]:

$$X_{Hawaii} = \overline{x}_{Honolulu} w^*_{Honolulu} + \overline{x}_{Kauai} w^*_{Kauai} + \overline{x}_{Maui} w^*_{Maui}.$$

Table 2 displays summary statistics for the relevant variables for the pre-intervention period for Hawaii Island and for its synthetic counterpart (as calculated above).

4.3 Inference with the Synthetic Control Method

Adapting the process of classical permutation tests, Abadie et al. (2010, 2012) calculate a synthetic control for each of the other regions unaffected by the intervention. These "placebos" are calculated as explained above (removing the affected region from the respective "donor pool"). For a given $t > T_0$, $\hat{\alpha}_{1t}$ is compared to the distribution of "placebo" values of $\hat{\alpha}_{jt}$ for $j \in \{2, \ldots, J+1\}$. This comparison permits the calculation of easily interpretable p-values when J is sufficiently large. In our case with $J = 3$, we graph the values for $\hat{\alpha}_{1t}$ with the values for $\hat{\alpha}_{jt}$ for Kauai County and Maui County[15] for both pre and post-intervention periods. If the control regions are good controls for each other then a plot of the estimated gaps ($\hat{\alpha}_{jt}$) between each control and its controls should approximate a horizontal line at zero following

[14] In the case of unemployment data, the synthetic is calculated using simple averages, avoiding estimating two coefficients with two observations.

[15] The $\hat{\alpha}_{i,t}$ for the City and County of Honolulu is excluded from the graphs following the process in Abadie et al. (2012) of removing "placebos" with large values during the pre-intervention period. In the case of unemployment, Kauai County is removed as a result of this process and both Maui County and the City and County of Honolulu are displayed.

the intervention (the grey lines in our Gaps graphs), whereas the gap for the affected region should be on a visibly different trajectory (the black line in our Gaps graphs). This falsification test lends credibility to the effects implied by the synthetic control methodology.

5. Hilo after the tsunami and the counterfactual synthetic control

5.1 Estimation results

What did happen in Hilo and the island of Hawaii after the 1960 tsunami? We first examine civilian population on the island (figure 1). We observe a dramatic deviation from the counterfactual trend that starts in 1960; the population of the island does not increase as the counterfactual estimates suggest it would have in the absence of the tsunami event. At a total of 77,221 people in 1975, the true population of the island appears to be about 9% lower fifteen years after the tsunami than it would have been otherwise (the counterfactual population is estimated to be 85,159). The veracity of this result appears to be confirmed when we examine the placebo gap estimates (figure 2).[16] The placebo results suggest that the model becomes less precise in the 1970s (as the gaps for other islands increase as well); but the gaps we estimate for Hawaii Island are noticeably larger than for our placebo controls.

In figure 3, we further investigate the reasons for the population deviations we observe in figures 1 and 2. Figure 3 demonstrates that the number of employers also appears to be decreasing (relative to the counterfactual). This observation is in line with the Hung (1961) observation that most of the businesses that failed in the immediate aftermath of the tsunami were small "mom-and-pop" businesses rather than bigger firms that had an easier time

[16] By "gap estimate", we mean $\hat{\alpha}_{i,t} = Y_{i,t}^{I} - E\left[Y_{i,t}^{N}\right]$.

obtaining credit to fund reconstruction or relocation. Once again, the placebo evidence seems to strongly support this finding (figure 4).

With a lower population but fewer employers, it is unclear what the aggregate effect on employment will be. Figure 5 suggests that the tsunami had a negative and persistent impact on employment on Hawaii Island. The unemployment rate is above the counterfactual for all years post-tsunami and the model suggests that unemployment is approximately 33% higher in 1975 than what it would have been otherwise (8.6% compared to 6.5%). Figure 6 lends credence to figure 5 although the difference between the intervention and placebos is not as pronounced as before.

The most important sector in the island's economy at the time was sugar (this period preceded the rapid increase in tourism that started in the 1970s). For sugar, we observe a very dramatic decline around 1960 (relative to an increasing trend), and the sugar economy never fully recovers to its counterfactual level (figure 7). The 1970s see the beginning of the terminal decline of the industry, but 1960 appears to be a shift unique to Hawaii Island. The other agricultural islands (Kauai and Maui) do not experience a similar relative decline in the 1960s (see figure 8). Although there was no significant damage to sugar cane fields on Hawaii island, the tsunami destroyed key infrastructural, commercial and institutional support underlying the sugar industry on the island.

Finally, we examine total wages on the island (figure 9). We observe no significant deviation from the counterfactual (no-tsunami) Hawaii island economy, until the early 1970s. By then, the counterfactual and the actual observations deviate from each other. However, we observe the same phenomena in the gap estimates for our placebos (the other Hawaiian counties) – see figure 10. This suggests that total wages on the island were not severely impacted by the tsunami. However, there are a number of reasons to be cautious about drawing conclusions from the total wages data since data reporting methods changed dramatically over the period of interest and not necessarily in a consistent way across counties (see Appendix for more explanation).

5.2 Comparing results to previous research

How do our results compare to previous attempts to estimate the long-term impact of catastrophic natural disasters? Using similar methodology to the one described above, Coffman and Noy (2012) described the impact of a 1992 hurricane on Kauai Island and duPont and Noy (2012) described the impact of the 1995 Kobe earthquake in Japan. In Kauai's case, Coffman and Noy (2012) also describe a similar population decline as the one we observe for the post-1960 tsunami period on Hawaii Island, while DuPont and Noy (2012) describe only a brief population loss with a full demographic recovery within 3-4 years. They find, however, that in contrast with Kauai where income per capita recovered fairly quickly as population emigrated, Kobe's per capita incomes never fully recovered from the earthquake, and were still noticeably lower 15 years after the fact.

It seems that in all these cases the aggregate level of economic activity never fully recovered, but the exact patterns in which these aggregate difficulties manifested themselves varied depending on location, culture, institutions and time-period. Observation of a long-term adverse local effect of a natural catastrophe was also recently confirmed by Hornbeck (2012). In his paper, Hornbeck examines the long-term impact, at the county level, of the American Dust-

Bowl event during the 1930s. This was a period of repeated droughts in the American Mid-Western Plains that led to the erosion of topsoil and dramatic consequent changes in agricultural productivity. Hornbeck finds that while there was some adjustment in agricultural activities, there were still substantial declines in productivity and land prices that lasted at least into the 1950s. The main adjustment mechanism he describes, emigration, is the same one we observe for Hilo after the tsunami and that Coffman and Noy (2012) observe for post-hurricane Kauai.

6. Conclusion

What were the long term impacts of the Hilo tsunami of 1960 on Hawaii Island? Years of hindsight and a newly developed comparison methodology for case studies with an appropriate control group make it possible to assess the long-term economic damages of the 1960 tsunami in Hilo. We observe a significant relative population decline; people moved away from the affected county in the decade following the tsunami. Since no other shocks that were unique to Hawaii Island occurred around 1960, we conclude that population trends deviated for the island because of the tsunami event. We also describe a corresponding decrease in the number of employers and sugar production in the county, as well as a rise in the unemployment rate that explains the motivation behind this emigration.

It is impossible to know whether the impacts we describe were a direct result of the damage wrought by the natural disaster, or because of the attendant shift in expectations regarding the likelihood of future events that it most likely generated. We have no direct evidence on that point, but the tsunami's magnitude was clearly unexpected (as many people were injured or killed in spite of an operational warning system), and since this followed on the heels of another large tsunami in 1946, it seems likely that the event did generate a new realization about the dangers of living and operating businesses in Hilo. The zoning changes that resulted from the tsunami, in particular the decision not to rebuild most of the areas destroyed by the 1960 tsunami, suggest that the event generated an increase in the expected probability of the occurrence of future events. It is important to note that similar changes in perceptions about future vulnerabilities also appear to be factors in the aftermath of the Kobe earthquake of 1995 as Kobe was previously considered a relatively seismically stable area (compared to Tokyo, for example).

In an assessment of the relevance of these observations to developing countries, we note two factors. First, while Hawaii was part of an industrialized country at the time of the 1960 event, the island was still largely agricultural. However, the presence of a wealthy government (at the State and Federal level) that can mobilize significant fiscal resources to provide a stimulus and reconstruction support may be important. Poor developing countries are less likely to be able to adopt counter-cyclical fiscal policies (Ilzetzki and Végh, 2008); and this will make the disaster's adverse consequences more severe and more persistent. Foreign aid, an important source for reconstruction money for developing countries is also unlikely to fill in this financing gap (see Becerra *et al*., 2012).

A second relevant observation is that Hawaii Island, our unit of observation, is composed of two geographically separate parts: the East Coast that includes Hilo – the county seat, and the North-West coast that includes the area now typically referred to as Kailua-Kona, after the coastal town and its surrounding region, respectively. Since the tsunami affected only the Hilo side, but we measured aggregate impacts for the entire island, one should view our estimates as lower-bounds on the true local impacts. We suspect that should more detailed data for Hilo itself become available, larger impacts than we described would be observed.

The long-term impacts of disaster events are ‘hidden’ due to the difficulty in attributing them to an event with the passage of time. As we document, the long-term regional and local costs of disasters can be substantial. An appropriate evaluation of disaster risk reduction and mitigation policies should take these regional impacts into account when implementing cost-benefit analyses.

Projected climatic changes provide an additional level of complication in determining the likelihood of future disasters and planning for disaster risk reduction. As a recent Intergovernmental Panel on Climate Change report concludes: “Data on disasters and disaster risk reduction are lacking at the local level, which can constrain improvements in local vulnerability reduction.” (IPCC, 2012, p. 10). They further note that: “Disasters associated with climate extremes influence population mobility and relocation, affecting host and origin communities (medium agreement, medium evidence). If disasters occur more frequently and/or with greater magnitude, some local areas will become increasingly marginal as places to live or in which to maintain livelihoods. In such cases, migration and displacement could become permanent and could introduce new pressures in areas of relocation.” (IPCC, 2012, p. 16). Thus, the emerging literature on the long-term costs of coastal disasters should play a useful role in understanding and planning for the costs of future climate change.

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Table 1: Summary Statistics

Civilian Resident Population (Thousands of People)
1940-1975

	Min	Max	Mean	Std. Dev.
Hawaii County	59.33	77.22	64.64	4.30
C&C of Honolulu	243.27	660.16	430.46	120.45
Kauai County	25.05	33.71	29.65	1.81
Maui County	42.24	56.79	46.79	3.67

Total Wages (Millions of Constant 1982-84 USD)
1951-1975

	Min	Max	Mean	Std. Dev.
Hawaii County	95.00	338.40	182.48	85.40
C&C of Honolulu	815.80	3811.00	2088.95	1027.83
Kauai County	50.43	149.60	93.38	33.57
Maui County	66.51	291.30	139.51	70.54

Number of Employers
1951-1975

	Min	Max	Mean	Std. Dev.
Hawaii County	864	1579	1117.60	231.40
C&C of Honolulu	6093	13097	9169.08	2146.58
Kauai County	334	633	462.92	93.47
Maui County	496	1243	741.32	218.20

Unemployment Rate
1958-1975

	Min	Max	Mean	Std. Dev.
Hawaii County	2.7	9.2	4.9	1.92
C&C of Honolulu	2.6	7.2	4.4	1.58
Kauai County	3.3	8.2	5	1.61
Maui County	3.5	10.2	5.8	2.33

Sugar Production (Thousands of Tons)
1948-1975

	Min	Max	Mean	Std. Dev.
Hawaii County	272.32	464.60	393.32	49.67
C&C of Honolulu	154.19	238.27	206.17	22.62
Kauai County	173.89	272.81	235.92	26.94
Maui County	158.49	303.21	248.57	35.94

Table 2: Relevant Variables Before Hilo Tsunami

		Hawaii County	Synthetic Hawaii
Civilian Resident Population	Min	60.55	60.35
(Thousands of People)	Max	69.45	70.89
	Mean	64.78	64.87
	Std. Dev.	2.66	2.75
Total Wages	Min	95	95.4
(Millions of constant	Max	138.9	140
1982-84 USD)	Mean	103.66	103.63
	Std. Dev.	12.74	13.1
Number of Employers	Min	864	861
	Max	919	925
	Mean	887.33	887.57
	Std. Dev.	17.33	17.95
Unemployment Rate	Min	2.7	2.7
	Max	3.9	3.9
	Mean	3.30	3.30
	Std. Dev.	0.60	0.60
Sugar Production	Min	272.32	274.89
(Thousands of Tons)	Max	412.21	432.36
	Mean	355.74	354.44
	Std. Dev.	49.46	51.63

Note: Civilian Resident Population statistics are calculated for the period 1940-1959. Total Wages and Number of Employees cover 1951-1959. Unemployment Rate pre-tsunami periods are 1958 and 1959. Sugar Production statistics are calculated from 1948 to 1959.

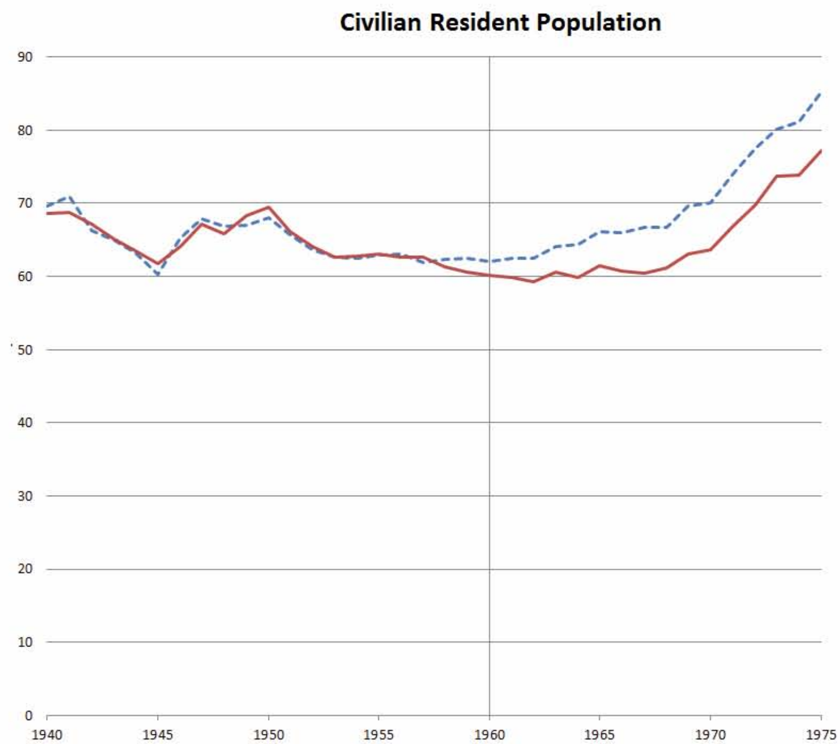

Figure 1: Civilian Resident Population (in thousands), 1940-1975. The synthetic control is the dashed line, while the actual series is the solid line. Source: Intercensal population estimates, Dept. of Planning and Econ. Development, State of Hawaii.

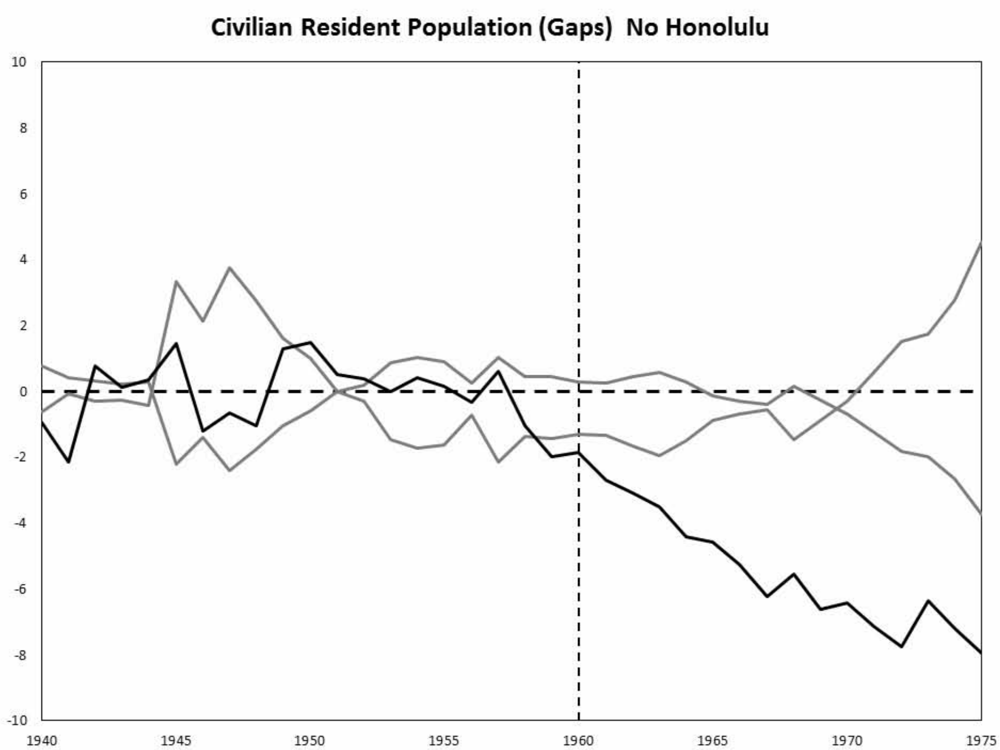

Figure 2: The black line represents the estimated effect for Hawaii County (in percentage points). The gray lines represent the "placebo" effects for Kauai County and Maui County. Source: authors' calculations.

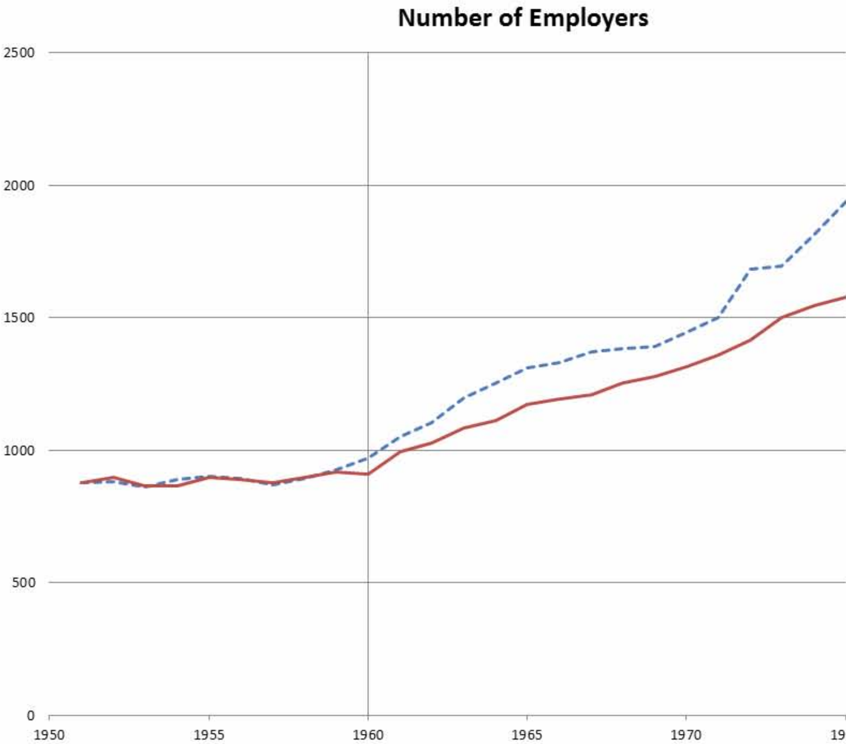

Figure 3: Number of Employers, 1951-1975. The synthetic control is the dashed line, while the actual series is the solid line. Source: Employment and Payrolls annual reports, Department of Labor and Industrial Relations, State of Hawaii.

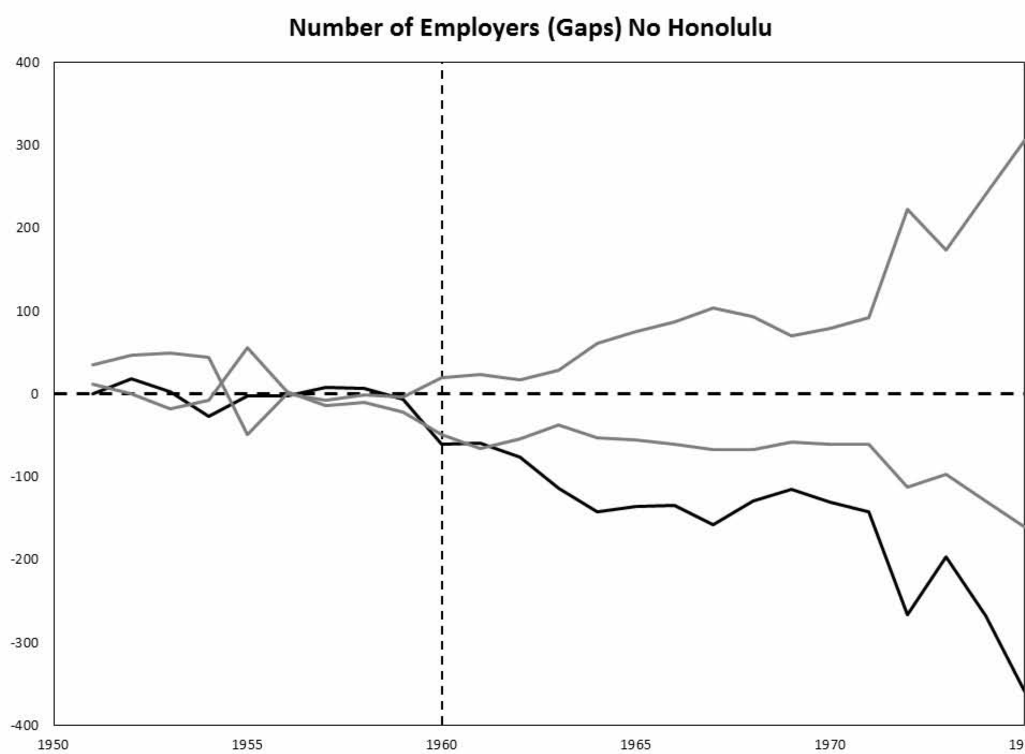

Figure 4: The black line represents the estimated effect for Hawaii County. The gray lines represent the "placebo" effects for Kauai County and Maui County. Source: authors' calculations.

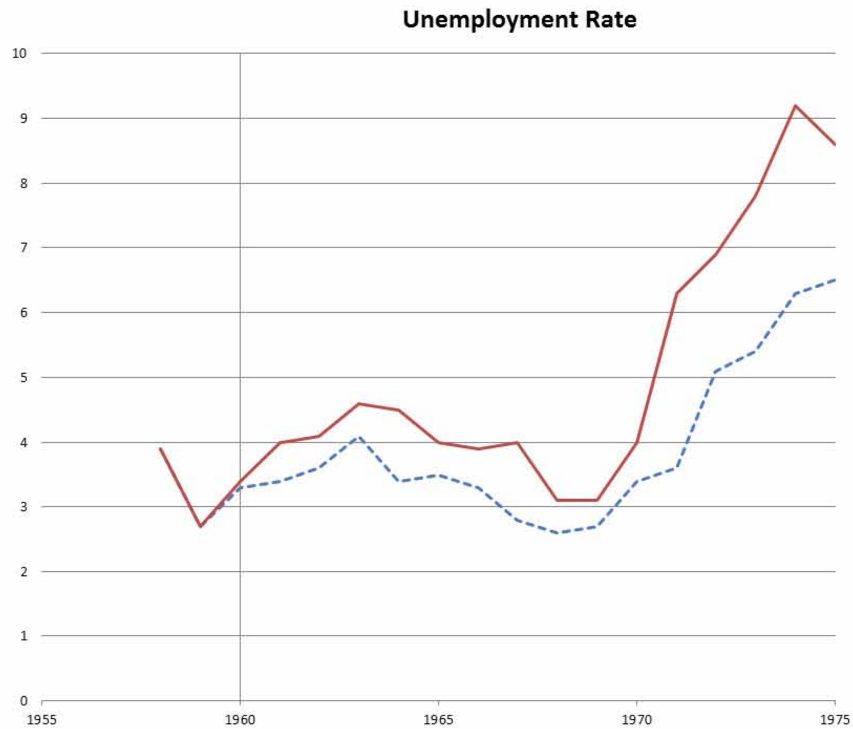

Figure 5: Unemployment Rate (%), 1958-1975. The synthetic control is the dashed line, while the actual series is the solid line. Source: Hawaii County Data Book, State of Hawaii Data Book.

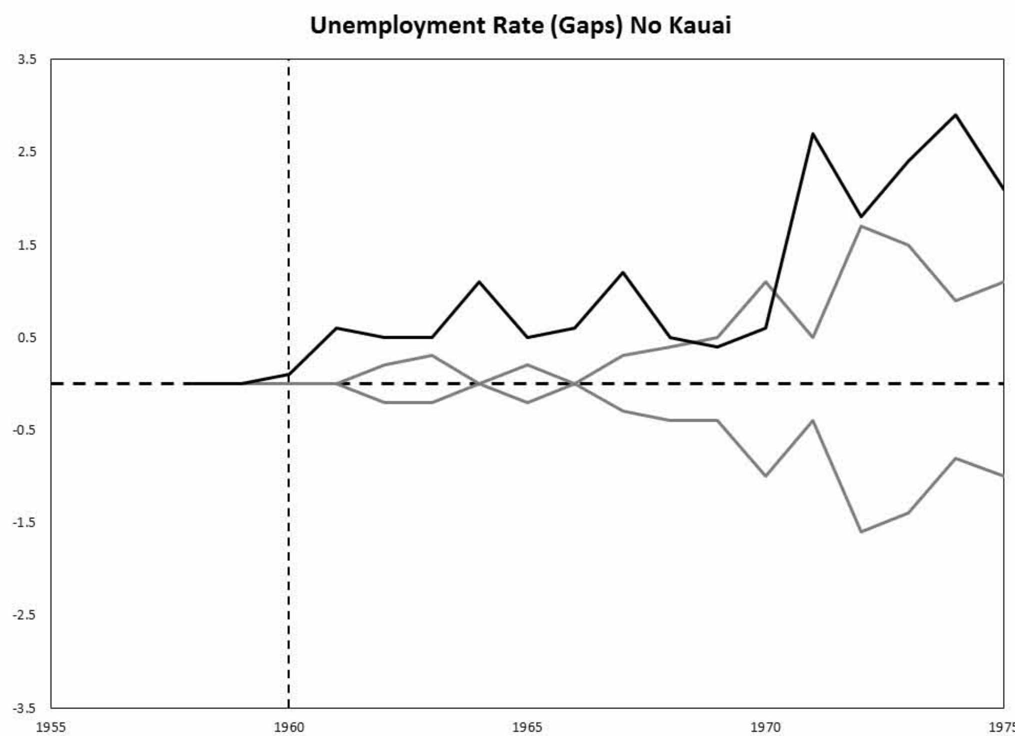

Figure 6: The black line represents the estimated effect for Hawaii County. The gray lines represent the "placebo" effects for Kauai County and the City and County of Honolulu. Source: authors' calculations.

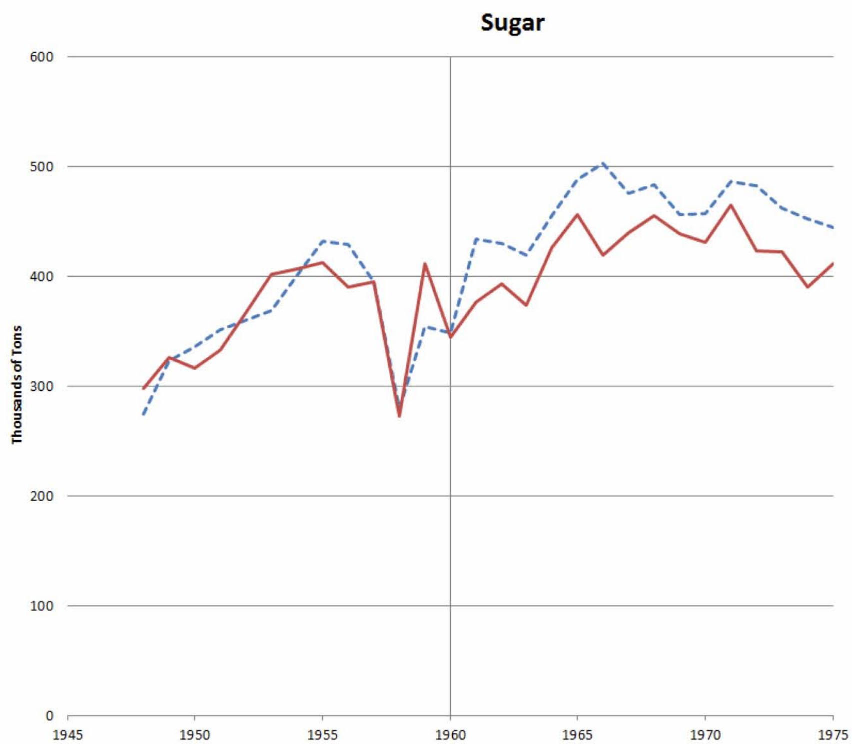

Figure 7: Sugar Production, 1948-1975. The synthetic control is the dashed line, while the actual series is the solid line. Source: Annual Reports, Chamber of Commerce of Hawaii.

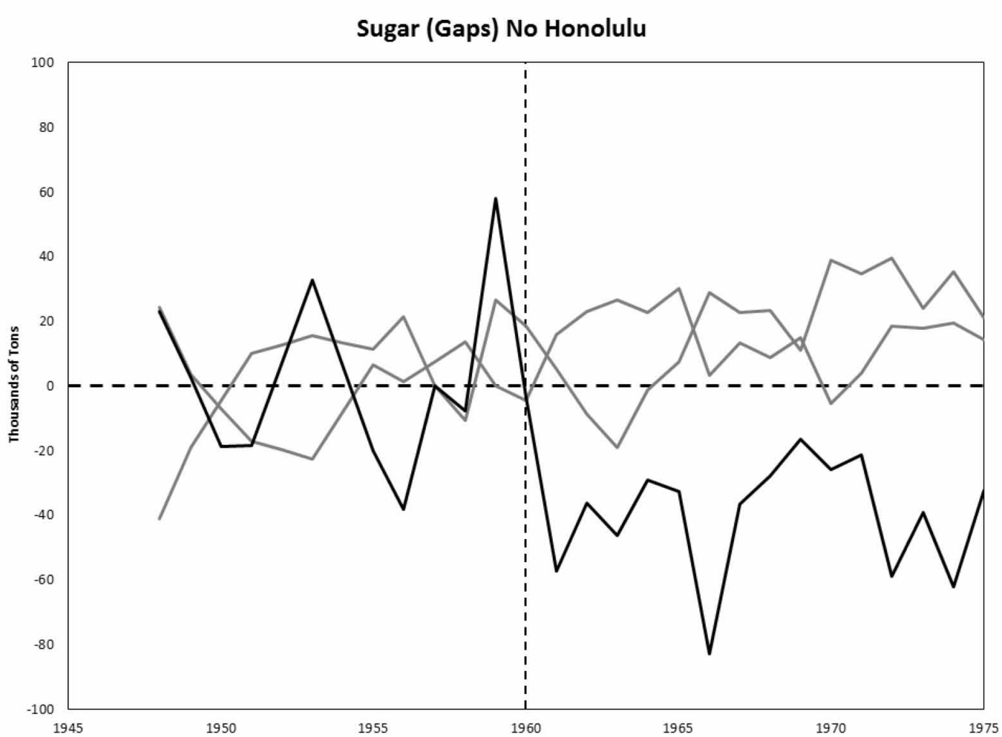

Figure 8: The black line represents the estimated effect for Hawaii County. The gray lines represent the "placebo" effects for Kauai County and Maui County. Source: authors' calculations.

Figure 1: Total Wages, 1951-1975. The synthetic control is the dashed line, while the actual series is the solid line. Source: Employment and Payrolls annual reports, Department of Labor and Industrial Relations, State of Hawaii.

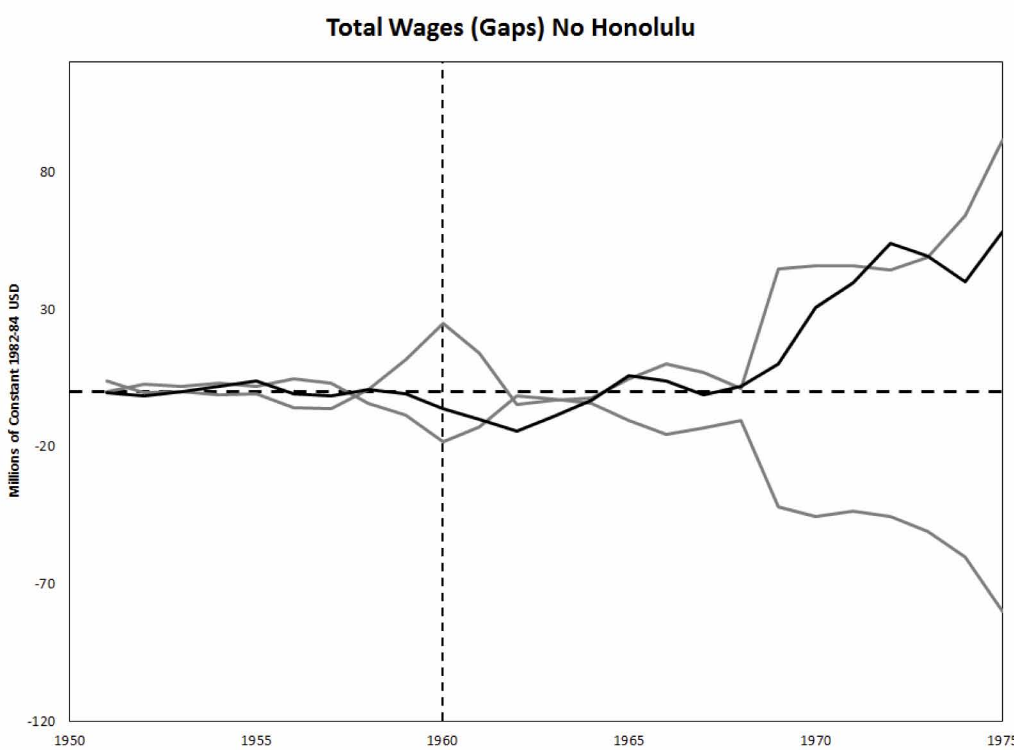

Figure 2: The black line represents the estimated effect for Hawaii County. The gray lines represent the "placebo" effects for Kauai County and Maui County. Source: authors' calculations.

Appendix

Job Count (figure A1) and Total Wages (figure A2) data, from the "Employment and Payrolls" reports, exhibit erratic behavior as seen in the percentage change figures below. We believe this is related to a series of legislative reforms affecting reporting requirements for agricultural employment beginning in 1957 and ending in 1961. The same volatility is not present in the Number of Employers (figure A3) data from the same source.

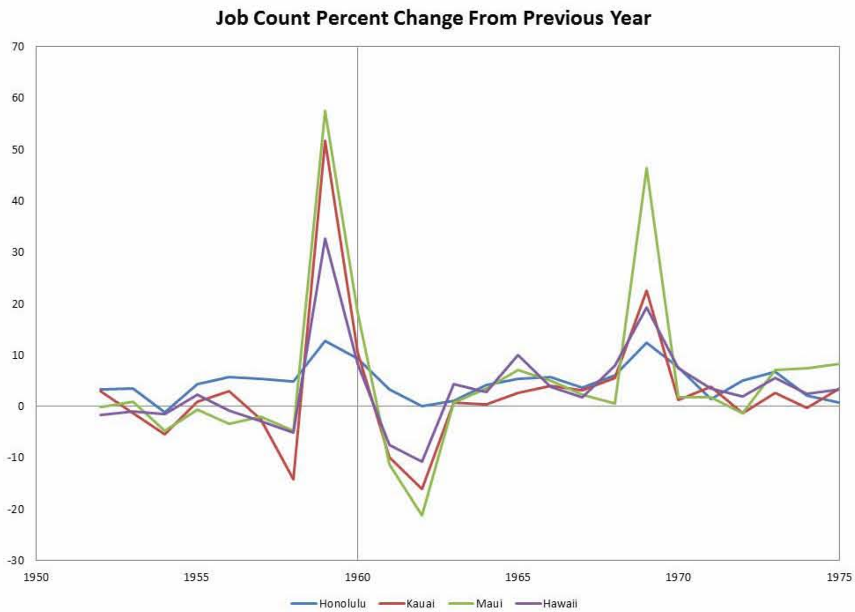

Figure A1: Percent change of Job Count from previous year, 1952-1975. Source: Employment and Payrolls annual reports, Department of Labor and Industrial Relations, State of Hawaii.

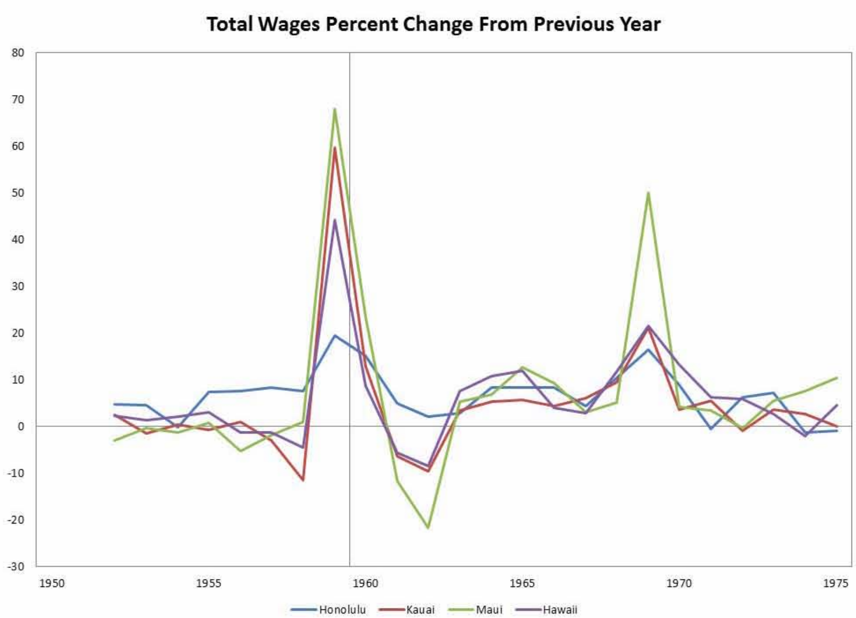

Figure 3: Percent change of Job Count from previous year, 1952-1975. Source: Employment and Payrolls annual reports, Department of Labor and Industrial Relations, State of Hawaii.

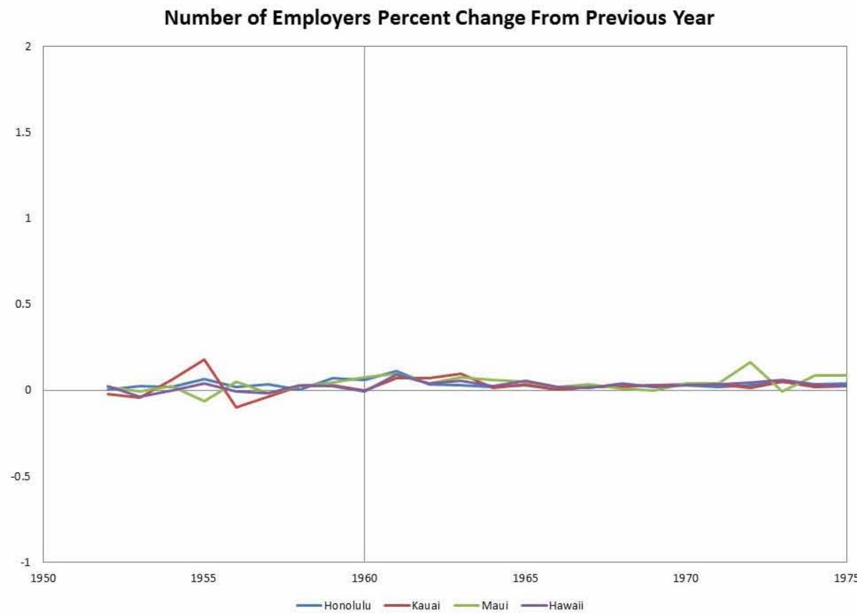

Figure 4: Percent change of Job Count from previous year, 1952-1975. Source: Employment and Payrolls annual reports, Department of Labor and Industrial Relations, State of Hawaii.