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Evidence from Barbados

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The Impact of Coastal Infrastructure Improvements on Economic Growth: Evidence from Barbados*

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Abstract

This paper presents the first rigorous impact evaluation of a shoreline stabilization program in Barbados and attempts to assess whether shoreline stabilization investments indeed have beneficial effects on medium-term economic growth in Small Island Developing States through stimulating tourism demand and real estate development. The analysis relies on a carefully designed geographic information systems (GIS) dataset, which comprises extensive panel data from Barbados' touristic West and South Coasts on key infrastructure, beach characteristics, and real estate activity, as well as remotely-sensed luminosity data as a proxy of economic growth. The synthetic control method is employed to construct a counterfactual from a combination of all control beach sites and subsequently estimate program impact on per capita luminosity as a proxy for GDP p.c.. Results indicate that even in the first three years after treatment, economic effects are positive and indicate a strong positive trend. This suggests that shoreline stabilization works may not only help preserve fragile ecological conditions, but further lead to sustainable growth in the local economy.

JEL Classification: O44; Q54; D04; N56

Keywords: Shoreline Stabilization; Economic Growth; Luminosity; Synthetic Control; Barbados

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1. Introduction

In most Small Island Developing States, or SIDS, there exists a crucial interdependency between the island's local environment and natural resources, and a sustainable growth of the economy. Importantly, in most small island countries, a large share of economic activity focuses on the provision of tourism services. Among the Caribbean islands, tourism generated an average of 14.2 % of the GDP and employed 2.2 million people – which represents 1 in every 8 jobs – in 2011 (Mahon, 2013). Given that tourism represents a narrow economic base that strongly relies on environmental features, the economic vulnerability of many SIDS in the face of ecological fragility has received increasing attention by local agents and governments, as well as the international community.

Beginning with the UN Conference on Environment and Development in the early 1990s, environmental problems due to climate change, and particularly the rise of sea levels, were identified as a major environmental challenge to the sustainable development of SIDS (Wong et al., 2014). At low altitudes above sea level, the steady rise of sea levels due to climate change as well as excessive coastal development is resulting in continuous coastal degradation and beach reduction (Ghina, 2003). This projected loss of beaches may result in severe impacts on the tourism industry and thereby be detrimental to the economic growth in many small island states whose local businesses, including hotels and restaurants, employment, and real estate markets rely crucially on tourist demand. Clearly, the attractiveness of SIDS as tourist destinations relies on the environment of generally warm temperatures, clear water, and fine, sandy beaches. In a survey of more than 300 tourists visiting the Caribbean island of Barbados, it was found that more than 80 % of tourists would be unwilling to return for the same holiday price if beach areas were reduced (Uyarra et al., 2005).

Recognizing the economic importance of maintaining shorelines and beaches in order to protect the livelihood of most local inhabitants, SIDS and other countries facing the issue of coastal degradation have taken measures to protect and rehabilitate shorelines, where topographic evaluations have shown that beach areas can successfully be rehabilitated in this way (Johnston and Ellison, 2014). However, despite the investment of large government funds in rehabilitation efforts, long-term evaluations of program impact are largely lacking in the literature and generally limited to the use of ex-ante cost-benefit analyses. Such studies have focused mostly on identifying the potential pecuniary benefits of counter-erosion efforts relative to the costs accruing due to engineering work and negative environmental impacts of project efforts. However, such studies are limited to estimating the potential, and not the de facto impact of erosion control on economic development, which depends not only on the actual outputs of such investments, but also on the direct response of beneficiaries to the improved quality of beaches and associated amenities.

In this context, this paper aims to present the first rigorous impact evaluation of shoreline stabilization efforts and takes advantage of a coastal infrastructure program in Barbados. The Coastal Infrastructure Program (CIP), which was implemented by the Ministry of Physical Development and Environment (MPE) of Barbados with support from the Inter-American Development Bank (IDB) between 2001 and 2010, comprises a range of coastal rehabilitation and management works. Specifically, the activity of shoreline stabilization focuses on creating coastal infrastructure to create and enhance the amenity value of beaches for local and tourist use and protect it from further erosion in three beaches on the southern and southwestern coast of Barbados. Among these three beaches, Rockley Beach located on the west coast received the largest investment and therefore represents the treatment unit for this study.

Under the hypothesis that shoreline stabilization can enhance overall access to and quality of publicly accessible beaches on Barbados' popular South and West coast, the coastal infrastructure program is therefore expected to support economic growth in Barbados. In order to assess the effect of the CIP on economic activity near individual beach sites, the analysis requires that economic activity be measured at a sufficiently small geographic level to capture the localized impact of the program. Unfortunately, beach-level disaggregated data for Barbados could either not be obtained or simply does not exist, as the overall small size of the island makes it more feasible to present data at the national level. To address the challenge that traditional measures such as the gross domestic product (GDP) or employment data are not available, we employ a different and rather novel indicator, namely remotely sensed nightlight density or luminosity. Since luminosity data captures human economic activity carried out during nighttime at considerably low levels of spatial disaggregation, an increasing number of studies have relied on nightlight density to approximate economic growth (Alesina et al., 2014; Storeygard, 2012; Agnew et al., 2008). To address a concern raised in the literature regarding the phenomenon of overglow, or blurring, of luminosity that may misattribute light from its emitting source to neighboring areas, we further employ a deblurring methodology recently proposed by Abrahams et al. (2015) so that the deblurred luminosity data renders a more appropriate proxy and accurate measure of economic activity at the beach level.

Given that the impact indicator, as well as the overall impact assessment are crucially linked to the location of the beaches that received shoreline stabilization measures, the study relies on a geographic information system (GIS) to create a multilayer visual map of the island that can combine geo-referenced panel data for luminosity with relevant beach characteristics, such as beach size and topography, as well as information on local real estate activity, infrastructure and demographic data. This carefully designed GIS dataset includes such information on a total of 23 beaches within a 40 km stretch along the south and west coast of Barbados. Importantly, while most of the pertinent beach characteristics are available only for one time period prior to treatment of Rockley Beach in 2007, information on the impact indicator is available at annual intervals from 1992 to 2010.

In order to identify the true causal impact of the CIP investments on local economic growth based on this extensive GIS panel dataset, the empirical approach needs to identify a valid counterfactual from the available pool of control beaches, all the while relying on a limited number of observations per time period. These two challenges are addressed by employing the synthetic control method as introduced by Abadie and Gardeazabal (2003), which uses a weighted average of all potential control units to construct a control group that can mirror the trajectory of the aggregate outcome in the absence of treatment. In this manner, the study estimates that the effect of the CIP program on economic activity at Rockley Beach accumulates to approximately 9 % in three years post-treatment. A number of placebo and sensitivity tests confirm that this result is robust, suggesting that extensive shoreline stabilization can indeed increase beach quality and hence promote medium-term economic growth of tourism-dependent small island development states.

The remainder of the paper is organized as follows: Section 2 lays out the conceptual framework that underpins the analysis. Section 3 then describes the data set used and discusses in more detail luminosity as an impact indicator for economic growth. Section 4 presents the methodological approach used and discusses potential empirical issues and how these are addressed. Results of the impact analysis and appropriate sensitivity tests are presented and analyzed in Section 5. Finally, Section 6 contains concluding notes and policy implications.

2. Conceptual Framework

Small Island Developing States, or SIDS for short, tend to rely on a narrow economic base due to their relatively small size, limited resources, and economic isolation (UN, 2010). Oftentimes, economic activity is focused solely on tourism, which contributes to a large share of GDP and employs a majority of the islands' population. In the Caribbean, tourism generated an average of 14.2 % of the GDP and employed more than 2 million people – 1 in every 8 jobs – in 2011 (Mahon, 2013). The appeal of the small islands as attractive tourist destinations crucially lies within their natural environment, including generally warm temperatures, clear water, and fine, sandy beaches. However, since the environment represents such an important economic asset upon which tourism activity, and consequently local businesses and employment, rely, it also makes the economies of many SIDS vulnerable to the fragility of their island's ecological system (Dixon et al., 2001). In addition to this direct economic stimulus, beach protection further affects the livelihoods and welfare of local residents if their homes and establishments are better protected from the potential economic losses caused by erosion and storm damage.

Given that the socio-economic progress in SIDS depends so critically on the islands' natural environment, environmental problems due to climate change represent a major challenge to the sustainable development of small island nations. The increasing rise of seas levels as a predominant result of global warming combined with excessive coastal development in most small island states has affected widespread erosion that adversely impacts tourist facilities, settlements, and infrastructure (Nurse et al., 2014). Currently, up to 70 % of all beaches worldwide are experiencing some erosion, and this is expected to further increase with the global rise of sea levels (Johnston and Ellison, 2014). This projected loss of beaches may result in severe economic impacts, as any degradation of the beach environment is likely to reduce the demand for coastal tourism and real estate, and directly as well as indirectly affect the income of beach-adjacent businesses and residents.

Conceptually, one can establish a clear link between coastal erosion and local economic growth by identifying the key beneficiaries of shoreline stabilization. The primary stakeholders in this regard are agents in the tourism industry, as well as businesses and local residents who rely on tourism activity for income. In a theoretical framework that establishes the link between coastal protection and tourism activity, tourist demand for recreational beach amenities is usually derived based on an individual's utility as a function of the number of visits to or days at the beach over a specified period of time, and other non-recreational goods and services (Ha, 2007). Given a budget constraint that consists of expenditures on recreational activities as well as all other goods, the demand for beach recreation can then be derived from a utility maximization and is usually conceived to depend on the costs of travel and on-site activities, individual income and socioeconomic characteristics, as well as the tourist's perception of the beach's characteristics (Bell and Leeworthy, 1990). In this context, the last variable is of special significance, as an individual's demand will depend directly on the quality of a beach's characteristics, including the amount of available space[††], overall cleanliness of beach and coastal water, and amenities offered on site (Shivlani et al., 2003).

Therefore, the utility a tourist derives from his or her recreational beach experience is increasing in beach quality, so that quality directly affects the overall demand for visits to and time spent at the beach location. Consequently, if beach erosion leads to a degradation of overall beach quality by diminishing space availability or the overall physical appearance of the beach, this would result in a decreasing demand for recreational activities by tourists there (Kragt et al.,

[††] It is assumed, especially in the Barbadian country context, that a larger beach size does not affect the supply of tourist accommodation (i.e. hotels and lodges), as the public nature of beaches prohibits construction directly on the beach, so that the available space for additional lodging facilities would not be affected by shoreline stabilization works.

2009). Note that the described relationship between beach quality and tourist demand is expected to be very similar for local residents, who are likely to also derive utility from a larger and improved beach space for their leisure and recreation activities. As a result, if the demand of tourists (and local residents) for time spent at the beach increases due to infrastructure works that stabilize and improve the coastline, it can be expected that this stimulates the local tourism industry and results in higher revenues for hotels, restaurants, and other beach-adjacent businesses. An additional positive effect may be a rise in employment opportunities at such businesses for local residents.

Other main stakeholders that stand to benefit from shoreline stabilization are owners of beach-adjacent properties. In this context, two distinct economic benefits to property owners and potential buyers are derived from the protection of beaches from erosion and other sources of degradation, as well as the improvement of beach amenities and quality. With regards to erosion protection, Cordes and Yezer (1998) propose a model of shoreline development shoreline in which coastline protection activities can stimulate additional real estate activity through a simple supply-side mechanism: Assuming that beachfront structures provide tourists and local residents with access to recreational services from which they derive benefits, a market demand for beach services can be derived. The market supply of such services, which requires the construction of adequate beachfront structures, then depends on the cost per unit of beachfront structure. However, the cost of constructing beachfront structures is crucially determined by the amount needed to cover depreciation and pay a competitive return, *plus* a premium to compensate investors for hazards associated with expected losses and damages to facilities from possible erosion (ibid). Therefore, shoreline stabilization can also positively affect the economic return to the construction of beachside structures, which will increase local real estate activity.

A second benefit to property owners may be derived from improvements to the scenic amenities and size of property-adjacent beaches. As Landry and Hindsley (2011) point out, coastal property values are crucially affected by spatially variable environmental amenities, which include the view on and quality of water, as well as a beach's size. Based on a hedonic property model, the authors show that beach width positively affects values of properties located in close proximity of the beach (ibid). If shoreline stabilization therefore increases beach size, it can be argued that property owners reap the benefit of seeing their property's value rise. In combination with lowered risk of damages from erosion and storm events, shoreline stabilization is expected to stimulate growth in the coastal real estate sector.

Based on the identification of the individual stakeholders that may benefit from shoreline stabilization, a beach erosion control program such as the CIP may positively affect local economic growth in a number of ways: First, because tourists value the improved quality and size of targeted beaches, increases in tourism demand benefits beach-adjacent hotels, restaurants, and other local businesses, generating additional income and employment opportunities. Second, as coastal properties face lower risks of potential damage from erosion and storm events, as well as increased valuation due to improved scenic amenities of targeted beaches, the local real estate sector is expected to be stimulated as well. Overall, this should be reflected in a significant increase of local economic activity as a result of the shoreline stabilization program.

Of course, the identified relationship between shoreline stabilization and local economic growth depends on certain assumptions about the nature of beach protection efforts and need not necessarily be positive if these assumptions do not hold. To some extent, growth in the tourism and real-estate industry can indeed be damaging to the local ecosystem, where overcrowding of tourists and excessive coastal development may accelerate beach erosion and therefore adversely affect economic growth in the long run (Ghina, 2003). As Garcia and Servera (2003) illustrate for the Mediterranean island of Mallorca, a sudden, rapid growth of tourist demand and resulting chaotic development of tourist facilities can result in significant degradation of beach size and quality. It is therefore important to take into consideration both the positive and adverse effects of a shoreline stabilization program to identify whether the net effect on economic growth remains positive. However, the size of these potentially adverse effects need to be evaluated relative to the significant economic costs that would have occurred due to structure damage, loss of land, and decreased tourism demand in the absence of erosion control works implemented under the CIP (Kriesel and Friedman, 2003). Taking this into consideration, it is assumed that the potential adverse effects resulting from the CIP are outweighed by the avoided costs resulting from economic losses caused by beach erosion.

Nevertheless, a sustainable and scientifically motivated coastal management strategy appears crucial to preventing adverse effects of shoreline stabilization (Garcia and Servera, 2003). In this context, the Government of Barbados has made large strides in pursuing a strategy of integrated coastal zone management that is able to support the island's tourism industry while ensuring coastal resilience. In 1996, the Coastal Zone Management Unit (CZMU) was instituted as a permanent government agency that is responsible for monitoring and managing the complex physiological processes of Barbados' shoreline. Importantly, the CZMU represented a key stakeholder in the design and execution of the CIP, and ensured that all shoreline stabilization works were preceded by a careful analysis of shoreline dynamics and identification of potential economic and environmental impacts (Halcrow, 1999). Assuming that the careful design of the program took into account the potential for adverse impacts of the program that can prevent damaging tourist overcrowding and excessive coastal development, it is expected that a positive relationship between shoreline stabilization and local economic growth prevails in the case of Barbados and the Coastal Infrastructure Program.

Having argued that the maintenance and improvement of beach quality appears to be an important task for economies that rely on the economic value of their shoreline, and given the fact that positive impacts on local economic activity would likely accrue to private agents, such as real estate investors, hotel, and business owners, it may be surprising that most shoreline stabilization projects are in large part funded by public sources. This general need for public intervention has been referred to in the literature as "the tragedy of the tourism commons", with reference to the occurrence of overuse and underinvestment that typically arises from the unregulated use of a public good, which is rival, but non-excludable in its consumption (Briassoulis, 2002). This issue concerning the management of common property resources (or CPR) is relevant with respect to beaches because even though erosion is a direct result of overuse by private agents, and any revenues generated by improved beach amenities would be captured almost exclusively by hotel, business, and property owners, the lack of clearly assigned property rights leaves the social costs of erosion and its prevention in the hands of public sources (Ostrom, 2008).

This applies especially to SIDS where, including on the island of Barbados, beaches cannot be privatized since the foreshore is designated as public land (Cambers et al., 2003). Therefore, even though private agents might gain from investing in the quality of nearby beaches by attracting more tourists, they have little incentive to do so given that they do not own exclusive property rights to the stretch of beach to which they are adjacent (Healy, 1994). With regards to the social cost of overusing beach resources, individual private agents tend to ignore the adverse effects of their usage because they expect others to capture the benefits of beach amenities in their absence (Wade, 1987). In other words, due to the "multiple, overlapping, and potentially conflicting uses and user groups", it becomes almost impossible to clearly assign the benefits and costs incurred through a beach nourishment project to individual, private agents

(Briassoulis, 2002). Public administration is therefore often the only solution of this collective action problem if erosion and the resulting decrease in tourism, business revenue, and property values are to be avoided. To some extent, costs can be recovered in the form of taxation, where the largest effect is often expected through a rise in land tax revenues – as is the case in the coastal infrastructure program in Barbados (IDB, 2001). Nevertheless, sustaining the shoreline and the important economic benefits it brings requires an effective coastal protection strategy that takes into consideration the most efficient allocation of limited public resources.

In recognition of the potential economic benefits of shoreline protection, governments and international institutions have invested heavily in coastal stabilization projects. With respect to the Coastal Infrastructure Program in Barbados, for instance, the government invested funds in the amount of $13.5 million, while the Inter-American Development Bank provided support with a loan of an additional $16.8 million (IDB, 2011). In southern Europe, efforts were made to rehabilitate coastal dunes affected by erosion due to heavy tourist volumes: In Spain, beaches and dunes were successfully restored in the 1990s using fencing and elevated boardwalks to reduce effects of trampling, while dune erosion in western France was successfully reversed in the 1980s using vegetation replanting (Johnston and Ellison, 2014). Therefore, studies relying on the topographic evaluation of rehabilitation success suggest that shoreline stabilization programs can indeed maintain and improve the size and quality of coastal areas important to tourism, and therefore local economic growth.

However, despite the investment of large government funds in rehabilitation efforts and the conceptual identification of considerable economic benefits, long-term evaluations of the economic impact of shoreline stabilization projects is largely lacking in the literature. Based on the review of available studies, the assessment of beach rehabilitation efforts has thus far focused on identifying potential beneficiaries of shoreline stabilization and estimating the likely pecuniary effects of counter-erosion efforts. Such ex-ante cost-benefit analyses have relied on several approaches. While the cost component of such analyses generally measures the engineering expenditures, opportunity costs, as well as the costs of negative environmental impacts, the measurement of project benefits has varied widely. A traditional approach to measuring the benefits of shoreline stabilization projects in the form of recreation demand for a particular beach relies on the travel cost method to provide an estimate of consumer surplus derived from the intervention (Hang et al., 2006). Others, such as Parsons et al. (2000) and Hang et al. (2006), study the benefits derived from beach recreation sites in the context of a random utility framework. For instance, Hang et al. (2006) rely on a survey of coastal households in New Hampshire and Maine to assess the welfare effects of different beach erosion control programs using two empirical choice models. Based on the conditional logit and mixed logit models that they employ, they find that the welfare induced by an erosion control program depends on both the positive (amount of beach preserved) and negative effects (visibility of protective structures, impact on water quality and beach access) that the program entails (ibid). Others, such as Silberman et al. (1992), also include the benefits accruing to non-users of the beach by employing the contingent valuation method in an attempt to represent a more holistic measure of willingness-to-pay for erosion control programs (ibid).

Beyond the benefits accruing to recreational users of treated beaches, previous evaluations of shoreline stabilization programs have further considered the effects on the values of properties near the coast. Among others, Pompe and Rinehart (1995), Landry et al. (2003), and Gopalakrishnan et al. (2010) rely on a hedonic property price analysis to estimate the effect of beach quality on coastal property values. Using beach width as a proxy of beach quality, these authors find that the marginal willingness to pay for a unit increase in beach quality ranges from \$143/foot in South Carolina to \$1,440/foot in North Carolina (Landry, 2011). In this context, Landry (2009) provides a detailed review of the varying approaches to hedonic price analysis that have been employed and introduces a dynamic optimization model as a more rigorous methodology that incorporates the complexity of beach dynamics using a state equation for beach quality and erosion (ibid).

It should be clear from the approaches described above that studies employing such a cost-benefit analysis assess the potential impact of the program on select beneficiaries, meaning that they estimate how much value can potentially be created by maintaining or improving a beach in terms of its valuation by beach users or the additional value accruing to a business or land owner, relative to the cost of the program. However, none of these approaches are able to assess the real, de facto impact of erosion control on economic growth, which depends not only on the actual outputs of such a program, but also on the direct response of selected beneficiaries to the improved quality of beaches. The assessment of the actual impact of a beach erosion control program would then require the availability of adequate panel data for tourism-related facilities and real estate investment properties both before and after the implementation in order to conduct a rigorous impact evaluation. In this context, only Cordes and Yezer (1998) use panel data on over 40 coastal communities along the East Coast of the continental U.S. and Florida over the time period of 30 years between 1960 and 1992 to assess how varying levels of exposure to federal beach erosion control programs affected economic development, as measured by the issued number of new building permits (ibid). They find that economic growth in beachfront communities resulted from generally rising levels of income and employment in inland areas rather than public investment in shoreline protection (ibid). However, the authors considered only the effect on property values and did not take into account the potential increases in tourism demand that are likely to occur.

To this date, therefore, Cordes and Yezer appear to provide the only rigorous assessment of the de facto impact of shoreline stabilization on economic development. However, their analysis remains limited to the construction of new buildings and falls short of assessing the impact on local businesses and other factors that may contribute to overall changes in economic growth as a result of the investments. Therefore, rigorous evaluations that provide a more comprehensive assessment of shoreline stabilization projects are still lacking in the literature, and especially so for small-island developing countries. Considering how important the maintenance and rehabilitation of shorelines is for the local economy, in which tourism usually represents a large source of income for most SIDS, any complete evaluation of a coastal rehabilitation project needs to take into account all sectors that may benefit from shoreline stabilization. It is therefore crucial to capture the overall, aggregate impact of coastal protection efforts in order to inform policy can help allocate resources more effectively.

In order to assess the impact of shoreline stabilization efforts on local economic growth in a way that accounts for all potential channels of impact, including the tourism and real estate sectors, an adequate impact indicator should capture all economic activity near the treated beach sites. However, since traditional measures of economic activity, such as the gross domestic product (GDP), employment indicators, or even household-level survey measures of income and employment, are not available for sufficiently small administrative areas in Barbados, this study relies on a different and rather novel indicator for local economic growth, namely remotely sensed night light density or luminosity data, which detect Earth-based lights (Henderson et al., 2012). While it was pointed out as early as 1978 by T.A. Croft that nighttime light might reflect human economic activities on the ground, it was not until the data became systematically digitized and publically available in 1992 that attempts were made to utilize luminosity data to approximate economic and demographic activities (Sutton, 2011). Elvidge et al. (1997) were the first to attempt and use the remote sensing data for the purpose of economic analysis by estimating population, GDP, and electricity usage globally (Keola et al., 2015). Since then, an increasing number of contributions to this literature has emerged, and authors such as Sutton and Costanza (2002), Doll et al. (2006), Ghosh et al. (2010), and Henderson et al. (2012) have attempted to assess the viability of night light intensity as a proxy for traditional measures of economic activity such as the GDP (ibid).

A number of recent papers have employed luminosity data as a proxy for GDP growth at low levels of spatial disaggregation. For instance, Alesina et al. (2014) rely on nighttime light data combined with the historical location of ethnolinguistic groups to construct an index of ethnic income inequality in over 150 countries, finding a strong negative correlation with contemporary comparative development. Storeygard (2012) investigates the effect of inter-city transport costs on urban economic activity in sub-Saharan Africa as proxied by luminosity data, and finds that an exogenous oil price shock that hikes transportation costs lowers income in remote cities relative to cities located on the coast. Agnew et al. (2008) even go as far as conducting analyses of intra-city economic development, as they assess the effect of the U.S. military surge into specific neighborhoods of Baghdad in 2007 on levels of violence and consequently the quality of life. Overall, these studies support the concept that the intensity of night lights reflects both outdoor and indoor use of lights, which is required for consumption of almost all goods past night fall. It can then be postulated that as income rises, the increase of both consumption and investment activities should be reflected in a rising lights usage per person (Henderson et al., 2012).

Consequently, this study relies on luminosity as a proximate measure of local economic activity to conduct an economic evaluation of a coastal infrastructure program in Barbados. This rigorous study attempts to fill an apparent gap in the literature by providing evidence that shoreline stabilization supports sustainable economic growth by protecting tourism, real estate, and other local businesses from the negative effects of beach erosion. Barbados is the most easterly island in the Caribbean and a popular tourist destination due to its pleasant climate, warm temperatures, and year-round sunshine. Like many other SIDS, a large share of the Barbadian economic activity focuses on tourism, with more than two-thirds of its foreign exchange earnings being derived from this sector (Cashman et al., 2012). The program, which was implemented by the Ministry of Physical Development and Environment (MPE) of Barbados with support from the Inter-American Development Bank (IDB) between 2001 and 2010, comprises a range of coastal rehabilitation and management works including (i) shoreline stabilization and erosion control, (ii) restoration of coastal habitats, (iii) improvement of amount of public coastal access, and (iv) institutional strengthening for coastal management. Specifically, the activity of shoreline stabilization, which received \$27.2 million out of \$30.5 million, or 90 % of the project's total budget, focuses on creating coastal infrastructure to create and enhance the amenity value of beaches for local and tourist use in three beaches on the southern and southwestern coast of Barbados (IDB, 2011).

Shoreline stabilization efforts included three core infrastructure projects at the coastal stretches of Rockley to Coconut Court (hereafter referred to as Rockley Beach), Holetown Beach, and Welches Beach. In Rockley, this included constructing 38 meters of breakwater and five landscaped headlands to prevent future erosion, as well as recharging more than 10,000 m^3 of beach sand, and building a boardwalk with a length of 1.2 km, as well as revetments and steps for added amenity value. At Holetown Beach, two headlands and a walkway with boulder revetments were constructed, and approximately 2,300 m^3 of sand recharged. Lastly, the Welches Beach Improvement Project saw the construction of a retaining wall with walkway, new access steps to the beach, revetments and three new groynes, as well as sand recharging of 12,000 m^3.

While a total of three beach sites were targeted by the program, the analysis will focus on Rockley Beach as the beach that received the largest share of the investment (US$9.1 million compared to US$3.1 million and US$1.4 million invested in Holetown and Welches respectively[‡‡]). In comparison to Holetown and Welches Beach, construction in and around Rockley Beach was of a significantly larger scale, and entailed not only sand replenishment, the construction of groynes and sea walls, but also the construction of a scenic boardwalk that has attracted residents and tourists alike and has provided increased lateral access to the beach front in an area were many hotels, restaurants, and stores are located. Given these drastic improvements to the beach size and quality at this location, it is expected that any positive effects of the program would be greatest at Rockley Beach.

In concurrence with this impact evaluation, Banerjee et al. (2016) conducted a retrospective stated preference study to confirm that identified stakeholders benefited from the program by assessing the willingness-to-pay of tourists and residents for the maintenance of the improved beach sites, as well as the avoided costs by local business owners as a result of CIP.[§§] Based on the resulting estimates, the authors find that the annual value that tourists place on the improved beach amenities is $20.7 million BBD, while this value is approximately $4.5 million BBD for residents (ibid). While the number of interviewed businesses was too small to make precise statement about the impact of CIP on revenue and employment, it does appear that businesses close to treated beaches made significantly larger investments, and enjoyed higher revenue growth (if their revenue did in fact increase) than at untreated beaches (ibid). These

[‡‡] BA-0019 Project Completion Report

[§§] Tourist and resident surveys were conducted at Rockley and Holetown Beach, while the business surveys included businesses located near all three treated beach sites as well as five additional beaches that were not improved.

results provide complementary insights into the effectiveness of the program through the conceptually identified channels and render motivation for the estimation of program impact on local economic growth.

In summary, considering how important the maintenance and rehabilitation of shorelines is for economic growth in most SIDS, and that, to date, the effectiveness of such projects has been exclusively assessed with cost-benefit analysis techniques, this paper attempts to fill the apparent gap in the literature by conducting a more rigorous impact evaluation of shoreline stabilization efforts. Under the hypothesis that shoreline stabilization enhances overall access to and quality of publically-accessible beaches on Barbados' popular South and West coast, this study of a coastal infrastructure program provides evidence that such a project can support economic sustainability in Barbados, specifically due to an increased valuation and use of beaches by tourists, as well as improved attractiveness of the location to tourists and residents alike. Based on these outcomes, increases in activity within the tourism and real estate industry near treated beaches should be reflected in significant growth of the local economy. If extensive shoreline stabilization can indeed increase beach quality and hence promote economic growth of tourism-dependent small island development states, a significant impact should be found, where it is expected that, in comparison to non-targeted beaches that present a valid counterfactual, the area surrounding targeted beaches experiences significantly more growth in touristic and other economic activity, as proxied by remotely-sensed night light density.

3. Data Description

3.1. Dataset Design

The evaluation relies on the use of a comprehensive dataset and appropriate econometric methodology to adequately create a valid counterfactual and subsequently identify impact. Since the evaluation is designed and conducted post-implementation, an extensive data collection informs the identification of a valid counterfactual with respect to beach areas that are similar to beaches targeted under the CIP in a number of key attributes, including beach topography as well as characteristics of the surrounding infrastructure and demography. Geographically, the dataset is restricted to the tourism-heavy West and South Coast of Barbados, which represents an approximate 40 km of shoreline between Maycocks Bay in the West and Enterprise Beach in the South, along which all three treated beaches are located. Since the North and East Coast of Barbados face the Atlantic Ocean and are subject to rougher seas and higher wave intensity, little of the typical beach and sand tourism takes place along that stretch of the coastline, so that beaches there differ dramatically from beaches within the designated study area. Furthermore, because the area of influence of the CIP is restricted to the coastal zone, the dataset includes information within a distance of approximately 1 km inland from the shoreline.

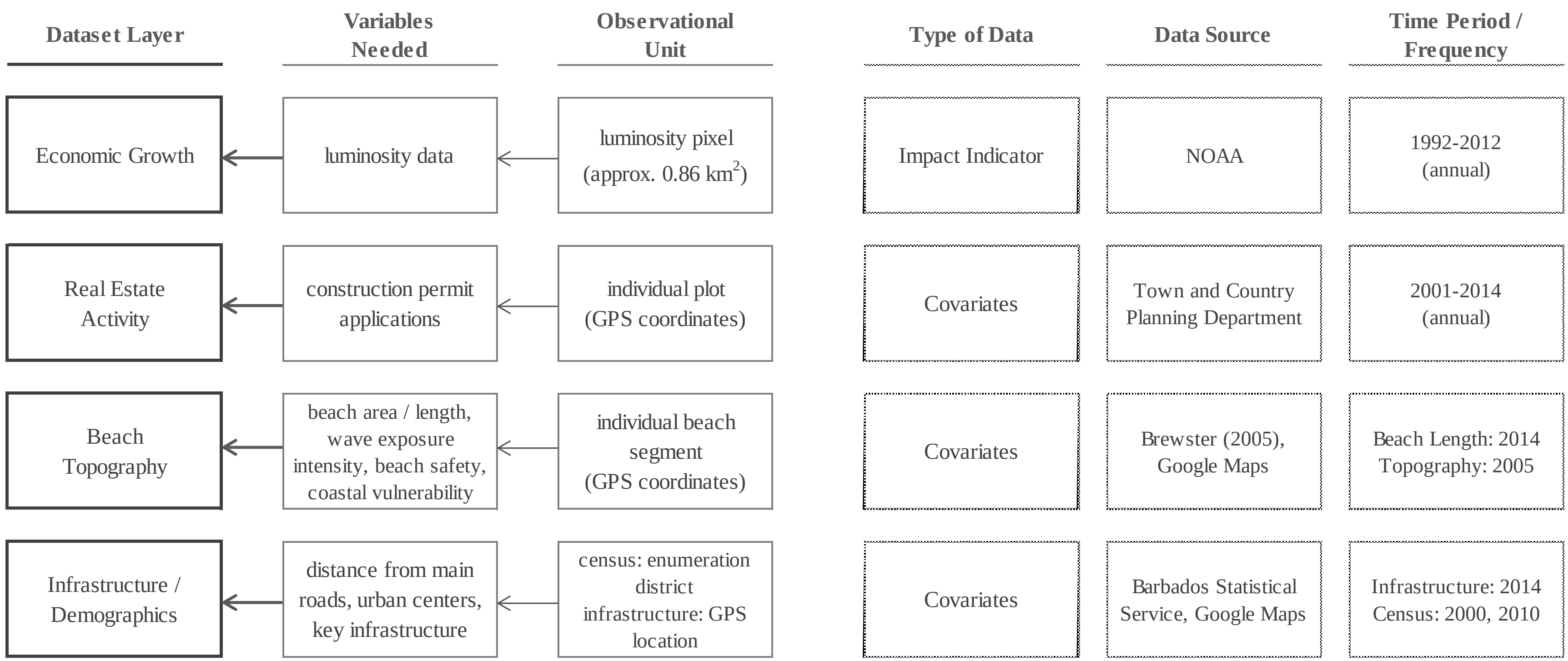
Given that the selection of a valid counterfactual, as well as the impact indicator and beach-level characteristics are crucially linked to the location of the beaches in question, a logical design of the evaluation method is to rely on a geographic information system (GIS), which allows the combination of spatial information for relevant beach characteristics, such as the location of tourist amenities, with other types of information, including the night light density data, as well as infrastructure and demographic data. With the tool of GIS, this can be combined to create a multilayered visual map of the island, and enables a researcher to “identify patterns or relationships between [the] program’s environment and its performance” (Azzam and Robinson, 2012). To this date, GIS has only rarely been used in the context of impact evaluations since its initial introduction to the field in 2002 by Renger et al. (ibid). As a tool, GIS provides the opportunity to incorporate contextual features of the program into the evaluation design and organize such complex data into a single map with multiple geographical layers. Importantly, the impact of the Coastal Infrastructure Program is inherently geographical, as effects are expected to occur within a certain proximity to targeted beaches.

Related to the geographical nature of the evaluation is the key challenge of identifying a unit of observation in the GIS dataset. Whereas traditional longitudinal or panel data relies on the identification of a unit of analysis that links all relevant information to the individual person, household, or community that are at the center of the empirical study, spatial analysis introduces an additional analytical hurdle that needs to be addressed with great care. Given that all relevant data is tied to a geographic location, the size and shape of the dataset's observational unit must be chosen carefully, as manipulation, aggregation, or interpolation of said shape and size may significantly affect data values (Azzam and Robinson, 2012). Specifically, this geographical issue is called to MAUP, or "modifiable areal unit problem", and refers to the correlation and autocorrelation between variable changes and different spatial scales (Anselin, 1992). Keeping in mind that such spatial clustering can occur in the process of aggregation, the unit of analysis can be a pixel or cell in a user-defined grid, or an administrative unit, such as a parish or constituency. Each such unit in the GIS then represents a single observation for which all variables collected and georeferenced in the multi-layered dataset take on a single value (Blackman, 2012). In the subsequent discussion, a main focus lies on the identification of an adequate unit of observation for each impact indicator, taking into account both the available data as well as the purpose of the analysis.

Since this study focuses on the impact of a program administered at the beach level, a logical choice for the unit of observation is the individual beach within the study area. Because not all beaches in Barbados have natural boundaries such as sea walls or groynes that separate them, the analysis will rely on the division of beaches into so-called "segments" as used by the country's Coastal Zone Management Unit. These segments usually consist of one to four smaller adjacent beaches that often typically lack distinct physical boundaries and together form a longer stretch of beach, usually of a length between 500m to 1km. Along the coastline, the boundary of each beach segment is easily identified. It further makes sense to limit the extent of each beach segment (as a unit of observation) to 1 km inland, as most commercial business, including tourism amenities, are located within this thin stretch along the coast. Therefore, each unit of observation is manually created based on the geographical outline of the coast, the identification of individual beach segments following CZMU guidelines, and the 1 km radius inland. As aforementioned, the study area is restricted to the tourism-heavy West and South Coast between Maycocks Bay in the West and Enterprise Beach in the South. Within this 40 km stretch, a total of 23 beach segments are located, three of which received treatment under the CIP.

Once the overall study area and the unit of observation are identified, a GIS dataset is being set up for the purpose of a spatial and temporal analysis within the framework of this impact evaluation. Figure 1 presents the design of this dataset with respect to its individual data layers, the specific variables needed for each layer, the observational unit, as well as the type of data and source from which it is obtained. The GIS consists of four geographical layers that contain all necessary information on the impact indicator and covariates. Figure 10 in the appendix displays a map to demonstrate visually how the GIS dataset was created.

At the very bottom of the four categories is the base layer, or map, upon which all other layers are projected. This consists of the geographical outline of the island of Barbados and should include some key locational information, such as basic infrastructure and demographic data. Specifically, besides the border of Barbados, it is important to include the boundaries of any smaller administrative units – in this case the parish –, as well as road networks, the location of key infrastructural sites such as urban centers, airports, harbors, as well as population density information. Most of this information could be obtained using Google Earth, which provides the



Note: Dataset layers are organized by the category of required data (impact indicator or category of control variables). The observational unit varies with the type of impact indicator (specifically for the luminosity data), but the data is all aggregated to the individual beach segment.

Figure 1. *GIS Dataset Design*

most recent state of infrastructure, but of course with no variation over time. However, it was verified with the Barbados Lands and Surveys Department that the major road network and key infrastructure had not changed significantly during the 1990s and 2000s in this tightly populated coastal stretch. In order to link this data to the individual beach segment, these infrastructural variables will be measured in terms of distance from the center of the beach segment to the respective road, urban center, or key infrastructural location.

Additionally, key information on land use surrounding individual beaches is obtained from the doctoral work of Leonardo Brewster, the former director of the Barbados Coastal Zone Management Unit (2005). Brewster focused on applying littoral vulnerability assessment (LVA) to the coastal management of the island and conducted a detailed analysis of the south and west coast's beaches. For the purpose of this analysis, the coastal land use was categorized into vacant lots, tourism facilities (hotels, restaurants), residential facilities, as well as government facilities. Since this information was compiled prior to the beginning of construction under CIP, these land use variables provide a helpful characterization of individual beach segments. Lastly, information on population density is obtained from the census data provided by the Barbados Statistical Services (BSS) for the years 2000 and 2010. Since this census data is measured in smaller spatial units denoted by enumeration district, population size could be easily aggregated to the beach segment level.

The second layer provides information on beach topography, which is a crucial determinant for the purpose of finding adequate control beach segments. Such measures of beach topography include the total area within the segment with sand coverage, as well as beach and shoreline length, where the first measures the total length of the longest axis in each segment, and the latter measures the total length of shoreline within the segment. Furthermore, additional information from Brewster (2005) provides a measurement of coastal vulnerability within each beach segment. In the course of the littoral vulnerability assessment, Brewster created a number of coastal vulnerability measures, including the degree of coastal wave exposure, beach safety, and beach vulnerability. Note that since additional information on specific beach amenities is not available, beach quality is captured here in terms of the recreational potential of individual beaches. Specifically, it is assumed that the level of wave exposure at and safety of a beach affects if tourists can enter the water to swim, snorkel, and conduct similar recreational activities, which will affect the quality of the beach as perceived by them.

The wave exposure and intensity (WEI) index assesses how susceptible a shoreline stability along individual beaches are to wave attack and uses physical oceanographic variables, including wave height, wave period, wind speed and longshore current within two one-month periods to construct a categorical score of “highly exposed”, “exposed”, “fairly sheltered” or “sheltered” and with values ranging from 1 to 12. Brewster also assesses beach safety from a recreational perspective as a measure of typical wave height, categorized into “safest”, “moderately safe”, “low safety”, and “least safe”, with a score ranging from 1 to 10. Lastly, the most elaborate measure uses factor analysis to determine overall coastal vulnerability based on 28 variables measuring morphology and sedimentology, prevalent lithology, presents of land forms and human intervention, littoral processes, and trends in shoreline evolution. The resulting coastal vulnerability index (CVI) assigned each beach segment a percentage score, where a higher score implies higher vulnerability with regards to shoreline stability and extent of beach erosion. Given the purpose of the CIP program and that these variables were measured prior to the beginning of the program, these indices represent pre-treatment characteristics that can help adequately identify control beaches for the analysis.

The third layer captures real estate activity near treated beach sites. The variable available to measure real estate activity is the number of construction permit applications from the Barbados Town and Country Development Planning Office (TCDPO). Since 1990, the TCDPO has registered all applications for a permit to begin construction on a land parcel on hard-copy maps of the island. For each application, the office logs the date on which the permit was received, when it was reviewed, and the final decision status, as well as the street address pertaining to the permit, and what type of construction is intended on the parcel. In an effort to digitize this information, the TCDPO has begun entering this information into a GIS system, for which data beginning in 2001 is complete and was made available. During the time period of 2001 to 2015, a total of 13,657 permits were granted, and over 12,000 of these are for residential real estate purposes. For the purpose of this analysis, the number of permit applications that were accepted per year are aggregated at the beach segment level, as it is assumed that actual construction as proxy for real estate activity would begin in closer proximity to the date the permit was granted, rather than the date it was submitted. Based on the hypothesis that real estate activity affects overall economic growth at the local level, this annual permit application data will be helpful in the selection of appropriate counterfactual beaches.

Lastly, the fourth and final layer refers to the central impact of the program that focuses on overall economic growth on and near treated beaches. Unfortunately, traditional measures of economic activity for Barbados, such as the gross domestic product (GDP), employment status at the household level or changes in employment rate at the business level, as well as business revenues are not available at sufficiently disaggregated levels to assess the localized nature of the CIP’s impact. For the small island of Barbados, data is usually presented aggregated at the country, or, sub-nationally at the parish level, which is too large of a spatial aggregation to capture changes in economic activity near treated beaches. Given the unavailability of traditional measures of economic activity at sufficiently small administrative areas necessary for the purpose of this impact evaluation, the study relies on remotely sensed night light density data available from the National Oceanic and Atmospheric Administration (NOAA) to approximate economic growth. Specifically, this night light density, or luminosity, data has been recorded since the 1970s by satellites from the United States Air Force Defense Meteorological Satellite Program, or DMSP for short, which use so-called Operational Linescan System (OLS) sensors to detect Earth-based lights (Henderson et al., 2012). In contrast to most other economic or demographic indicators that are based on estimates and censuses, light emission can be measured instantaneously, objectively, and systematically in this way (Cauwels et al., 2014).

The raw data that becomes available from the satellites, which observe every location on the planet at a nightly interval, undergo extensive processing before being publicized. Light sources that may disturb the measurement of human-made luminosity, including forest fires, auroral activities, and extensive lunar light, are removed, and data is then averaged from all valid, cloud-cover free observations in a given year (ibid). The available satellite-year dataset reports intensity of lights in a latitude-longitude grid of 30 arc-second output pixels, which approximates 1 km^2 near the equator (ibid). Night light intensity is then represented as the index of an integer scale from 0 to 63, zero meaning no light and 63 being the most intense (Keola et al., 2015). To date, annual data is available from 1992 to 2013. Based on latitude-longitude coordinates inherent to the luminosity data, the observational unit for the luminosity index will be the rectangular pixel of 30-arc seconds, in a grid that is imposed on the map of Barbados.

In this manner, all relevant information for this impact evaluation is projected onto a visual map of Barbados that includes information on infrastructure, demographics, beach topography, real estate activity, as well as the impact indicator luminosity as a proxy for local economic growth. Once all of these variables have been assigned a geographical location on said map, the information can be linked to the targeted beach segments and any effects of the investments made can be attributed to changes in the impact indicator under the use of the adequate methodological approach.

3.2. Luminosity as a Proxy of Economic Activity

Since NOAA made Earth-based lights captured by satellites publically available in the early 1990s, an increasing number of papers have relied on luminosity as a proxy for income and GDP growth. Numerous studies, including those by Elvidge et al. (1997), Sutton and Costanza (2002), Doll et al. (2006), Ghosh et al. (2010), and Henderson et al. (2012) have attempted to assess the viability of night light intensity as a proxy for traditional measures of economic activity. In this context, there appears to exist a positive, linear relationship between a rise in economic activity and greater lights usage per person (Henderson et al., 2012). However, given that so many studies now rely on luminosity as a proxy for income and GDP growth, it becomes important to assess the exact relationship between these economic measures and their proxy. While the exact relationship varies by country context, reasonable estimates indicate an elasticity of around one between income and luminosity.[9] But as the level of spatial disaggregation increases, issues of measurement error inherent to the luminosity data need to be addressed.

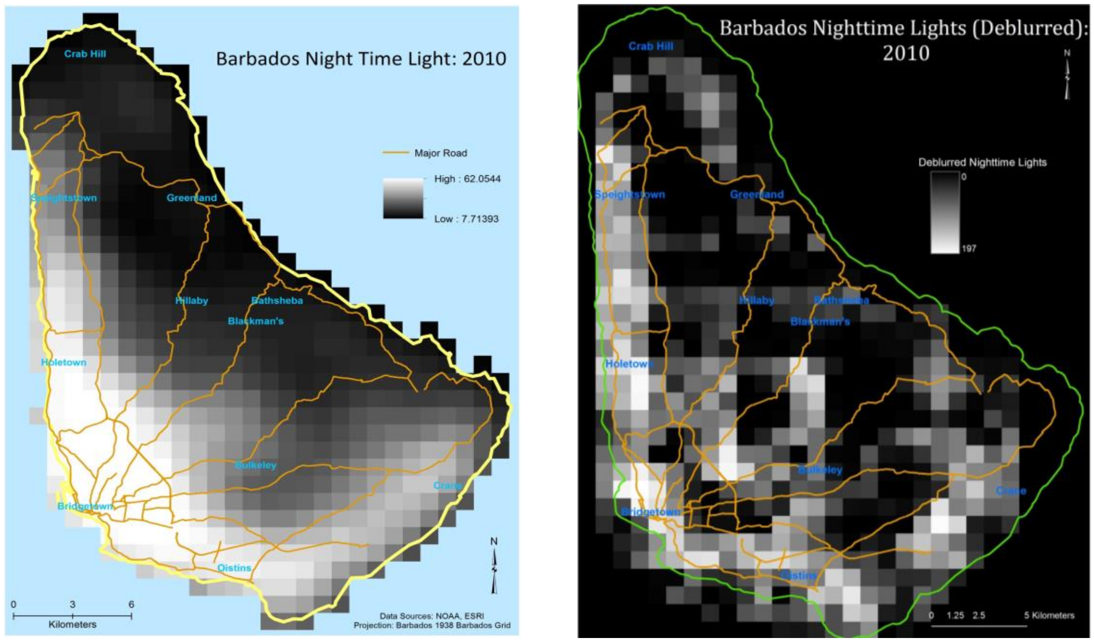
The measurement of Earth-based lights is imperfect, but the "raw" data undergoes a considerable correction process to eliminate as much measurement error as possible. Various optical and atmospheric distortions, including water vapor, fires, lunar illumination, and sun

[9] For country-specific estimates, please see Elvidge et al. (1997) or Henderson et al. (2012). Others, such as Sutton and Costanza (2002) or Ebener et al. (2005) find a high correlation between GDP measures and luminosity.

glare, as well as errors in scanning and mapping are removed to present a stable measurement of human-created lights (Chen and Nordhaus, 2011).[10] However, a remaining issue of the remotely-measured luminosity data is that luminosity imagery may suffer from so-called overglow, or blooming, which refers to the phenomenon of blurring that misattributes light from its emitting source to neighboring areas (Croft, 1978). Specifically, as several studies have found, cities may appear magnified to approximately 10 times their true size based on the luminosity estimate (Small et al., 2005). Of course, at lower spatial levels of economic analysis, overglow may represent a serious challenge as it implies a tendency to significantly overestimate economic growth based on luminosity. In the context of this study, where individual beach areas are located close to each other, the cross-spillage of light emitted from one area into the other can severely confound estimates of impact on economic growth.

In a recent paper by Abrahams, Lozano-Gracia, and Oram (2015), it is argued that blurring occurs due to the on-board optics of DMSP satellites, because the sensor scans the Earth's surface in elliptical areas, but ascribes the observed light to smaller, square-shaped pixels (ibid). Understanding how overglow is generated, the authors rely on detailed information about the satellite's altitude, the radius of its optics, and it's location above the Earth's surface on any given night to recreate the geometry of the satellite's data collection process and ultimately remove all overglow effects from the luminosity data. It is then shown that this "deblurring" method is successful at more accurately estimating the extent of city boundaries in the case of over 11 sub-Saharan African and South Asian cities. Consequently, applying this deblurring methodology to the nightlight imagery of Barbados also renders a more appropriate proxy and accurate measure of economic activity at the beach level.

[10] For a more detailed discussion of how luminosity data is cleaned of measurement error, see Doll (2008).



(i) Raw Luminosity (ii) Deblurred Luminosity

Figure 2. *Luminosity for Barbados (2010).*
Created by Naijun Zhou.

Figure displays the raw and deblurred luminosity data for Barbados for 2010. Panel (i) depicts raw luminosity, where each individual square, or pixel, represents the annual average of night light intensity measured for this area. The brighter the shade of the pixel, the more night light activity is detected in this area. The concentration of high levels of luminosity can noticeably be detected for the urban corridor along the west and south coast and is centered at the capital Bridgetown. This image also confirms the decision to focus on this side of the island as the study area, as very little economic activity appears to be occurring on the north and east coast. However, this imagery is also telling with regards to the overglow phenomenon: Almost the entire study area is illuminated, so that it would be difficult to discern any marginal increases in luminosity that may have occurred near a specific beach segment. In contrast, Panel (ii) depicts the deblurred luminosity data for Barbados and illustrates clearly that light sources are distributed among fewer pixels, which may also make it easier to identify local determinants of increased night light activity.

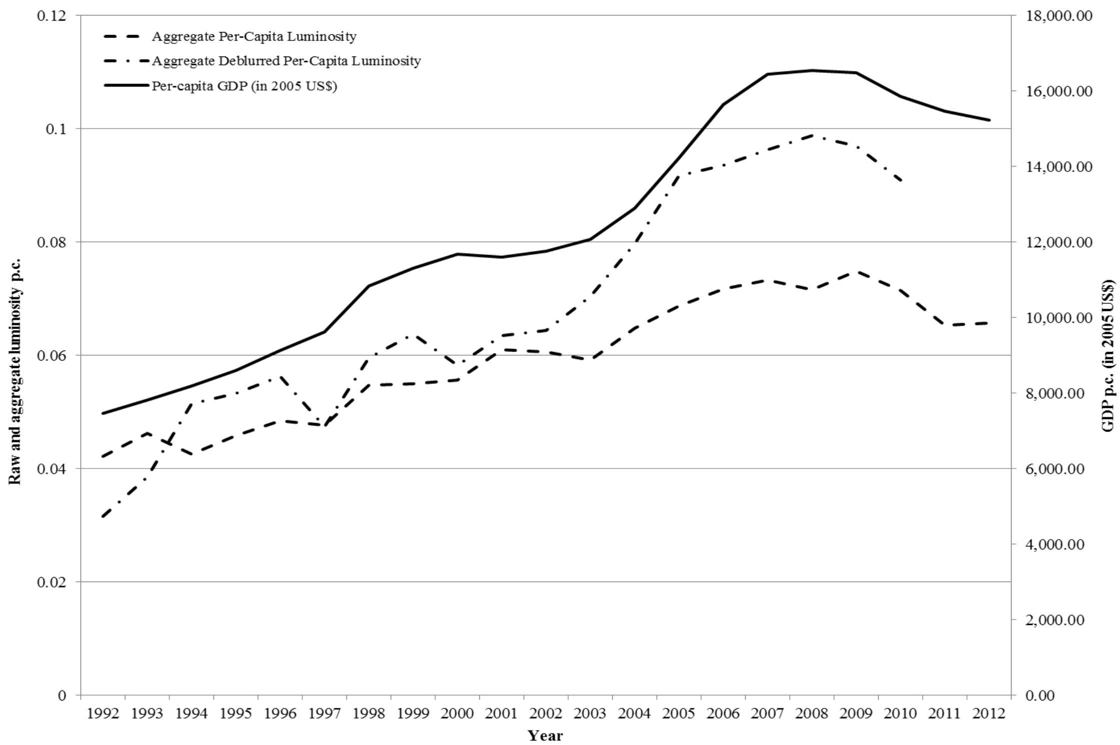


Figure 3. *Luminosity as a measure of economic activity.*

Due to the lack of subnational GDP information, it is impossible to directly assess the accuracy of luminosity as a measure of economic activity at the chosen unit of analysis. Nevertheless, in order to motivate and justify the use of nightlight imagery, we examine the correlation between GDP p.c. and luminosity p.c. at the country level between 1992 and 2012. Figure 3 depicts GDP p.c. and raw as well as "deblurred" luminosity per capita aggregated for Barbados. Importantly, the correlation between GDP p.c. and both raw and deblurred per capita luminosity lies at around 0.97. However, the raw luminosity p.c. data does not follow as closely the clear upward trend that exists in the GDP p.c. data. In comparison, luminosity data that has been deblurred following the methodology of Abraham et al. (2014) exhibits less volatility, reflects the clear upward trend visible in the GDP data. This provides strong motivation to rely on deblurred luminosity as a proxy of economic activity in the case of Barbados. A restriction of this choice, however, is that deblurred luminosity is only available until 2010, as the frequency data available from NOAA[11], which is necessary for the deblurring methodology, is incomplete for the remaining two years.

In order to ensure that nighttime lights are the most accurate proxy of economic activity possible at the individual beach level, a number of additional steps are taken to adjust the luminosity data. As an exemplary illustration of these steps, represents the varying adjustments to luminosity p.c. for the case of the treatment unit Rockley Beach. Note that in contrast to the national aggregate, applying the deblurring methodology appears to introduce more volatility to the luminosity data. This is reasonable, since economic activity may vary more over time depending on local conditions. A further step is to take the natural logarithm of the deblurred luminosity p.c. data, since this will allow us to interpret any change in luminosity over time in percent. Given that the high correlation between luminosity and GDP p.c. illustrated above, and the approximate elasticity of around one between income and luminosity, a one percent increase in luminosity p.c. could reasonably be interpreted as an approximate one percent increase in local GDP per capita. Lastly, since we are interested in the long-term impact of the CIP on economic activity, the Hodrick-Prescott (HP) Filter is applied to remove the cyclical component from the time series and make it more sensitive to long-term rather than short-term fluctuations (Hodrick and Prescott, 1980). In its essence this decomposition procedure is based on the conceptual framework that a given time series,y_t, consists of a long-run growth component, g_t, and a short-term cyclical component, c_t, where time $t = 1, \dots, T$:

[11] This identifies the number of cloud-free nights during which a pixel is lit.

$$y_t = g_t + c_t$$

The trend component g_t is determined as follows, where the cyclical component $c_t = y_t - g_t$ is assumed to represent deviations from the trend that average to zero over the long term, and where the smoothness of the trend is determined by the sum of squares of its second difference:

$$\min_{g_t} \left\{ \sum_t c_t^2 + \lambda \sum_t [(g_t - g_{t-1}) - (g_{t-1} - g_{t-2})]^2 \right\}$$

The above equation presents how the optimal filter is found, where the first term penalizes the cyclical component, and the second term penalizes variations in the growth rate of the trend component. In this context, parameter λ needs to be chosen carefully, as it determines the magnitude of the penalty. The parameter represents the square root of the ratio of the variances of the cyclical component and the second difference of the trend component. In their original work, Hodrick and Prescott (1997) make certain assumptions about typical variations of the two components for quarterly data and arrive at a value of $\lambda = 1600$, which has proven to be reliable and robust value in subsequent studies. Ravn and Uhlig (2002) revisit the original approach and point out that, due to time aggregation, the optimal parameter value changes by the fourth power of the observation frequency. For annual data, this implies an optimal value of $\lambda = 1600/4^4 = 6.25$, which they show to renders robust and reliable smoothing results.

As Figure 4 depicts, applying the HP filter to the logged and deblurred luminosity p.c. data renders a smoother time series that still reflects the trend in the data. Importantly, there appears to be an initial rise and subsequent substantial drop in luminosity in the 1990s that require closer examination. Based on anecdotal evidence, the volatility in economic activity during this time may have been caused by an important local factor: Between 1995 and 2002, the

South Coast Sewerage Coast was a large-scale infrastructure project that took place along large parts of the South Coast of Barbados.

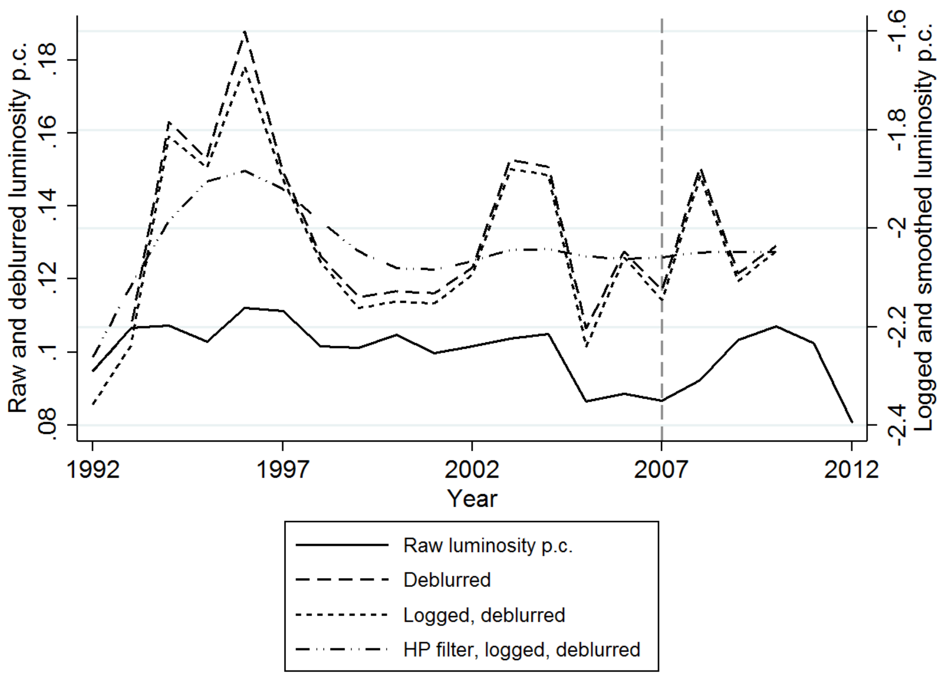


Figure 4. *Adjusting per capita Luminosity*.

While it aimed to put in place infrastructure that could capture all sewage emanating from private and commercial entities in the area to protect fragile coral reefs and to help sustain the fishing and tourism industry, its short-term effects on the local economy were rather negative. During construction, air quality decreased significantly, and noise from construction increased substantially, which not only disrupted traffic but also affected businesses and restaurants located, as well as tourism along this stretch of coast (Husbands and Dey, 2005). Given the extent of the program and its short-term effects, it is therefore unsurprising that local economic activity was inhibited during that time period.

4. Empirical Framework

In order to identify the true causal impact of the CIP investments on local economic development, the empirical approach needs to address two key challenges. The first challenge represents the identification of a valid counterfactual. While treated beach segments have already been identified as those three beaches that received investments under the CIP (and specifically Rockley Beach for this analysis), control areas which can represent a counterfactual, i.e. the measurement of what would have happened in the absence of the investments, need to be selected based on the collected data. Closely related to this first challenge then is choosing an appropriate econometric method to estimate impact, which crucially depends on the nature of the available data.

In the case of this study, those two empirical issues fall together due to the nature of the impact indicator and the available panel data. Since luminosity is measured in pixels with a size of approximately 1 km^2 and individual beach segments are relatively small, there exist only few pixels for each segment, and, when aggregated to the segment level, only one observation at any given time period. Therefore, the limited number of observations per time period is prohibitive to the use of any traditional approaches to impact evaluation, such as double difference, matching, or a fixed-effects regression. Luckily, a seminal paper by Abadie and Gardeazabal addressed exactly this restraint that researchers face when trying to assess the effect of an intervention or policy on the evolution of an aggregate outcome. In 2003, the authors introduced a method that would allow researchers to go beyond the means of a comparative study, and synthetically construct a control group that mirrors the trajectory of the aggregate outcome in the absence of treatment. Specifically, Abadie and Gardeazabal (2003) propose that longitudinal data can be used to build a weighted average of non-treated units that best parallels characteristics of the treatment group over time, prior to treatment. In their original application, the authors pioneered the method when estimating the impact of the terrorist conflict in the Basque region of Spain on economic growth using other Spanish regions as a synthetic control (ibid). In a later publication, Abadie et al. (2007) highlight that the synthetic control approach has a number of methodological advantages over the more commonly used difference-in-difference approach, as its prominent features include both transparency and safeguarding against issues of extrapolation (ibid). Specifically, using a weighted average of all potential control units makes transparent the relative contribution of each unit to the counterfactual, and reveals similarities between treated and synthetic control units with respect to the important common trend assumption prior to the intervention (ibid). Furthermore, since individual weights are usually restricted to be positive and sum to one, extrapolation can purposefully be guarded against.

The creation of a synthetic control group that most resembles the treatment group in key pre-treatment characteristics crucially relies on $\boldsymbol{W} = \left(w_1, \ldots, w_J\right)'$, a $(Jx1)$ vector of nonnegative weights for all potential control units J, where w_j represents the weight for unit j of the synthetic control, and all individual weights sum up to one. Let $\boldsymbol{X_1}$ be a $(K\ x\ 1)$ vector of K pre-treatment covariates in treatment group and $\boldsymbol{X_0}$ a $(K\ x\ J)$ vector of the same variables for all possible control units. Additionally, define $\boldsymbol{V}$ as a diagonal matrix with nonnegative values reflecting the relative importance of the different covariates. Then, the vector of optimal weights $\boldsymbol{W}^*$ is found by minimizing the distance in pre-treatment characteristics between treated units and the weighted average of control units:

$$\min_{\boldsymbol{W}}(\boldsymbol{X_1} - \boldsymbol{X_0 W})'\boldsymbol{V}(\boldsymbol{X_1} - \boldsymbol{X_0 W})$$

$$s.t.\ \ w_j \geq 0,\ \ w_1 + \cdots + w_J = 1 \qquad \forall\ j = 1,2,\ldots,J$$

Note that for the diagonal matrix $\boldsymbol{V}$, components are optimally chosen to linearly weigh variables of $\boldsymbol{X_0}$ and $\boldsymbol{X_1}$ so that the mean square error of the synthetic control estimator is minimized, which can be achieved, for instance, by choosing $\boldsymbol{V}$ such that the mean squared prediction error (MSPE) of the outcome variable is minimized for pre-treatment periods (ibid).

The estimated treatment effect $\hat{\alpha}_{0t}$ on an outcome Y over the period $t \in \{T_0 + 1, \dots, T_1\}$ for an intervention that occurred in time T_0 is then the difference between the observed outcome of the treated unit ($j = 0$) and the weighted average of outcome values for control units:

$$\hat{\alpha}_{0t} = Y_{0t} - \sum_{j=1}^{J} w_j^* Y_{jt}$$

In this context, the estimated impact is computed by measuring the ex-post difference between the outcome of an indicator in the treatment group, Y_{0t}, to the outcome for the synthetic control group as an optimally weighted average of all control units in the donor pool, $\sum_{j=1}^{J} w_j^* Y_{jt}$. In this context, the choice of pre-treatment characteristics crucially determines the weights and composition of the synthetic control. Therefore, one should choose that specification for which included pre-treatment characteristics generate the smallest mean squared prediction error that can be achieved to find the optimal weight distribution (Abadie and Gardeazabal, 2003).

Using the methodology described above, we can therefore take advantage of the twenty years of longitudinal data for per capita luminosity. In the spirit of Abadie and Gardeazabal, a synthetic Rockley Beach is constructed that can mirror levels of economic activity prior to the implementation of the Coastal Infrastructure Program at the treated beach area in 2007, i.e. for a pre-treatment period of 15 years from 1992 to 2006. Pre-treatment characteristics that determine optimal weights of the synthetic control group must be chosen to accurately predict, prior to treatment, the evolution of per capita luminosity over time at Rockley Beach. As a proxy of local economic activity, a number of categories should be included here: For one, a synthetic Rockley Beach must be similar in general beach characteristics, including size, length, wave exposure, coastal vulnerability, and location with respect to key infrastructure, proximity to commercial facilities (restaurants and shops, for instance), as well as similar levels of real estate activity.

In the following, the effect of the CIP program is estimated as the difference in luminosity p.c. levels between Rockley Beach and synthetic Rockley during the post-treatment period of 2007-2010. To assess whether the results obtained in this manner are robust, a number of placebo tests are performed to confirm that the estimated impact for Rockley Beach is large in comparison to the distribution of effects if the methodology is applied to other beaches in the donor pool, and that the results are robust to variation in the composition of the donor pool.

5. Results

5.1. General Results

As described in the previous section, the impact evaluation of the CIP program on economic activity as measured by luminosity is conducted using a synthetic control approach. Since the purpose of the synthetically created control group for Rockley is to reproduce the luminosity p.c. values that would have occurred in the area around Rockley Beach if the program had not occurred, other beach segments that received treatment under the CIP program, namely Holetown and Welches Beach, are a priori discarded from the donor pool. This leaves us with a total of 20 beach segments in the donor pool.

Table 1. *Pre-CIP Characteristics (1992-2006 average).*

Variable	*Study Area*	Rockley Beach	
		Treated	*Synthetic*
Luminosity p.c.	-1.57	-2.04	-2.04
Population (in thousands)	3.86	5.78	4.35
Real Estate			
Permit applications (2001-2006)	49.07	85.33	32.29
Beach Characteristics			
Beach area (in sq. km)	0.02	0.02	0.02
Beach length (in km)	0.81	1.11	1.00
Shoreline length (in km)	0.89	1.21	1.11
Wave Exposure / Intensity Index (WEI)	10.33	8.12	8.94
Beach Safety Index	4.21	4.81	4.35
Coastal Vulnerability Index (CVI)	31.82	42.50	42.07
Location			
Distance to nearest major road (in km)	0.31	0.27	0.26
Distance to Bridgetown Harbor (in km)	9.21	5.90	7.10
Distance to Bridgetown Center (in km)	9.57	4.62	6.21
Distance to nearest bus stop (in km)	7.34	0.39	0.83
Distance to nearest restaurant (in km)	6.44	0.33	0.75
Land Use			
Share of restaurants	0.03	0.14	0.06
Share of vacant lots	0.04	0.14	0.06
Share of hotels	0.05	0.29	0.08

Following this pre-selection, a synthetic Rockley Beach is constructed from a convex combination of beach segments in the donor pool. Table 1 displays the mean values of all pretreatment characteristics for actual and synthetic Rockley Beach, as well as the average values for the entire study area. Looking at study area averages, it is clear that not all beaches in the donor pool would have provided a reasonable counterfactual for Rockley Beach. Average levels of per capita luminosity along the South and West coast are substantially lower than at Rockley Beach, which makes sense considering that Rockley Beach is relatively close to Bridgetown and a popular location for hotels and restaurants. This is also reflected in the locational covariates, which indicate that on average, beaches in the donor pool are located further from Bridgetown and the harbor, as well as nearby restaurants and main roads. In terms of land use, donor pool beaches had significantly less restaurants and hotels in their proximity. There also appears to be lower levels of real estate activity, as beaches received an average of 50 construction permit applications per year in contrast to more than 80 near Rockley Beach. Furthermore, donor pool beaches tended to be smaller and of shorter length, and were less exposed to waves. In contrast, synthetic Rockley is able to reproduce more accurately the average pre-treatment values for key characteristics of beach type and location. Some characteristics, notably annual construction permit applications, are not reproduced as accurately. However, a look at the optimal weight distribution for included covariates (captured in the diagonal matrix $\boldsymbol{V}$) reveals that these variables received a weight approaching zero in the optimization, as they do not appear to have substantial predicting power with regards to pre-treatment luminosity p.c. levels.

Table 2. *Optimal Beach Weights for Synthetic Rockley.*

Beach	*Weight*	*Beach*	*Weight*
Batts Rock	0	Mullins Bay	0
Bridgetown Harbour	0	Welches	-
Brighton	0.138	Paynes Bay	0.008
Carlisle Bay	0	Porters	0
Casuarina	0.44	Royal Pavilion	0
Dover	0	Sandy Lane	0
Fitts Village	0	Smittons Bay	0
Gibbs Bay	0	South Point	0
Goddings Bay	0	Speightstown	0
Hastings	0.397	St. Lawrence	0
Holetown	-	Worthing	0.017

Table 2 displays the weights that each beach in the donor pool received to create synthetic Rockley. In the specification that renders the best fit (as expressed in the smallest mean squared prediction error, or MSPE), synthetic Rockley is composed of a combination of Brighton

Beach, Casuarina Beach, Hastings Beach, Paynes Bay and Worthing Beach, while all other beaches in the donor pool received a weight of zero in the vector $\boldsymbol{W}$. A look at a map of the study area[12] reveals that these five beaches are all located relatively close to a treated beach site (either Rockley, Holetown, or Welches Beach). Initially, this raises concerns about potential spillover effects that may bias the post-treatment trajectory in synthetic Rockley. However, it must be emphasized that, if anything, adjacent beaches would benefit from the stabilization efforts at treated beaches, so that the impact estimate for Rockley Beach provided here can serve as a reasonable lower bound estimate of possible impact.

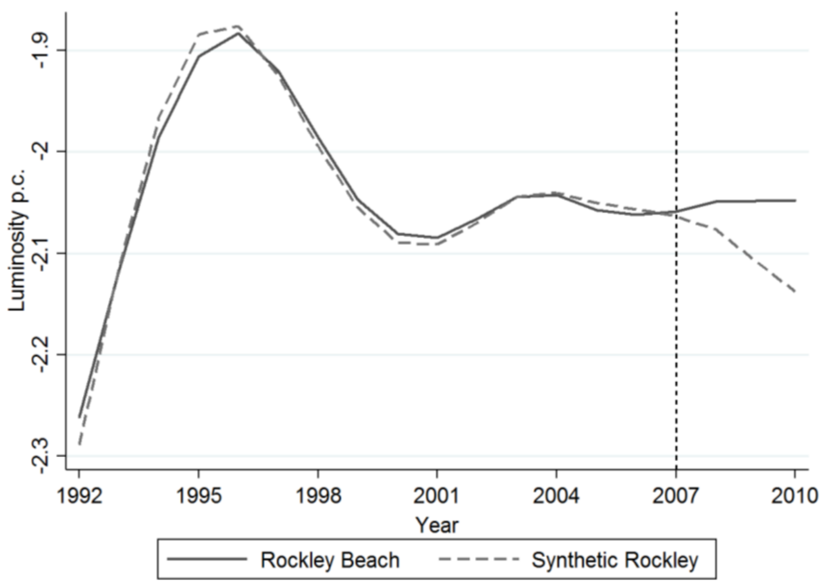


Figure 5. *Luminosity p.c. for Rockley and Synthetic Rockley*

Having constructed a synthetic counterfactual that adequately reproduces pre-treatment luminosity p.c. levels in Rockley Beach, the post-treatment impact for 2007-2010 can now be estimated. It should be noted that construction at Rockley lasted from August 2007 until December 2008, so that the choice of 2007 as the year when treatment occurred represents a

[12] A map that indicates the respective location of these five beaches relative to Rockley can be found in Figure 11 in the appendix.

conservative approach. Assuming that once public investment begins, private agents immediately start to adjust their behavior, the impact estimate presented here once again provides a lower bound estimate of what total impact could be.

Figure 5 depicts luminosity p.c. for Rockley and synthetic Rockley over the period 1992-2010, where the treatment occurring in 2007 is indicated by the vertical dotted line. Despite the large increase and subsequent drop in luminosity p.c. in the 1990s, the synthetic counterfactual visibly provides a good fit for the trajectory of nightlight activity near Rockley Beach and therefore is a reasonable estimate of the economic activity that would have occurred in Rockley Beach in the absence of the CIP.

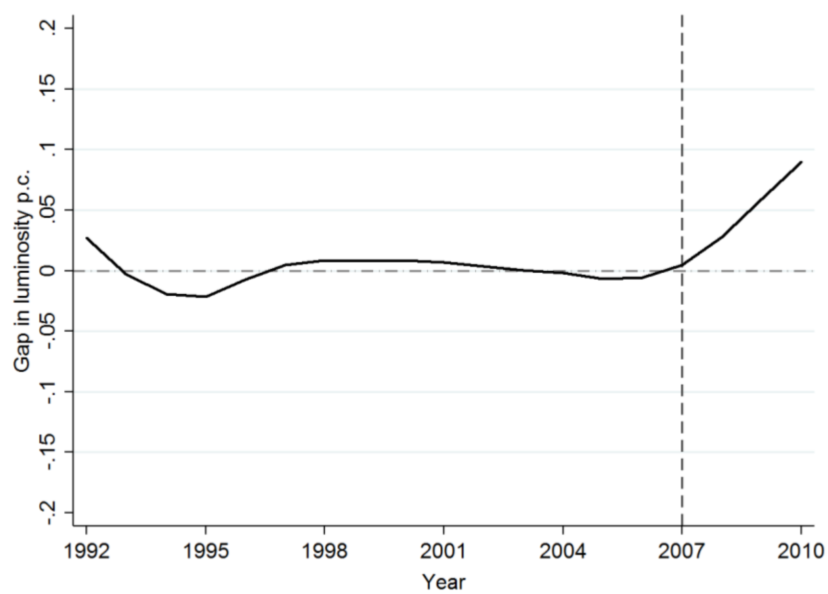


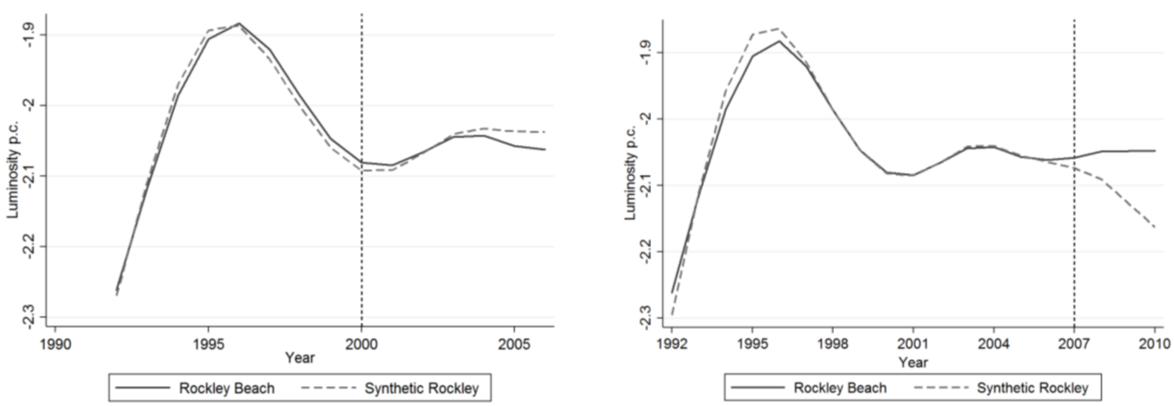
Figure 6. *Per-capita Luminosity Gap between Rockley and Synthetic Rockley.*

The impact of the Coastal Infrastructure Program on economic activity in Rockley is measured as the estimated difference between luminosity p.c. in actual and synthetic Rockley. As is clearly visible from the figure above, the two lines diverge immediately after the coastal infrastructure works have been completed. For synthetic Rockley, one can observe a noticeable downward trend of luminosity p.c., which appears to be in line with the onset of the global economic crisis and simultaneous decrease in tourism and real estate activity starting in 2008. In contrast, nightlight activity in actual Rockley Beach remains constant with a slight upward trend, leading to an increasing positive gap to the synthetic counterfactual over time. This indicates that, in the context of the global economic recession, the CIP may have prevented similar declines in economic activity at treated beach sites. In terms of the external validity of these results, it can be argued that, absent a major economic downturn, the impact of a shoreline stabilization program is likely to not only sustain, but boost local economic activity. Therefore, overall impact may have been even larger, had the timing of the intervention not coincided with the global recession.

The impact gap is illustrated more clearly in Figure 6, which depicts the annual difference in luminosity p.c. between Rockley and synthetic Rockley. Prior to the intervention in 2007, the gap remains close to zero, again reinforcing the notion that the synthetic control can create a robust counterfactual. Starting in 2007, the gap is increasingly positive and the effect increases over time. Note that because luminosity p.c. has been transformed to natural logarithms, the difference between actual and synthetic Rockley in 2010 can be interpreted as program impact three years post-treatment, measured in percent. Therefore, the magnitude of this impact is quite substantial, as the estimated gap suggests that, over the post-treatment period of 2007-2010, luminosity p.c. was increased by 9 %, which can be approximately interpreted as a rise of 9 % in local GDP. Note that with a large-scale infrastructure program such as the CIP, it is likely that any positive effects develop slowly over time, so that this short-term impact observed during the three years after the completion of construction works may be only an indicator of what long-term effects may be. The decisive upward trend suggests that it will be positive.

5.2. Robustness Checks

While the impact estimates based on the synthetic control approach appear promising, it is possible that these results are driven by some anomaly in the data, rather than a significant effect of the CIP program. To assess whether the results are robust, a number of placebo tests that follow Abadie et al. (2003; 2010) are conducted. As a first robustness check, the choice of optimal weights in the diagonal matrix $\boldsymbol{V}$ is reviewed. While the synthetic control process ensures that covariate weights that are assigned through $\boldsymbol{V}$ are chosen so that the mean square error of the synthetic control estimate is minimized, it is still possible that the optimal choice of $\boldsymbol{V}$ may be affected by the researcher's subjective assessment of the predictive power of individual covariates included in the specification (Abadie et al., 2003).



(i) Training and Validation Period (ii) Results with Cross-Validation

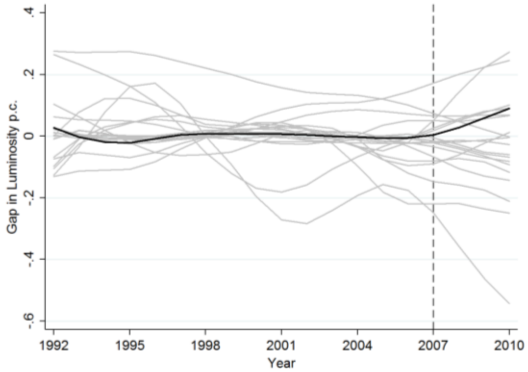
Figure 7. *Constructing a Synthetic Control using Cross-Validation.*

To confirm that this method still renders the best fit for the available data, Abadie et al. (2010) suggest a method of cross-validation, dividing the time before treatment into a "training period" and "validation period", so that if an optimal fit is found for the initial "training period", the synthetic control should mirror as closely as possible the movement of actual Rockley during the "validation period", because no treatment has yet occurred that could let actual and synthetic Rockley diverge. If this is achieved, the chosen matrix $\boldsymbol{V}$ can then be used to compute optimal covariate weights to create a synthetic control that has proven accurate in mirroring the actual data trend and now extends through the post-treatment time period.

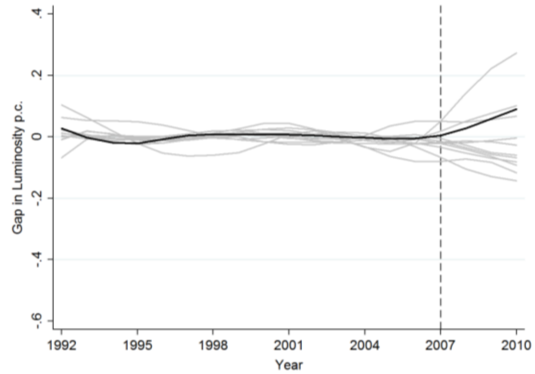
Figure 7 presents the results of creating a synthetic Rockley using this alternative cross-validation method. The year 2000 is chosen as the cut-off point that divides the pre-treatment period evenly into training and validation period. As shown in Panel (i), synthetic Rockley is able to measure the development in actual Rockley very well during the validation period of 2000-2006, which indicates that it is a good fit for the data. As a confirmation of the original approach, the trajectory for the post-treatment period obtained thusly as displayed in Panel (ii) appears very similar to that in Figure 5 and is of similar magnitude.

The second robustness check again follows Abadie et al. (2010). In order to rule out the possibility that the positive estimate is driven entirely by chance, it is assessed how often results of the same magnitude can be obtained if the treated beach is chosen at random from the donor pool. Therefore, the synthetic control method is iteratively applied to all 20 beaches from the potential control group, while shifting Rockley Beach to the donor pool. If this process were to produce positive gaps of similar magnitude for beaches that were not targeted by the program, this would suggest that the impact results are not robust.

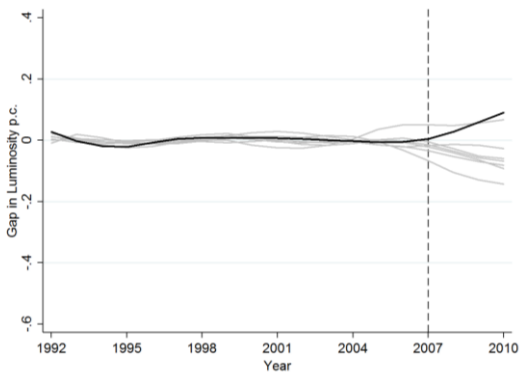
This iterative process renders a distribution of estimated placebo gaps, which are displayed in Panel (i) of Figure 8. The grey lines represent the gaps in per capita luminosity for the 20 beaches in the donor pool, while the bold black line represents the original result obtained for Rockley. In comparison to all other beaches from the donor pool for which a synthetic counterfactual was created, the estimated gap for Rockley at first appears relatively small.



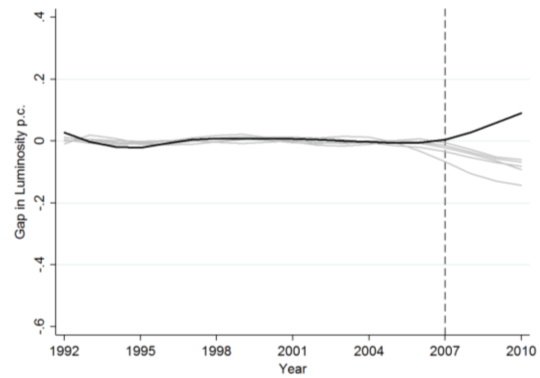
(i) Placebo gaps in all 19 control beaches



(ii) Placebo gaps in 12 beaches (excluded if pre-CIP MSPE twenty times higher than Rockley's)



(iii) Placebo gaps in 8 beaches (excluded if pre-CIP MSPE five times higher than Rockley's)



(iv) Placebo gaps in 6 beaches (excluded if pre-CIP MSPE two times higher than Rockley's)

Figure 8. *Gap in Luminosity p.c. for Rockley and Placebo Gaps for Beaches in Donor Pool.*

However, it is noticeable that the pre-treatment fit is decidedly less accurate for most of these donor beaches. While the pre-treatment mean squared prediction error (MSPE) for Rockley has a value of 0.0001, the median pre-CIP MSPE for all other donor beaches is 0.0012, which is more than 10 times larger. This indicates that a convex combination of available donor beaches cannot adequately reproduce pre-treatment levels of luminosity p.c. for all beaches in the panel.

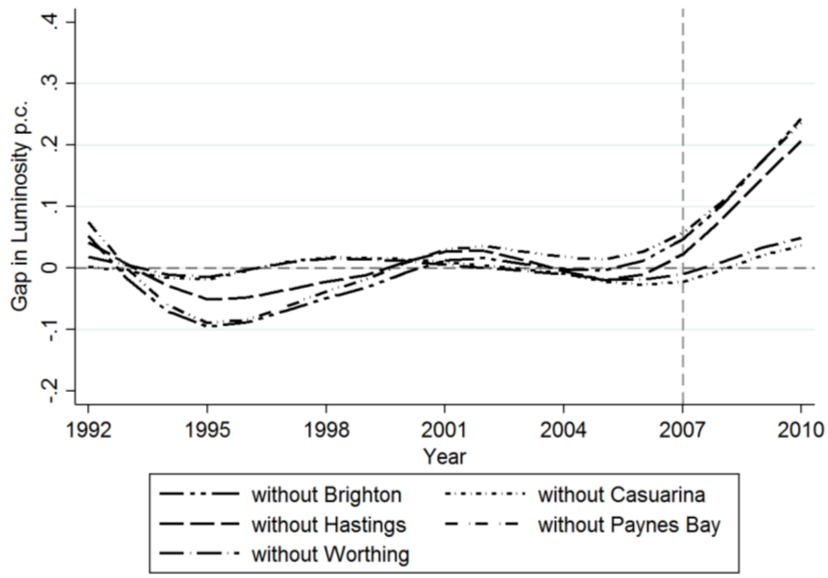


Figure 9. *Sensitivity Test of Sequentially Excluding Beaches from Synthetic Control Unit.*

Of course, placebo runs that are unable to create a good fit pre-treatment can provide little reliable information about the significance of any post-treatment gap. Therefore, Panels (ii) – (iv) present only those placebo runs that provide a reasonably good fit relative to that of the Rockley synthetic counterfactual, as measured by the size of their pre-treatment MSPE relative to that of Rockley. Under a rather lax restriction of not exceeding Rockley's MSPE by more than 20 times, Panel (ii) excludes 8 placebo runs. This large cutoff point is already sufficient to paint a clearer picture of the significance of the impact for Rockley, as its post-treatment gap in per capita luminosity is larger than all but one placebo run. In Panel (iii), an additional 4 placebo runs are excluded as they exceed Rockley's MSPE by more than 5 times. Here, the impact for Rockley is one of only two that are positive post-treatment. Lastly, Panel (iv) focuses on those beaches that can reproduce Rockley's fit as closely as possible, so that two additional beaches are excluded because they exceed Rockley's MSPE by more than a factor of two. Here, the impact for Rockley stands out most clearly as both the only positive impact as well as relatively large in magnitude.

Another concern that the following robustness check will address is that results are driven by one particular beach that strongly determines the trajectory of synthetic Rockley, potentially due to the particular characteristics of that beach. Following a recent approach by Mideksa (2013), if the results are to be insensitive to the omission of specific beaches, the beaches that received positive weights in the original synthetic control specification are sequentially removed from the estimation. Figure 9 displays the results of this sensitivity test by plotting the estimated annual gap in per-capita luminosity, with each line excluding one particular beach from the donor pool. A comparison to the results displayed in Figure 5 indicates that the specification appears robust, as the overall fit and post-treatment effect are similar when individual beaches are excluded. In fact, post-treatment impact seems appears more pronounced under the exclusion of certain beaches. Interestingly, this is the case when those beaches are excluded that are located most closely to Rockley or one of the other two treated sites – for instance, Hastings is located relatively close to Rockley, while Paynes Bay lies near Holetown Beach – which indicates that if there are any spillover effects to neighboring beach areas, the tendency would be to under- and not over-estimate impact if such beaches form part of the synthetic control.

Overall, the results of this synthetic control estimation indicate that, in the first three years after extensive efforts to provide shoreline stability and expand coastal infrastructure, there appears to be a robust and positive impact on the levels of luminosity p.c. at Rockley Beach. This illustrates that, through the positive effect of coastal infrastructure improvements on beach quality, the local economy can be stimulated, which leads to higher medium-term economic growth in such locations.

6. Conclusion

It comes as no surprise that the economies of many Small Island Independent States (SIDS), with their year-round sunshine, tropical climate, and white, sandy beaches, rely heavily on the tourism activity that their environmental features attract. Therefore, the threats of climate change, with its ever-rising sea levels, increasingly severe storm events and resulting shoreline erosion, present not only an ecological, but a real economic risk to these countries: Continuous coastal degradation and beach reduction make them less attractive as tourist destinations, which affects not only local businesses and residents that rely on tourism for economic opportunities, but may also threaten coastal structures and cause significant damages and economic costs. Recognizing the severe consequences of this direct link between ecological fragility and economic vulnerability, many local agents and governments have increased their efforts to rehabilitate and preserve shorelines. Given the large-scale investments that are necessary for these interventions, as well as the potential incentive a significantly positive economic impact could present for private investors to share the financial burden, it is critical that a comprehensive study provide credible evidence on the effectiveness of such shoreline stabilization measures.

This study presents the first rigorous evaluation of the Coastal Infrastructure Program (CIP) in Barbados. This large-scale project administered shoreline stabilization works to numerous beach sites along the island's tourism-oriented South and West Coast between 2001 and 2010. The CIP sought to improve beach size, quality, and accessibility in order to protect the shoreline from long-term erosion as well as preserve and further attract tourism activity near targeted coastal locations. The largest investment focused on Rockley Beach in South-West Barbados, and included not only counter-erosion measures but also the construction of a scenic boardwalk that has proven popular with residents and tourists alike. Under the hypothesis that this investment has made the Rockley Beach location more attractive for recreational tourism and has thus stimulated increased tourism and real estate activity in the area, the study assessed whether the construction works administered in 2007 had a significant effect on local economic development. Economic activity is proxied by remotely-sensed nighttime light activity.

Given the limited number of available luminosity pixel within the study area, the nature of the panel data proves prohibitive to the use of traditional econometric approaches to impact evaluation. However, based on a comprehensive GIS dataset that contains information on beach characteristics, as well as beach-adjacent infrastructure and real estate activity, the study takes advantage of the synthetic control approach introduced by Abadie and Gardeazabal in 2003. By identifying the optimal combination of all 20 available control beaches, a synthetic Rockley Beach is constructed to mirror the evolution of luminosity p.c. over 14 pre-treatment years and serve as a valid counterfactual for the post-treatment trajectory at Rockley Beach in the absence of the program. In this manner, the study estimates that the effect of the CIP program on economic activity at Rockley Beach accumulates to approximately 9 % in three years post-treatment. A number of placebo and sensitivity tests confirm that this result is robust.

This positive impact is significant for two reasons: For one, the trajectory for synthetic Rockley after 2007 indicates that due to a general worsening of economic conditions as a result of the global economic crisis, there was a downturn in local economic activity. Therefore, the results of this study capture the impact of shoreline stabilization in a unique economic context and time period that requires a careful examination of the evaluation's external validity. In other words, it is likely that, in the absence of a severe economic recession, there may have been significantly higher levels of tourism demand and investment in local businesses and real estate, so that an even higher impact of similar shoreline stabilization interventions is possible.

Secondly, the magnitude of the impact is substantial given the short time period after treatment that can be observed. One would assume that any positive effects of the infrastructure works would take time to reach the real estate and tourism industry, so that total impact is measured in the long run. Therefore, the present evidence suggests potentially even larger long-term effects that shoreline stability efforts can have on both environmental and economic sustainability. This result stands in stark contrast to what is to our knowledge the only other impact evaluation of shoreline stabilization efforts by Cordes and Yezer (1998), who found that public investment in shoreline protection along the East Coast of the continental U.S. did not significantly affect economic growth in coastal communities.

Of course, this study is not able to answer all relevant questions, so that future research in this area is crucial. For instance, it is of interest whether long-term impact (i.e. from 2007 until 2015) is as positive as the short-term trend suggests; something that needs to be verified once the relevant data becomes available. It is also pertinent to establish with empirical evidence the theoretical channels of impact through the tourism and real estate industry. While the available data on tourism and real estate activity unfortunately prohibited a rigorous analysis of the exact relationship, this is something that future research should address. Of course, this will also depend on the specific country context within which a project is implemented. However, obtaining a deeper understanding of how exactly shoreline stabilization efforts can affect local economic activity will allow researches and policy makers alike to design and implement more effective coastal protection measures that can fulfill the dual challenge of preserving ecological conditions while stimulating the local economy.

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Appendix

Additional Tables and Figures

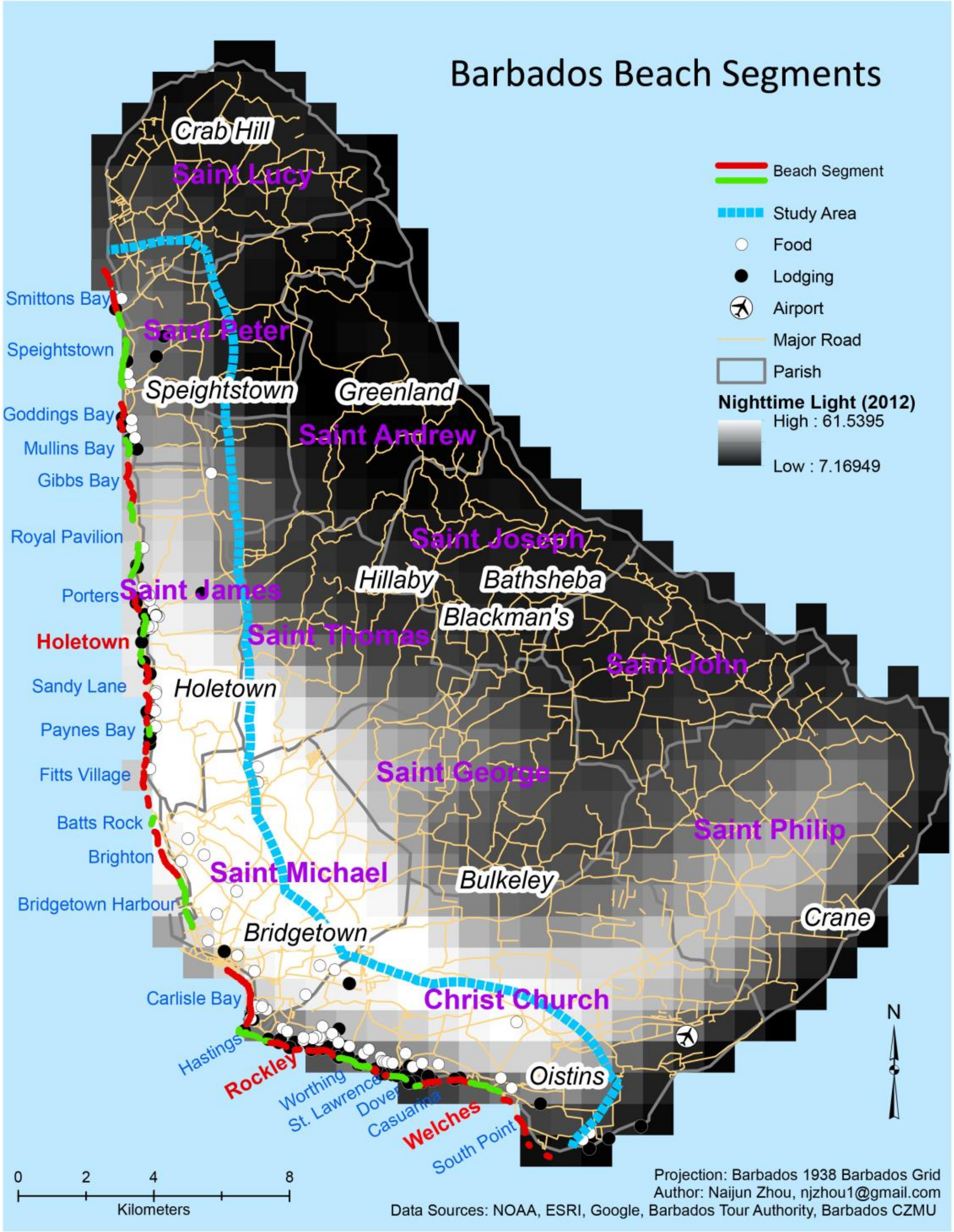

Figure 10. *Map of Barbados with GIS dataset layers.*
Created by Naijun Zhou.

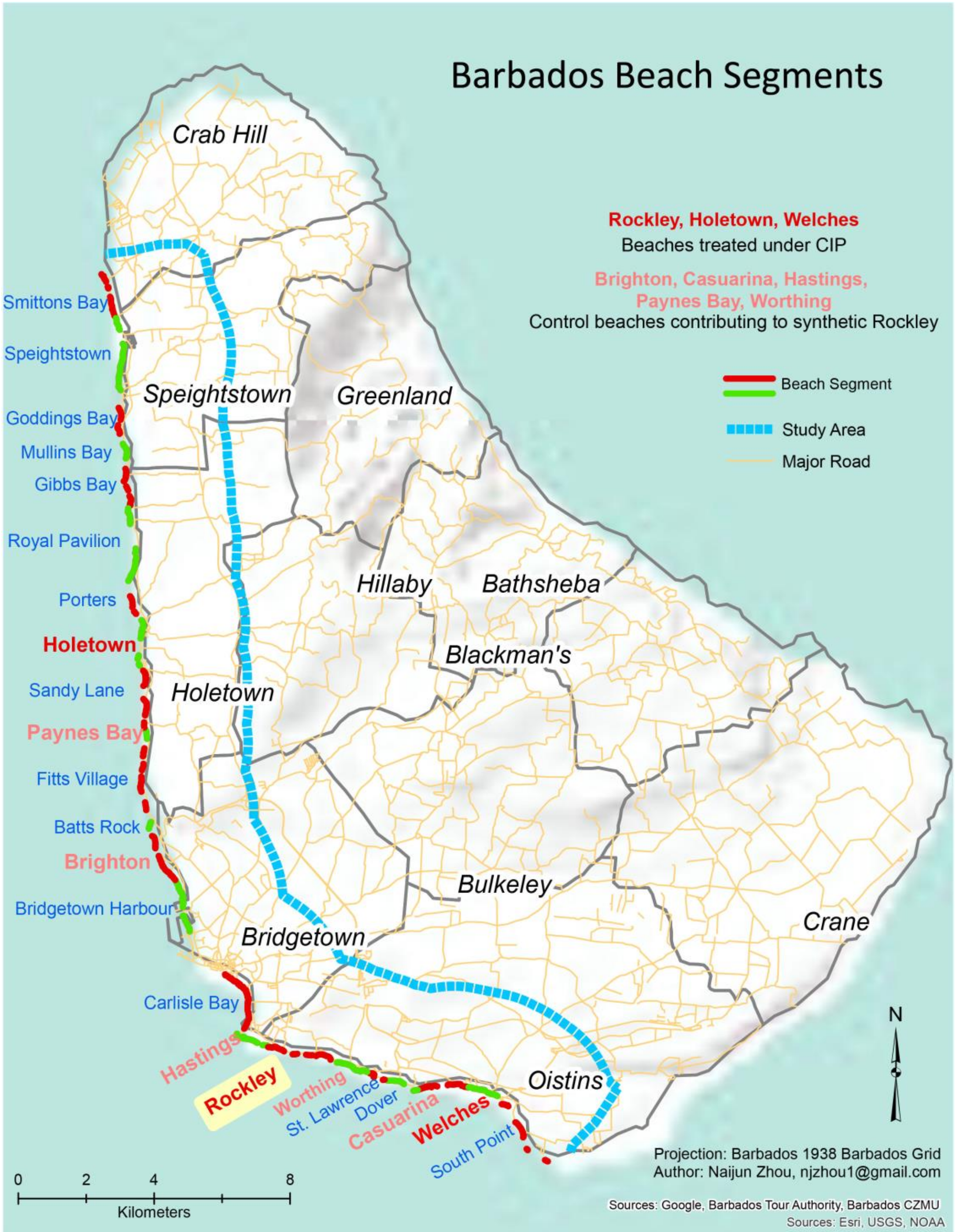

Figure 11. *Map of study area with beach segments contributing to synthetic Rockley.* Created by Naijun Zhou.